

BGCI Technical Review

The economic, social and environmental impacts of botanic gardens

BGCI





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Paul Smith & Yvette Harvey-Brown

The authors gratefully acknowledge the advice and information received in compiling this report from BGCI's International Advisory Council members Graciela Barreiro, Stephen Blackmore, Richard Deverell, Gerard Donnelly, Jean Franczyk, Ren Hai, Yonghong Hu, Emiliano Sanchez Martinez and Christopher Willis.

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BACKGROUND

In 2017, at the request of BGCI's International Advisory Council, BGCI produced a Technical Review on defining the botanic garden, and how to measure performance and success (Smith and Harvey-Brown, 2017). This study was based on the results of an online survey that BGCI carried out early in 2017 entitled 'Defining botanic gardens and key performance indicators'. In addition, a literature survey of botanic garden annual reports was undertaken to gather further data on how gardens measure success. In total, data was gathered from over 200 gardens in more than 50 countries.

In carrying out this survey and review, it became clear that too few botanic gardens measure the impacts of their work. Instead, there is a strong tendency to measure areas of activity. For example, the review found that nearly all the gardens that were assessed measured visitor numbers but only half of the gardens measured visitor attitudes (usually visitor satisfaction) or changes in visitor behaviour following a visit. Similarly, while monitoring and curation of collections was carried out by three quarters of the gardens surveyed, many fewer gardens recorded the use of their collections by third parties, and in many cases the kinds of uses were not recorded. In short, the 2017 Technical Review revealed a gap in best practice by botanic gardens – the need to measure impact rather than activity.

INTRODUCTION

For the purposes of this study, we have broadly categorised the results of the activities of botanic gardens into **economic, social and environmental impacts**. Wherever possible, this Technical Review has highlighted case studies where impact evaluation studies have been carried out by objective, third parties - usually auditors, consultants or academics.

The results of such studies are useful to policymakers and funders because they enable decision makers to weigh up the **cost: benefit ratio** or **return on investment** associated with particular activities carried out by botanic gardens. Such studies are useful to botanic garden leaders for the same reasons. They can be used to persuade funders and influencers that botanic gardens are institutions that are worth supporting.

For small gardens that are unable to invest in studies of this kind, the principles and case studies illustrated in this Review may be useful in general terms by persuading supporters that botanic gardens are sound investments even if impacts can't be measured precisely for a particular institution.

Barney Wilczak

1. THE ECONOMIC IMPACTS OF BOTANIC GARDENS

Ian Harvey-Brown

1.1. Introduction

Economic return on investment or impact studies are attractive to national governments, local municipalities and statutory funders of botanic gardens because monetary measures are easily integrated into budgets and the business models that governments increasingly use to justify their public spending. Similarly, corporate sponsors and philanthropic organisations have to justify their investments to their shareholders or trustees and, compared to social and environmental benefits, economic benefits are relatively easy to measure.

1.2. Measures of economic impact

The contribution of a botanic garden to the local and national economy is measured in a number of ways, including:

- As visitor attractions, bringing tourists and day trippers from outside the region with significant spill over spending that benefits the wider community
- As employers and purchasers of goods and services
- As initiators of capital investment which supports a significant volume of local economic activity
- As organisations that enhance the aesthetic and recreational value of a neighbourhood, increasing the value of nearby properties, and local government income attached to taxes etc.

In addition, although harder to measure, economic impact studies may include activities such as:

- Educational and training impacts where, for example, fee-paying students are attracted from outside the region and where skills are acquired for the local economy
- Scientific research, where research activities attract external funding and skills for the local economy

Ian Harvey-Brown

Finally, attempts have been made to assess the financial value of scientific collections in terms of the costs involved in building such collections as research infrastructures, analogous to the books in a library. Such calculations can be valuable in articulating the level of investment that has already been made by previous administrations or generations – particularly if budgets for continuing to build or maintain those collections are in danger of being cut.

1.2.1. The economic value of botanic gardens as visitor attractions

Botanic gardens are major tourist attractions, successfully competing with other tourist destinations worldwide to attract a large number of visitors. For example, Singapore's two botanic gardens attracted more than 10 million visitors last year and, collectively, it is estimated that the world's botanic gardens attract 500 million visitors each year (Mounce *et al.*, 2017). These impressive numbers highlight the contribution that botanic gardens make to their region's economy.

CASE STUDY 1.1

The economic value of botanic gardens as visitor attractions

Greater Philadelphia Gardens (GPG), a consortium of more than 30 public gardens, arboreta and historic landscapes within 30 miles of Philadelphia, commissioned Econsult Solutions, Inc. (2017) to evaluate their input to the regional economy, including the impact of attracting visitors from outside Philadelphia. GPG member gardens annually attract approximately 2.5 million visitors and, importantly, it was found that a large proportion of these visitors were from outside the Philadelphia region, and have a high disposable income. Ancillary visitor spending (money spent on services outside GPG member gardens) was calculated to be approximately $37 million annually (for example in hotels and restaurants), bringing significant economic benefits to the region and demonstrating the vital role of GPG member gardens in attracting visitors to Philadelphia.

1.2.2. The economic value of botanic gardens as employers and purchasers of goods and services

A direct contribution that botanic gardens make to regional economies is through the employment of staff and the purchase of goods and services. In many areas, botanic gardens are major employers. Kadoorie Farm and Botanic Garden in Hong Kong employs over 200 staff and Missouri Botanical Garden in the USA over 400 (Kadoorie Farm and Botanic Garden, 2017; Missouri Botanical Garden, 2018). As botanic gardens continue to develop and refine their role within society, they are increasingly seeking expertise not traditionally found within their institutions. For example, in recent years there has been a significant increase in the number of concerts and art exhibitions being held at botanic gardens (Gratzfeld, 2016). Skills now commonly sought by botanic gardens include communications, events management, hospitality, and marketing.

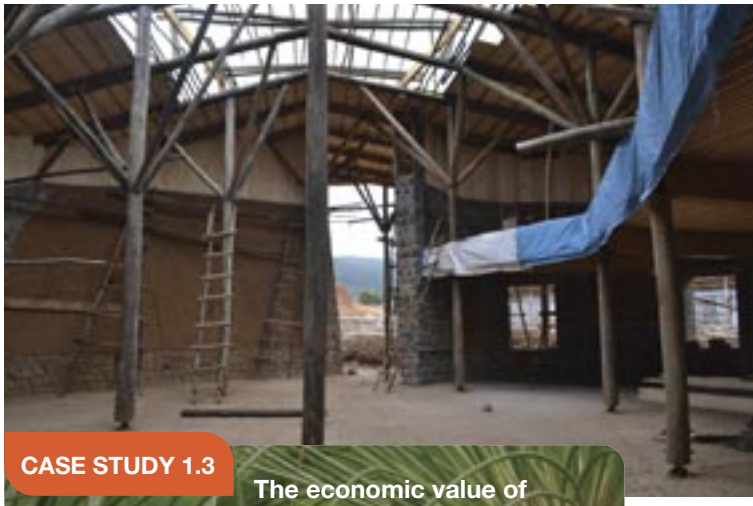
CASE STUDY 1.2

The economic value of botanic gardens as employers and procurers of goods and services

The Royal Botanic Garden Edinburgh spends £11.23 million per year on staff salaries, procurement of goods and services from suppliers, and other items. Over 99% of this expenditure is spent within Scotland, therefore directly benefiting the Scottish economy (ARCADIS, 2016).
The Royal Botanic Garden Edinburgh actually comprises four separate gardens in different regions of Scotland, ensuring that these benefits are spread across the country and not just restricted to Edinburgh.

1.2.3. The economic value of botanic gardens as investors in capital infrastructures

Botanic garden collections often need to be housed in specialist buildings such as greenhouses, herbaria, fungaria and seed banks. When these buildings are built or need upgrading, they require specialist teams and materials.



CASE STUDY 1.3

The economic value of botanic gardens as investors in capital infrastructures

From 2013-2018, the Royal Botanic Gardens (RBG) Kew's Temperate House cost £41 million to restore, and involved 400 staff members and contractors taking 1,731 days to complete (RBG Kew, 2018a).

Over a three-year period, Greater Philadelphia Gardens invested approximately $116 million in construction projects. This activity supported construction-related jobs (1,460 jobs with $96 million in earnings), created demand for various goods and services, and generated state wide taxes (Econsult Solutions Inc., 2017).

