Future scientific research in botanic gardens

Huang Hongwen

South China Botanical Garden/South China Institute of Botany andBotanical Garden Working Committee, Chinese Academy of Sciences, Guangzhou, Guangdong, China

Introduction

Plants are the core component of biodiversity on earth. They are the primary source of material for human living and sustainable economic productivity, as well as the ultimate guarantee for the environment that the survival of humankind depends upon. They are also the basic sources for provision of human necessities including food, timber, oil, medicine and source of spiritual needs. So far we have only explored and utilized a small amount of all plant species, the potential of the vast majority of wild plants has yet to be understood and is still beyond human knowledge despite their great economic and social values. Tens of thousands of plants have enormous potential as resources to meet the demands of our daily life for food, clothing, shelter and transport in support of sustainable development; they are a treasure reserve of Mother Nature for all human beings. Although, we depend on plants for our livelihood and socio-economic development, the damage of plants by human activities has reached an unprecedented level so that human survival is gravely threatened.

Currently about one third of the world's 300,000-450,000 vascular plant species face the threat of extinction due to a variety of devastating activities, including over-harvesting, over exploitation by destructive agricultural and forestry practices, urbanization, environmental pollution, land-use changes, exotic invasive species, and the global climate change. It is an even more alarming estimate that up to two thirds of higher plants will have disappeared by the end of this century. (CBD Secretariat, 2003; Pitman & Jørgensen, 2002; BGCI, 2000). The impact of human destructive activities is taking its toll in nature, the current extinction rate of plant species is 2,000-5,000 times faster than would normally occur in nature.

The role of botanic gardens in plant Conservation

An estimated 6,130,900 accessions of living plant collections of more than 80,000 plant species are conserved in about 2,400 botanic gardens around the world. (Wyse Jackson, 2001). An analysis of 445 world major botanic gardens showed that the botanic gardens have cultivated 80,070 species, of which 8,823 were endangered species categorized in the IUCN-1997 Red List (Walter & Gillett, 1998). Obviously botanic gardens in the world have played an important role in *ex situ* conservation. Moreover, 152 botanic gardens in the world are equipped with seed or field bank facilities and *in vitro* collections. These facilitate conservation of at least 255,832 accessions of plant germplasm and 17,069 living plant collections, of which about 77% were collected directly from the wild, and 27% are endangered species (Laliberte, 1997).Botanic gardens are institutions with an integrated function of plant conservation, botanic research and public education. They also serve as life science research centres and an important platform for biodiversity conservation and sustainable utilization of plant resources. In recent years, botanists from all around the world are increasingly facing the challenge of the crisis of rapid reducing plant diversity. Plant conservation has become one of top priorities within the botanic garden communities worldwide. Through the efforts of the parties to the Convention on Biological Diversity (CBD), international organizations and non-governmental organizations, Botanic Gardens Conservation International (BGCI), together with internationally renowned botanists and conservationists, initiated the *Global Strategy for Plant Conservation* (GSPC), which was adopted unanimously at the 6th Conference of the Parties to the CBD at the Hague (Decision VI/9), in April 2002 (CBD Secretariat, 2003). The ultimate and long-term objective of the GSPC is "to halt the current and continuing loss of plant diversity". The GSPC provides a guidance framework for plant diversity conservation at the global, regional, national and local levels. Meanwhile, plant introduction, cultivation and domestication of economic

crops still remain a key role of botanic gardens in contributing to social and economic development, particularly in developing countries.

The roles of botanic gardens in conserving wild plant resources and using plant diversity sustainably in China

One of the major challenges facing humanity in the 21st century is how to resolve the paradox of the increasing demand on plant resources (food, timber, natural medicines, energy, oil, fruit and vegetables, flowers etc) versus our sustainability in the future. The convergence of our knowledge intending to solve this paradox is managed hopefully by developing revolutionary biotechnologies, i.e. exploration of useful genes widely existing in wild plant resources (genes for cold-hardiness, drought-tolerance, disease-resistance, fast-growing and high-yield and quality) in order to develop new super plant varieties to keep pace with the fast and continuing social and economic development. A special gene can affect a country's prosperity, and one important species can affect a country's economy (Li Zhen-sheng, 1996). The botanic research, knowledge and technology innovation and sustainable utilization of plants in a country can be a reflection of the country's overall development and strength. In the 21st century, biological resources may be one of the most crucial resources for global, social and economic sustainability. Whoever possesses rich plant resources, innovative knowledge and new technologies for conservation and sustainable utilization will have a distinct advantage.

