Plant Genetic Resources in Botanical Gardens

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Abstract

The world's botanical gardens house some 80,000–100,000 species, and ca. 15,000 species hereof are threatened in the wild. However, representation of natural biodiversity is imbalanced. There is strong bias towards certain plant families and genera, and towards certain functional groups. Apart from this, bias towards species from temperate regions as a result of the imbalance in geographic distribution of botanical gardens is obvious. Tropical regions and the southern hemisphere are highly underrepresented. Most species cultivated in botanical gardens are on an average represented by only two or three specimens, and the genetic diversity within wild species is not reflected. Further limitations include poor documentation and poor maintenance. These limitations reduce the value of the collections as plant genetic resources. However, botanical gardens are the standard institutions for ex situ conservation and propagation of wild plants and should be the main authorities for wild plants. With their huge collections on display botanical gardens are the most effective multipliers for increasing public awareness of the value of biodiversity and conservation needs. There is growing awareness of the ecological, economic and cultural significance of wild plant species and their potential value as genetic resources. Botanical gardens should establish seed gene banks for wild plants for promoting integrated conservation efforts and for protection and conservation of our natural plant genetic resources. They should establish database networks and should provide information services for science, politics and the general public. Botanical gardens play a significant role in promoting public awareness of the value of biodiversity. They have a remarkable potential to contribute to the conservation of plant genetic resources.

PLANT GENETIC RESOURCES

The Convention on Biological Diversity (CBD) defines genetic resources as "genetic material of actual or potential value" (CBD 1992, article 2), in which "genetic material" means any material of plant, animal, microbial or other origin containing functional units of heredity. Plant genetic resources (PGR) "represent plants or parts of plants which are capable of generative or vegetative propagation with actual or potential value" (FAO Commission on PGR). Plant genetic resources may be classified into eight groups according to the respective conditions for use and conservation (Keller et al., 2002): agricultural crops (food, fodder, raw material); pasture plants (meadows and pastures for fodder production); vegetables; fruit crops (fruit trees and shrubs); special crops (medicinal plants, spices, aromatic and dye-plants); ornamentals (flowers, shrubs, ornamental woody plants); forest plants; wild plants. About 30,000 plant species are considered edible. Of these, 7,000 have been cultivated or collected by humans (FAO, 1998). About 120 food crops are of importance on a national scale. Only 30 crop species make up 90 % of the worlds calorie intake. In some countries, especially Africa and South America, wild species contribute a significant source of food in addition to cultivated species. The markets for plant genetic resources products is immense and according to Ten Kate and Laird (1999) annually somewhere between 500 and 800 billion US $.

Methods of conservation of PGR currently in use are listed in Table 1. Cultivation of plants in a botanical garden is a classical, probably the oldest ex situ strategy with the focus of botanical gardens traditionally on ornamentals and wild plants.

BOTANICAL GARDENS AND THEIR COLLECTIONS

Potential of Ex Situ Collections in Botanical Gardens

Botanical gardens have a long history. The roots of the modern botanical gardens go back to the medieval monastery gardens which were laid out for studying and using plants as medicinal herbs and spices (horti medici). The first botanical gardens in Europe, as defined by affiliation with a University and the appointment of a director, were founded in the mid 16th century in Italy. In the 18th and 19th century, many botanical gardens were founded in European colonial countries (Table 2). In Germany, there are presently about 90 botanical gardens, 51 of which are University gardens.

About 1.800 botanical gardens are registered worldwide. The distribution of botanical gardens throughout the world is considerably imbalanced with regard to the global distribution of plant diversity. About 60 % of the botanical gardens are situated in Europe, the countries of the former Soviet Union and North America. A severe lack is evident especially in Africa and South America. Approximately 75 % of the germplasm preserved in botanical gardens and arboreta is located in Europe and North America. Botanical gardens in the temperate regions of the northern hemisphere house more species than the corresponding natural diversity, whereas in the Tropics and the southern hemisphere it is quite the opposite. This discrepancy is especially pronounced in South America and Africa with very few botanical gardens in these parts of the world (Fig. 1).