CASE STUDY 1.4

The total economic impact of botanic gardens

The Cincinnati Zoo and Botanical Garden commissioned The Economics Center (2013) to calculate its annual economic impact on the region at large by taking into account the impact of visitor spending ($60.4 million), capital projects ($20.9 million) and spending on operations ($61.7 million). The total annual economic impact of Cincinnati Zoo and Botanical Garden was therefore calculated at $143 million, nearly 3.9 times the organisation's spending. The Zoo and Botanical Garden created 1,700 jobs and produced $51.7 million in household earnings and benefits for people on and off site annually.

Similarly, but at a smaller scale, St. Norbert College's Center for Business and Economic Analysis (2016) was contracted by the Green Bay Botanical Garden to calculate the total economic impacts of their operating, visitor and capital expenditures. The total annual economic impact of the botanic garden to Northeast Wisconsin was calculated at nearly $6 million and it was estimated that the garden generated 83 jobs throughout the region. This report was used to leverage funding to expand the garden.

1.2.4. The economic value of botanic gardens in enhancing the aesthetic and recreational value of a neighbourhood

The aesthetic and recreational value of gardens is frequently reflected in the purchase value of nearby properties. Increased property prices not only benefit local residents, they also result in increased property taxes for local government, providing a very tangible return on any initial investment made in establishing the gardens.

CASE STUDY 1.5

Botanic gardens enhancing the economic value of the local neighbourhood

The Economy League of Greater Philadelphia, Econsult Corporation and Keystone Conservation Trust (2010) estimated that $16.3 billion was added to the value of South East Pennsylvania's housing as a result of protected green spaces and that, on average, 5% is added to the value of each property.

A study of property prices within a one kilometre radius of Carlos Thays Botanic Garden in Buenos Aires, Argentina (Barreiro, 2018) showed increasing property values with proximity to the garden (Table 1).


Mehmet Kursat-Deger

Location	US$/m2	
300 m radius	3974	Base 100
600 m radius	3301	- 17%
1000 m radius	3267	- 18%

Table 1: Average sale price per square metre for three room apartments according to their proximity to Carlos Thays Botanic Garden, Buenos Aires, Argentina

In addition, for properties in close proximity to the garden, apartments with a view of the garden attracted a higher price.

Facilities	With a front view of the botanic garden	Without a front view of the botanic garden
3 room apartment	3155	3329
4 room apartment	3966	2362
5 or more room apartment	2941	3255
Average	3354	2982

Table 2: Average price per square meter for used apartments in front of the garden (analysing apartments for sale in June-July 2018)

1.2.5. The economic value of the training and educational activities of botanic gardens

Many botanic gardens play an important educational role in the fields of botany and horticulture, providing people with an opportunity to connect to nature and learn about plants (Willison, 1994).


Guanhua Ming

CASE STUDY 1.6

The economic value of botanic garden training and education

RBG Kew offers a variety of different education and training opportunities. These include:

- **School visits** – RBG Kew's primary vehicle for engaging with young people from schools across the UK.
- **School of Horticulture courses** – RBG Kew's School of Horticulture offers a number of qualifications and courses including apprenticeships in botanical horticulture and a three-year diploma course.
- **Specialist training** – Specialist courses targeting researchers and PhD students are available from RBG Kew including two-week courses on tropical plant identification.
- **University courses** – A MSc in Plant and Fungal Taxonomy, Diversity and Conservation has recently been established and over 50 PhD students carry out their doctoral training and research at RBG Kew.
- **Teacher training courses** – RBG Kew offers a selection of professional development courses for teachers, technicians and support staff.

Drawing upon academic literature on the returns to education, Oxford Economics (2016) valued the educational benefits for UK students and international students generated by RBG Kew in 2014/15 at £25.8 million and £676,000 respectively.

ARCADIS (2016) used an alternative approach to evaluate the economic impact of the Royal Botanic Garden Edinburgh's education and training activities by calculating the net additional gross value added (GVA) to the Scottish economy. Net additional GVA was estimated at £21 million over a 10 year period, £29 million over 15 years and £41 million by year 25. Two factors were included to calculate this figure (i) fees paid by learners coming from outside Scotland (ii) learners who remain in Scotland upon completion of their course and through the skills acquired increase regional productivity.

1.2.6. The economic value of scientific research in botanic gardens

Botanic gardens participate in many areas of cutting-edge research particularly in the fields of taxonomy, phenology, conservation genetics, seed science, ecological restoration and horticulture. Many of the outputs of this research are of economic importance and can have commercial applications. For example, the Breadfruit Institute at the National Tropical Botanical Garden has been researching the use of breadfruit for food and reforestation for over 30 years. The institute supplies breadfruit trees across the tropics providing an important source of food and income (National Tropical Botanical Garden, 2018).

Barney Wilczak

CASE STUDY 1.7

The economic impact of botanic garden scientific research

Oxford Economics (2016) calculated the total value of RBG Kew science to the UK economy at £56.2 million in 2014/15. ARCADIS (2016) estimated that the Royal Botanic Garden Edinburgh's science activities, in total, generate a potential economic benefit to the global economy of £783 million GVA (£294 net to the Scottish economy) over a 10 year period, £1.5 billion GVA (£0.5 billion to Scotland) over 15 years and £4.5 billion GVA (£1.2 billion to Scotland) over 25 years.

Barney Wilczak

1.2.7. Other measures of the economic value of botanic gardens

Botanic garden collections are a vitally important source of plant and fungal knowledge. As research infrastructures, significant investment is required to build scientific collections. Quantifying this investment is useful not only for calculating return on that investment but also for demonstrating to policymakers and funders that collections should be maintained or added to.

CASE STUDY 1.8

The economic value of access to botanic garden collections

In demonstrating their value in supporting scientific research, it is important to stress that collections are used not only by botanic garden staff to conduct scientific research but also by external researchers. For example, in the past five years RBG Kew's Millennium Seed Bank (Chapman *et al*., 2018) has supplied:

- 930 UK collections to support research into disease susceptibility, biological control, pollination research, plant breeding etc.
- A further 154 UK collections for conservation (reintroduction and restoration).

ARCADIS (2016) estimates the benefits to the Scottish economy that derive from researchers accessing the Royal Botanic Garden Edinburgh's collections to be £171 million over a 10 year period, £248 million over 15 years and £385 million over 25 years.

CASE STUDY 1.9

The cost of building scientific reference collections

- Oxford Economics (2016) estimates the cost of building RBG Kew's scientific collections at £868 million (herbarium), £155 million (fungarium) and £150.5 million (Millennium Seed Bank).
- Mann (1997) estimates the cost to collect, identify and mount vascular plant specimens and incorporate them into Royal Botanic Garden Edinburgh's herbarium at £24.90 per specimen.

1.3. Conclusions and recommendations

The case studies presented above make a compelling case for the economic impact and benefits of botanic gardens as:

- Visitor attractions that bring in tourists and attract people to neighbourhoods
- Employers and contractors
- Scientific organisations that train people and carry out or support research.

However, authoritative studies carried out by third party evaluators are still rare, and are primarily commissioned by larger botanic gardens or consortia of gardens. It would be useful to have some examples from smaller gardens.

In urban centres, botanic gardens are valued for their aesthetic appeal and recreational facilities (see Section 2), and this is usually reflected in house prices and the cost of renting accommodation in close proximity to gardens. It would be valuable to have a larger number of independent studies of this phenomenon, including the value in property taxes that goes back to local government.

Similarly, more examples of the *economic* value of botanic garden collections that support vital research into major challenges such as food security, water, energy, health and climate change (see Section 3) are urgently needed if we are to make the case for continuing to build and maintain diverse plant collections.

RECOMMENDATIONS

- **More studies are needed on the effect that botanic gardens have on property prices in surrounding areas, and the effect on property taxes that go back to local government. Not only are such measures a useful proxy for valuing recreational and aesthetic services that botanic gardens provide, they also represent a sizable monetary return on investment for local authorities that support botanic gardens.**

- **Where collections can demonstrably be shown to support vital research, botanic gardens should commission research into the current or potential economic return on investment provided by those collections.**

2. THE SOCIAL IMPACTS OF BOTANIC GARDENS

Fraser Allen

2.1. Introduction

Worldwide, botanic gardens attract an estimated 500 million visitors a year (Mounce *et al*., 2017) and most visitor surveys indicate that the major incentives for visitation are aesthetic and recreational. In addition, botanic gardens are providers of both formal and informal education to adults and millions of schoolchildren worldwide. The impacts of the social services provided by botanic gardens are hard to measure and even more difficult to monetise but it is likely that these are amongst the most valuable services to society provided by botanic gardens – particularly in urban settings where the majority of botanic gardens are situated.

