Part C: The Plant Collection – Linchpin of the Botanic Garden

Chapter 6: Horticultural Management

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Kate Hughes and Leigh Morris, Royal Botanic Garden Edinburgh

6.0 DEFINITIONS

Biosecurity: The protection of plants from any type of infectious agent whether viral, bacterial, fungal, or parasitic. People, other organisms, the wind and water can spread these as they move within a facility and from one facility, or plant to another.

Fertigation: Application of fertilisers and soil conditioners into irrigation systems in order to provide nutrients to growing plants along with water.

Growing media: The material used to support the growth of a plant, particularly in containers and pots. Commonly in botanic gardens this can include soil, organic matter and compost, bark, sand, coconut fibre, peat, rice husks, vermiculite and perlite amongst other materials.

Isolation: Keeping plants separate from the main collections in order to monitor for and treat pests and diseases thereby protecting the site from unwanted infections (see also Quarantine).

Organic matter: The remains of dead and decomposing organisms. A good source of nutrients and soil conditioner for growing plants.

Pesticide: A chemical or biological agent used to control pests, diseases and weeds.

Provenance: The original source of the plant material. The term is used both to denote a location (wild population or nursery-grown) and a concept (wild-collected or cultivated stock).

Quarantine: Measures put in place to isolate and screen plant material as a potential pest or disease carrier (see also Isolation). Moreover, the term is used to denote the legal requirement for organisms to be inspected and cleared for health on entry to an area.

Stratification: To subject seeds to temperature change in order to stimulate germination. This usually involves lowering the ambient temperature for a period of time.

Viability: The capability of a seed or spore to germinate.

6.1 INTRODUCTION

Without living plants there is no botanic garden. While the collection policy (Chapter 3) determines the species to be grown, cultivated plants need horticultural care and management. This chapter describes the core elements of conservation horticulture in botanic gardens and key considerations for horticultural operations.

6.2 PLANTS AND HABITATS

KEY MESSAGE

For successful growth and display of plants the correct environment needs to be provided. This may mean adapting the prevailing on-site conditions. These should be assessed first before deciding on the adaptations required.

This section discusses the considerations that should be made with respect to the plants and habitats to be represented in the botanic garden, governed by the collection policy (Chapter 3), and the climatic modifications and horticultural environments that will need to be provided. The requirements of the plants that will be cultivated as well as the climate and other environmental features of the site and how this may affect the plants, will have to be well understood. Determining how the environment can be manipulated, and how to do this with the resources available for the plants selected, is an important part of growing plants successfully:

Key questions

- What plants will be grown?
- What habitats do they come from?
- What is the climate of the site?
- What habitats and ecosystems will be represented?
- What environmental conditions are needed to cultivate them?
- What possible changes can be anticipated?
- What are the options for creating the habitats sought?

6.2.1 Habitats and Plant Types

A key decision with any planning for a botanic garden is the choice of plant groups and habitats to be represented within the collections. Once a conclusion has been reached, the suitability of the climate and soil of the site, as well as the level of environmental modifications needed, should be examined.

- Habitats

Habitats commonly represented in botanic gardens that fall under various ecosystem categories such as aquatic, woodland, rainforest, cloud forest, savannah, steppe, desert, etc. have variable characteristics, including soil type, precipitation and water regime, temperature, light level, wind and air flow, altitude and biodiversity at large. An understanding of these features in relation to the prevailing conditions in the botanic garden site is important

A planting bed has been adapted with the addition of drainage and a gravel mulch for alpine plants in a low altitude location at the Royal Botanic Garden Edinburgh. (Image: Kate Hughes)

for successful plant cultivation. It is recommended that, whenever possible, this habitat information is obtained from secondary sources such as climate and soil maps, but it may be necessary to collect data from the habitats the plants originate from as well as the site of the botanic garden. For instance, this can be done by collecting and analysing soils and using data loggers for temperature information.

- Plant types

Plants within botanic garden collections are typically grouped into broad categories, such as alpines, trees and shrubs, aquatics, herbaceous perennials, ferns, xerophytes, food plants, herbs and epiphytes. The prevailing site conditions will determine the types of plant that can be grown easily, but for those that will not establish well, conditions will need to be modified and permanently maintained. Examples include modifying water supply, temperature and soil pH.

- Natives or exotics?

It is important to consider whether mostly native species will be grown (which may require little site manipulation) or exotics (which may entail changing the natural site conditions considerably). Whatever is decided, the most important information for successful cultivation is consideration of the plants' requirements, and this will be informed by detailed habitat analysis, not simply by replicating the general climate in the country of origin. Decisions over whether to grow exotics or natives will always require referring back to the collection policy (Chapter 3) which in turn is derived from the botanic garden's vision and mission (Chapter 1, Section 1.2.4). Consideration should be given to the user groups who will interact with the living collections. For example, a botanic garden in a temperate climate may wish to display and use tropical plants as part of its education strategy or to attract more paying visitors.

6.2.2 Climate and Environment

It is fundamentally important to know and understand the climate of the botanic garden site and how this compares to the adaptations of the plants to be grown. This will enable botanic garden managers and horticulturists to understand what changes are to be made for successful cultivation. Information on climate and environment from existing external sources, as well as data collected from the botanic garden should be carefully studied, especially pertaining to microclimatic conditions on the site. It is particularly important to have access to local information if the species to be grown are at the edge of their tolerance or have a reputation for requiring very specific environmental conditions.

- **External sources of information**

- Airports: All major airports have weather recording stations.
- Governments: Meteorological data for longer term weather patterns and soil data.
- Local growers, parks and reserves: Soils and local climate information.
- Local societies, agencies and environmental organisations: Any other insights to an area that may be relevant.
- Data loggers: Placed into the habitats that are planned to be represented within the botanic garden which measure maximum and minimum temperatures over a number of months.

- **Collecting data on-site**

- Soil analysis: Soil type influences plant growth and this should in turn inform plant selection and horticultural practices in a number of ways. It is fundamental that a good understanding of the soil type(s) on-site at the botanic garden is achieved, including its physical, chemical and biological properties.

  Soil samples can be taken from across the site and tested for acidity (pH) and texture quite simply and cheaply. Soil profile pits can be dug to determine soil depth and structure. For more detailed analyses of nutrient levels and organic matter content, more specialist equipment is required and soil samples may have to be sent for testing externally for instance to a university, agricultural research station or private company. Likewise, information on bedrock type, watercourses and topographical features needs to be gathered as these may affect the establishment and growth of the plants on-site.

  It is important to compare the soil(s) of the botanic garden with those of the habitats from where the plants intended for cultivation are originating. This will be particularly important in propagation and nursery growing media for any young plants.

- Weather data: It is advisable to collect weather data on-site to gain a comprehensive understanding of the overall local climate and within-site microclimate. Weather monitoring equipment can range from a simple maximum / minimum thermometer and a plastic rain gauge, to a weather monitoring station containing more complex electronic devices that measure a range of factors including air and soil temperature, sunlight level, wind speed, humidity, rainfall and air pressure.

Table 6.1 Natural habitat factors that can be manipulated and how these relate to the horticultural requirements

Natural habitat factors	Horticultural considerations and applications
Soil type: texture, structure, pH, nutrient levels and organic matter content.	Choice of propagation and growing media, and choice of substrate in final planting; soils can be changed completely for some areas, particularly in containers or planting pits; soil additives can be incorporated such as grit, sand, organic matter and fertilisers.
Precipitation and water regime: quantity, quality (pH), seasonal changes, types.	Choice of irrigation or fogging system(s) and frequency of application; drainage systems can be installed if required.
Temperature: maximum and minimum, diurnal fluctuation.	Use of greenhouses (glass, polythene, netting, etc.) and heating or cooling systems within them.
Light levels: full sun or shade, sunshine hours per year.	Use of supplementary lighting or shading.
Wind and air flow: plants from exposed sites, requirement for high humidity.	Use of ventilation (open or closed) and/or fans to increase or reduce air circulation; wind break mesh material to reduce wind speed.

6.2.3 Manipulating the Environment

Most botanic gardens are manipulations of the environment to a greater or lesser degree. It is possible to adjust the growing conditions for plants in a number of ways, and an understanding is needed of the options available with the resources at hand. The more deviation from the prevailing conditions on-site, the more complex and expensive manipulating the environment becomes. This has a direct impact on plant and habitat selection for the botanic garden (Table 6.1).

Some species or individual plants are extremely adaptable and can survive or thrive in a range of different conditions. Others are much less adaptable and need specific conditions with small margins of change. It is important to know these features for the plants intended for cultivation before expending resources on sourcing, transportation and propagation. The more energy required to create the conditions that the plants need, the greater the cost. Consideration must also be given to the purpose of the collection, such as whether the plants are aimed at *ex situ* conservation or display. Maintaining plants for a stunning exhibit is likely to require more resources overall and possibly more environmental manipulation, dependent on the groups of plants selected.

Pot culture and polytunnels are both examples of manipulating the environment to create conditions which are more suitable for plant growth in the prevailing climate. (Image: Kate Hughes)

Impacts of climate change should be taken into account when planning long-term plantings. These include drainage, irrigation and hard landscaping as well as the materials and the design used. Climate change trends in the area should be examined regularly, including the occurrence of extreme weather events. This may also be a time to look at the tolerance levels of the plants, whether their requirements are within very narrow parameters or whether they will tolerate a range of conditions or extremes.

6.3 SOURCING PLANTS

KEY MESSAGE

Plants can be acquired from a number of sources. The sourcing of plants should be compatible with the mission and collection policy of the botanic garden. There are regulations governing the movement of plants, and ensuring legal compliance is essential to this. At the sourcing stage, comprehensive plant information needs to be recorded as this is the starting point for the part that the plant will play in the future of the botanic garden.

This section discusses the methods by which plants can be obtained by the botanic garden. Acquisition of plants for conservation, display or any other purposes should be driven by the institution's collection policy (Chapter 3). Once key decisions regarding landscape design and species selection have been made, various aspects of sourcing the plant material need to be considered:

Key questions

- What living collections are planned?
- What provenance information is required for the living collection?
- Do they need to be grown on-site or can they be procured externally?
- Can seeds or plants be obtained from other botanic gardens?
- Do seeds or plants need to be collected from the wild?
- What propagation and production facilities are required for the initial plantings?
- How will these fit with the long-term requirements of the botanic garden?