It is estimated that about 80,000–100,000 species of higher plants are cultivated in botanical gardens (Heywood and Watson, 1995) and would comply with approximately one third of the ca. 250,000 higher plants described. Although this figure might be quite exaggerated, Heywood's (1992) statement that botanical gardens house "the largest assemblage of biodiversity outside nature" is unchallenged. For example, the Royal Botanic Gardens at Kew hold about 34,000 species – more than most countries hold in the wild (Tab. 3). The total number of living plants (not species) in cultivation in botanical gardens is estimated at 3–4 million, which represents between 80–100,000 species (Heywood, 1991), and illustrates the remarkable potential of botanical gardens to contribute to plant conservation. However, most botanical gardens have been primarily interested in plant taxonomy studies, and emphasis was given to inter-species rather than to intra-species variation. The number of plants per species ranges on average between 2 and 3, which imposes severe constraints to genetic conservation interests. Only 45 % of all botanical gardens are considered to have germplasm collections (assemblies of genotypes or populations), i.e. sufficient numbers of samples per accession and sufficient capacities to manage the collections (FAO, 1998). According to FAO (1998), 410 botanical gardens have conserved ornamental or wild native endangered species, 169 conserve medicinal, or forest species, and 119 conserve germplasm of cultivated species (including land races and semi-cultivated species). Some 15,000 species cultivated in botanical gardens are threatened in the wild (WRI, IUCN and UNEP, 1992). Many botanical gardens house special collections of high scientific value. These collections contain a wide range of wild material of genera and species concerned. They are often not included in the botanical garden's database of accessions, despite being held in the gardens or associated institutions. Such collections depend on the specialists who built them up and unfortunately often deteriorate after the specialists are no longer active at the respective institutions.

Problems and Limitations

Problems with the collections of the botanical gardens include imbalanced representation and lack of genetic diversity. These factors limit the value of the collections as plant genetic resources.

1. Imbalanced Representation of Natural Biodiversity. Despite the impressive total numbers of species cultivated in botanical gardens, the proportion of different taxonomic groups represented in botanical gardens is very diverse. Bias towards species from temperate regions as a result of the imbalance in geographic distribution of botanical gardens is obvious and to be expected. Apart from this fact, some taxonomic and functional groups are well represented including orchids, bromeliads, succulents, epiphytes, bulbous species, carnivorous plants, water plants, and trees from temperate regions. The imbalanced representation of taxonomic groups is particularly obvious. For instance, more than 25 % of all species of the largest monocotyledonous plant family (Orchidaceae with ca. 19,000 species) are cultivated in botanical gardens but less than 10 % of the largest dicotyledonous plant family (Asteraceae with ca. 23,000 species) (WCMC, 1992; BfN, 1999).

2. Lack of Genetic Diversity and Proper Documentation. Problems with Plant Genetic Resources in botanical gardens include: (1) Poor initial sampling: Most species are represented by only very few individuals (average number per accession is between two and three). Accessions, therefore, cannot reflect genetic diversity found within the wild species. (2) Poor documentation: The original locality of the accessions and their subsequent handling is often not known. (3) Poor maintenance of collections: The bulk of collections is propagated for generations within gardens, and inbreeding and hybridisation are common. Beside that, unintentional selection for floral and other traits is always present. (4) The exchange systems among gardens have led to extremely low genetic variation between and within collections due to the spread of clones. (5) Strong financial pressure to maintain species that can be relatively easily cultivated in botanical gardens. (6) A serious problem, which is often overlooked, is the rather high percentage of mislabelled plants, either from erroneous determination (lack of taxonomists) or inadvertent misplacement of the correct label (which easily happens).

The potential and value of the collections in botanical gardens and their limitations for plant genetic resources are summarised in Tab. 4.