2.2. Measures of social impact

The social benefits of botanic gardens are measured in a number of ways, including their:

- Positive impacts on mental and physical health
- Educational and learning benefits
- Cultural and aesthetic value

Ian Harvey-Brown

Ian Harvey-Brown

CASE STUDY 2.1

Motivation for visiting botanic gardens

Cambridge University Botanic Garden commissioned a visitor survey in 2015 to evaluate the motivations of their visitors for coming to the garden (The Audience Agency, 2016). When asked to consider all of the possible motivations for visiting 'to enjoy the atmosphere' was the most popular choice (63%), followed by 'for peace and quiet' (43%) and 'to spend time with friends and family' (42%). When asked to choose the main motivation for visiting the botanic garden the most popular choice was 'to spend time with friends and family'. When compared to results from Cambridge University Museums, the botanic garden had the highest proportion of visitors motivated by social reasons, to enjoy the atmosphere and for the peace and quiet. In another study, visitors to Leaning Pine Arboretum in California cited one of the most important consequences of their visit as 'stress relief and relaxation' (Wassenberg *et al*., 2015). Similar motivations were recorded at the University Botanic Garden Sofia, Bulgaria (see Figure 1).

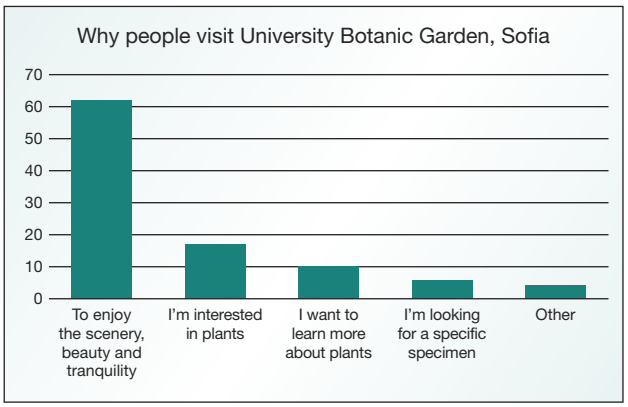


Figure 1: Motivation for people visiting University Botanic Garden, Sofia, Bulgaria (n=412)

These studies highlight the importance of botanic gardens as places of tranquillity and social interaction.

2.2.1. Mental and physical health benefits

There is growing evidence from psychologists that green spaces are regarded by vulnerable people as 'safe spaces', which both improves mental health and stimulates creativity and learning (e.g. Shaw, 2015). This is true for both adults and children (see Education and learning).

There is a wealth of literature that shows a positive correlation between mental health and physical health, and access to plants and green spaces (e.g. Taylor *et al.,* 2001; Kaczynski and Henderson, 2007; Berman *et al*., 2008; Richardson *et al*., 2013; Nowak *et al*., 2014). In addition, although there isn't a great deal of research that has centred around botanic gardens specifically, there is an increasing body of evidence highlighting the importance of biodiverse green spaces for promoting higher levels of human well-being (e.g. Fuller *et al*., 2007; Sandifer *et al*., 2015).


Westonbirt Arboretum

CASE STUDY 2.2

The impacts of botanic gardens on mental health and well-being

Westonbirt Arboretum in the UK runs a community project to increase its engagement with vulnerable groups including young people with autism, adults with mental health, drug and alcohol problems and older people with dementia. These groups were invited to visit the Arboretum where a range of activities was provided depending on the needs of the participants. An independent evaluation of the programme was undertaken to determine whether participation led to well-being outcomes (O'Brien, 2018). It was found that the programme clearly illustrated that a wide range of well-being outcomes were gained by the majority of participants from outreach, day and multi-visits to the Arboretum. Multi-visits to the Arboretum were found to have greater impact than a single visit and could lead to changes in behaviour such as increased confidence, learning new skills and considering different career options. It was recommended that three to four weeks of visits should be the minimum to gain these benefits. Some of the key elements of the project that were identified as being successful and which led to well-being outcomes included a non-clinical or residential setting, a large attractive wooded setting and practical 'hands on' activities.

Since 2000, the Royal Botanic Garden Sydney's Community Greening programme has reached almost 100,000 participants and established 627 community gardens. Truong *et al*., (2018) analysed the impact that the program has had on the health and well-being of communities in social housing in New South Wales, Australia. Nearly 80% of participants reported that community gardens have benefited their community. Important behavioural changes were observed, particularly in relation to health; participants were now eating vegetables and cooking healthy food more regularly since becoming active in a community garden. Participants also noted that gardening reduced anxiety and stress.

Sahlin (2014) explored the benefits to mental health of Nature-Based Therapy at Gothenburg Botanical Garden. Those who participated in a nature-based rehabilitation programme (which included elements such as guided nature walks, handicrafts made using natural materials and garden activities) were found to suffer reduced burnout, depression, and anxiety, and had a reduced reliance on public health care. Similarly, those who attended a nature-based stress management course displayed less burnout and stress-related symptoms and had increased work ability. There was also a reduction in the number participants reporting more than 14 days sick leave due to stress and exhaustion, upon completion of the course.

2.2.2. Educational and learning benefits

Humans are an increasingly urban species, disconnected from nature, and with children subject to so-called 'nature deficit' childhoods. In the case of plants, 'plant blindness' can be a symptom of this disconnect (Wandersee and Schussler, 1999) and, given the vital importance of plants to our lives, society can't afford for citizens to see nothing. At their best, plants in botanic gardens have the potential to be ambassadors for their wild relatives, the ecosystems that they represent and their importance to people. Plants may be used as part of a narrative to tell stories, as functional objects of use to people, or as the subjects of scientific enquiry (Sanders *et al*., 2018). Rare plants, for example may illustrate the story (and perils) of extinction, particularly where those plants are viewed as an intrinsic part of people's culture, and the consequences of their loss is understood. On a more positive note, botanic gardens can stimulate discussion and thought about man's relationship with the environment and nature, and the things that it provides us with (food, medicines, shelter etc.). In many cases, the green environment and 'hands on' opportunities provided by botanic gardens result in the most tangible impacts on learners, including benefits that go beyond gaining new knowledge. For example, there is increasing evidence that children's cognitive development is improved in green spaces (e.g. Dadvand *et al*., 2015) and that working with plants can lead to improved self esteem and behaviour.

Fraser Allen

CASE STUDY 2.3

Impacts of botanic gardens on improved learning, self-esteem and behaviour

Morgan *et al*., (2009) investigated the influence of Brooklyn Botanic Garden's Project Green Reach (PGR) on urban youth in New York, USA. PGR provides unique hands-on outdoor environmental education activities for inner city students. The study found that children from challenging home and school environments, showed improved understanding of scientific concepts, gained gardening skills, developed increased environmental awareness, exhibited social and personal growth, considered PGR to be a positive life experience, and benefited from the cultural aspects of the programme.

CASE STUDY 2.4

Impacts of botanic garden education on attitudes to nature

Currently 55% of the world's population live in urban areas, and this is expected to increase to 68% by 2050 (UN DESA 2018). The impact that urban living is having on attitudes to nature is not yet known. China is an excellent country to explore this relationship as it has experienced rapid urbanisation in the past century, with the proportion of living in urban areas rising from 39.1% in 2002 to 51.3% in 2011 (Zou, 2011). Zhang *et al*. (2014) investigated how interaction with nature affects children's tendency towards biophilia and biophobia, and their conservation attitudes. Students from fifteen schools in China with different degrees of urbanisation were selected for the study. It was found that students from urban schools do indeed have less contact with nature than those from rural schools. Furthermore, a student's contact with nature was significantly positively correlated with biophilia and negatively related to biophobia. Importantly, student's biophilia significantly affected their willingness to conserve animals and their attitudes towards conservation in general. It is recommended that contact with nature should be enhanced by public outreach campaigns run by botanic gardens, increasing urban green spaces and organising summer camp programmes.