6.3.1 Provenance Information

Detailed provenance information is the ideal for any botanic garden collection. The more information, the greater the flexibility for display, research or conservation in the future. Standard provenance information (Chapter 3 and Section 6.3.3) for plant material should include name, type of material collected (such as seed, herbarium specimen, tuber), date, locality, altitude, habitat, associated species, descriptive information such as flower colour or other features which may be lost once a specimen has dried out (Barber and Galloway, 2014). Gathering additional information and details on the locality may prove beneficial for other purposes. For example, if a collection has been made from an arid habitat but the plant material was found in a damp and shady overhang with different conditions from the prevailing environment, this information could be valuable for future cultivation of the species as it could provide particular indications on how to grow the plant well. Soil types and conditions should also be noted (Section 6.2.2) because they could affect cultivation of the plant. Other features may be worth noting. For instance, if a plant is locally abundant and in flower with a range of colours, this could have implications for the flower colour from any seed collected. Other features of the habitat, such as evidence of seasonal changes in the environment, are important to record as well. An example of these could be waterlines which demonstrate levels of inundation in monsoon seasons but which change through the seasons. These offer clues regarding environmental changes of a habitat which may have to be considered for successful cultivation.

6.3.2 Seeds or Plants?

Plant material for propagation can be brought in as seed, spores or as vegetative material. Clonal and non-clonal material both have benefits and constraints as a starting point for the living collection. The selection will be informed by the types of collections, growth forms and displays which the botanic garden is aiming to create.

- **Benefits of material sourced from seed:**

- Can be easier to collect from the parent plant as they already come in their own biological 'package';
- Generally light and easy to transport in bags and envelopes as well as relatively small containers;
- Large quantities can be gathered and stored for potentially long periods;
- Flowers, fruits and seeds are key identifying features and therefore immediate verification is more likely if seeds are present;
- The genetic variation of seed collections may be more suitable for species of conservation concern and for botanical and conservation collections.

- **Disadvantages of material sourced from seed:**

- Genetic variation in seed means that desirable features, such as flower colour, particularly for display, may not be guaranteed;
- Seed-grown plants can take longer to reach maturity than vegetatively propagated plants;
- Species may have dormancy and germination requirements which may not be fully understood or be difficult to replicate in the botanic garden;
- Seed production may be very limited or absent as some species may not produce seed, or not abundantly, or not every year, or it may be rapidly predated;
- Some seeds have very low viability, are difficult to store and may be found to have been contaminated by pests or disease on sowing.

- **Benefits of material sourced from plants:**

- Lack of genetic variation in the propagules means predictability in the features;
- If identifying features are present, species can be immediately verified;
- Propagules may grow and reach maturity more quickly than seed-grown plants;
- Plants which are easily propagated can make large numbers of plants and expand collections relatively rapidly;
- The time period for collecting vegetative material during the year is longer than the seed season;
- Mature plants allow the creation of an 'instant garden';
- Mature plants can be rescued from habitats being destroyed;
- Highly specific germination requirements can be avoided.

- **Disadvantages of material sourced from plants:**

- Lack of genetic variation may mean that a collection has limited conservation value;
- Biosecurity issues and regulations may restrict the transportation of rooted plants across state boundaries;
- If whole plants are to be transported, the removal of soil may be required to cross state boundaries which can cause stress, thereby compromising the plant's health;
- Plant material can be more difficult to transport and establish in a new location as it may resent transplantation, and requires more coordination, space and resources;
- More horticultural resources and skills may be required, such as heated propagation equipment and daily checking by staff to process plant material and generate rooting.

Gathering plants from a government nursery in Tistung, Nepal, for planting at the National Botanic Garden Nepal. (Image: Kate Hughes)

6.3.3 Sources of Seeds or Plants

• Commercial nurseries and seed suppliers

A number of questions need to be considered before purchasing seeds or plants from commercial nurseries or seed suppliers. These include: Are taxa reliably verified? Is plant health assured? Is provenance information sufficient and accurate? Were the plants legally sourced? Based on the collection policy, decisions concerning the extent and accuracy of provenance and collection information need to be made when exploring sources of plants, as the amount of data available from different suppliers will vary. Plants can be procured within a country or imported.

- **Local in-country suppliers:**
  Local nurseries may be able to supply the plants required. These facilities could also be used to grow larger numbers of plants under contract (Case study 6.1). It is recommended that time is spent visiting local nurseries during the initial planning phase for the botanic garden, to gauge plant availability, local capacity and expertise.

- **Importation:**
  A far wider range of plant material is available internationally, but the issues of verification, plant health, legal acquisition and provenance are amplified. It is important to adhere to the country's plant health and phytosanitary regulations, which need to be abided by before purchase of any plant material (Sections 6.4 and 6.8).

CASE STUDY 6.1

Sourcing plants from local nurseries – Sulaimani Botanic Garden, Kurdistan

Sophie Neale, Edinburgh, United Kingdom

Briefing on the planting strategy at the Sulaimani Botanic Garden, Kurdistan. (Image: Saman Ahmad)

The Sulaimani Botanic Garden (SBG) is located in the south of Iraqi Kurdistan. It is part of the Kurdistan Regional Government Ministry of Agriculture and Water Resources. In late 2013, the SBG planning committee approached the Centre for Middle Eastern Plants (CMEP) based at the Royal Botanic Garden Edinburgh, to provide consultancy skills for the master planning and establishment stages of this botanic garden including a habitat restoration project. In December 2013, a brainstorming and planning workshop was held in Sulaimani in order to define the aims and remit of the institution and to guide initial stages of the establishment of the botanic garden. In February 2014, CMEP submitted a master plan document providing information on the plans, requirements and next steps for the botanic garden. Construction began mid-2014 and the first specimens were planted in October 2014.

The master plan of SBG contains a section dedicated to the spatial, structural and staffing requirements for a nursery. The mission statement, collection policy and aims of the institution were examined carefully to establish that a nursery facility was in fact essential to create and maintain the planting plans which the SBG wished to realise. In the consultancy process CMEP discovered that there were government-run nurseries, growing thousands of native oaks and other native trees, the very species which would be required for the restoration element. Due to the fact that the nurseries and this project are run by the same government institution, it was easily agreed that the nurseries could provide an initial supply of the appropriate native oak species. In October 2014, planting of some 5,000 one- to two-year seedlings began, thus initiating the landscape development and the plant collections. The plants did not come with the provenance information which the botanic garden would have ideally liked. However, they were the appropriate species, plants were of the right size and they were immediately available. This enabled the project to start swiftly and without delay caused by collecting and cultivating slow-growing woody species.

Prior to planting, service and access roads had to be constructed, and irrigation points had to be installed. A plan of service roads, irrigation points and channels were made in the initial consultation process as an essential part of the planning. In contrast, the nursery facilities had not yet been designed or constructed and were not needed in this case to make these initial plantings, although they are planned for the future.

Primary issues for the establishment of plants at Sulaimani Botanic Garden:

1. Water availability is extremely limited in the local environment and therefore water needs have an important influence on the landscape design. Water conservation was covered in extensive detail in the master plan. The irrigation points and possible systems were provided on a separate map. Water conservation was, and will continue to be, strongly considered in the landscape and planting design. For example, native species tolerant of dry conditions will be selected, which also fits with the mission of the botanic garden, and areas of lawn requiring much irrigation will be avoided altogether.

2. Native plants tolerant of the environmental conditions will be planted. As many of these species have not been grown in botanic gardens before, experience of their cultivation is limited. This means that it is essential to document propagation and cultivation requirements and develop a core, skilled horticultural team right from the initial stages of the botanic garden's establishment.

- **Botanic gardens**

Sharing plant material among botanic gardens is a common practice. Guidance and resources on mechanisms, issues and international standards related to the exchange of plant material among botanic gardens are provided in Chapters 3, 4 and 5.

There have always been professional and informal relationships between staff working in different botanic gardens, which greatly facilitates the exchange of plant material as, for instance, is illustrated in Case study 6.2. However, it is essential to ensure that such exchanges fulfil national and international conventions and standards such as the Nagoya Protocol on Access and Benefit-sharing (Chapter 4, Section 4.5) and phytosanitary regulations (Sections 6.4 and 6.8).

- **Wild collection**

Wild collected material is considered to be the best source of plant material because the full range of habitat and location data can be recorded. This makes such plant samples most useful for research and conservation. The collection of plant material from the wild must abide by national and international conventions and standards such as the Nagoya Protocol on Access and Benefit-sharing, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Chapter 4, Sections 4.3 and 4.5) and phytosanitary regulations (Section 6.4 and 6.8). Plant collection methods by botanic gardens should serve as a model in terms of legal compliance, habitat and biodiversity conservation, access and benefit sharing, working in partnership and applying scrupulous recording methods. For botanic garden displays it can be equally useful to have material from the wider

CASE STUDY 6.2

Well-documented plants from partner botanic gardens and other botanical institutions for the Muséum national d'Histoire naturelle, Paris

Denis Larpin, Paris, France

The public display glasshouses (Les Grandes Serres) of the Muséum national d'Histoire naturelle (MNHN) in the Jardin des Plantes, Paris were reopened to the public in June 2010 after five years of renovation. Once the structures were ready for planting, plants were supplied from a number of sources. One of the most difficult aspects of the project was the acquisition of living plant specimens with reliable names and good provenance data. A request was made to colleagues in the botanic garden community. In all cases the plants were obtained on the condition that distribution outside the MNHN was restricted.

In this way plants of wild collected origin with detailed accession data and horticultural knowledge of their cultivation were obtained from various botanic gardens in France, the United Kingdom, the United States and New Caledonia. For instance, the Royal Botanic Garden Edinburgh offered conservation plant material from their fern and tropical conifer living collections, including *Acmopyle pancheri, Araucaria schmidii, Falcatifolium taxoides, Podocarpus lucienii, P. sylvestris, Retrophyllum comptonii* and *R. minus* to complement the New Caledonian endemics collection already existing at the MNHN. The Jardin des Serres d'Auteuil, Paris provided a large palm, *Chambeyronia macrocarpa,* amongst other species. Additional plant material was made available by the Conservatoire botanique national de Brest and the Montgomery Botanical Center, Florida.

Specimens directly sourced from New Caledonia were offered by different organisations. Species in Myrtaceae, Cunoniaceae, Proteaceae and Euphorbiaceae were supplied by SIRAS Pacifique, a company specialised in ecosystem restoration, while Apocynaceae, Arecaceae, Casuarinaceae, Fabaceae, Lamiaceae, Moraceae, Pittosporaceae, Rubiaceae, Sapindaceae, Sapotaceae and Sterculiaceae specimens were provided by nurseries in Eriaxis, Mango, La Nea, Tipinga and Tuaiva. Additionally, unique species from the dry and mangrove forests were generously offered by the 'Programme de Conservation des Forêts Sèches' and the 'Point Zéro Baseline' environmental association.