EXPANDING THE ROLE OF BOTANICAL GARDENS IN PLANT CONSERVATION EFFORTS

As institutions, botanical gardens are as diverse as the collections they hold. Once, botanical gardens played a key role in plant taxonomic research and in plant introduction from one continent to the other. The number of species introduced into cultivation by botanical gardens especially in the field of ornamental plants runs to 80,000 or even more (Guarino et al., 1995). Those days are gone for most of the botanical gardens. It is difficult for many botanical gardens to convince research institutions and funding bodies that useful functions are being performed. In recent years an increasing number of botanical gardens is looking to conservation as one of their major goals (Hawkes, 1987; Bramwell et al., 1987; Bermejo et al., 1990; Falk and Holsinger, 1991; Hurka, 1994; Guarino et al., 1995; BfN, 2000; Hawkes et al., 2000; Hurka, 2000; Wyse Jackson and Sutherland, 2000; Global Strategy for Plant Conservation, 2002). The growing interest of botanical gardens in conservation efforts is clearly documented in the recent establishment of specialised collections (Fig. 2).

In 1987 IUCN established the Botanical Garden Conservation Secretariat (BGCS) based in London to coordinate and promote the role of botanical gardens in conservation. In 1994 BGCS became independent of IUCN as Botanical Garden Conservation International BGCI. BGCI has currently about 800 botanic gardens members from more than 80 countries. BGCI is not the only international organisation to coordinate botanical garden activities. Several other agencies exist, e.g. “The International Association of Botanical Gardens” (established in 1956) and the “American Association of Botanical Gardens and Arboreta”. In Germany, the “Verband der Botanischen Gärten e.V.“ established in 1993.

In expanding their role in conservation efforts botanical gardens are increasingly involved in gene banking of seeds, and in education programs. Botanical gardens with their huge collections on display are the most effective multipliers for increasing public awareness of the value of biodiversity and conservation needs. Yearly, 20 million people are visiting the 350 botanical gardens in the EU. In Germany, the number of visitors is estimated at 14 millions yearly (BfN, 1999). Efforts to display plant species as members of natural communities, reinforces the central role of habitat preservation in conservation.

SEED GENE BANKS

Seed gene banks are the preferred method of ex situ storage (cp. Table 1). It is often seen as the easiest and least expensive way for preserving plant genetic resources. However, the limitations of seed gene banks must be clearly seen (Hawkes et al, 2000; Schoen and Brown, 2001) (Tab. 5).

Traditionally, seed banks play their largest role in the conservation of domesticated plants whereas the main targets in botanical gardens are wild species, especially endangered species, ornamental and medicinal plants. During the last two decades many botanical gardens began to establish seed banks for the purpose of conservation. These range from fully equipped facilities like that of the Royal Botanic Gardens at Kew to simple collections in deep freezers or under medium-term conditions (about 0°C or above). Few seed banks in botanical gardens apply to internationally accepted gene bank standards, which include sampling guidelines, proper documentation, factors controlling longevity during storage, and long-term conditions for orthodox seeds. Sampling strategy and documentation are crucial for the suitability and value of the seed gene bank as plant genetic resources. Based on sampling theory sampling practicalities and guidelines have been developed. The Centre for Plant Conservation (CPC) at St. Louis, Missouri, has published “Genetic sampling guidelines for conservation collection of endangered species” (CPC, 1991), and Botanic Gardens Conservation International has also produced a set of “Guidelines for the ex situ conservation of germplasm by botanic gardens” (BGCI, 1993). The most comprehensive publication for plant germplasm collectors so far are the technical guidelines for collecting plant genetic diversity (Guarino et al., 1995) covering generic as well as specific, and theoretical as well as practical information. Guidelines for the management of orthodox seeds have been published by the Centre for Plant Conservation, St. Louis, Missouri (Wieland, 1995).