Few studies have investigated the direct impact that botanic gardens have on influencing environmental attitudes. Williams *et al*. (2015) surveyed just over 1000 visitors to five UK botanic gardens and found that environmental attitudes are more positive amongst those leaving a botanic garden compared to those entering a garden. Evaluating changes in visitor attitudes is an important step in determining the effectiveness of botanic garden education schemes and developing methods to maximise their ability to raise environmental awareness.

2.2.3. Impacts of environmental education in changing attitudes and behaviour

It is estimated that approximately 10% of botanic gardens listed within BGCI's GardenSearch database have established education facilities such as Visitor Education Centres (VECs) (Wyse Jackson and Sutherland, 2000). VECs provide an opportunity to engage with visitors and enhance their knowledge of botany, biodiversity and local natural history. He and Chen (2012) examine the extent to which VECs in botanic gardens increase their educational function. The authors found that for five botanic gardens throughout mainland China, visitors to VECs thought that they had gained significantly more knowledge on plants and environmental protection compared to those who did not visit VECs. However, research in zoos suggests that simply imparting knowledge has comparatively little impact on changing people's attitudes and behaviour (see Moss *et al*., 2017). Instead, botanic gardens need to empower and enable visitors to become involved in conservation or environmental actions.

Similarly, although children's contact with nature is often cited as positively influencing children's attitudes towards animal and plant conservation, very few studies have attempted to quantify this relationship. This dynamic is particularly important to botanic gardens, as they provide an opportunity for children to connect with nature, particularly for those located in urban areas without access to other green spaces.

CASE STUDY 2.5

Impacts on changing behaviour – renewable energy

In order to gain a greater understanding of the attitudes of its visitors to climate change, Phipps Conservatory and Botanical Gardens developed a survey, where a series of questions were designed to identify participants' attitudes, behaviours and policy preferences about climate change. Of 1,000 participants, 90% of visitors believed in climate change, however only 8% felt that it requires urgent action. This survey indicated that the most important challenge was not to convince visitors that climate change exists but rather help them to take the next step - action.

The botanic garden therefore collaborated with a green energy company in January 2017 to help visitors to switch to green power on site. They were also offered free family membership to the botanic garden for one year or for existing members a six-month extension, as an added incentive (Smith and Harvey-Brown, 2017). Since January 2017, more than 3,100 households have switched, reducing CO_2 emissions by 24,800 tons (Phipps Conservatory and Botanical Gardens, 2018).

CASE STUDY 2.6

Impacts on changing behaviour – growing native plants

New England Wild Flower Society's (NEWFS) Garden in the Woods in Massachusetts, USA, promotes the conservation of native plants in the wild and their use in gardens and designed landscapes. NEWFS has trained more than 1,200 volunteers to monitor 3,300 populations of rare plants in six states (NEWFS Garden, 2018a); and 4 million people have used its Go Botany website to identify and learn about the region's plants (NEWFS Garden, 2018b). Increases in visitors (20%), school groups (50%), and participants in courses and field trips (10%) indicate a growing interest in native plants and their environmental value. Plant sales are also increasing by 15% a year, with visitors, institutions, and restoration projects buying 35,000 pesticide-free native plants, mostly grown from seed collected by nursery staff. NEWFS also offers resources for gardening with the region's native plants, including books, online courses, and a tool for finding the right plants for your site (NEWFS Garden, 2018c).

2.2.4. Cultural benefits and value of botanic gardens

Botanic gardens, like museums, often house culturally significant collections, including native plants, artefacts and works of art. They may also feature historic or culturally important buildings. For example, The Lyon Arboretum in Hawai'i participates in a programme called Welina Mānoa to engage primary schools with Hawaiian culture and environmental education (Dunn, 2017). The arboretum has developed a native species trail and associated resources to teach children about native species and their cultural significance. The increased cultural knowledge gained through this programme has not yet been quantified.

2.3. Conclusions and recommendations

There is a wealth of academic literature on mental and physical health benefits of green spaces, particularly in urban settings. The fact that most studies are not specific to botanic gardens is not really important – there are plenty of studies on people's motivations for visiting botanic gardens that confirm the value of botanic gardens in providing beauty, space and tranquillity.

CASE STUDY 2.7

The cultural value of botanic gardens

Botanic gardens, like museums, are regarded as cultural assets that stimulate local and national pride – even in people who do not actually visit the garden. For example, the total gross 'non-use' and 'option' value of RBG Kew was estimated in 2016 by asking 1,199 people (35% of whom had visited RBG Kew) whether funding for RBG Kew should be retained at current levels (£0.9 per annum for an average UK tax payer), increased or decreased. Sixty percent of respondents said that funding levels should be retained at current levels, 34% said it should be increased and 5% said that funding levels should be decreased. Although past visitors to RBG Kew were more likely to suggest an increase in funding, the mean valuation for all respondents was £0.97 and for those who had never visited RBG Kew it was £0.85. Multiplying £0.85 by the estimated total number of UK residents aged 16 and older yields a total non-use and option value of £44.3 million (Oxford Economics, 2016).

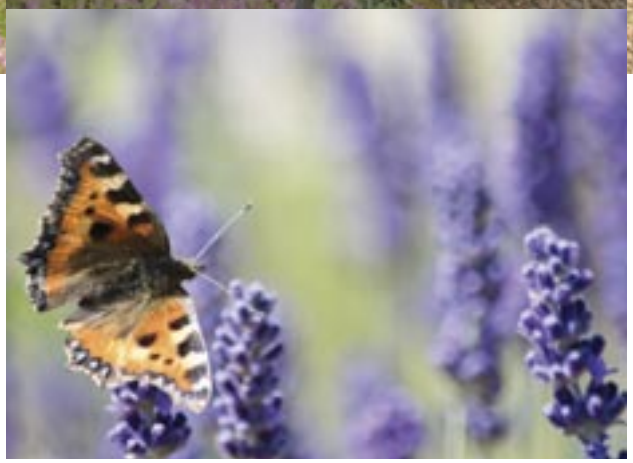
There is less available literature on the impacts of informal and formal botanic garden education. Gardens tend to report on activity (e.g. number of visitors, schoolchildren, teaching days etc.), rather than impact. Whether it is formal classroom training, school days out or passive education of adult visitors, we are desperately short on studies looking at the short, medium and long term impacts of that exposure to plants and new knowledge. The case studies, above, on bringing about changes in attitudes or behaviour, suggest that simply imparting knowledge is not enough – gardens also need to provide people with the tools and knowledge to do something tangible themselves. Furthermore, influencing adults to become conservation volunteers or to switch to renewable energy is a different proposition to influencing children in the long term. Given that millions of schoolchildren visit botanic gardens each year to learn about plants, it is essential that we understand the impact of these visits on children in the way they interact with the environment, for example through the courses they go on to select, the clubs they join and their subsequent career choices. Such studies are difficult to devise (especially attribution), and expensive to undertake but this is a major gap in our knowledge.

RECOMMENDATION

- **Long term studies on the impacts of botanic garden schools education programmes are needed, in particular whether they have the potential to be life changing for children in the way they interact with plants and the environment.**

Westonbirt Arboretum

3. THE ENVIRONMENTAL IMPACTS OF BOTANIC GARDENS



Barney Wilczak

3.1. Introduction

As indicated in case studies 2.5 and 2.6, botanic gardens can have positive impacts on the environment by influencing visitors in the way they interact with nature. However, botanic gardens can also have a more direct impact on plants and the environment by deploying their specialist skills in science and horticulture, and through the collections and landscapes themselves. It is estimated that the botanic garden professional community includes some 60,000 horticulturists and scientists who manage and study plants across the taxonomic spectrum. Where botanic gardens differ substantially from museums, is in holding diverse collections of living plants in their landscapes and seed banks. This living material opens up a wide range of possibilities for conservation and use, including prevention of extinction, species reintroductions, ecological restoration and scientific investigations into a wide range of uses, encompassing agriculture, horticulture, forestry and biotechnology (Smith *et al*., 2011).