This type of sharing is useful in reducing the resources required to obtain wild collected plants, and decreases pressure on natural populations. Well-documented provenance information assures the relevance of the material both for display as well as for research and conservation.

New Caledonian Glasshouse of the Muséum national d'Histoire naturelle, Paris, with wild-origin specimens sourced from botanic gardens. (Image: Manuel Cohen) natural range of the species to rejuvenate a particular collection. In many cases, specimens in cultivation originate from one or a few clones introduced many years ago. These can lack genetic vigour and be susceptible to pests and diseases, or can succumb to climatic conditions if they are at the edge of their distributional range.

For horticultural purposes, detailed provenance data including date of collection, location, altitude, habitat, associated species, growth habit and any other features regarding the way in which the plant is growing, may prove vital information for successful *ex situ* cultivation. The abundance of the species should also be noted, as well as the number of individuals from which the collection was made, and whether other mature plants or seedlings were present. Ideally accompanied by a herbarium specimen, which provides the opportunity to name the species accurately, information of this type will help horticultural staff at the botanic garden to better appreciate the plant and its growth behaviour in the wild, in turn informing appropriate cultivation techniques (Rae, 2011), for instance:

- Some species may be widely cultivated in the botanic garden, but all the specimens may originate from the same clone from one collection made a long time ago. Vegetative propagules of a clone may weaken over time. The 'garden population' of such a species can be augmented and invigorated by introducing additional genetic material. Increased genetic variety is also essential for the conservation of a species.

- If collections from wild populations are made by horticultural staff, the specific propagation and cultivation needs and conditions of the species may be more adequately described. To know it better is to grow it better and this will have great benefits for the long-term health of the species and the collection.

It is generally acknowledged by botanic garden managers that the health and successful cultivation of plants are improved by continued personnel development (Section 6.9). Particularly valuable is the active involvement of botanic garden staff in field work, leading to a greater familiarity with, and knowledge of the species and its habitat.

Examining propagation challenges in the field with staff from the Oman Botanic Garden. (Image: Peter Brownless)

6.4 PLANT HEALTH – QUARANTINE AND ISOLATION

There are potential long-term plant health hazards associated with the introduction of plant material, growing media and soil. It is strongly recommended that biosecurity facilities and procedures are developed and implemented before any material is outplanted. 'Quarantine' is used here to describe the practices as well as the legal requirements for organisms to be inspected and cleared for health on entry to an area. Some quarantine facilities may need to be regulated by national government agencies. 'Isolation' refers to what an organisation may do for its own benefit to protect the plants and the site.

To further address the hazards associated with the introduction and spread of new and damaging plant pests and pathogens, the International Plant Sentinel Network (IPSN) has been set up. A network of botanic gardens and arboreta, national plant protection agencies and plant health institutions, the aim of this global alliance is to provide an early warning system for new and emerging pest and pathogen risks (Box 6.4).

Further information on plant health and biosecurity management is given in Section 6.8 on page 129 cont.

Mist unit for epiphytic species in the quarantine area of the Royal Botanic Garden Edinburgh. (Image: Fiona Inches)

Plant material arriving in quarantine at the Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

6.5 PLANT PROPAGATION AND PRODUCTION – THE NURSERY

KEY MESSAGE

All botanic gardens will need plant production facilities. These do not have to be large, complex or expensive but should be compatible with the collection policy, budget and staff resources. Planning prior to construction and regular review once established will assist in the creation of effective facilities. Equally important is to have a functional plant records management system in place at propagation and production stages.

Nursery facilities at the Oman Botanic Garden (shade house) (top) and Pha Tad Ke Botanic Garden respectively. (Images: Leigh Morris)

CASE STUDY 6.3

A comparison of nursery requirements for two different botanic gardens

Leigh Morris, Edinburgh, United Kingdom

This case study compares and illustrates the nursery requirements and facilities at two distinctly different, new botanic gardens, in terms of their scale, ambition and finances. The Oman Botanic Garden, in the Sultanate of Oman, involves major government funding and a large team of Omanis and international experts, consultants and contractors. It aspires to provide world-class facilities, collections and other visitor attractions with high impact on native plant and biodiversity conservation at large. Pha Tad Ke, conversely, is a small, privately owned botanic garden situated on the bank of the Mekong River near Luang Prabang in northern Laos. Both botanic gardens require nursery and propagation facilities, however, their needs, specifications, resources and budgets are very different.

The Oman Botanic Garden aims to represent all of the diverse habitats of Oman and grow the majority of the approximately 1,407 Omani flowering plant species based on wild-sourced material. The target production of some 250,000 plants (excluding plant material directly sown in the botanic garden's ground) required a large, state-of-the-art nursery, with the capability of producing plants from different habitats, ranging from high mountains to sand deserts in climate-controlled environments (Patzelt *et al*., 2008 and 2009; Morris, 2011). The nursery contains environmentally controlled and zoned areas including a propagation and two large production glasshouses, a number of large polythene greenhouses, a large expanse of shade houses and an outdoor growing space as well as a nursery building with offices, potting, propagation, seed bank and storage facilities. The nursery was built by an international firm and the majority of the materials, tools and equipment were imported from overseas.

Far smaller in size, Pha Tad Ke Botanic Garden aims to grow and showcase only plants from similar climatic regions in Laos and southeast Asia. Plant propagation and production is carried out at a small scale and nursery facilities consist of benches and shade-houses constructed with local bamboo. Equally, the tools, equipment and materials are locally sourced, including the potting medium which is made from Mekong River sand, elephant dung, coconut bark and rice husk.

In conclusion, the propagation and production facilities of both botanic gardens are very different. The Oman Botanic Garden has an expansive and appropriately 'hi-tech' nursery capable of efficiently growing very large numbers of plants. It is working towards a clearly defined production list and targets and is comparable with a large scale commercial grower. Pha Tad Ke Botanic Garden, on the other hand, has a suitably 'low-tech', small scale nursery, using locally sourced materials and built to support the horticulture operations of the botanic garden, without fully prescriptive production targets. Importantly however, the respective facilities fulfil their functions very well whilst their differences highlight the diversity of nurseries based on the mission and objectives of the botanic garden.

Once plant material has been sourced, it may need to be propagated or grown-on in a nursery before planting out. Not all botanic gardens need nursery facilities, but the majority do have at least a small propagation facility. The specific requirement for plant cultivation and production facilities will depend on the type and scale of the planned plantings, and the overall ambitions for the botanic garden. 'Nursery' can refer to a diverse range of facilities from large, state-of-the-art production nurseries to small, low cost areas growing a small number of plants (Case study 6.3). To identify the appropriate features of the facility, various aspects need to be considered:

Key questions

- Is a nursery required or can propagation and production be carried out elsewhere?
- What scale of production is needed in the short-term for growing the initial plantings and in the long-term for maintaining the collections?
- How much propagation is planned in the short, medium and long-term?
- What types of propagation methods will be used?
- How much water will be required and where will this be obtained?
- Will any production be done off-site?
- Which habitat types are the plants from?
- How many and what sizes of plants will be grown in the nursery?
- What human and financial resources can be allocated to production facilities?
- Will production be containerised or field-grown?
- Is it planned to grow plants for sale or planting in conservation programmes off-site?

6.5.1 Production Planning

It is recommended that a production plan is produced prior to nursery construction (Chapter 1, Section 1.7.5). This plan should include the type and number of plants required, and the environmental conditions necessary to grow them. It may also be possible to spread plant production out over a longer period of time to save nursery space. Once these decisions have been made, it will be possible to calculate the size of the nursery and constructions needed, such as greenhouses and equipment facilities.

6.5.2 Site Considerations

As far as possible, the location of the nursery should consider the following aspects:

- Within the botanic garden area or as close to it as possible;
- In shade or full sun, depending on the material to be grown, preferably with the provision of both conditions;
- On level ground with the same soil as in the botanic garden;
- Provide shelter structures for plants and staff – either planted or constructed;
- Vehicle access;
- Have access to services including clean water, electricity, gas, an alternative energy source, sewage and data connection;
- Security and controlled access.

6.5.3 Nursery Design

The layout and design of the nursery should aim to reduce labour and transport distances for plants and materials. A huge amount of time and money is spent in moving plants and materials around a nursery and the design must aim to minimise the resources required to do this.

Careful consideration must be given to the handling and transport systems that will be used in the long-term, as this directly influences the size and surfaces of paths and roadways. For example, if small trollies are to be used then a good/smooth path surface is required. The unloading and subsequent handling of bulky materials such as growing media, pots, trays and fertilisers may require mechanisation, such as a tractor or forklift truck, and a yard and storage area.

Ergonomic principles should be applied throughout the design process in order to have a production system that allows propagules (seeds, cuttings and plants) to start at one end and established, grown plants at the other end. The ideal nursery layout has the buildings and propagation facilities in the centre and production beds and greenhouses surrounding them, which facilitates shorter paths.

6.5.4 Specific Structures and Facilities

Secure buildings and covered structures are required for most nurseries to operate efficiently. These are dependent on the purpose and staffing of the nursery, but most medium-sized nurseries will require the structures listed here.

- **Potting and propagation shed**

These can be separate facilities, however in all but the largest nurseries, the same building will serve both functions. The potting shed is the central work area for many nurseries and, along with pesticide storage, is one of the most important structures. For a potting shed to function well it should comprise of:

- Benches to work on which can be easily kept clean;
- Ventilation;
- Clean water;
- Space to store pots, compost and other equipment;
- Knife storage and sharpening;
- Space to carry out seed and vegetative propagation;
- Access to cool storage such as a refrigerator for biological controls and chemicals or seed and spore storage.

Above: Potting shed area in a nursery in Kathmandu Nepal with benches which are easy to clean as well as space for storing potting mixes and other equipment. (Image: Kate Hughes)

Left: Potting bench, Pha Tad Ke Botanic Garden, Laos. (Image: Leigh Morris)

- **Office and staff amenities**

These facilities are typically adjacent, connected to, or within the potting shed. Provisions for computers and data management, and cloakrooms, kitchen and toilets should be made. These buildings will require heating/cooling and a consistent supply of mains water and power.

- **Equipment and materials store**

This includes facilities for storing gardening appliances and machinery, pots, trays, growing media, fertilisers, etc. These should be located close to the potting shed.

- **Compost storage and mixing area**

A large outdoor covered, or partially covered area, for storing and mixing bulky organic materials. This area needs to have adequate drainage, run-off and hygiene systems to ensure that materials are safely stored.

- **Pesticide store**

Local legislation with regard to storage and application of chemicals will need to be considered. Related buildings should be constructed and managed with awareness of health and safety for users, other botanic garden staff, visitors and the environment at large.

