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Reducing Environmental Impacts at the Royal Botanic Garden Edinburgh

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Abstract: The Royal Botanic Garden Edinburgh (RBGE) has put the climate emergency and biodiversity crisis at the centre of its organisational strategy and is making changes to reduce the environmental impact of its activities and to adapt to the conditions created by changes in climate. This article looks at actions towards the Sustainable Development Goals (SDGs) within the physical boundaries of the four gardens of RBGE in Scotland. The article considers two areas. Firstly, the Horticultural sphere, including the reduction of the impacts on the environment made by horticultural practice to maintain the gardens, and adaptation of the landscapes to improve visitor access and the biodiversity benefits of plantings. Secondly, influencing behaviour and engaging visitors with respect to growing food and the enjoyment of being with plants for health and wellbeing. In both these areas, RBGE activities are contributing to targets within SDGs 11, 12, 13 and 15. These targets, the actions to realise them and subsequent outcomes are described below. Finally, a major project underway at the Garden which will significantly reduce the environmental impacts of the institution, the Edinburgh Biomes, is introduced.

Keywords: sustainable horticulture; rain garden; integrated pest management; biocontrol; community engagement; health and wellbeing; inclusive; accessible

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1. Introduction

1.1. The Royal Botanic Garden Edinburgh

The Royal Botanic Garden Edinburgh (RBGE) is a non-departmental public body (NDPB) largely funded by the Scottish Government (Royal Botanic Garden Edinburgh, 2021) [1]. There are over 280 full- and part-time staff at the institution over four gardens in Scotland (Royal Botanic Garden Edinburgh, 2021) [1]. The gardens are in Edinburgh; Dawyck in the Scottish Borders (in the south-east); Benmore in Argyll (in the north-west) and Logan in Dumfries and Galloway (in the south-west). Over 36,000 accessions and 200,000 individual plants in 2553 genera are cultivated over all four gardens in an area totalling 116 hectares (Knott et al., 2021) [2]. Over one million visitors come to one or more of the gardens each year (Royal Botanic Garden Edinburgh, 2021) [1]. The Edinburgh garden is the administrative centre and is the most visited due its location in the city of Edinburgh. It is also the most species-rich due to the 1.5 ha glasshouse complex, including display propagation and research glasshouse units (Knott et al., 2021) [2]. The garden is intensively planted with landscaped areas dedicated to the cultivation of exotic and native plants. Areas include a rock garden and specialized glasshouses and structures for alpine plant cultivation, an arboretum and pinetum, herbaceous border and extensive mixed herbaceous beds, a woodland garden, pond and marginal plantings and areas dedicated to British native plants and the cultivation of food plants. The display glasshouses consist of ten separate houses connected by walkways. A range of temperate, sub-tropical and tropical environments create suitable conditions for the cultivation and display of plants from lowland and high-altitude tropical regions and arid zones. Over 4000 species are cultivated

under glass (Knott et al., 2021) [2]. This range of environments provides an incredible resource for the diversity of both plants and animals, and records indicate that mammals and amphibians, birds, insects and other invertebrates that make their home in the Edinburgh garden numbered 1133 species in March 2020 (Mill, 2020) [3].

The RBGE launched its Science and Biodiversity Strategy in June 2021 as a direct response to the Biodiversity Crisis and the Climate Emergency (RBGE, 2021) [1]. The document outlines the RBGE's commitment to its research priorities, collections and the individuals and communities in the context of these urgent issues. Enhancing the environmental sustainability of collection management is an important part of this commitment.