China has over 30,000 species of higher plants, representing about10% of the world total. China is one of the countries with the richest plant diversity. China's rich plant diversity is well known in terms of species richness, endemic abundance, paleo-floristic origin and a rich germplasm reservoir of cultivated plants (State Environmental Protection Administration of China, 1998).

However, the sustainable utilization of Chinese plant resources and the sustainable social and economic development in China is increasingly facing challenges due to rapidly depleting plant resources and a deteriorating ecological environment caused by rapid economic development and population growth in the past 30 years. For instance:

- Increasing number of endangered plants: The *China Species Red list* (Wang and Jie, 2004) listed 4,408 Gymnosperm and Angiosperm species as endangered or threatened, accounting for about 14% of total plants in China.

- Accelerated extinction of wild ancestor and relatives of crop plants: The well known examples are wild soybean, wild rice, endemic fruits and vegetables, landscape and garden plants are at a high risk of extinction at an alarming rate.

- Lack of research and development of cash crops from native plant resources: Many developed countries are rapidly developing commercial varieties by using China's endemic plant resources to develop their plant industries, which lead to fruit, vegetable and ornamental varieties, which are widely used in China**.** For example, Yunnan province supplies 80% of the cut flower market in China, but over 95% of these cut flowers are cultivars imported from other countries.

- Fast erosion of plant genetic resources: The loss of genetic diversity and narrowing base of the genetic pool of traditional cultivars and landraces is severe. For example, China had 10,000 wheat cultivars and varieties in 1949, but only 1,000 remained for cultivation in 1970s, and may even be much less at the beginning of 21st century (FAO, 1998).

- Invasion of alien species and ecological degradation has also increasingly impacted on China native flora and ecological health

China highly values the role of botanic gardens in conservation, building a national reserve of plant resources, and sustainable utilization. With the enhancement of infrastructure and capacity, botanic gardens have been

designated as research and development centres for conservation and sustainable utilization of plant resources. The Chinese Academy of Sciences (CAS), as the principal national academic organization in natural science in China, is dedicated to the exploration, utilization and conservation of strategic plant resources since its establishment in 1949. The CAS botanic gardens are designated as a essential organisations for exploration and utilization of plant resources. Now there are 14 botanic gardens under the management of CAS or jointly by CAS and local government including South China Botanical Garden (SCBG), Wuhan Botanical Garden (WBG), Xishuangbanna Tropical Botanical Garden (XTBG), Beijing Botanical Garden (BBG), Nanjing Botanical Garden, Kunming Botanical Garden (KBG), Turpan Botanical Garden, Shenyang Arboretum, Dinghushan Arboretum, Guilin Botanical Garden, Lushan Botanical Garden, Qinling Botanical Garden, West China Subalpine Botanical Garden, and the Three Gorges Botanical Garden. Of which, five (Nanjing Botanical Garden, Guilin Botanical Garden, Lushan Botanical Garden, Qinling Botanical Garden and the Three Gorges Botanical Garden) are under the joint managment with the local government and one is a national nature reserve (Dinghushan Arboretum). These 14 botanic gardens are distributed over 10 provinces (or autonomous regions) in China, occupying a total area of 13,500 hectares.

Up to 2004, CAS botanic gardens collected and conserved *ex situ* about 20,000 vascular plant species, accounting for approximately 90% of all plant species maintained by all Chinese botanic gardens, which demonstrates that CAS has attained the target of conserving at least 60% of the China's native flora and provided an important reserve of plant resource for sustainable economic development in China. CAS also established 90 specialized gardens, which created a solid foundation for botanic garden research, conservation and utilization of plant resources, as well as public education in China. These efforts also greatly contributed to global conservation of plant germplasm.