- **Irrigation house and water storage**

These facilities, including the pump house, can also facilitate the application of liquid fertilisers.

- **Greenhouses and growing rooms**

A wide range of types and sizes of growing structures are available for plant production. Greenhouses can be glass houses, polythene tunnels or shade houses. It is fundamental that these are chosen carefully to suit the plants to be produced. In addition, heating and cooling systems, ventilation, supplementary lighting, irrigation and fertigation systems need to be considered.

- **Other facilities**

Depending on the requirements by the botanic garden, additional facilities may include:

- Heated benches;
- Cold frames;
- Outdoor seedbeds;
- Vermin-free areas;
- Closed cases;
- Mist or fog units;
- Weaning unit for gradual acclimatisation of propagated material from heated propagation equipment to ambient conditions;
- Refrigerators for stratification;
- Micro-propagation facilities;
- Quarantine and inspection area for suspected or diseased material.

If horticultural education is one of the aims of the institution, a practical classroom and other areas kept for educational purposes will be useful within the nursery. Additional and separately maintained equipment and facilities as well as space for teaching is likely to be needed to enable educational activities even on a small scale.

Compost needs to be turned regularly in order to maintain the temperature and ensure an even breakdown of the constituents. (Image: Royal Botanic Garden Edinburgh)

Compost from leaf mould. Leaves will break down quickly in warm conditions, especially if dug down below ground level. ICIMOD Knowledge Park, Godavari, Nepal. (Image: Kate Hughes)

Propagation tunnel at Pha Tad Ke Botanic Garden, Laos. (Image: Leigh Morris)

The nursery as a classroom, Jardín Botánico Francisco Javier Clavijero, Jalapa, Veracruz, Mexico. (Image: Laura Cohen)

6.5.5 Propagation Protocols

To standardise propagation and plant production systems it is useful to establish propagation protocols. Examples of these are the protocols developed by the UK Overseas Territories Programme based at the Royal Botanic Gardens, Kew for the propagation of endangered species (Boxes 6.1 and 6.2).

6.5.6 Management of Nursery Records

Nursery propagation and cultivation methods form an important pool of knowledge useful for replication elsewhere or for further development of a plant collection. Related data should therefore be carefully recorded in the botanic garden's collection record management system (Chapter 5).

Box 6.1 Quick Reference Sheet 1 for the germination of *Acacia anegadensis* developed from propagation trials (Corcoran *et al*., 2014)

- **Seed Compost Ingredients**
- 50% loam: sterilised, particle size < 3 mm
- 50% sharp sand, fine grit or a mixture of the two: washed or
- 70% coir: screened to < 3 mm
- 30% sharp sand: washed

- **Container**

Pot or similar: 70-90mm in depth, 60-80 mm diameter, with drainage holes

- **Environment**
- Sterile growing conditions (pots, bench etc.)
- Bright filtered light but not direct sunlight (provide shading if necessary)
- Ambient temperature/humidity (in the tropics)

Day 1

a) 'Nick' the hard seed coats with a sharp blade (at the opposite end of the seed to the seed-stalk) to expose a small area of the seed's food-reserve (endosperm): **NICKING IS ESSENTIAL FOR GERMINATION**.
b) Sow the seeds on the firmed compost surface, leaving no less than 15 mm between seeds.
c) Carefully cover the seeds to a depth of approx. 4-5 mm, or a little more, with the seed compost.
d) Water the compost from above with a fine rose or stand the container in shallow water until moisture can be felt at the surface (1-2 minutes).
e) Place the newly sown seeds in a propagation case (see notes) or place on a bench out of direct sunlight.
f) The soil must be kept moist, but not waterlogged.

Day 14 (approx.)

a) Seeds germinate.
b) The soil must be kept moist, but not waterlogged.

Day 42 (approx.)

Prick-out the seedlings into individual pots when the first true leaves can be seen (approx. 5-6 weeks after sowing).

Box 6.2 Quick Reference Sheet 2 for potting up of *Acacia anegadensis* developed from propagation trials (Corcoran *et al*., 2014)

- **Growing Compost Ingredients**
- 50% loam: pasteurised, screened to < 9mm
- 20% home-made compost: pasteurised, screened to < 9mm
- 30% grit/sand: washed, < 3-5 mm

- **Container**

Any sterile plastic pot or similar container with drainage holes

- **Environment**
- Sterile growing conditions (pots, bench etc.)
- Bright filtered light but not direct sunlight (provide shading if necessary)
- Ambient temperature/humidity (in the tropics)

1. Prick-out the seedlings into individual pots when the first true leaves can be seen.
2. Water well.
3. The compost will provide adequate nutrients for the first 2-3 weeks.
4. After 2-3 weeks and as the plants increase in size, a soluble feed with a low nitrogen fertiliser can be applied.
5. Water as needed, make sure compost is moist but not waterlogged and do not allow to fully dry-out.
6. If plants become 'leggy', prune back shoots by a third of their length, this will encourage them to bush out.
7. Check the bottom of the plant pots regularly to see if roots are visible.
8. If roots can be seen at the drainage holes, gently 'knock' the plant out of its pot and check the extent of the root system.
9. If the roots are spreading around the 'ball' of compost it is time for them to be re-potted.

Note: Subsequent re-potting should follow the above instructions.

6.6 PLANTING AND ESTABLISHMENT

Following successful propagation, a number of aspects should be considered prior to outplanting in the grounds of the botanic garden:

Key questions

- Do the institution's development or review plans, including master plan, detailed design, construction plans and the collection policy, inform detailed planting plans?
- How should the landscape be prepared for the plantings?
- How should the plants be prepared for transplanting?
- How many staff are required for preparation and planting?
- Are there any training requirements for staff?
- What tools, equipment and materials are required for planting and establishment?
- What immediate and medium term aftercare measures are required to ensure successful establishment?

6.6.1 Preparation for Planting

A good start to a plant's life in the final planting position makes an enormous difference to the future success of plant establishment and the planting scheme. There are many cases where much effort has been put into the acquisition and propagation of planting material, and where plants have been subsequently placed in the ground with no further consideration for their establishment needs, only for the plantings to fail, causing wastage of the efforts made up to that point.

Preparing beds for planting at the National Botanic Garden Nepal. First, weeds are removed, then soil is dug over. (Image: Kate Hughes)

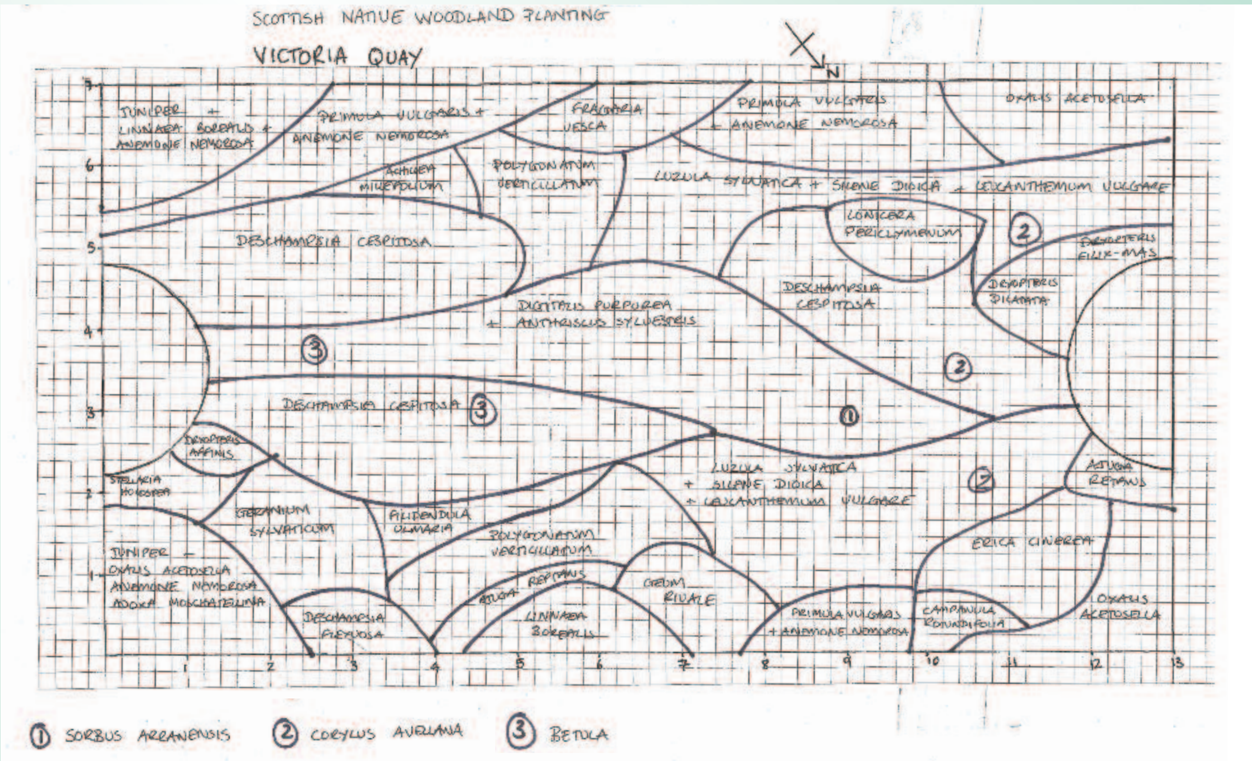
Plants need to be sited according to their growing requirements and this should be part of the planning process. Many species will grow well in conditions and positions which are different from those in which they are found in the wild. However, certain key conditions must be provided for most species. Therefore, prior to establishment, the site should be assessed for suitability for the planned plantings as informed by the institution's collection policy (Chapter 3). The prevailing environmental conditions such as maximum and minimum temperatures, soil type, soil pH, wind and rainfall levels should all be assessed before initiating the groundworks. The establishment process must consider many factors, some of which may need to be carried out well before planting is planned. This could include the preparation of planting material, such as hardening off propagated material over a period of weeks or months, potting on to build up a root system, and root pruning large woody plants over a period of 1-2 years in advance of transplanting.

- **Preparation of the site**

This will include:

- Preparation of the soil and substrate, the addition of organic matter, minerals or drainage; the creation of shelterbelts or microclimates, installation of irrigation.
- Drawing up a planting plan (Figure 6.1), bed numbers and records for material to be planted out.
- Provision of appropriate hand or mechanical tools and materials for each process at each stage, such as tractors, pallet lifters, mechanical diggers, trolleys, wheelbarrows, hand tools, buckets, hoses, watering cans, bags and hessian cloth, additional compost and substrate, organic matter, stakes and ties, granular fertiliser, mulching materials and labels.