1.2. Horticulture

Horticultural professionals are notoriously sensitive to the environmental impact of their activities. They spend their days interacting with plants, associated biodiversity and the weather (the day-to-day effects of the climate) and hence have an affinity with concepts of sustainability. However, the practice of maintaining a garden to standards which are considered by the visiting public to be 'acceptable' has an environmental impact. The use of manufactured substrates, soil ameliorants and fertilisers, and landscape maintenance with mechanised tools all require controls and measures which can negatively impact biodiversity. These measures also emit CO_2 and other toxins that can deplete natural resources. The RBGE has sought to reduce such impacts for decades, and these efforts have accelerated in recent years as the consequences of biodiversity loss and climate change have become more apparent (RBGE, 2021) [1]. Alternatives to traditional horticultural standards and practice have become more widespread. This section of the article describes measures implemented at the RBGE to reduce the use of pesticides and herbicides, fossil fuelled tools and of peat as an ingredient in potting composts. These measures contribute to SDG Target 11 ('sustainable cities and communities'), Target 12 ('responsible consumption and production') and Target 15 ('life on land').

In addition to the changes in quotidian practice to more sustainable actions, the Horticulture Department has looked at how the landscape can be adapted to cope with the changing climate, to ensure that visitor access is not unsafe or restricted and to increase benefits for biodiversity. An experimental rain garden was created at the Edinburgh Garden in 2019 to mitigate against the impacts of more frequent and intense rainfall events. This accessible feature offers an opportunity to inform and inspire the public and contributes to SDG 13 'climate action'. A case study of this collaborative research project with practical applications follows.

1.3. Engaging Gardens

The RBGE has long had a commitment to community engagement, currently within the Engaging Gardens programme. Such work helps achieve Scottish Government priorities in areas including health, learning and citizenship and RBGE objectives relating to public engagement, visitor services, environmental stewardship, learning and education and sustainability.

Engaging Gardens aims to ensure that every person can access and benefit from the health, wellbeing and learning opportunities that RBGE's gardens, collections and expertise offer. It facilitates engagement with visitors who might not ordinarily visit the garden, breaking down barriers to visiting and engaging people with RBGE work. Connecting health and wellbeing, environmental sustainability, people and plants is at the core of the programme. This section of the article describes the activities of the community engagement team and the contribution they make to SDG 11 'sustainable cities and communities' and SDG 12 'responsible consumption and production'.

2. Materials and Methods

2.1. Cultivation Practices

Integrated Pest Management and the use of Biocontrols

RBGE has used biological organisms to control pest and disease outbreaks for decades. However, in 2018 a programme began to replace the use of chemicals with biological organisms to control pests in the glasshouse complex. This required more extensive application of a more diverse range of predator species. Confidence in the effectiveness of biological solutions has grown among RBGE horticulturists and they have substantially reduced the application of toxic chemicals, in particular neonicotinoids, which control populations of sap-sucking insects (Ives, 2018) [4]. Neonicotinoids especially have been shown to have lethal effects on a wide range on non-target insects and invertebrates and usage is counter to the development of a healthy ecosystem (Pisa et al., 2015) [5]. Some treatments are predator organisms, such as *Encarsia formosa*, which targets species of whitefly. Other treatments contain a combination of predators applied at one time, an example being Aphiscout, which contains five different predatory wasps, which seek out a range of Aphid species pests and thrive in a range of protected glasshouse environments and temperatures (David Tricker, pers. comm.).

The introduction of living organisms precludes the use of chemicals to solve other problems, such as the outbreak of disease, because they can negatively impact the biocontrol. Therefore, when the use of biocontrols was increased, the use of chemicals necessarily went down. The glasshouse environment is treated as a living system and all organisms—plants, insects and other life—need to be considered. Reduction in the use of chemicals to manage plant health contributes to SDG 12, Target 4:

> *12.4. By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment*

The tropical orchid and cycads biome is now cultivated entirely without applications of toxic chemicals. Its exotic and unfamiliar plant groups, displays of bright flowers which change weekly, sheets of the bromeliad *Tillandsia usneoides* and the preponderance of plants with extraordinary shapes and forms (*Pandanus* sp. (screw pine) and *Philodendron* sp. amongst others), make it one of the most popular glasshouses with visitors. Predatory *Cryptolaemus montrouzieri* feed on mealybug species *Planococcus citri* (citrus mealybug) (Figure 1) and *Pseudococcus viburni* (obscure mealybug), keeping populations below the level at which they cause unsightly damage and weaken plants. The glasshouse is heated to 18 °C (night) and 25 °C (day). This temperature also suits the predators, and some are active year-round, preventing the build-up of the pest species. In addition, cultivation practices, such as pruning and maintaining high standards of hygiene, reduce habitats and favourable conditions for pests. For example, the removal of senescing screw pine leaves which harbour pest insects and the regular pruning of fast-growing climbers increases air circulation that mealybugs do not like. No accessions have been lost under this change in pest management technique (Louise Galloway, pers. comm.).

Different predators require different levels of management by horticultural staff. *Aphidoletes aphidimyza* is effective at controlling greenfly (Aphidae), and following release in a tropical environment the predator has migrated and naturalised in the adjacent warm temperate glasshouse where it is effectively keeping greenfly populations to a minimum with no additional applications (David Tricker, pers. comm.). In contrast, booster applications of *Cryptolaemus montrouzieri* are required to maintain the effectiveness of this predatory species to reduce mealybug species populations as described above.

Figure 1. Adult *Cryptolaemus montrouzieri* mating and feeding on egg sacs of *Planococcus citri*. Photo: Paulina Maciejewska-Daruk.

The RBGE at Edinburgh cultivates 1.5 hectares of living collections under glass, and all these environments, both temperate and tropical, have experienced a 65 percent reduction in the use of chemicals to control pests (Louise Galloway, pers. comm.). The use of biocontrols is easier to manage in tropical glasshouses because they are better suited to the warmer temperatures. If pest populations have an isolated bloom in winter, these are spot-treated with a non-toxic fatty acid or washed off with water. The only toxic chemical used in the glasshouses is a specifically developed chemical targeted at *Periplaneta australasiae* (Australian cockroach) populations. This is a species which can cause a lot damage if unchecked and can spread to office buildings.

2.2. Impacts of Decreasing the Application of Chemicals

The reduction of contact with toxic chemicals has health benefits for staff and the other forms of life that make their home opportunistically in the glasshouses, such as native birds, bees, hoverflies and butterflies, which find their way in through open vents and doors. When chemicals are applied, glasshouses have to be closed to reduce risk of contact. This disrupts working practices and visitor access. For houses with entrance fees, there is loss of income and a reduction in visitor satisfaction. Access is possible during or immediately following the application of biocontrols, and they are safe for other forms of life.

The management of collections with biological controls requires the acceptance of a different aesthetic. In glasshouses which have self-sustaining populations (or almost, requiring only small 'booster' applications annually), the presence of the pest is essential to maintain the predator. Therefore, nibbled or sticky leaves and deposits of exudates and frass are occasionally visible. The interpretation of how and why the collections show evidence of other life can help to manage expectations. Visible positioning of the sachets of predators (Figure 2) also provides an opportunity for engagement about sustainability, biodiversity and the relationships between plants, animals, fungi and people. The concepts of 'problem', 'solution' and 'dependence' can also be explored: one organism viewed by humans as a pest or a problem is a food source, or a solution, for another.

Figure 2. Sachet of *Amblyseius montdorensis* in the Temperate Palm House at the Royal Botanic Garden Edinburgh. Biological controls are applied by hanging sachets of predatory insects on plants in the glasshouses as near as possible to the outbreak of a pest organism. Photo: Kate Hughes.

2.3. Replacement of Peat as Growing Media

Peatlands are fragile upland ecosystems, which hold proportionally large amounts of CO_2 in the ground because they are made of dead and decaying organic matter (IUCN Peatlands Programme, 2021) [6]. When peat moss is commercially extracted for fuel and growing media, this habitat and the specialised species that grow there is removed and the carbon is released into the atmosphere. The cessation of peat extraction contributes to Target 5 in SDG 15 'life on land'.