The most noteworthy seed gene bank project of botanic gardens is the Millenium Seed Bank Project at the Royal Botanic Gardens Kew. It aims to store 10 % of the world’s plant diversity, concentrating on species of the dry tropics as well as all plant species native to Great Britain. Similar efforts though less ambitious are underway in North America sponsored by the Centre for Plant Conservation at the Missouri Botanical Garden in St. Louis, and regional initiatives are being carried out in many parts of the world. In Germany, ex situ conservation of wild plants is still in its infancy. The integration of the seed gene bank of the BFA für Züchtungsforschung in Braunschweig into the gene bank of the IPK Gatersleben does explicitly exclude wild plant species (with the exception of wild relatives of crop plants). Wild plants should be the target of botanical gardens, but many nature agencies in Germany – governmental and non-governmental organisations - are still not in favour of ex situ conservation of wild plants. Recently, however, the German Federal Agency for Nature Conservation BfN has argued for integrating in situ and ex situ measures in nature conservation (BMVEL, 2002).

The aim of a seed gene bank in a botanical garden is not to compensate for in situ conservation. The foremost aims for seed gene banks for wild plant species are (1) providing proper seed material for reintroduction programs and reinforcement of endangered populations at their natural site; and (2) providing genetic resources for research and plant breeding programs. Of the 3,200 wild higher plants in Germany, about 1,000 are already judged as valuable plant genetic resources (BMVEL, 2002), e.g. pest and disease resistance; stress tolerance against temperature, against water, salt and heavy metals; and quantitative characters of high interest for breeders.

There is a growing awareness of the ecological, economic, and cultural significance of wild species and their potential value as genetic resources. In Osnabrück, we have launched an initiative to conserve and protect our natural plant genetic resources and to implement a decentralised network of regional gene banks for wild plants associated with botanical gardens. The Ministry of Science and Culture of Lower Saxony (MWK) has funded adequate storage facilities fulfilling international seed storage standards. In October 2003, the seed gene bank at the Botanic Garden of the University of Osnabrück was officially opened and named "Loki Schmidt-Genbank für Wildpflanzen" to honour her significant contributions to nature conservation. Already 20 years ago, Loki Schmidt was one of the first in Germany to strongly advocate seed gene banks for indigenous wild plants.

CONCLUSIONS

Botanical gardens with their huge collections have high potential for plant conservation efforts. They are the most effective multipliers for increasing public awareness of the value of biodiversity and conservation needs. Botanical gardens can provide information services for science, politics, and the general public. To fully explore their potentials we strongly advocate seed gene bank networks for wild plants fulfilling international gene bank standards. In doing so, botanical gardens can play an active part in integrating in situ and ex situ measures in nature conservation, and in protecting and conserving our plant genetic resources. There is growing awareness of the ecological, economic, and cultural significance of wild plant species. Botanical gardens should be the main authorities for wild plants in displaying natural biodiversity and in plant genetic resources ex situ conservation programs.

Literature Cited

Bermejo, J.E.H., Clemente, M. and Heywood, V.H. (eds.) 1990. Conservation techniques in botanic gardens. Koeltz Scientific Books, Koenigstein, Germany.

BfN, Bundesamt für Naturschutz, ed. 1999. Botanische Gärten und Biodiversität. Landwirtschaftsverlag Münster.

BfN, Bundesamt für Naturschutz, ed. 2000. Beitrag der deutschen Botanischen Gärten zur Erhaltung der biologischen Vielfalt und genetischer Ressourcen. Landwirtschafts-verlag Münster.

BfN, Bundesamt für Naturschutz, ed. 2002. Pflanzensammlungen in Deutschland, Österreich und der Schweiz. Landwirtschaftsverlag Münster.

BGCI, Botanic Garden Conservation International. 1993. Guidelines for the *ex situ* conservation of germplasm by botanic gardens. Botanic Garden Conservation International and Cabildo Insular de Gran Canaria. Las Palmas, Gran Canaria.