Figure 6.1 Planting plan at the Royal Botanic Garden Edinburgh



6.6.2 Planting

Protocols and methods for planting out should be produced and followed for each site as these may vary according to the species and types of plants. General considerations which should be observed for all species and situations include:

- **Care during the time of planting** – plants will establish better if they are not exposed to stress during the moving process. Before planting, they may need to be watered and protected from excessively low or high temperatures and with the roots shaded.
- **Planting at the appropriate point in the plant's lifecycle** – while for some species this is likely to be when the plant is not in active growth and when temperatures are least extreme, others may prefer to be transplanted when in a state of growing rather than resting. It is also important to observe the correct planting sequence, that is, large plants which provide structure to the scheme first, followed by plants of decreasing size.
- **Records and data management** – records should be made and the overall database updated as planting is carried out with data kept for each species and numbers planted (Chapter 5). This information should be stored securely for reference during maintenance. Bed numbers should be marked on the Planting Plan and plants provided with temporary, or, if available, permanent labels. One person should have ultimate responsibility for, and control of, this element of the planting operation.
- **Team engagement** – ensure the availability of appropriate numbers of staff for each process at each stage. Taking the time to dig the right holes for the plant can help quick establishment, the benefits of which will be reaped after planting. This is important in areas which may have never been dug before or exhibit stony soils which are notoriously difficult to permeate with hand or mechanical tools. It is a task which can take a surprisingly long time.

Planting up a herbaceous bed. Fertiliser is added to the planting hole to provide nutrients for the establishing plant. (Image: Neil Davidson)

Planting up a rock garden bed at a cool and shady time of day at the National Botanic Garden Nepal to ensure that plants do not dry out too much in the planting process. (Image: Neil Davidson)

6.6.3 Establishment

Immediate and subsequent care at appropriate points post-planting is essential for successful establishment of new plantings. In the short-term aftercare should include application of water and mulches, protection from unusual weather conditions and pests, and provision of support. Examples of these could be fleece, shading, mulching mats, wire cages and stakes. In the weeks and months after planting they should be regularly and thoroughly inspected, especially regarding the appearance of pests or diseases and adjustment of stakes and ties.

To increase success, a planting plan (Section 6.6.1) including positioning of plantings plus a written work programme noting all the tasks, procedures and important dates starting up to a year in advance is useful. This can help to ensure that these considerations are made early and therefore a smooth transition is made from nursery to the final planting position. Efficient aftercare procedures also reduce any remedial work which can be required if plantings do not establish well, thereby saving time and resources and increasing the chances of successful plantings in the long-term.

Newly planted beds have been watered thoroughly and mulched with leaves to maintain moisture levels. All the plants should be watered regularly in dry conditions until they show signs of establishment. (Image: Kate Hughes)

6.6.4 Maintenance – Establishing a Horticultural Management Plan

Once outplanted and established, ongoing maintenance is required to sustain the plants and planting schemes so that they fulfil their purpose. Appropriate horticultural standards and maintenance regimes are crucial to a successful botanic garden, but the level of maintenance varies depending on the objectives and size of the institution:

Key questions

- What specific aftercare measures are required in the short and long-term?
- What are the seasonal maintenance requirements?
- What are the likely pest, disease and disorder issues?
- Is irrigation required in the long-term, post establishment?
- How will a long-term maintenance regime be implemented – are specific staff skills and training required such as arboriculture operations or pesticide application?
- Is specialist equipment required?
- Are there structures housing living collections which require maintenance?
- What type of plant records and level of detail should be documented for the collection(s)?

A horticultural management plan either for specific groups of plants (Case study 6.4) or the plantings as a whole will ensure that the main horticultural tasks are considered and resourced, and that any issues with these are more easily anticipated. Once plantings have established there will be a need to review them and consider the need for replacement, gapping-up or thinning out.

CASE STUDY 6.4

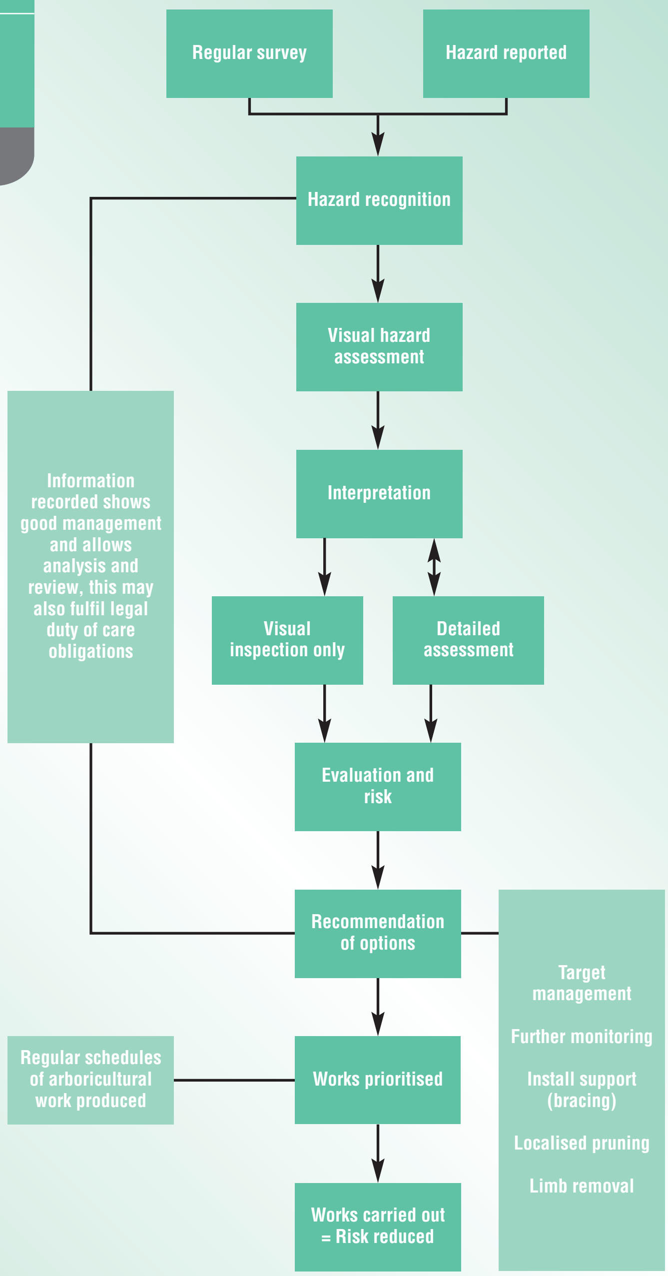
Tree Risk Management at the Royal Botanic Garden Edinburgh

William Hinchliffe, Edinburgh, United Kingdom

There is a clear professional responsibility for botanic gardens to give consideration to the risk of injury to staff or visitors from falling branches or trees. An effective system for managing risks from trees must identify trees and groups of trees by their position and degree of public access. A map with areas identified as either frequent or low public use is useful. This allows risks associated with tree stocks to be prioritised and helps identify any checks or inspections required.

At the Royal Botanic Garden Edinburgh, a Tree Risk Management Strategy has been prepared and is implemented by a team of trained arborists. They are responsible for reporting on, maintaining, developing and protecting the tree collection. In places where trees are not subject to frequent public access individual tree risk management records are unlikely to be necessary. Documentation may however be desirable for other reasons such as growth rate data collection and monitoring plant health.

For trees in frequently visited zones, a system of periodic checks is implemented. The flow chart on the right shows how tree works are generated and scheduled following periodic checks or reporting of a hazard. In this way the risks associated with the trees on-site are reduced.



Key components of the horticultural management plan:

• Labelling and record keeping

Accuracy of the plant records is a vital part of maintaining botanical collections (Chapter 5). Plants can move locations by themselves in the botanic garden by self-seeding, layering or suckering. They can also interbreed or be pollinated and then disperse seed. Horticulturists caring for the plants need to keep track of these events and treat them accordingly, whether this involves removal or re-naming and labelling. Regular checking and removal of labels of dead individuals is important to prevent errors in plant identification and record keeping.

Verifying that the recorded names are correct prior to planting, National Botanic Garden Nepal. (Image: Kate Hughes)

Drawing up the label order and verifying names involves computer and literature checks. National Botanic Garden Nepal. (Image: Kate Hughes)

• Irrigation and feeding

Almost all plants in all conditions require initial irrigation on transplantation to their final position. Some will require high levels of irrigation to establish, depending on the prevailing weather conditions and the requirements of the species. If required, fertiliser can be added in granular or liquid forms, the former in particular, can be incorporated in the planting hole. The latter is especially relevant for long-term maintenance of plants in pots. Liquid feed can also be applied through the irrigation system.

Liquid feeding at the Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

• Pruning (including arboriculture)

Regular pruning and training of plants is an essential part of the maintenance regime of all botanic gardens regardless of their size or plant collections. The purposes of pruning include regulating flowering and fruiting, removing dead and diseased branches, shaping shrubs if they are growing unevenly or removal of branches if they are in the way of paths or roads. Some species and cultivars display coloured stems more vividly if coppiced close to the ground each year.

• Pest, disease and weed control

Collections will at times develop pests and diseases. The acceptable threshold needs to be decided before control methods are implemented. Measures can either be preventative or eradicative. It is to the advantage of any botanic garden to keep the application of chemicals to a minimum and instead, where possible, employ cultural and physical measures. Application of chemicals should be the last resort or reserved for environments where there are no other options. This can be done by operating a system of Integrated Pest Management (IPM). This integrates a range of control methods to eradicate, or keep a pest/disease problem below the threshold of concern (Case study 6.5). Methods employed can include biological control agents, selective pesticides, cultural and physical control techniques (Helyer *et al.*, 2003). In some areas, certain pesticides should not be used such as near fish ponds or other waterways where further spread of, and contamination with the chemicals, would be highly likely.

Above and below: protection from small pests and cold temperatures, Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

Weed control is one of the main occupations of the horticulturist as weeds compete with planted specimens for water and can be unsightly. Where optimum conditions are being created for the cultivation of desired plants, many other undesired ones also find the conditions that they need to thrive. The methods of weed control will vary widely dependent on the type of weed.

The most environmentally sustainable approach to weed control is through cultural methods and physical removal. However, this requires sustained activity by staff, possibly with machinery which increases the costs of this approach. Many institutions manage a balance of different methods on the basis of IPM principles to manage weed control (see Smyth *et al.*, 2013).