> *15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*
>
> *15.5. Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species*

The use of peat in compost mixes is contradictory to the aims of RBGE as an organisation dedicated to the conservation of plant species. RBGE has had a 'no peat' policy since the early 1990s, at which point the purchase of pure peat ceased. It has been a challenge to completely remove peat from all growing media for a garden with a specialism in the acid-loving genus *Rhododendron*. This challenge was met in the late 1990s with the use of four different grades (particle sizes) of milled pine bark to accommodate the needs for the range of species cultivated at the RBGE. Experimental cultivation and exploration of the effectiveness of bark-based mixes for species which either have never been cultivated before or which are not commonly cultivated are cited by Hughes et al. (2014) [7]. Pine bark is the basis for the compost mixes in use at the RBGE.

More recently, further collaboration with commercial manufacturers to develop a range of mixes suitable for the species cultivated at the RBGE have led to the successful establishment of 'RBGE1' and 'RBGE2' mixes, which are used in the nursery for sowing seed and potting up. They contain sylvafibre, a macerated woody material with similar

properties to peat, as well as pine bark. No peat is present in any of the many bespoke mixes which staff make up for each group of plants as cultivation needs demand (Figure 3).

Figure 3. Plants are potted into peat-free 'RBGE 2' nursery potting mix. Photo: Kate Hughes.

2.4. Replacement of Fossil Fuelled Vehicles and Tools for Battery-Powered Equipment

In 2017, the global tool company Husqvarna hosted a 'silent city' conference at the RBGE. The company donated the remotely controlled, battery-operated lawn mower to the organisation, later named 'Isaac' by horticulture staff. The success of this mower led staff to trial other equipment to replace tools fuelled by two-stroke oil and petrol. The petrol equipment is noisy, heavy and emits toxic fumes and CO2. There are negative impacts on operators, visitors and the environment.

Horticultural managers made a commitment to spread the cost of the purchase of new equipment over the financial years of 2019/20 and 2020/21. In 2021, over 80 per cent of the petrol-fuelled hand tools have been replaced with electric and rechargeable batteries (P. Ashby, pers. comm.). The RBGE has also committed to purchasing energy tariffs with a high component of renewable electricity.

A battery-powered vehicle with a trailer was purchased in 2019 for transporting tools, plants and people, and in 2021, the first battery-operated push mower was bought. Trials of large machinery, such as chippers, ride-on mowers, diggers and telehandlers, have all been successful and the intention is to replace all fossil-fuelled machinery with a battery-operated fleet by 2030 at the latest.

2.5. Landscape Adaptations

The RBGE has made adaptations to its landscapes in response to changing climatic conditions. In Edinburgh this means increasingly intense periods of heavy rainfall and longer periods of hotter-than-average weather without rain (Martin, 2014) [8]. In some cases, these changes might require the installation of path materials with improved drainage capacity or mulching over planting beds to retain moisture. The establishment of an experimental rain garden at Edinburgh has been successful in mitigating the problems

caused by heavy rain and as a demonstration of the benefits of such features. These measures contribute to targets within SDG 13:

SDG 13 Climate Action

13.1. Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

13.2. Integrate climate change measures into national policies, strategies and planning

13.3. Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

Case Study: An Experimental Rain Garden

Rain gardens offer a sustainable, nature-based solution to flood mitigation by mimicking natural rainwater retention and infiltration characteristics within a constructed bioretention system. In a collaborative trio, researchers from Heriot-Watt University, worked with RBGE staff as part of the Scottish Government-funded ClimateXchange programme and with RBGE horticulture staff to identify an area of the Edinburgh garden which was prone to serious flooding (Kelly et al., 2020) [9]. Periodic floods damaged mature trees, shrubs and other plantings and the area had to be closed off to visitors after heavy rainfall (Martin, 2014) [8]. The team carried out studies into the filtration capacity of the soil. Following analysis of how quickly the water drained away and the components of the existing soil, structural amelioration was carried out. Some of the soil was dug out and mixed with compost, sand and gravel to a specified range of particle sizes and proportions. The composition of the soil was developed to ensure better filtration, as well as providing sufficient organic material and nutrients to support the plants. Plant species that can withstand both very wet and very dry conditions were selected (Kelly et al., 2020) [9].