BMVEL, Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, ed. 2002. Nationales Fachprogramm zur Erhaltung und nachhaltigen Nutzung pflanzen-genetischer Ressourcen landwirtschaftlicher und gartenbaulicher Kulturpflanzen. Bonn.

Botanic Gardens Conservation Strategy. 1989. IUCN Botanic Gardens Conservation Secretariat, Richmond, UK. WWF and IUCN, Gland, Switzerland

Bramwell, D., Hamann, O., Heywood, V. and Synge, H. 1987. Botanic gardens and the world conservation strategy. Academic Press, London.

CBD, Convention on Biological Diversity, 1992. United Nations Conference on Environment and Development. Rio de Janiero

CPC, Centre for Plant Conservation at St. Louis, Missouri. 1991. Genetic sampling guidelines for conservation collection of endangered species. p. 209–238. In: Falk, D.A. and K.E. Holsinger (eds.), Genetics and conservation of rare plants, Oxford Univ. Press, New York.

Falk, D.A. and Holsinger, K.E. 1991. Genetics and conservation of rare plants. Oxford Univ. Press, New York.

FAO, Food and Agricultural Organization. 1998. The state of the world's plant genetic resources. FAO, Rome Global Strategy for Plant Conservation. 2002. Secretariat of the Convention on Biological Diversity (CBD, UNEP) in association with Botanic

Gardens Conservation International (BGCI).
Guarino, L., Ramanatha Roa, V. and Reid, R. (eds.) 1995. Collecting plant genetic diversity. Technical guidelines. CAB International, Wallingford, Oxon, UK
Hawkes, J.G. 1987. A strategy for seed banking in botanic gardens. p. 131–149. In: Bramwell, D., O. Hamann, V.H. Heywood and H. Synge (eds.), Botanic gardens and the world conservation strategy, Academic Press, London.
Hawkes, J.G., Maxted, N., Ford-Lloyd, B.V. 2000. The *ex situ* conservation of plant genetic resources. Kluwer Acad. Publ. Dordrecht.
Heywood, V.H. 1991. Developing a strategy for germplasm conservation in botanic gardens. p. 11–23. In: Heywood, V.H. and P.S. Wyse-Jackson (eds.), Tropical botanic gardens: Their role in conservation and development,. Academic Press, London.
Heywood, V.H. 1992. Conservation of germplasm of wild species. p. 189–203. In: Sandlund, O.T., K. Hindau and A.H.D. Brown (eds.), Conservation of biodiversity for sustainable development, Scandinavian Univ. Press, Oslo.
Heywood, V.H. and Watson, R.T. 1995. Global biodiversity assessment. Cambridge Univ. Press for the United Nations Environment Program UNEP, Cambridge.
Hurka, H. 1994. Conservation genetics and the role of botanical gardens. p. 371–380. In: Loeschcke, V., J. Tomiuk and S.K. Jain (eds.), Conservation Genetics. Birkhäuser Verl., Basel.
Hurka, H. 2000. Die Rolle der Botanischen Gärten bei der Erhaltung der pflanzengenetischen Vielfalt. Bundesamt für Naturschutz, BfN. Landwirtschaftsverlag Münster. Schriftenreihe für Vegetationskunde 32, 101–110.
Keller, T., Korn, H., Schmid, H. and Weisser, Ch.F. 2002. Chances and limitations of „*ex situ*“ conservation of species and genetic diversity on a global perspective. Bundesamt für Naturschutz, BfN, ed. Landwirtschaftsverlag Münster.
Schoen, D.J., Brown, A.H.D. 2001. The conservation of wild plant species in seed banks. BioScience 51: 960-966.
Ten Kate, K. and Laird, S.A. 1999. The commercial use of biodiversity: access to genetic resources and benefit sharing. Earthscan, London.
WCMC, World Conservation Monitoring Centre. 1992. Global biodiversity: status of the earth’s living resources. Chapman and Hall, London.
Wieland, G.D. 1995. Guidelines for the management of orthodox seeds. Centre for Plant Conservation, St. Louis, Missouri, U.S.A.
WRI, IUCN and UNEP (World Research Institute, International Union for Conservation of Nature and Natural Resources, United Nations Environment Program). 1992. Global biodiversity strategy: guidelines for action to save, study and use Earth’s biotic wealth sustainable and equitably. WIR, World Research Institute, Washington DC.
Wyse Jackson, P.S. and Sutherland, L.A. 2000. International Agenda for botanic gardens in conservation. Botanic Gardens Conservation International, U.K.