Plant resources introduced, conserved and evaluated by botanic gardens under CAS have made a significant contribution to developing new industries, fostering new economic growth and enhancing economic development. Historically, in plant introduction and new cultivar development, CAS botanic garden research had made many significant innovations and transferring technology to agricultural and industrial developments in China. Many new cultivars of plant resource in current agricultural industries are derived from knowledge and technical support from early research conducted by CAS botanic gardens. For example, KBG successfully introduced the "Golden Dollor" tobacco cultivar from the USA. This introduction and subsequent cultivar improvement substantially changed the cultivar structure of tobacco production in Yunnan, and made a significant contribution to the tobacco industry in the Yunnan province. A SCBG's 30-year research programme of introduction and evaluation of sandalwood (*Santalum album* L.) has filled the gap of sandalwood production in China; The research achievement of Chengdu Diao, a CAS founded enterprise, in the development of a cardio-vascular drug, and the subsequent formation of the Chengdu Diao medicine cooperation was originally initiated from a survey and R&D on peltate yam (*Dioscorea zingiberensis*) resources in China by CAS botanic gardens during the Seventh and Eighth Five-Year National Economic Plan periods. BBG developed about 10 high-quality grape varieties which has resulted in these varieties being widely cultivated in commercial production of hundreds of thousands of hectares and great economic benefits to theChinese grape industry and growers. XTBG's project on the "Rubber-Tea inter-cropping system " resulted in a total plantation area of about 133,000 hectares, contributing significant benefits in economic, ecological and social aspects. The new resource of dragon-blood plants (*Dracaena cochinchinensis* (Lourt) S.C. Chen) discovered by XTBG ended the history of the importat of such herb medicines for China, with a dozen Chinese pharmaceutical factories manufacturing this Chinese traditional medicine regarded "King drug for blood circulation". WBG bred and selected a series of new kiwifruit (*Actinidia*) and lotus (*Nelumbo nucifera* Gaertn) root varieties, which has become the major varieties widely grown for fruit and vegetable production in China. A recently developed new yellow-flesh kiwifruit variety of Jintao has been patented in Europe and South America and the propagation right was licensed for 28 years worldwide. The cultivar has now been promoted in the European kiwifruit production and marketing; this is the first good model of China's intellectual property in terms of new crop varieties transferred to the international market. More importantly, the new kiwi fruits developed in China have changed the rangeof varieties used in global kiwifruit production. Subsequently, a 3R model "Resource, Research, and Resolution" for the sustainable use of plant resources has been formulated within CAS botanic gardens.

Since 1998, with the re-evaluation of the global view of China's role in plant conservation and using plant diversity sustainably, CAS developed a new strategy for botanic garden research and formulized a 5-years master plan forward CAS botanic garden development into the 21st century. Subsequently, CAS re-organized

its botanic gardens and designated three National Core Botanic Gardens and also promoted the concept of Scientific Botanic Gardens. CAS encapsulates its efforts for enhancement of its botanic gardens as a *Supporting Platform for Innovation Research in Life Science*, so as to be in line with leading international botanic gardens. CAS initiated a *Knowledge Innovation Programme in Botanic Gardens* at the three core gardens, namely XTBG, WBG and SCBG. This marked the idea of establishing a National Scientific Botanic Garden in China. As the projects continue successfully, the capacity in science and technology innovation have shown great improvement in these core botanic gardens.

In terms of the conservation of plant resources, the core botanic gardens have reinforced their efforts in *ex situ* conservation; collection and conservation of resource-plant species have been extensively enhanced. XTBG increased its number of species under *ex situ* conservation from about 4,000 in 2002 to about 10,000 in 2005, in which 8,518 have been identified correctly. Thus XTBG becomes the first garden in China to conserve 10,000 plant species and one of the few botanic gardens in the world with such a large number of plant species in living collections. WBG increased its number of species in *ex situ* from about 4,000 in 2002 to about 8,000 today. It also built the largest aquatic plant collection and the largest *Actinidia* (kiwi fruit) germplasm repository in the world. SCBG increased its number of species from about 4,500 in 2002 to more than 10,000 in 2006. All these core botanic gardens have become important centres in China to conserve strategically important plant resources. With their species conservation standard pegged to that of international first-class botanic gardens, these core botanic gardens are also an important resource platform to serve social and economic sustainable development in China.