Another purpose of the rain garden was to provide enhanced biodiversity provision. The mix of plants chosen encourages a diversity of wildlife, providing nectar sources for insects and bees in summer (Figures 4 and 5) and homes for invertebrates and food for seed-eating birds in winter. The planting includes both Scottish native and non-native plants. There are strong ethical and ecological reasons as to why native plants are the first choice, but the use of non-natives can be just as effective in this environment. The RBGE has a remit to enhance biodiversity and displays plants from around the world; this global perspective being an important part of its mission. The selected native plants include *Saxifraga granulata*, *Succisa pratensis*, *Anthyllis vulneraria*, *Filipendula ulmaria*, *Cicerbita alpina*, *Knautia arvensis* and *Festuca altissima*. The non-native plants include *Aruncus gombalanus* (China), *Ligularia fischeri* (E Asia), *Aquilegia formosa* (western N America), *Primula poissonii* (China) and *Hosta sieboldiana* (Japan). All were grown from seed at the RBGE Nursery.

Soil amelioration and plantings were carried out in April and May 2019 and over the following year the rain garden was shown to attract insects and bees that enjoy the nectar from its flowers, and other wildlife sought shelter in its growing canopy. The area also remained accessible at times of high rainfall and the surrounding area has not flooded. With the rain garden now functional for more than two years, researchers at Heriot-Watt are continuously monitoring plant evapotranspiration and gaining an insight into soil moisture and how plants manage both exceptionally low and high availability of water, conditions which occur with increasing frequency in Scotland.

In June 2021, eight soil moisture sensors that spanned the full width, breadth and depth of the rain garden were inserted into the soil and a data logger was installed. To quantify the amount of rainfall interception that vegetation can achieve, two leaf wetness sensors (product Phytos 31; METER) were also installed. The sensors were set up to record every two minutes and the measurements recorded in a data logger (Campbell Scientific, CR1000x) with the data downloaded every two weeks (Kalaichelvam and Kelly, 2021) [10].

Figure 4. Figure 3 Butterfly *Pieris rapae* (small white) on *Ligularia fischeri*. Photo: Kate Hughes.

Figure 5. The raingarden in July 2021 showing the raised berm of grass on the right. The design prevents water flooding on to the path at times of high rainfall. Photo: Kirsty Wilson.

Data from the sensors enables the monitoring of the performance of the rain garden during and after heavy rainfall events. It also monitors the duration of periods when the soil might become very dry, and observations can be made of the impact on plant health. Data from the leaf wetness sensors allow an assessment of rainfall interception by the plants and also allow estimates of evapotranspiration. Further studies in 2022 involve assessment of the volume and coverage of the vegetation using drone images. Aerial images of the raingarden were captured in August 2021 at different fields of view and altitude. These were fed into a computer programme to stitch and render a 3D map of the vegetation.

The 3D map will calculate the vegetation coverage more accurately and will feed into the calculation of estimates for evapo-transpiration. The exercise will be repeated throughout the year to map the variations of vegetation coverage at the rain garden in different seasons.