Tables

Table 1. Conservation strategies and techniques (modified from Hawkes et al., 2000).

Strategies	Techniques	Definition
Ex situ conservation	• Seed storage	Transfer of seed samples to a gene bank for storage.
	• In vitro Storage	Tissue culture in a sterile, pathogen-free environment.
	• Field Gene Bank	Cultivation at a second site.
	• Botanic Garden/Arboretum	Collections of species in a garden or for tree species an arboretum.
	• DNA/Pollen Storage	DNA or pollen storage in appropriate conditions.
In situ conservation	• Genetic Reserve	Management of genetic diversity in natural wild populations within defined areas designated for active, long-term conservation.
	• On-farm	Management of locally developed traditional crop varieties by farmers within traditional cultivation systems.

Table 2. Foundation of Botanical Gardens.

16th Century	17th Century	18th Century	19th Century	Recently in Germany
Pisa (1543)	Copenhagen (1600)	Moskau (1706)	Sydney (1816)	Bayreuth (1978)
Padua (1545)	Paris (1626)	St. Petersburg (1714)	Bogor (1817)	Düsseldorf (1979)
Leipzig (1580)	Oxford (1632)	Mauritius (1733)	(= Buitenzorg)	Ulm (1981)
Jena (1586)	Uppsala (1657)	Vienna (1754)	Melbourne (1853)	Osnabrück (1984)
Leiden (1587)	Berlin (1679)	Kew Gardens (1759)	St. Louis, Miss. (1859)	
Basel (1588)	Cape Town (1694)	Madrid (1781)	Christchurch (1863)	
Heidelberg (1593)			New York (1891)	
Montpellier (1593)				

Table 3. Some examples for number of taxa housed in Botanical Gardens.

Botanical Garden	Number of Taxa
Royal Botanical Gardens Kew	34,000
Botanical Garden Berlin-Dahlem	20,000
Royal Botanical Garden Edinburgh	17,000
New York Botanical Garden	15,000
Botanical Garden Munich	14,000
Frankfurt Palmengarten	13,000
St. Petersburg	12,000
Sydney	11,000

Table 4. Potentials, value and limitations of plant genetic resources in Botanical Gardens.

Potentials and value	Limitations
• largest assemblage of biodiversity outside nature	• imbalanced representation of natural biodiversity
• 80,000–100,000 species are cultivated	• poor initial sampling and documentation
• ~15,000 plants globally threatened with extinction are maintained , representing some 30% of known threatened species	• poor maintenance of collections, genetic erosion
	• strong financial pressure
• remarkable potential to contribute to plant conservation	• certain percentage of taxonomic mislabelling

Table 5. Advantages and Disadvantages of Seed Gene Banks (modified from Hawkes et al., 2000).

Advantages	Disadvantages
• Efficient and reproducible	• Problems of storing seeds of 'recalcitrant' species
• Feasible for medium and long-term secure storage	• Freezes evolutionary development
• Wide diversity of each target taxon conserved	• Genetic diversity may be lost with each regeneration cycle (but individual cycles can be extended to periods of 20-50 years or more)
• Easy access for characterisation and evaluation	
• Little maintenance once material is conserved	