In terms of science and technology innovation, while the academic targets are being refined, the CAS core botanic gardens strengthened their capacity for science and technology innovation in many scientific disciplines and in delivery of technologies to society. Since the initiation of the innovation programme, the core botanic gardens of XTBG, WBG and SCBG have attracted more and more prestigious research funds of “863”, “973” national programmes, Natural Science Foundation of China, and other provincial, city and ministries. These botanic gardens have also received over 20 national, provincial and city awards since then. By 2006, the three core botanic gardens published over 300 SCI articles in journals such as *Science*, *Nature*, *Am. J. Bot*, *Ann. Bot*, *Conservation Biology* and *Global Change Biol*, five times higher than that in 2001. In 2002, WBG and others published an article in *Science* to present the strategies and action plans of China's native plant conservation. The article raised substantial attention from related international experts and academics. In 2001, XTBG published another article on systematic research and the name of a new pollination mechanism, "Flexistyly” pollination mechanism in *Nature*, which aroused attention from international biologists in pollination study. In 2004, SCBG published an article also in *Nature* to report the discovery of a new self-pollination mechanism - by “sliding pollen”. It, too, aroused considerable attention from international biologists.

The above 3 core botanic gardens have applied for over 100 patents and have been granted 50 patents. In recent years, they have developed and released more than 40 new cultivars or varieties for agriculture, forestry and horticulture industries. Most of these new varieties have contributed new developments to the industries.

The initiation of the *Knowledge Innovation Programme* at CAS core botanic gardens have not only stimulated science and technology innovation within CAS botanic gardens, but also provided guidance to other Chinese botanic gardens and played a leading role for healthy development in botanic gardens all over China. Furthermore, these core botanic gardens will play an important role in the international botanic garden community and a leading position in Asian botanic gardens which is greatly appreciated.

Future scientific research in China’s botanic gardens in the 21st century

Although thebirth of the “garden” could date back to Yin-Zhou dynasty in China, more than 3000 years ago, the modern concept of a botanic garden originated in Europe, with a history of about 460 years (Italy's Padova Botanic Garden was built in 1545). In general, scientific botanic gardens in a modern sense, started from the collection, evaluation and display of medicinal plants. The expansion started when the West began its colonization across the world, where plants were collected, introduced, domestication, utilized and studied in an unprecedentedly large scale. About a century ago, botanic gardens gradually settled to be integrated

scientific institutions to conduct botanic research. In the 19th century for example, the botanic research conducted by scientific botanic gardens, such as comparative morphology and comparative anatomy, made important contributions to the foundation of modern plant science. For example, in the 19th century and early 20th century, the Engler plant classification system was developed (Raven, 1981). Also, to a certain extent, most of the original research on agricultural or forestry species (even medicinal plants) and plant breeding resources stem from plant collection, evaluation and research in the early history of botanic gardens. There is a strategic need to think deeply about the research focus and direction of Chinese botanic gardens in the 21st century from a global perspective of plant resource conservation and sustainable utilization. As Wagner stated (1972), "A botanic garden without scientific research is just a park. A botanic garden with scientific research plays an important role in social development." Moreover, modern life science has entered the era of molecular biology. Scientific researches of traditional botanic gardens now face a great opportunity as well as a serious challenge, particularly in the aspect of macro-botanic research.

1. Research scope and targets of Chinese botanic gardens in early 21st century

Chinese botanic gardens should take into account the current status of China's native resources and the nationwide needs in shaping their position. While they should focus on the safety of plant resources and the sustainable utilization of plant resources in China, they should also support the sustainable development of thenational economy and the establishment of a harmonious society in China. Botanic gardens should reinforce the construction of specialized gardens of endemic and native plant resources (especially plants with economic and environmental potential). Focus should be placed on the selection, evaluation, sustainable utilization and research of critical plant resources that are required by China's various biological industries.