On the 4 July 2021, there was an exceptional intense period of summer rainfall, with 41 mm falling within one hour in the Edinburgh area. This event was well documented in popular media as torrents of water streamed down the city's roads. Many areas outside and inside the garden which are usually unaffected by high rainfall were flooded. The deluge caused thousands of pounds (GBP) worth of damage to buildings and infrastructure. The data logger measured this rainfall event and staff observed that the raingarden experienced no flooding at all (Kirsty Wilson, pers. comm.). The records demonstrate that the raingarden has mitigated high rainfall and the plants have survived periods of dry weather. This piece of landscape design provides an effective and engaging demonstration of a landscape-based solution to changing climatic conditions (Figures 3 and 4).

2.6. Engaging Gardens Influencing Behaviour and Engaging Visitors

The RBGE's community engagement programme is known as Engaging Gardens. Supported by players of People's Postcode Lottery, it consists of the Edible Gardening Project, Skills Share programme, the Kitchen Garden and a series of health and wellbeing activities. Community engagement in some form has always been an integral part of the organisation, and since the RBGE's very beginnings its work has involved bringing people and plants closer together. When the garden was founded in 1670 it was a physic garden used 'to supply fresh plants for medical prescriptions and help teach medical botany to students' (RBGE, 2022) [11].

RBGE is open daily (excluding Christmas day and New Year's Day) and is free to enter. In 2021 there were 546,904 visitors to the Edinburgh site. Engaging Gardens aims to build on the diversity of the visitor profile. The programme reaches out to members of the public who may not ordinarily visit RBGE, aims to reduce the barriers to participation and welcomes all members of the local community to access the safe green space offered at the RBGE. This dedicated community engagement programme contributes to SDG 11.7:

> *SDG 11. Sustainable cities and communities*
>
> *11.7. By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities*

The programme, as it currently stands, began in 2011 when the Edible Gardening Project received funding initially for one year. The application stated:

> 'Our shared ambition is to involve people of all ages, abilities, and ethnic backgrounds. Everyone is interested in food and we believe a project based around growing edible plants is an excellent way of sharing and celebrating the cultural variety that exists within modern society. There will be a particular emphasis on reaching those groups who have been under-represented among participants in the RBGE programmes in the past'.

The Edible Gardening project 'grows skills to grow food'. A team of dedicated volunteers help the RBGE community gardeners to teach horticultural skills to garden visitors at events and 'meet the gardener' sessions. They also help with community groups who visit the garden for workshops and tours.

The project had a hugely successful first year and received additional funding to continue for a second. The project developed further in 2012 when the RBGE took part in the Botanic Garden Conservation International 'Communities in Nature—Growing the social role of botanic gardens' programme. The social role of the botanic gardens was defined as: 'Gardens working in partnership with their local communities on common issues of social and environmental importance'.

Communities in Nature involved groups attending the garden on a weekly basis to look after their own vegetable plots, working alongside RBGE community gardeners. They built relationships and learned how to plan, grow, maintain, harvest and prepare

their crops. The community plots are still part of the Edible Gardening project today, 10 years after the programme began. The Edible Gardening Project and involvement with Communities in Nature has shaped the community programme, now known as Engaging Gardens. Engaging Gardens activities have counted 65,878 interactions at the time of writing in Oct 2021 (please note that interactions rather than individuals are counted as there are many repeat visits).

Engaging Gardens has the following mission and vision:

Mission: To ensure that every person can access and benefit from the health, wellbeing and learning opportunities that RBGE's gardens, collections and expertise offers.

Vision: To become a world leader at connecting health and wellbeing, environmental sustainability, people and plants.

Inclusivity and accessibility drive the programme and the RBGE community team prioritises those participants who are underrepresented in the regular visiting demographics. The RBGE actively invites people to take part in free, accessible activities. Some of the groups who have participated in the Edible Gardening Project include:

- Move more (people affected by cancer);
- Edinburgh and Lothians Regional Equality Council (who work to reduce inequality and promote a culture of human rights);
- Networking Key Services (empowering women and their families to make better choices) (Figures 6 and 7);
- Teens + (working with young people with complex additional support needs);
- Garvald (supporting people with learning disabilities).