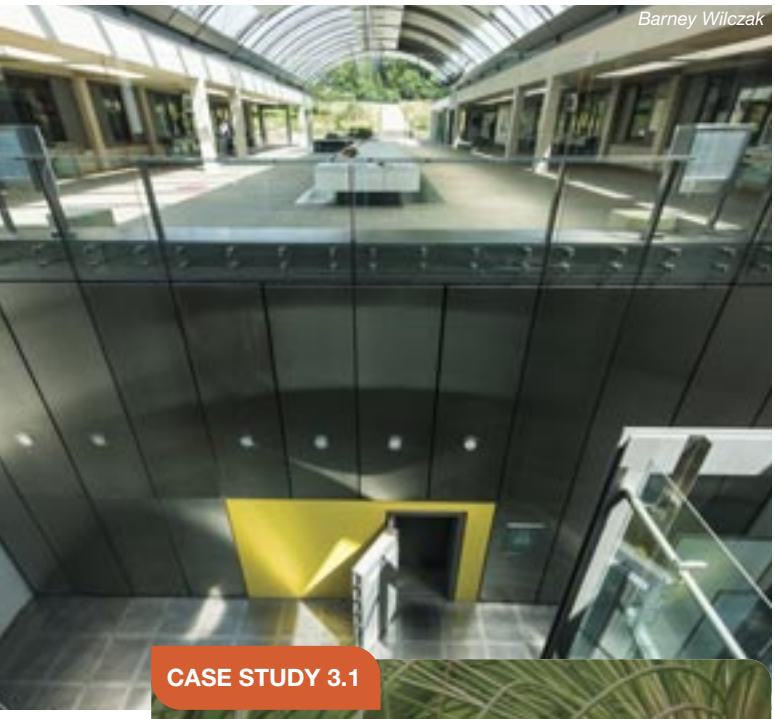
3.2. Measures of environmental impact

In broad terms, the environmental impacts of botanic gardens include:

- Impacts of plant conservation activities
- Impacts of scientific and horticultural research
- Direct environmental impacts.

3.2.1. The impacts of plant conservation activities

Probably the greatest environmental benefit and impact provided by the botanic garden community is the options value related to the living plants that botanic gardens conserve in their landscapes and seed banks. Botanic gardens conserve or cultivate at least a third of all known vascular plant diversity and more than 40% of threatened plant species – including many species that are extinct in the wild (Mounce *et al*., 2017). Prevention of the extinction of a plant species ensures its availability to future generations for human innovation, adaptation and resilience (Smith *et al*., 2011). While not all species can be accurately assessed for their future value, for some species estimates can be made based on the current value of similar species (see case studies 3.1 and 3.2).


Barney Wilczak

CASE STUDY 3.1

The economic value of collections

Japanese Knotweed (*Fallopia japonica*) is a major invasive weed costing hundreds of millions of pounds to control in the UK. The Centre for Agriculture and Bioscience International (CABI) required access to native seeds to ensure that the biological control that they had developed did not have any adverse effects on native plant species. RBG Kew's Millennium Seed Bank (MSB) was able to supply 48 seed collections of 21 UK native plants, including threatened species, for CABI to test to make sure that they were not susceptible to CABI's biological control (a beetle). Due to the immediate availability of the MSB's collections, CABI was able to release their biological agent a year earlier than anticipated (Oxford Economics, 2016), and the value of this support was estimated by London School of Economics at between £27 million and £121 million (Gorst, 2012).

Forty nine percent of RBG Kew's Millennium Seed Bank collections have at least one identified use to humans and, of the 99 known Crop Wild Relative (CWR) genera, 81% are conserved at the MSB (Liu *et al*., 2018). The Millennium Seed Bank Partnership is part of a US$50 million project called '*Adapting agriculture to climate change*' (www.cwrdiversity.org/) which aims to collect and make available to plant breeders crop wild relatives from 29 major crops (including rice, wheat and potatoes) that are not currently conserved in seed banks (see RBG Kew, 2018a). As part of this project, PWC assessed the *current* value of benefits from CWR traits in those 29 crops at US$42 billion (PWC, 2013).

CASE STUDY 3.2

Integrated species conservation (WIPS-DE Consortium, Germany)

The WIPs-De programme is a national network for the conservation of endangered plant species for which Germany has special responsibility. The WIPs-De botanic garden partners are Berlin-Dahlem, Karlsruhe, Osnabruck, Potsdam and Regensburg (see www.wildpflanzenschutz.de/), and the programme carries out seed collection, augmentation planting and *in situ* protection activities for 15 threatened German plant species.

CASE STUDY 3.3

Ecological restoration

Botanic gardens are ideally placed to take a leading role in the field of ecological restoration due to their horticultural and botanical expertise (Hardwick *et al*., 2011). The Ecological Restoration Alliance of Botanic Gardens (ERA) was established in 2012 with the aim of scaling up the restoration of damaged and destroyed ecosystems (see www.erabg.org/). The consortium now has over 30 members and collectively has over 540 specialists engaged in restoration activities (see case study 3.5).

In the wake of Hurricane Sandy on the East Coast of the United States in 2012, the federal Department of the Interior budgeted $800 million for the repair of infrastructure and coastal habitats in national parks, wildlife refuges, and other sensitive lands. But where would they get the genetically-appropriate plant material for the restoration projects? Typically, such efforts in the Eastern United States have relied on plants and seeds from other parts of the country; and the one federal program focused on high-volume seed collection, Seeds of Success (SOS), has a mandate limited to the western states. Working together, North Carolina Botanical Garden, New England Wild Flower Society, and the Mid-Atlantic Regional Seed Bank successfully proposed that the federal government fund the first large-scale, coordinated seed banking effort in the East and an expansion of the SOS program. Over three years, with the assistance of interns trained by Chicago Botanic Garden, the partners made 2,124 collections in coastal habitats from North Carolina to Maine, encompassing more than 150 common species and totaling 932 pounds of seed. To date, those seeds have been used in 27 projects, including dam removals and salt marsh, dune, and seashore restorations. The remainder of the seed is in long-term storage for use in future restoration and land management projects.

3.2.2. The impacts of scientific and horticultural research

The potential value of plant diversity conserved or cultivated in botanic gardens can also be ascertained from the impact of the research that such collections support. In some cases, that research has immediate value and in other cases, future value can be estimated.

CASE STUDY 3.4

Climate research and adaptation

Botanic gardens are in an excellent position to track the impacts of climate change through phenological changes recorded in flowering and leafing times of plants in their collections. Gardens are able to harness several different sources of information including direct observation of their living collections, herbarium specimens and photographs. The International Phenological Gardens (IPG) project, founded in 1957, records the phenology of 23 plant species at approximately 50 botanical gardens across Europe. They have found that their target species are flowering and leafing out on average 6.3 days earlier in the spring than 50 years ago. By contrast, in the autumn, leaf colouring and leaf fall are taking place 4.5 days later (Primack and Miller-Rushing, 2009).

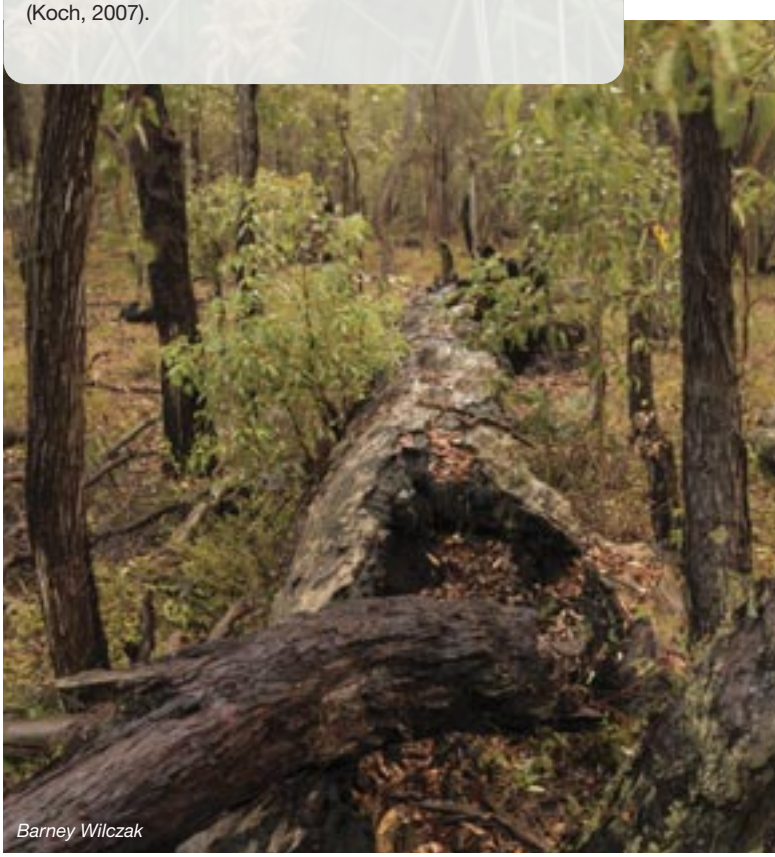
The Royal Botanic Gardens Victoria is carrying out vital research in climate proofing its living collections, research that also has important implications for the horticultural industry, urban tree planting and for the field of ecological restoration. They have developed a Landscape Succession Strategy 2016-2036, which outlines how the botanic garden will adapt its landscape plantings to a more sustainable collection, by taking into account projected environmental change and known climatic and abiotic tolerance ranges for different species (Kendal and Farrar, 2017). This approach has already been adopted by a number of local government authorities in Australia.