- The scope and targets of the Chinese botanic garden system should be focussed on the basis of current plant resource collections, conservation and research; the focus should shift from germplasm collection and conservation to the discovery and sustainable utilization of useful resources. The main principle should be securing quantity, improving quality, enhancing discoveries and encouraging utilization.

- In order to enhance scientific exchange and data sharing nationally and internationally, a national scientific criterion system for the strategic conservation reserve of plant resources and sustainable utilization practices in the Chinese botanic garden network (including establishment of a digitalized botanic garden system) should be formulated and developed.

- The national conservation network should be strengthened to cover at least 80% of all native plant resources in China (about 30,000 higher plant species). This makes China one major platform of the international system of biodiversity conservation; and to be a key component and leader in the sustainable utilization of biological resources.

- Chinese botanic gardens should take advantage of their accumulated research experience and the fact that China accounts for about 10% of total number of plants in the world. Chinese botanic gardens should take a leading role in the East Asia botanic garden network, and strengthen its role in guiding those neighbouring countries which are dedicated to Asian plant resource research.

2. Strengthen capacity and scientific research in Chinese botanic gardens

A) The construction of specialized gardens and related scientific research

To keep pace with social and economic development in China, Chinese botanic gardens should further reinforce the construction of practical specialized gardens on the basis of current plant collections and enhance plant germplasm evaluation and discovery of useful plant genetic resources to meet China's social and economic development.

- Medicinal plant gardens: Considering the growing demand for health care by the Chinese population, and on basis of the geographic distribution of medicinal plants and the traditional status of Chinese medicines, the construction of medicinal plant gardens and the discovery and research on medicinal plant resources should be reinforced. Botanic gardens should focus on the research of medicinal plant

resources that can serve as a health supplement, tonic or special regulatory medicine and provide such information and products to the industry and the society.

- Industrial bio-energy plant gardens: Considering the demand of energy source in China, the construction of gardens for industrial bio-energy sources and research on bio-diesel plants should be enhanced. Botanic gardens should focus on the research of bio-diesel plant resources that are rich in carbon-hydrogen content. Research on bio-diesel plant screening, evaluation and cultivation and applications for industrial uses should be encouraged.

- Landscaping and ornamental plant gardens: Considering the demand of urban landscape development and environmental improvement in China, with the history of China's abundant endemic ornamental plant resources, the construction of gardens for landscaping and ornamental plants should be reinforced. Botanic gardens should conduct research on new cultivars of flowers, landscaping plants and turf that will be suitable for different climate zones in China and for commercial production.

- Special fruit and vegetable gardens: Considering the demand for food quality and diversity from national development of well-off society in China, botanic gardens should discover more native plant resources so as to reinforce the construction of fruit and vegetable gardens, to develop and release new varieties of fruits and vegetables (such as special aquatic vegetables and healthy, medicine-functional fruit and vegetables).

- Specialized gardens of plant collections for degraded habitat restoration and environmental melioration: Considering the demand for massive constructions in China, resulting in the damage to the environment especially caused by mining, large-scale construction projects and urbanization, with the background in the selection and genetic improvements of pioneer native plants in China, botanic gardens should set up specialized gardens to conduct research on useful tree and shrub species and improved varieties.

B) Research and development platform of molecular biology that supports research in life sciences and modern comparative biology should be enhanced

For more than 400 years of modern biology development, scientific botanic gardens have made significant contributions to comparative biology research, e.g. traditional comparative morphology, comparative anatomy and comparative physiology, etc. Modern life science and biotechnology researches have now entered into an era of molecular level research. The substantial resource materials held by botanic gardens will provide valuable material and common-garden or intra-region research venues for the modern frontier of life sciences, such as comparative functional genomics, comparative phytochemistry, comparative proteinomics. Also, research on model genes and model plant species discovery should be considered in botanic gardens by taking account of enriched plant resources in *ex situ* collections. Intellectual property rights for new genes and new model species will be obtained so that the botanic gardens will become a fundamental research platform that will support China's modern life science and biotechnology.