- **Composting**

Recycling the plant waste material is a good way to recycle nutrients in the botanic garden, and has horticultural and sustainability benefits. All botanic gardens should aim to make and use compost from the plant waste generated on site, although additional organic matter

Weed control at the Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

may need to be purchased to address specific requirements. If the plant waste contains pests, a separate, insulated compost heap, or burning the material will have to be considered.

- **Growing media**

Additional substrates and additives to the prevailing soil conditions may be required for some species, particularly for plants in containers under the protection of structures such as polytunnels or glasshouses. The types of growing media available are extremely variable, and the availability and use of these will vary according to local and international markets.

- **Managing climate change**

In addition to managing light availability, insolation, wind, etc. for instance through shading structures and selection of sheltered locations, botanic gardens should consider the possible impacts of climate change both for infrastructure and the collections. Where impacts are noted due to climate change, these should be incorporated into the horticultural management plan and changes in practices and resources accounted for.

Preparing soil mixes at the Royal Botanic Garden Edinburgh (Image: Royal Botanic Garden Edinburgh)

CASE STUDY 6.5

Integrated Pest Management of tropical water plants at the Royal Botanic Garden Edinburgh

Pat Clifford, Edinburgh, United Kingdom

Despite the strictest acquisition and quarantine procedures, botanic gardens can host a wide range of pests. Decisions have to be made regarding acceptable levels of pests. In the past staff at the Royal Botanic Garden Edinburgh (RBGE) have discussed whether there might be an educational role for allowing a level of pest presence in some living collections. Currently, there is an expectation that there should be no pests accepted for plants of conservation concern, or into which many resources had been invested to source and raise the plants.

A system of Integrated Pest Management (IPM) is in operation at RBGE in order to keep chemical use to a minimum. For instance, the victoria water lily, *Victoria amazonica*, from the Amazon rainforest of Brazil, grown in the tropical glasshouses, produces enormous leaves with beautiful flowers much loved by visitors. Due to the high temperature, soft growth and lack of predators, the plants easily succumb to sap-sucking aphids preventing leaf growth and ruining the display if an infestation is allowed to take hold. Chemicals cannot be used because they would kill the fish in the pond. The following measures are taken to prevent this without the use of chemicals:

1. A cultivar is selected with faster and more vigorous growth.

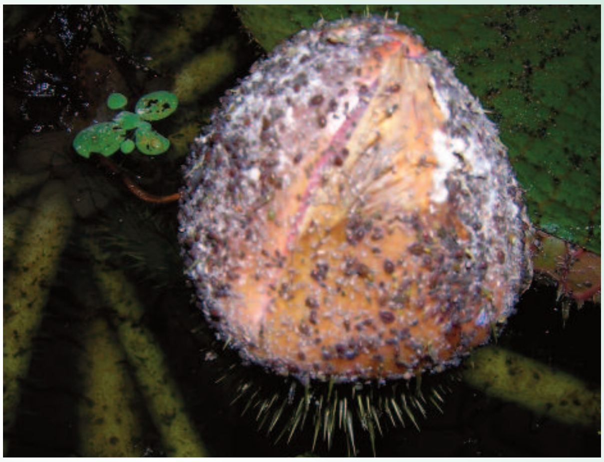
2. The plant is completely free of any pests when it is moved from the propagation facilities where seed was germinated and grown on to the final planting position.

3. When the leaves are small and aphids are spotted, a hose is used to spray the insects into the water; the fish will feed on them.

4. When the leaves get bigger and produce the characteristic pronounced lip, it is no longer possible to wash the insects off the leaves. Biological controls are introduced at this point. This involves a parasitic wasp (*Aphidus colemanii*) and a predatory midge (*Aphidoletes aphidomyza*) (Clifford, 2005). It is important that biological control is introduced at the right time and at the correct dosage, both in the season and appropriate to the growth stage of the plant and pest.

5. It is fortunate that these insects are successful at keeping the aphid populations at a negligible level because chemicals cannot be used in the pond. However, the same steps and considerations are made for plantings where chemical control is an option.

If this solution had not been successful, the next step would have been to introduce 'soft chemicals' (i.e. chemicals with a physical mode of action), where there is no risk of developing pesticide resistance (e.g. with plant and fish oil-based preparations, urea-based products and horticultural soaps). The choice of the product will depend on national legislation and the context in which the chemical is being used. If this is ineffective, the use of 'hard chemicals', governed by strict guidelines, could be considered. When these chemicals are applied, areas should be spot-treated to keep the quantity used to a minimum. The mode of action should also be considered. A contact-action insecticide will be active for less time than a systemic one (i.e. it will be less persistent). A soft chemical can be used in conjunction with a hard chemical to increase the effectiveness of the latter. Cultural methods can also be used to minimise chemical use, for example by simply removing any heavily infested parts.



Aphid infestation of Victoria water lilies, Royal Botanic Garden Edinburgh. (Image: Pat Clifford)

Biological control application, Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

6.7 HUMAN RESOURCES FOR HORTICULTURE

At every stage of planning and establishing living collections, personnel are required. A number of aspects need to be considered to ensure appropriate skills and training to maintain the plants to a high standard:

Key questions

- What skills and type of work are required to maintain the collections?
- What are the legal, mandatory training or qualification requirements?
- Could or should any skills or operations be contracted out?
- How many plants under structures are maintained?
- Is machinery available to mechanise some tasks?
- Can volunteers be used for some tasks?

Training in the use and maintenance of horticultural tools, Jardín Botánico Francisco Javier Clavijero, Jalapa, Veracruz, Mexico. (Image: Kate Hughes)

Training in pruning techniques, Jardín Botánico Francisco Javier Clavijero, Jalapa, Veracruz, Mexico. (Image: Kate Hughes)

6.7.1 Factors Influencing Staff Requirements

The scale and size of the botanic garden, diversity of the collections and the funding structure will influence the staffing of the institution (Chapter 2, Sections 2.3.1 and 2.3.2). All botanic gardens will require a horticultural manager or senior horticulturist, or, as often referred to, a head gardener or curator. While roles and responsibilities overlap, generally the head gardener would manage the care of the collections while the curator would also review and maintain the species' content of the collections in accordance with the missions and strategies of the institution. The extent of the staff portfolios and functions required varies according to the nature of the institution but personnel will be required for the management of biosecurity and quarantine facilities (Section 6.8.3), pesticide and chemical treatment and record keeping and labels. In a large botanic garden, staff may focus on one particular area of specialisation, but generally, horticulture staff are multi-skilled and deliver a variety of roles.

- **Scale and size**
  The scale and size of the botanic garden will influence the number of staff required. Under almost all circumstances, the greater the size, the more staff are needed. However, staff complement will also depend on the diversity of the collections, planting style and corresponding intensity of labour required to manage and maintain these areas. Many botanic gardens of both medium and large sizes include a range of lower maintenance sections which tend to have a smaller number of species in greater quantities, such as meadows and arboreta, to areas with high numbers of species which are more maintenance-intensive, such as rock gardens and glasshouses.

- **Diversity of plants and habitats**
  The diversity of the species cultivated and the divergence of the botanic garden environment compared to their native habitats will have a great impact on the intensity of maintenance required and therefore the numbers of staff required. A botanic garden which maintains a number of different types of collections and species, for example alpine plants as well as tree collections, will require a greater range of skill sets, qualifications and therefore people to look after this diversity. It is common to find proportionally smaller areas which may house a greater diversity of species, or species which are not native to the local environment. As plants are moved further away from their native habitat and environmental conditions they require more intensive horticultural input.

- **Use and purpose**
  How the collection is used and what for (Chapter 7), including the audience for which it is maintained, will impact on the type of cultivation and input required. Collections maintained for education or research may involve more input because they have to be closely observed or cultivation conditions are varied, and require regular adjustment and monitoring. Collections used extensively by school groups will need high levels of maintenance to ensure that the necessary elements for educational use are present at the appropriate times and cater for large numbers. A botanic garden with a reputation as a dazzling tourist attraction will also have high inputs to maintain a formal gardening standard which corresponds to the reputation. A range of extremes and priorities exist across the spectrum of botanic gardens. An institution with a primary purpose of research and conservation may not prioritise high visual standards, whereas botanic gardens which rely heavily on income from visitors and tourists will need to prioritise the displays in their maintenance regime.

Ornamental beds of seasonal displays have higher maintenance requirements than mixed or native plantings which are not changed regularly. Here, protection of tender ornamentals from frosts at the National Botanic Garden Nepal has been installed. (Image: Kate Hughes)

- **Gardening style**
  The style of gardening and horticultural methods applied will impact on staff numbers required. For example, herbaceous border displays which are changed throughout the season, such as annual bedding plants, will tend to need greater management input.

- **Growing environment and changing the prevailing microclimate**
  Plants under structures generally require more management in order to maintain the intended conditions. The more a plant cultivation environment is adjusted from the prevailing climate, the greater the input by staff required. This is comparable with the incremental increase in resources required with every move away from the natural growing conditions (Section 6.2).

- **Use of machinery**
  In some cases, the maintenance of plants can be assisted effectively with the use of machinery. Automation, or more usually, semi-automation of tasks still requires significant human input and resources but machinery can reduce the amount of human effort required and therefore impacts on the levels of staffing required (Case study 6.6).

6.7.2 Engaging Volunteers

Many botanic gardens draw on volunteers to help with horticultural work (Chapter 2, Section 2.3.2). They can provide a welcome boost to manpower in a botanic garden. However, a number of considerations should be made when working with volunteers. There should be a formal application and interview process in which both the botanic garden staff and volunteer can find out whether they are suitable for the work which is required and that it is suitable to the individual. An agreement should be reached by both parties whereby a specified commitment is made by each. The botanic garden may also cover an agreed amount of expenses incurred by the volunteer while they are working for the institution (e.g. long-distance travel to the botanic garden). The volunteer should be given the same access to facilities, health and safety clothing and equipment as core staff while working on behalf of the botanic garden. Other stakeholder groups who may have a mutually beneficial role in working for the botanic garden are people in training, including students, interns and apprentices. Advantages and disadvantages of working with volunteers include:

Advantages:
- Free of charge (except for nominal expenses);
- Enthusiasm;
- Support the paid staff;
- Alternative experiences and ideas – often way beyond what botanic gardens can afford;
- 'One-off', short-term jobs.

Disadvantages:
- Variable skills;
- More supervision may be required than for paid staff;
- Induction time;
- No guarantee of their time commitment;
- Staff may feel uncomfortable working with unpaid volunteers.