Figures

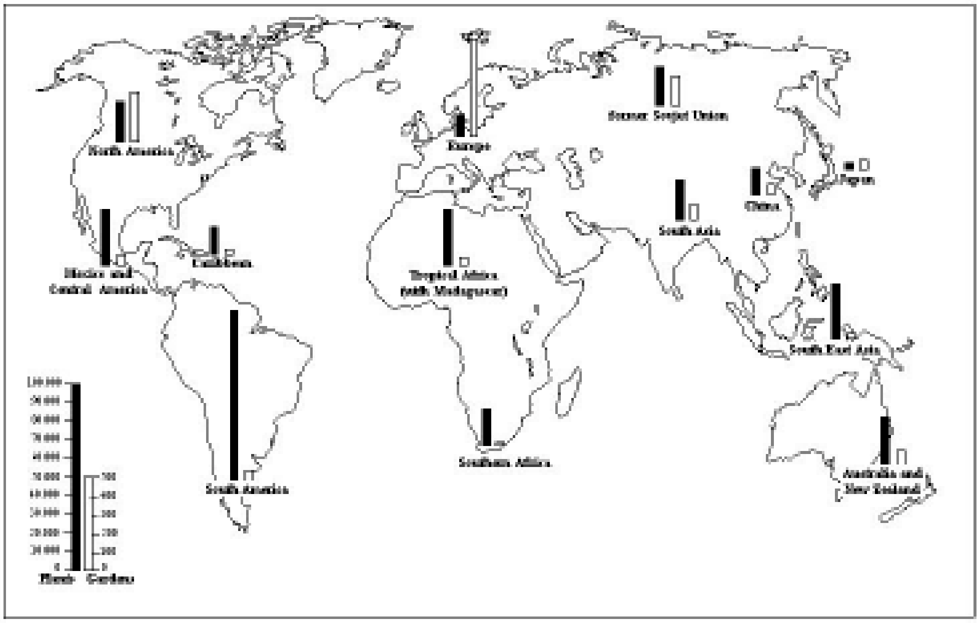

Fig. 1. World distribution of plant species and botanical gardens. (Modified from Botanical Gardens Conservation Strategy, 1989).

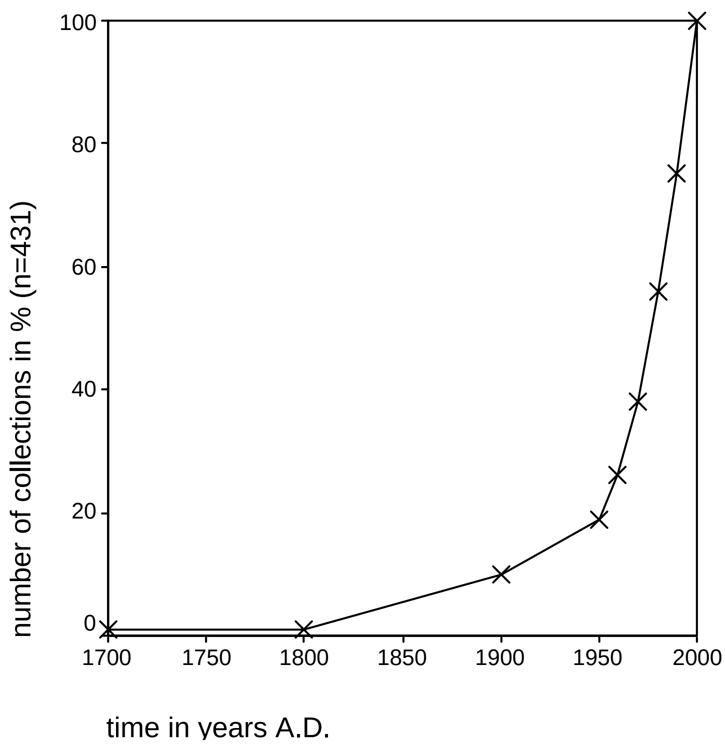

Fig. 2. Frequency (in %) of specialized collections in botanical gardens in Germany, Austria and Switzerland from 1700–2000 A.D. (n=431). (Data from BfN, 2002.)