C) Construction of digitalized botanic gardens

A germplasm collection management system and an information sharing system for a National Botanic Garden System of China should be set up in order to enhance the resource management within the botanic garden network, improve the efficiency on application, R & D, and information exchange, and raise the level of popular science education of the public media.

- Set up a National Botanic Gardens information management protocol (policies and technical standard)

- Set up a digitized platform (geographic information system) on information management covering all members of Chinese botanic gardens

- Set up a National Botanic Gardens popular science education website (public service)

- Set up a wireless Intranet within all National Botanic Gardens in China (the information system should cover whole boundaries of the botanic garden)

3. Priority of important research targets

The extent of conservation on of existing biological and genetic resources is strong proof of the sustainable development of China's economy and society. Certain key research targets should be greatly enhanced and prioritized in China, such as implementation of *ex situ* conservation for plant communities structures and the scientific basis for sustainable reproduction in garden *ex situ* conservation; the genetic mechanism and population eco-genetic equilibrium of inbreeding or outbreeding depression resulting from species co-existence in the process of genetic enhancement in garden cultivation; the genetic mechanism, community reproduction and structural stability of the ecological adaptability for endangered species when returned to their natural habitats. These science-based researches should enhance botanic gardens in China, as a reserve for strategically important plants to accomplish the conservation goal of covering over 80% of native plant species and half a million special genetic accessions in garden *ex situ* conservation. This in turn guarantees the safety of China's biological and genetic resources. There is also a need to set up a phytochemical-resource bank for China's medicinal plants, a DNA bank for rare, endangered and endemic plants, and related data information management. All these will be in support of knowledge innovation and valuable raw materials for the development of relevant biological industries in China. It is necessary to conduct research and development for the sustainable utilization and effective models for economic plants which are urgently needed by biological industries in China. Such research and development should reach the standard of industrial testing. Below are some important research topics and directions that should be developed with priority in the near future:

- Theories and practices of plant genetic enrichment in garden *ex situ* conservation
- Population genetic basis of plant resource conservation and sustainable utilization of the garden conserved genetic resources
- Plant resource recovery and its ecological functions
- The impact of botanic bio-safety and plant resources on the global environment changes
- Theories and practices of integrated conservation for plant genetic resources

4. China's National Centurial Survey of Plant Resources and the compilation of Country Report on the Current Status of China's Plant Resources

The currently available information on China's plant resources and the published *Flora of China* was mainly based on specimen data from the last mid-century while some even came from specimen information gathered by overseas botanists in the early 19th Century. With the inadequacy and inaccuracy of information on the current status of plant resources in China, the current information is largely out of date for practical use consistent with the state policies of *Scientific Development Concept* and *Building a Harmonious Society* put forth by the Chinese Government. The initiation of the *National Centurial Survey of Plant Resources* is one of the urgent tasks in China's botanic research. The centurial survey will result in the completion of the Country Report on the *Current Status of China's Plant Resources* that should provide a solid scientific basis for the formulation of China's social and economic development strategies. The goal of the centurial survey will: 1) obtain an accurate information of status of plant resources in China after the rapid economic development over the past 25 years, and compile a Country Report on the *Current Status of China's Plant Resources*; and subsequently, compilation of the ongoing advisory report on *Monitoring Changes of China's Plant Resources* in every 3-5 years; 2) enrich the specimen collections in China's National Herbariums; 3) enhance capacity for

a young generation of experienced field botanists and taxonomists; 4) provide baseline data for new editions of Floras and vegetations of China.

To conclude, the botanic gardens in China are undertaking to secure the safety of China's plant resources and ensure the sustainable use of these resources. They are irreplaceable in achieving these two missions. Meanwhile, through further refining the research scope in botanic gardens as well as strengthening both the networking and research facilities for botanic gardens in China, the safety of plant germplasm resources in China, especially endemic plants, critically endangered plants, species with high economic or scientific research value, and keystone species in major ecosystems in China, but also the research and sustainable utilization of China's plant germplasm resources can be realized, and provide a solid foundation for the sustainable utilization of plant resources.

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