CASE STUDY 6.6

A large garden with a small team – Using machinery to good effect at Benmore Botanic Garden

Kate Hughes, Edinburgh, United Kingdom

Benmore Botanic Garden (BBG) is a well-respected visitor attraction located on the west coast of Scotland, 56 km from Glasgow. It occupies 49 hectares of densely wooded rural land which rises from 15 m to 137 m above sea level. Approximately one third of the botanic garden is fairly flat land, some of which has high maintenance formal plantings; the remaining two thirds are gradual to steep slopes. 11,000 individual accessioned plants grow in these 49 hectares and many of the plants are large trees, hundreds of them over 50 m in height, growing on shallow soil over rock. There is an enormous diversity of plants and environments, including a historic building housing over 70 species of ferns, which has to be maintained safely to a high standard for over 40,000 visitors per year, while ensuring that the botanic garden retains its wild and natural feel.

11 full time horticultural staff carry out all the work including plant records management and labelling. This is a small team for a large and diverse area all of which is maintained to a high standard. This team would have to be much larger just to keep the botanic garden safe for visitors, if it was not for the long list of large and small machinery and hand-held equipment which is used on-site. This includes large tractors and trailers, winches, timber grabs, a chipper, a band saw for cutting large trees, chain saws of various sizes, ride-on mowers, power barrows (motorised large wheelbarrows), blowers, hedge trimmers and fertiliser spreaders; all make the routine horticultural tasks quicker and easier.

The BBG team has a broad range of skills ranging from arboricultural expertise, collection and database management to formal garden maintenance. All the staff are trained to use the equipment appropriate to their main area of work. This training starts with how to use the equipment effectively and safely, and crucially includes maintenance and upkeep. It is essential to maintain equipment to get the most out of it and to ensure operator and visitor safety. As a result, training absorbs a significant part of the budget for running the botanic garden. However, the curator believes that this is a worthwhile investment because the equipment enables staff time to be used so much more efficiently. There are several levels to this training. Basic training for effective use of commonplace equipment is provided by experienced botanic garden staff, while an external contractor delivers the initial training for new equipment, or statutory and legally required training for specialised and more complex tools and machinery. The curator has to ensure that staff knowledge is always within the legal requirements for health and safety and insurance purposes, and has to be aware that legislation can change. The curator also keeps up-to-date with this by communicating regularly with colleagues and peers in the industry, and consulting industry literature.

Peter Baxter, Curator at BGG is keen to point out that there are some tasks which cannot be fully mechanised such as pruning and weed control. *"Machinery is fantastic but without the people, you can't ensure that time and valuable equipment is put to the best use. While machinery fulfils a vital function, people are essential to observe and evaluate collections, attend to visitor needs and to run a successful botanic garden. Machinery can never fully replace the staff who really enable the botanic garden to fulfil its mission"*.

Benmore Botanic Garden. (Image: Royal Botanic Garden Edinburgh)

6.8 PLANT HEALTH AND BIOSECURITY MANAGEMENT

Ellie Barham, Botanic Gardens Conservation International
Sara Redstone, Royal Botanic Gardens Kew

Invasive alien species refer to plant pests and diseases and plant species which pose a significant environmental, social and economic threat to biodiversity. Their impacts may be exacerbated by human activity, trade, habitat disturbance, pollution and climate change, amongst others. Globally, the impact of invasive alien species is second only to habitat destruction in terms of the most important cause of biodiversity loss (CBD, 2001). In vulnerable island habitats, which often represent some of the world's most precious, biodiverse and unique habitats, they can be the primary cause of extinctions.

Due to the way in which many plant collections are organised and because of the mobility of plants, staff and visitors, botanic gardens and arboreta can be especially vulnerable to the impact of invasive alien species. Such organisms can arrive in botanic gardens naturally, for instance through range extension, but introduction through human activity, whether deliberate or accidental, is the most common pathway. Plant material, especially large specimen plants, are a significant pathway for introduction of plant pests and diseases, but many other vectors and pathways exist. Commercially sourced plant material poses as great a risk in terms of the introduction of invasive alien species, as material which has been wild collected.

However, risks are not restricted to horticultural material managed by horticultural staff. Managers need to consider the risks associated with the movement of other commodities in other departments – including plants for sale areas and herbarium specimens, artefacts for economic botany and museum collections, dried goods, flower arrangements, soil and growing media, chipped bark and woody packaging material, including pallets.

Outbreaks of new pests, diseases or invasive plant species can be difficult and costly to identify and eradicate, and control measures may impact non-target organisms, so prevention rather than 'cure' should always be the objective.

Whether botanic gardens are receiving or sharing plant material, it is vital to ensure that neither the plant itself nor any associated pests or diseases affect the collections of the botanic garden or of the wider environment. Careful planning, preparation and management of plant material, good record keeping and robust procedures can help safeguard biodiversity and avoid serious environmental and economic impact. Annually 35 million hectares of forest are damaged by forest pests alone, with the temperate and boreal zones being most severely affected (FAO, 2010).

6.8.1 Structure and Plant Health Governance

Since the late 19th century nations have recognised the need for international cooperation to try and minimise the impact of invasive alien species. This was a result of tragedies such as the Irish potato famine and the introduction of Grape Phylloxera to France in the 1860s which rapidly destroyed two thirds of European *Vitis vinifera* vineyards causing enormous economic and social damage (Skinkis *et al*., 2009).

There are several tiers of plant health legislation and controls (Box 6.3). A key driver in many countries is to maintain high levels of trade whilst also providing a measure of biosecurity. In most countries legislation focuses primarily on known risks – pests that have already been identified and listed. New threats are constantly emerging and consequently pose a significant challenge for legislators to keep policies current. For these reasons, it is important that botanic gardens understand and address related issues. Reliance on complying with legal obligations alone will not safeguard plant collections or the environment (Brasier, 2008).

Box 6.3 General overview of plant health governance worldwide

National

National Plant Protection Organisations (NPPOs)
Organisations designated by a country's government responsible for protecting natural plant systems against invasive alien species and preventing native organisms becoming invasive in other countries.

https://www.ippc.int/en/countries/all/nppo/

Regional

Regional Plant Protection Organisations (RPPOs)
Inter-governmental organisation representative of particular regions; NPPOs are often (but not always) coordinated by RPPOs.

https://www.ippc.int/en/partners/regional-plant-protection-organizations/

International

International Plant Protection Convention (IPPC) The IPPC is a multi-lateral treaty for global cooperation in plant protection; making provisions for governments to protect their plant resources (cultivated and wild plants) from harmful pests. It is overseen by the Food and Agriculture Organisation (FAO).

https://www.ippc.int/en/

Commission on Phytosanitary Measures (CPM)
Reviews the state of plant protection around the world, identifies actions to control the spread of pests into new areas, adopts guidelines for the recognition of RPPOs; and cooperates with international organisations on matters covered by the IPPC. The CPM adopts International Standards for Phytosanitary Measures (ISPMs) which aim to prevent pest introductions and spread whilst still facilitating trade.

The CPM is an annual meeting held at the FAO headquarters in Rome, Italy, which governs the IPPC. RPPOs and NPPOs are members of the commission and each is responsible for implementing work for standards development, information exchange and capacity building within their respective countries/regions.

https://www.ippc.int/en/core-activities/governance/cpm/

6.8.2 Plant Health Terminology

It is a common convention in plant health legislation that both pests and diseases are referred to as 'pests'. Plant material that may or may not pose a biosecurity risk is legally categorised as one of three types:

- **Prohibited:** Poses such a serious risk to horticulture, agriculture, forestry or the environment that import is only permitted under authority of a licence. In the UK and EU this category includes many species of rooted plants and trees, often of genera or species related to those of economic or environmental importance within Europe. Importing, keeping and using material which is prohibited usually requires a licensed containment facility.
- **Controlled:** Normally requires a phytosanitary certificate issued by the plant protection service of the exporting country; includes those cuttings, rooted plants and trees that are not prohibited, bulbs, most fruits, certain seeds and some cut flowers.
- **Unrestricted:** Considered to present little or no biosecurity risk and is not subject to routine plant health controls; includes nearly all flower seeds, some cut flowers and fruit and most vegetables for consumption (except potatoes).

Quarantine organisms are plant pests listed in legislation and are prohibited for import. They normally pose a significant threat to plants in horticulture, agriculture, forestry or the environment. Many quarantine organisms are not only damaging in their own right but can act as vectors for important plant pests or diseases.

Botanic gardens that import prohibited plants, soil and growing media and plant pests and diseases normally need to operate a containment laboratory or quarantine glasshouse, licensed by their National Plant Protection Organisation, to enable them to manage this material safely.

6.8.3 Biosecurity Management

KEY MESSAGE

Botanic gardens and arboreta that acquire, move and share plant material on a regular basis, need to implement biosecurity measures to protect plants from potentially introduced pests and diseases.

There are potential long-term plant and human health hazards associated with the introduction of plant material, growing media and soil. Botanic gardens and arboreta that acquire, move and share plant material on a regular basis, sometimes internationally, need to implement biosecurity measures to protect plants from such threats. It is strongly recommended that biosecurity facilities and procedures are developed and implemented before any plant material is brought on-site. There can be significant plant health threats from material which is not controlled, particularly from commercial sources.

• Biosecurity measures

Biosecurity measures are precautionary and are aimed at reducing the risk of introducing and/or spreading harmful organisms. Preventing the introduction of plant pests and diseases, rather than eradicating or controlling new introductions, should be the priority as it is simpler, cheaper and less disruptive to an institution. It may be decided that biosecurity is not an issue, for example if all plants are purchased from local nurseries. However, it must be realised that once established a pest problem can be extremely difficult to eradicate (Long *et al*., 2006) and can threaten not only live plant collections but also herbarium specimens, art and archives too, as well as the wider environment (particularly in the case of pests which are able to move large distances of their own accord). Botanic gardens also have a responsibility to stop the spread of pests and diseases. They should ensure any plants leaving their collections are clear of any potentially harmful organisms, whether this is to share plants and plant material with other institutes, sell plants to visitors or use specimens in recovery programmes in the wild (Table 6.2).

Similarly, botanic gardens have a responsibility to report any findings of damaging organisms (particularly quarantine organisms as above) to their National Plant Protection Organisation. Quick discovery and identification can drastically improve any eradication, containment or control management programmes; thus mitigating the impacts of an outbreak (Case study 6.7).

Pinus muricata showing dieback symptoms. (Image: Peter Symes)

CASE STUDY 6.7

Melbourne Gardens, Royal Botanic Gardens Victoria discover first case of *Diplodia africana* on pines

Peter Symes and Chris Cole, Melbourne, Australia

Royal Botanic Gardens Victoria (RBGV) has a beneficial relationship with agencies charged with plant protection and biosecurity across the State of Victoria. For example, RBGV has made significant contributions through the development of weed risk management procedures, involvement in industry reference committees, and fulfilling a role as a sentinel site for exotic pest incursions. In order to detect new pests in a timely manner, staff have a high level of awareness.