Figure 6. Participants from a community group planting potatoes.

Figure 7. Community group sowing seeds with the Edible Gardening Project.

Further examples include RBGE-led groups, such as garden socials for people affected by dementia held monthly and fortnightly cook clubs where individuals cook a meal and enjoy sharing it together in an effort to combat isolation. In addition, in February 2022, RBGE will commence a series of tours delivered in British Sign Language (BSL). Tours are free and will be available at all four gardens in Edinburgh, Logan, Benmore and Dawyck.

2.7. Kitchen Garden

The RBGE's Kitchen Garden has been in operation since May 2016. Caterers Sodexo (now Heritage Portfolio Limited) and RBGE entered an agreement whereby a community gardener's salary was funded by Sodexo for 18.5 h a week. The community gardener grows a range of crops onsite using organic principles and crops produced are delivered directly to the kitchens at the catering outlets in the Edinburgh garden, approximately 250 m away.

The Kitchen Garden consists of 369 m^2 area of ground and a 29 m^2 polytunnel. The polytunnel is used to grow high-value baby leaf salad crops and achieved organic conversion in 2018. Full organic conversion for the Kitchen Garden will be achieved in April 2022. From January 2021 to September 2021, there was a crop yield of 111.6 kg from the polytunnel and 614.8 kg from the Kitchen Garden.

In addition to sustainable gardening techniques and very low food miles, the community gardener works closely with the chefs to select vegetables for the cropping plans, and the chefs plan menus seasonally and according to what will be available. The production and supply chain has only two components, so food losses are reduced to virtually nothing. The Kitchen Garden is a significant step and commitment for RBGE and the contracted caterers and contributes to SDG 12.3:

SDG 12 Responsible consumption and production

12.3. By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses

The quantities of crops delivered to the kitchens may only be a proportion of the vegetables required to supply the consumers, but it provides an added benefit of the Kitchen Garden's visibility. It is located in a vibrant, busy and popular area of the garden frequented by visitors who can learn more about growing organically and seasonally. Visitors can see the crops growing and interact with staff and volunteers.

2.8. Promoting Lifestyles in Harmony with Nature

Botanic Gardens are in a unique position to promote positive societal change in terms of environmental sustainability due to their location, purpose and history. 'Botanic gardens are predominantly located in urban areas. They provide oases of beauty and expertise and are committed in their DNA to the preservation of biodiversity.' (Lynch 2015) [12]. Much of RBGE's public and community programme contributes to SDG 12.8.

SDG 12 Responsible consumption and production

12.8. By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature

As previously mentioned, the vision of the RBGE's community engagement programme, Engaging Gardens, is to become a world leader at connecting health and wellbeing, environmental sustainability, people and plants. The RBGE's community programmes bring people closer to plants, greenspace and the natural world. Influenced by the research of the Common Cause Foundation, the RBGE aims to engage people's values around equality, friendship and being part of nature. One of the Foundation's key principles encourages engaging compassionate values as a means to driving positive environmental action.

> 'Research has repeatedly found that when people pursue environmental actions for more autonomous reasons—for example, because they want to help or connect with others or express their creativity—they are more likely to stick at these behaviours, and these behaviours are more likely to propagate to other environmental actions.' (Common Cause Foundation, 2018) [13].

Further recommendations include encouraging a more 'hands on' connection with nature and sharing experiences of the natural world. By giving people the opportunity to spend time in a vibrant, plant-rich greenspace and by inviting people to take part in physical activities, the RBGE aims to connect participants to the values that encourage behaviour that protects the environment (Blackmore et al., 2013) [14] (Figure 8).

Figure 8. A young visitor discovering the garden's biodiversity (credit Louise King).

In addition to engaging with these values, Engaging Gardens participants gain practical skills that enable them to lead more sustainable lifestyles. Growing, harvesting,

preparing and eating seasonal fruit and vegetables, gardening using organic principles and home composting skills are all an integral part of the programme (Figure 9).