Barney Wilczak

CASE STUDY 3.5

Water catchment restoration

Ecological Restoration Alliance member, Kings Park and Botanic Garden, in Perth, Western Australia has been working with the mining company Alcoa for the past 25 years to find ways to restore the jarrah forest that forms Perth's main water catchment. Approximately 70% of understorey richness is returned via the direct transfer of fresh topsoil. Additions of provenance–correct seeds of between 78 and 113 native jarrah forest species add significantly to post–mining species richness, with many of the broadcast seeds receiving heat or smoke treatment to increase germinability. Approximately 20 additional species are produced by vegetative multiplication or tissue culture and planted into restored areas. It is now possible to restore a complex forest structure in 10-30 years that includes the same number of native plant species as the natural forest (Koch, 2007).



Barney Wilczak

CASE STUDY 3.6 Pollinator health

The National Botanic Garden of Wales is leading research on pollinator health. The garden is utilising its DNA barcoding expertise and extensive horticultural resources to research the floral preferences of both economically important honeybees and wild pollinators. The botanic garden is an ideal location to study pollinator foraging as the garden contains over 8,000 taxa of flowering plants (including both native and non-native plant species). De Vere *et al*. (2017) found that despite high floral availability in the months of April and May, honeybees used the same core group of native or near-native plants, typically near hedgerows and woodlands. The botanic garden produces Pollinating Plant booklets to encourage people to plant pollinator friendly plant families (see National Botanic Garden of Wales, 2015).

Vernon Heywood

CASE STUDY 3.7 Invasive plant species

The spread of invasive species is one of the major threats to global biodiversity. Botanic gardens hold large and diverse collections of plants, many of which are exotic, and some that may be new to horticulture. For gardens that are developing or maintaining collections from geographically diverse regions, preventing the introduction of an invasive plant species is a major priority. Preventing the spread of invasive species is much easier and cheaper than removing them once they have become established.

Australian botanic gardens have developed a weed assessment methodology that uses a series of questions to assess the risk of species becoming weeds (Virtue *et al*., 2008). The major city botanic gardens in Melbourne, Hobart and Perth used the system to score 100 taxa. Separately, a national survey and a literature review of the same 100 taxa were undertaken to obtain two independent datasets for assessing their level of weediness. Testing of the system showed that it has good discriminatory power and cut-off scores were chosen that have about 80% accuracy for both low weed risk and high weed risk species.

The Botanical Garden of the University of Latvia assessed the adaptation potential of 536 taxa of herbaceous perennials in their collections to determine whether this can be used as a proxy for invasion risk (Strazdina *et al*., 2018). Adaptive potential was assessed using the following parameters: (1) the general condition of the plants, (2) overwintering capability, (3) resistance to pests and diseases, (4) vegetative reproduction capacity, (5) vegetative and generative mobility, and (6) self-sowing. These data were combined with information about species origin, life form and duration of cultivation in their present locations. It was found that 48 species (9%) had 'high' acclimatisation (i.e. high invasive potential), and that at least 11 of these species have already been recognised as garden escapers in Latvia. The botanic garden is using the results of its research to improve their plant collection strategy and the results can be used to identify other species with invasive potential, and to direct horticultural practices accordingly in Latvia.

CASE STUDY 3.8

Plant pests and diseases

Living collections in botanic gardens can also be used to assess vulnerability to pests and diseases. BGCI's International Plant Sentinel Network (www.plantsentinel.org/) uses botanic garden collections that are outside their native ranges as an early warning system to test the susceptibility and control of emerging pests and diseases before they reach natural populations. In phase one of the project, for example, new hosts and distribution of European mountain ash ringspot virus were identified (Harju *et al*., 2017).

Botanic garden seed or plant collections can also be used for testing for susceptibility or resistance to pests and diseases. Ash dieback disease (*Hymenoscyphus fraxineus*) was first detected in Britain in 2012, putting 126 million trees at risk. Since then, RBG Kew's Millennium Seed Bank has collected ash seeds from all 24 seed zones in the United Kingdom over the past 5 years in order to test different genotypes for their resistance/susceptibility to the disease (see RBG Kew, 2018c). Genotypes with high levels of natural resistance will form the planting stock to replace the susceptible genotypes that are lost. In addition, RBG Kew's living collections which comprise 43 different species of *Fraxinus* from Europe, Asia and North America are being monitored for potential susceptibility to this disease (RBG Kew, 2012).

CASE STUDY 3.9

Urban greening and tree planting

Many botanic gardens, particularly those managed by municipalities, have a role in the establishment and management of urban green spaces and planting. For example, the National Botanical Garden of Georgia carries out tree assessments for all new developments in the city of Tbilisi as part of the municipality's planning process. The assessment includes preservation orders on trees of conservation or cultural significance and a risk assessment for trees that are old or diseased and may need to be removed.

Shanghai Chenshan Botanical Garden has been working with the city authorities for the past six years to integrate biodiversity conservation into Shanghai's Green City Master Plan (Hu *et al*., 2017). More than 20% of the plants in the most urban and industrialised areas of China are under threat, and Chenshan has collaborated with local and central government to protect 14 Critically Endangered plant species in east China, and to integrate native species into urban planting.

The Morton Arboretum in the USA has developed several resources to support urban tree planting and management. These include:

- **The Chicago Region Trees Initiative** (chicagorti.org/) a partnership for coordinated action on key issues facing trees in the seven-county region of Chicago; current partners number 100.
- **The Community Trees Program** (www.mortonarb.org/trees-plants/community-trees-program), a resource that advocates for trees in 274 communities to help municipalities, organizations, professionals, and others effectively manage and care for the urban forest.
- **The Woodland Stewardship Program** (www.mortonarb.org/learn-experience/adults/conservation-and-restoration/woodland-stewardship-program) a training program for citizen-volunteers to gain knowledge and experience in natural areas restoration in their communities; 800 people have completed the program.
- **The Northern Illinois Tree Selector** (www.mortonarb.org/trees-plants/tree-and-plant-advice/tree-species-list/filters) an online tool to help match site conditions to the most appropriate species.
- **Plant Clinic** (www.mortonarb.org/trees-plants/tree-and-plant-advice/plant-clinic) a service that answers questions from people in the Chicago region about plant selection, health, and care; trained staff and volunteers -- available in person, by email, or by phone -- annually address 18,000 queries.
- **Grants** - are available for tree planting, conducting a tree inventory, and developing a tree management plan.
- **The Scientific Benefits of Trees:** A Literature Review (chicagorti.org/TreeBenefits) a document that provides an overview of citations about the benefits of trees to people and the environment from a scientific standpoint.

CASE STUDY 3.10

Pioneering innovative technologies

Researchers at the Botanic Garden Technical University of Delft in the Netherlands have been developing biologically inspired innovative products, in collaboration with other research institutions and the private sector. More than 25 patents have been secured by the botanic garden to date, including sanitary products made from a combination of antibacterial and moisture-absorbent plants. Botanic Garden TU Delft has also been fundamental in launching business enterprises to build on the discoveries made at the garden. For example, the company Flora Fluids, is building on the work conducted at the Botanic Garden TU Delft to develop and manufacture a new generation of harvesters that extract active chemicals from plants using electro-spraying technology (van der Wees, 2017).

The botanic garden has also been pioneering LED technology. A new LED lighting system, to improve plant growth and reduce energy and water use, was developed. A prototype of this lighting system was installed at the botanic garden in 2004 and further tested with a bell pepper and tomato grower in the Netherlands. It was found that the new lighting system increased yields by 10-15% while using 200 times less energy than conventional lamps and a third less water. This method has now been scaled up and is being utilised by the horticulture industry (van der Wees, 2017). For example, a tomato grower in the UK is using the LED lighting system to extend their growing season to supply tomatoes to British supermarkets all year round (ASDA, 2017).