Figure 9. Fresh produce harvested from the Kitchen Garden in November 2021, about to be delivered to the RBGE kitchens.

The examples given explore the work of the community engagement team and the Engaging Garden programme, but it is important to recognise that there are numerous further examples of the RBGE's work that contribute to SDG 12.8:

- The Creative Programme team curate exhibitions at Inverleith House. In May 2020, the space was transformed into Climate House as part of a five-year project funded by the Outset Transformative Grant. Throughout the project, 'Climate House will welcome artists from Scotland and around the world to showcase work that encourages conversations about life on earth and expand our understanding of biodiversity and our place in the world.'
- With partner organisations in Scotland's Environment and Economy Leaders Group, RBGE was involved in an exhibit at the COP26 climate conference. The exhibit highlighted the contribution that healthy ecosystems can make to tackle the climate emergency. It provided information about the importance of peatbogs, farming practices in relation to soils, rewilding and natural regeneration.

This list is not exhaustive and there are examples of work across the organisation in horticulture, education, science and public engagement that contribute to SDG12.8.

2.9. Future Projects: Energy Centre

A new energy centre occupying 500 m^2 will be constructed in 2023. The energy centre will contribute to SDG 12, Target 2:

SDG 12 Responsible consumption and production

12.2. By 2030, achieve the sustainable management and efficient use of natural resources

It will include Ground Source Heat Pumps (GSHPs) and a Combined Heat and Power plant (CHP), to provide heating to the glasshouses, office and visitor buildings both at

the Nursery site and for the main Garden. The energy centre will reduce RBGE's carbon footprint by 25%. Heat created from the GSHPs alone will account for 28% of all heat generated by the new energy centre.

GSHPs provide an excellent source of base heat. Temperatures of 25 °C are required year-round to maintain the living collections in the tropical glasshouses. This requirement creates a need for substantial uplift when ambient temperatures are low in the winter months. The new energy centre incorporates a Combined Heat and Power (CHP) plant and gas boilers to provide this uplift. The energy efficient CHP plant will be used to generate the base electricity load for the glasshouses, significantly reducing the use of natural resources to run them.

The energy centre is part of a larger ambitious project, Edinburgh Biomes, running from 2022 to 2027, involving the refurbishment of the heritage buildings and the construction of new buildings using technology, which will vastly reduce the environmental impact the Garden's activities. The sustainability of the institution and efficient use of natural resources are the central aims of the project to ensure that the RBGE's extensive living, preserved and archival collections are accessible to all in the future. The RBGE website provides information and updates about the project as it progresses https://www.rbge.org.uk/news/edinburgh-biomes/what-is-the-edinburgh-biomes-project/ (accessed on 1 January 2022) [15]

3. Conclusions

Many of the actions cited here are relatively small when seen in the context of the biodiversity crisis and climate change on a global scale. However, they are hard-won gains which have required internal debate and resources to implement against the challenges faced by all organisations with a diverse range of activities and stakeholders, heritage and new infrastructure and biodiversity to care for on their estates. The implementation of such actions requires continuous consideration, research and resources to reap the benefits. Some impacts take several years of action to make a visible difference, and they require constant revision and evaluation as circumstance, the climate and staff or visitor behaviours adapt and change.

A series of large redevelopment projects at the Edinburgh Garden with a completion date of 2027, the Edinburgh Biomes project (RBGE, 2022) [15] will result in a new sustainable energy centre, redeveloped infrastructure with energy-saving technology and the renovation of glasshouses to improve energy efficiency. The completion of these projects will reduce the environmental impacts of implementing the Science and Biodiversity Strategy and care of the collections. These are significant projects offering exciting opportunities to engage visitors and a global audience in the importance of plants and botanic gardens for our future. The daily activities of caring for the collections and engaging the people who use our gardens will continue to be as important as ever.

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