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CASE STUDY 3.11

Supplying plant material to support research by third parties

Supporting third party research is at the centre of Cambridge University Botanic Garden's mission and identity. Researchers can request a range of support including material transfers from the garden's documented living collections. The botanic garden annually surveys its users to find out how their research is progressing and whether their work has been published. In 2013/14 Cambridge University Botanic Garden supported research into plant evolution, pollination, bee pests, plant conservation, crop improvement, plant pests and diseases, herbivory, bioenergy, photosynthesis, plant-fungal associations, plant-insect interactions, bioremediation, carbon sequestration, biochemistry, ecology, tree shade cooling, the phytochemistry of vanilla and coffee, plant identification and species reintroduction (Cambridge University Botanic Garden, 2015).

3.2.3. Direct environmental impacts

CASE STUDY 3.12

Carbon sequestration and air quality

Jardin Botanico Carlos Thays in Argentina investigated the impact that their botanic garden has on carbon sequestration and improvement of air quality in Buenos Aires. They estimated that the garden offers an environmental service equivalent to US$ 159,140 in absorbed CO_2 and US$ 108,140 in retained carbon. The botanic garden also provides additional services through removal of air pollutants, increased rainwater retention and energy savings by reducing temperature extremes, worth an additional US$ 195,000. Importantly as the botanic garden receives public funding, they were able to estimate that for every US dollar invested by the public in the garden, it gives back almost 50 cents just in the environmental services it provides.

3.3. Conclusions and recommendations

Given the diversity of plant collections held in botanic gardens, and the breadth and depth of knowledge and skills of botanic garden staff, the potential to solve the big environmental challenges of our time (e.g. food security, water scarcity, energy, health, loss of biodiversity, deforestation and climate change) is enormous. However, due to competing priorities such as the need to attract visitors for revenue generation or publish research in academic journals, a small fraction of our horticultural and scientific expertise is deployed to support practical conservation, management and use of plant diversity

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in the landscape (Smith, 2018). Even where botanic gardens are passive partners in plant conservation or supporting vital research, for example, by supplying data or material, we are often not good at measuring our outputs and impact (Smith and Harvey-Brown, 2017). Botanic gardens need to demonstrate the value of their collections, science and specialist horticulture if they are to justify the expenditure associated with maintaining these activities. It is therefore vitally important that (a) we do more to support society in solving its environmental problems, and (b) that we accurately measure our contribution.

RECOMMENDATIONS

- **Botanic gardens should promote their unique collections, knowledge and skills by sharing their collections and data (e.g. on digital platforms and databases), by communicating directly with other professional communities conserving and managing plant diversity, and by adopting multidisciplinary approaches to problem-solving.**

- **Botanic gardens should document their activities that directly address environmental problems or support others trying to solve these challenges. In particular, gardens should try to measure societal impact rather than activity.**

REFERENCES


Paul Smith

ASDA (2017). Lighting innovation means we're now able to sell British tomatoes all year. www.corporate.asda.com/blog/2017/10/03/lighting-innovation-means-were-now-able-to-sell-british-tomatoes-all-year

ARCADIS (2016). Royal Botanic Garden Edinburgh: Economic Impact Assessment. United Kingdom. www.rbge.org.uk/assets/files/about_us/Corporate_Info/Economic%20Impact%20Assessment%202016.pdf

Barreiro, G. (2018). An informal analysis of real estate value related to proximity to the Carlos Thays Botanic Garden, Buenos Aires. Full report available from Botanic Gardens Conservation International, Richmond, United Kingdom.

Berman, M. G., Jonides, J. and Kaplan, S. (2008). The Cognitive Benefits of Interacting With Nature. *Psychological Science*, 19, 1207.

Cambridge University Botanic Garden (2015). University Botanic Garden: Annual Report 2013-2014. www.botanic.cam.ac.uk/CMSShared/Document.aspx?p=27&ix=343&pid=2711&prcid=4&ppid=2711

Chapman, T., Trivedi, C. and Miles, S. (2018). Capturing, protecting and restoring plant diversity in the UK: RBG Kew and the Millennium Seed Bank. *Plant Diversity*, 40, (in press).

Dadvand, P., Nieuwenhuijsen, M.J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., Rivas, L., López-Vicente, M., Pascual, M.D.C., Su, J., Jerrett, M., Querol, X. and Sunyer, J. (2015). Green spaces and cognitive development in primary schoolchildren. *PNAS*, 112, 7937-7942.

de Vere, N., Jones, L.E., Gilmore, T., Moscrop, J., Lowe, A., Smith, D., Hegarty., Creer, S. and Ford, C.R. (2017). Using DNA metabarcoding to investigate honey bee foraging reveals limited flower use despite high floral availability. *Scientific Reports*, 7, 42838.

Dunn, C.P. (2017). Biological and cultural diversity in the context of botanic gardens conservation strategies. *Plant Diversity*, 39, 396-401.

Economics Center (2013). Making an Impact. 2012 Economic Impact & Benefits of the Cincinnati Zoo & Botanical Garden. cincinnatizoo.org/wp-content/uploads/2013/07/Zoo-Impact-July-25_spreads.pdf

Economy League of Greater Philadelphia, Econsult Corporation and Keystone Conservation Trust (2010). The Economic Value of Protected Open Space in Southeastern Pennsylvania. www.chesco.org/DocumentCenter/View/5670/DVRPC_GSA_EconomicValueAppendices

Econsult Solutions, Inc. (2017). The economic impact of Greater Philadelphia Gardens. Philadelphia, United States. econsultsolutions.com/the-economic-impact-of-greater-philadelphia-gardens/

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H. and Gaston, K.J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, 3, 390-394.

Gorst, A. (2012). The Value of a Large Seed Bank: A Case Study of Kew's Millennium Seed Bank. Msc Thesis, London School of Economic, United Kingdom.

Gratzfeld, J. (Ed.). (2016). *From Idea to Realisation – BGCI's Manual on Planning, Developing and Managing Botanic Gardens*. Botanic Gardens Conservation International, Richmond, United Kingdom.

Hardwick, K.A., P. Fiedler, L.C. Lee, B. Pavlik, R.J. Hobbs, J. Aronson, M. Bidartondo, E. Black, D. Coates, M.I. Daws, K. Dixon, S. Elliott, K. Ewing, G. Gann, D. Gibbons, J. Gratzfeld, M. Hamilton, D. Hardman, J. Harris, P.M. Holmes, M. Jones, D. Mabberley, A. Mackenzie, C. Magdalena, R. Marrs, W. Milliken, A. Mills, E. nic Lughadha, M. Ramsay, P. Smith, N. Taylor, C. Trivedi, M. Way, O. Whaley and S.D. Hopper (2011). The Role of Botanic Gardens in the Science and Practice of Ecological Restoration. *Conservation Biology* 25:265-275.

Harju, V., Adams, I., Flint, L., Jackson, L., Fowkes, A., Skelton, A., Forde, S., Fairless, N., Field, C., Marsden, S., Lane, C., Barham, E. and Fox, A. (2017). A follow-up report regarding new hosts and distribution of European mountain ash ringspot-associated virus in *Sorbus* spp. in England. *New Disease Reports* 36, 13.

He, H. and Chen, J. (2012). Educational and enjoyment benefits of visitor education centers at botanical gardens. *Biological Conservation*, 149, 103-112.

Hu, Y, Vincent, G. and Chen, X. (2017). How can botanical gardens support sustainable urban development? A case study of Shanghai Chenshan Botanical Garden. *Annals of the Missouri Botanical Garden*, 102, 303-308.

Kaczynski, A. T. and Henderson, K. A. (2007). Environmental correlates of physical activity: a review of evidence about parks and recreation. *Leisure Sciences*, 29, 315–354.

Kadoorie Farm and Botanic Garden. (2017). Kadoorie Farm and Botanic Garden Annual Report 2016. www.kfbg.org/upload/Publications/annualreport2016_en.pdf

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L.J., Paus, T. and Berman, M.G. (2015). Neighborhood greenspace and health in a large urban center. *Scientific Reports*, 5, 11610.

Kendal, D. and Farrar, A. (2017). Assessment of the climate change risk to the living plant collections in the Melbourne Gardens, Royal Botanic Gardens Victoria. University of Melbourne, Australia.

Koch, M. (2007). Restoring a jarrah forest understorey vegetation after bauxite mining in Western Australia. *Restoration Ecology*, 15, S26-S39.

Liu, U., Breman, E., Cossu, T.A. and Kenney, S. (2018). The conservation value of germplasm stored at the Millennium Seed Bank. Royal Botanic Gardens, Kew. *Biodiversity Conservation*, 27, 1347-1386.

Mann, D. (1997). The economics of botanical collections. In: Nudds, J. R. and C. W. Pettitt, (Eds.). The value and valuation of natural science collections. The Geological Society, Manchester, United Kingdom.

Missouri Botanical Garden (2018). 2017 Annual Report: Missouri Botanical Garden. www.missouribotanicalgarden.org/Portals/0/Annual%20and%20Financial%20Reports/PDFs/MBG_AnnualReport_2017_WebPDF.pdf

Morgan, S.C., Hamilton, S.L., Bentley, M.L. & Myrie, S. (2009). Environmental education in botanic gardens: exploring Brooklyn Botanic Garden's Project Green Reach. *The Journal of Environmental Education*, 40, 35-52

Moss, A., Jensen, E. and Gusset, M. (2017). Probing the link between biodiversity-related knowledge and self-reported pro-conservation behavior in a global survey of zoo visitors. *Conservation Letters*, 10, 33-40.

Mounce, R., Smith, P. and Brockington, S. (2017). *Ex situ* conservation of plant diversity in the world's botanic gardens. *Nature Plants*, 3, 795-802.

National Botanic Garden of Wales (2015). Pollinating Plants. botanicgarden.wales/wp-content/uploads/2015/10/Polllinating-Plants-Booklet-final-copy.pdf

National Tropical Botanical Garden (2018). Breadfruit Institute. ntbg.org/breadfruit

NEWFS Garden (2018a). Recruiting Plant Conservation Volunteers. www.newenglandwild.org/conserve/saving-imperiled-plants/plant-conservation.html

NEWFS Garden (2018b). Go Botany: Discover thousands of New England plants. gobotany.newenglandwild.org/

NEWFS Garden (2018c). Plant Finder. plantfinder.newenglandwild.org/

Nowak, D. J., Hirabayashi, S., Bodine, A. and Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental Pollution* 193, 119–129.

O'Brien, L. (2018). A calm, peaceful and beautiful place: Evaluation of the Heritage Lottery Fund – Westonbirt Community Project. Forest Research, Farnham, United Kingdom.

Oxford Economics (2016). Economic Valuation of the Royal Botanic Gardens, Kew, United Kingdom. https://www.oxfordeconomics.com/my-oxford/projects/330449

Phipps Conservatory and Botanical Gardens (2018). Make the Switch at Phipps! Green Power Drive. www.phipps.conservatory.org/calendar/detail/make-the-switch-at-phipps-green-power-drive

Primack, R.B. and Miller-Rushing, A.J. (2009). The role of botanical gardens in climate change research. *New Phytologist*, 182, 303-313.

PWC (2013). Crop wild relatives. A valuable resource for crop development. Price Waterhouse Coopers. pwc.blogs.com/files/pwc-seed-bank-analysis-for-msb-0713.pdf

Queiroz, A., Espirito-Santo, D., Viegas, W. and Veloso, M.M. (2018). Wild *Pyrus* in Portugal: distribution and diversity assessment. Eurogard VIII Proceedings. In press.

RBG Kew (2012). Chalara dieback of ash – RBG Kew's response. www.kew.org/science/news/chalara-dieback-of-ash-rbg-kews-response

RBG Kew (2018a). www.kew.org/kew-gardens/attractions/temperate-house

RBG Kew (2018b). Adapting agriculture to climate change. www.kew.org/science/projects/adapting-agriculture-to-climate-change

RBG Kew (2018c). The UK National Tree Seed Project: 10 million seeds later. www.kew.org/blogs/kew-science/the-uk-national-tree-seed-project-10-million-seeds-later

Richardson, E. A., Pearce, J., Mitchell, R. and Kingham, S. (2013). Role of physical activity in the relationship between urban green space and health. *Public health* 127, 318–324.

Sahlin, E. (2014). To Stress the Importance of Nature: Nature-Based Therapy for the Rehabilitation and Prevention of Stress-Related Disorders. Doctoral Thesis, Swedish University of Agricultural Sciences, Sweden.

Sandifer, P.A., Sutton-Grier, A.E. and Ward, B.P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. *Ecosystem Services* 12, 1-15.

Sanders, D.L., Ryken, A.E. and Stewart, K. (2018). Navigating nature, culture and education in contemporary botanic gardens. *Environmental Education Research*, DOI: 10.1080/13504622.2018.1477122.

Shaw, S. (2015). The positive effects on mental health of visiting botanic gardens. *Sibbaldia*, 13, 51-59.

Smith, P.P. (2018). The challenge for botanic garden science. *Plants, Planet & People*. In press.

Smith, P.P. and Harvey-Brown, Y. (2017). BGCI Technical Review: Defining the botanic garden, and how to measure performance and success. Botanic Gardens Conservation International, Richmond, United Kingdom.

Smith, P.P., Dickie, J., Linington, S., Probert, R. and Way, M. (2011). Making the case for plant diversity. *Seed Science Research* 21, 1-4.

St. Norbert College's Center for Business and Economic Analysis (2016). Green Bay Botanical Garden Economic Impact. www.snc.edu/cbea/docs/GBBG_Economic_Impact_Study.pdf

Strazdina, L., Naburga-Jermakova, I. and Tomsone, S. (2018). Development of an evaluation system for herbaceous plant adaptation – a tool for invasion risk assessment. Botanical Garden of the University of Latvia. Eurogard VIII Proceedings. In press.

Taylor, A.F., Kuo, F.E., Sullivan, W.C. (2001). Coping with ADD - The surprising connection to green play settings, *Environment and Behavior*, 33, 54-77.

The Audience Agency. (2016). Cambridge University Museums benchmarking 2015: Cambridge University Botanic Garden. London, United Kingdom.

Truong, S., Gray, T. and Ward, K. (2016). "Sowing and Growing" Life Skills Through Garden-Based Learning to Reengage Disengaged Youth. *LEARNing Landscapes*, 10, 361-385.

Truong, S., Gray, T., Tracey, D. and Ward, K. (2018). The impact of Royal Botanic Gardens' Community Greening program on perceived health, well-being, and social benefits in social housing communities in NSW: Research report. Sydney, NSW: Centre for Educational Research, Western Sydney University, Australia.

UN DESA (2018). The 2018 Revision of World Urbanization Prospects. esa.un.org/unpd/wup/

Van der Wees, T. (2017). *One hundred years he Botanic Garden TU Delft*. Eburon Academic Publishers, Delft, The Netherlands.

Virtue, J.G., Spencer, R.D., Weiss, J.E. and Reichard, S.E. (2008). Australia's botanic garden weed assessment procedure. *Plant Protection Quarterly,* 23, 166-178.

Wandersee, J. and Schussler, E. (1999). Preventing plant blindness. *The American Biology Teacher*, 61, 82-86.

Wassenberg, C. L., Goldenberg, M.A., and Soule, K. E. (2015). Benefits of botanical garden visitation: A means-end study. *Urban Forestry and Urban Greening*, 14, 148- 155.

Williams, S., Jones, J.P.G., Gibbons, J.M. and Clubbe, C. (2015). Botanic gardens can positively influence visitors' environmental attitudes. *Biodiversity Conservation*, 24, 1609-1620.

Willison, J. (1994). Environmental Education in Botanic Gardens: Guidelines for Developing Individual Strategies. Botanic Gardens Conservation International, Richmond, United Kingdom.

Wyse Jackson, P. and Sutherland, L. (2000). International Agenda for Botanic Gardens in Conservation. Botanic Gardens Conservation International, Richmond, United Kingdom.

Zhang, W., Goodale, E. and Chen, J. (2014). How contact with nature affects children's biophilia, biophobia and conservation attitude in China. *Biological Conservation*, 177, 109-116.

Zou, X.J. (2011). Analysis of population movement and distribution based on Sixth Census. *Population Economics*, 6, 23-27.

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