In June 2010, horticultural staff reported unusual dieback symptoms on branchlets of some *Pinus* spp. Subsequent samples of *Pinus muricata* (Bishops Pine) were submitted to Crop Health Services (CHS), Department of Primary Industries, Victoria. The symptoms included stem cankers, dieback, needle death and resin seepage from infected branches. An initial assessment from CHS reported *Botryosphaeria* sp. as the likely cause of the damage. However, due to the unusual nature of the dieback, and past experience of *Botryosphaeria* sp. which is usually more commonly found as a secondary disease in stressed plants, staff decided to investigate further. A DNA sequence analysis revealed that the primary pathogen was in fact *Diplodia africana*, a species which had been previously identified in South Africa, but only on *Prunus* sp. Further surveying and diagnostic analysis revealed that a *Pinus patula* in close proximity to the original host was also infected with *D. africana*. This finding of the pathogen was a new record for both Australia and for *Pinus* as a host.

Diplodia species are associated with symptoms such as dieback, shoot blights and cankers. Often *Diplodia* infections are initiated due to biotic or abiotic stresses (such as physical injury). In the case of Melbourne Gardens, the precursor damage was thought to result from a severe hail storm that had occurred in March 2010.

Biosecurity Victoria (BV) is the state agency responsible for domestic quarantine and plant protection of natural and cultivated plant assets in Victoria. One key risk to be mitigated was the damage *D. africana* might cause to the *Pinus radiata* plantation industry (wood, pulp, potting mixes). Experts from BV worked closely with management and staff from Melbourne Gardens to contain and seek to eradicate this pathogen. Some of the measures included barricading the infected areas, restricting arboricultural works on *Pinus* to emergency works only, and halting movement of plant materials (especially *Pinus* spp.) within and across the Gardens' boundaries. Further surveillance (and pathogenicity testing) continued for a few months, to ensure the pathogen had not spread further within the Gardens or into the local environment. Providing accurate, grid-based locations and maps of all *Pinus* spp. to BV staff also resulted in more efficient surveys. It was eventually determined that this pathogen had not spread beyond the infected *Pinus muricata* and *Pinus patula*. In October 2010, the more severely infected *Pinus muricata* was removed to minimise the excursion risk of this pathogen. The removal was a joint operation between the Gardens and Biosecurity Victoria and occurred under stringent quarantine conditions; meaning containment zones were setup, and rigorous sanitation and hygiene protocols were observed. All plant material (including sawdust) removed was placed into a large transportable bin, sealed with plastic, and transported for disposal as deep burial in a prescribed landfill location.

Ultimately, *D. africana* was not found to present any more pathogenicity than other *Diplodia* sp. diseases already present in Australia that afflict Pines. This example highlights the importance of promoting staff awareness and the complementary roles of diagnostic institutes and botanic gardens. In this case, Melbourne Gardens were integral in providing early warning, active surveillance, identification and management. The Gardens also provided key information which enabled policy makers to make a reliable judgement of the threat the pathogen posed; e.g. pathogen pathogenicity and host range. For particularly damaging organisms; quick identification, the establishment and initiation of viable management programmes, and robust surveillance and continual monitoring are all paramount in mitigating impact.

This example of best practice shows the important role that botanic garden staff can play in diagnosing a problem. Supporting staff's professional development is a powerful tool in establishing effective biosecurity within botanic gardens. Specifically, the development of staff's profound knowledge of a given plant's life-history, recall of previous management regimes, recognition of 'out of the ordinary' symptoms, and identification of common abiotic causes can all aid biosecurity best practice.

Containing and wrapping of all vegetative material on-site. (Image: Peter Symes)

Inspection of plant material in quarantine at Royal Botanic Garden Edinburgh. (Image: Royal Botanic Garden Edinburgh)

- **Biosecurity staff**

Botanic garden managers should identify staff responsible for biosecurity and ensure they have adequate support and resources. All botanic garden staff working in science, catering, shops, maintenance, etc. need to be aware of and engaged with the organisation's approach to biosecurity.

Staff directly involved in ensuring biosecurity at the botanic garden should receive appropriate training and support. They should develop procedures for the management of incoming and outgoing plant material and ideally establish a single point of entry where plants and other materials are received, inspected and (where necessary) held and treated or destroyed. A single point of entry for a botanic garden will also assist with compliance with international conventions such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora as well as the Convention on Biological Diversity (Chapter 4, Sections 4.3 and 4.4). Herbaria (Chapter 7, Section 7.1.3) will also benefit from using similar procedures.

- **Quarantine and isolation facilities**

On arrival, plants should be held in a 'quarantine area'. This can range from a bench or bay in a glasshouse or polytunnel to an enclosed area in the botanic garden or a purpose-built facility (Case study 6.8). Unless the plant material requires a statutory quarantine period (consultation with the National Plant Protection Organisation) it should be held for a minimum of six weeks where possible.

Recommended essential requirements for effective quarantine facilities include:

- Secure and separate location, with regulated access for staff (and visitors), locked doors, barriers and appropriately signs;
- Controlled drainage;
- Separate, dedicated tools and equipment;
- Plant inspection and diagnostic skills and equipment;
- Facilities for pesticide application;
- Facilities for cleaning and disinfection;
- Facilities for incineration and disposal of infected material;
- Regular monitoring for pests and diseases; use of traps such as sticky traps, pheromone traps, light traps, etc.

Whether working in a quarantine area or carrying out field work in sensitive locations such as in island habitats, staff should always operate from areas of low to high biosecurity risk. This will help minimise the risk of transferring plant pests to new areas.

CASE STUDY 6.8

Plant material quarantine procedure at Royal Botanic Garden Edinburgh

Fiona Inches, Edinburgh, United Kingdom

When living plant material is collected in the field, plants are packed carefully and checked every day and all decaying or unwanted material is disposed of; soil or growing media is only removed prior to inspection for export. Only whole plants or sections of stem for cuttings or rhizomes are required to go through phytosanitary procedures. Seed and spores can be carried through borders without inspection in Britain. This may not be the case in other countries. Local and country regulations governing the movement of organisms need to be consulted before crossing borders with plant material.

Plant material is transported to the Royal Botanic Garden Edinburgh (RBGE) following phytosanitary inspection at the airport. It is carried in sealed boxes which are only opened once inside the quarantine facility. The door to these facilities is kept locked at all times when not in use. Once the plants have been inspected and descriptions written, they are potted up and processed within the quarantine reception area. Cultivated there for a minimum of 3-6 months, horticulture staff then establish whether they are free of pests and diseases. Tubers, rhizomes and corms are kept longer in the quarantine facility for a minimum of six months. The plants are then inspected by the RBGE plant pathologist before leaving the quarantine unit for planting outside. Sometimes plants do not pass this inspection and, even though growing well, have to remain in the isolation facilities until a specific pest or disease has been removed. There is a policy of zero tolerance for organisms in the facility which means that biological controls cannot be used as pesticides.

The quarantine unit is inspected four times per year to ensure that it complies with isolation and other requirements by the Agriculture, Food and Rural Communities Directorate, the regulation body of the Scottish Government. The licence is renewed every three years, which requires an additional inspection.

The longest a plant has ever been cultivated in the quarantine unit at RBGE is five years for a slow growing xerophytic Saudi Arabian member in the family of the Asclepiadaceae. Many plants are given a clean bill of health and released from quarantine within six months of collection. Plants received from within the United Kingdom go through a similar isolation and inspection process, plants from European Union countries go through the quarantine process described here although there is no legal requirement for this, while plants from other parts of the world are legally required to go through this process.

Door of quarantine facility at RBGE. (Image: Fiona Inches)

Table 6.2 Plant material biosecurity hazards and risk mitigation measures

Type of material	Risk	Notes	Actions
Certified seed	Low	Under ISTA (International Seed Testing Association) regulations certified seed has certain tolerance levels for infection by fungal and bacterial diseases so is unlikely to be totally disease free. This may be important if such material is grown close to plant collections that are also susceptible. seedtest.org/en/home.html	Monitor seedlings and surrounding plants once planted out.
Non-certified seed	Medium to high	Seeds have the potential to carry infections by fungal and bacterial diseases so are unlikely to be totally disease free. Similarly, insects can store themselves in seed, both in larvae and egg form.	Quarantine for 4-6 weeks and monitor seedlings and surrounding plants once planted out.
Natural source seed	Medium to very high	May carry viruses and other diseases as well as insects internally and a range of pathogens externally. Seeds and fruits collected from the ground should be treated with particular care. If there is sufficient material, break open a few seeds to check for signs of insect pests (e.g. weevils). These may not necessarily pose a risk to plant collections themselves but could escape and threaten natural aphid populations by affecting their ability to reproduce (e.g. rose seed weevils).	Where suitable, a short soak in a surface sterilant such as a dilute solution of hydrogen peroxide may help reduce microbes carried on the seed coat. Peroxide can also be a useful way of triggering germination, but is only practical for robust seeds – excluding fine seed from plants such as begonias and orchids. Careful inspection and screening of seedlings and young plants can also help identify pest or disease issues.
Tissue cultures	Low to high	Generally considered relatively low risk but this depends very much on the source, motherstock and growing conditions. May carry latent infections and viruses.	Monitor for a number of weeks upon arrival, where possible, keep separate from living plant collections.
Cut flowers	Low to high	Dependent on type, source and cultural conditions e.g. tropical flowers such as *Phalaenopsis* have been found to be infested with *Thrips palmi*; cut flowers have been found to be infested with quarantine pests such as *Bemisia tabaci* and leaf miners (e.g. *Liriomyza* spp.).	Carefully inspect upon receiving.
Dried flowers	Low	Low risk to live plants but check for storage pests – e.g. weevils and beetles – as these may cause havoc in areas such as herbaria, libraries and galleries.	These will need to be treated appropriately (e.g. fumigation, heat treatment, rapid freezing) if entering sensitive areas such as herbaria, libraries and galleries.
Dried artefacts	Low to medium	Risk to plant collections low-medium but risk to preserved collections (e.g. herbarium) or art library collections can be high.	Will need to be appropriately treated (e.g. freezing) prior to being added to collections.
Reproductive material or storage organs (e.g. bulbs, fruits, etc.)	Medium to high	It is common for interceptions of non-native plant pests and diseases, including quarantine organisms, to be found on and in imported fruits and vegetables.	Monitor for a number of weeks upon arrival, where possible, keep separate from living plant collections.
Plants	High	Pose a threat whether from commercial sources or from other organisations, from in-country or further afield.	Plants should be carefully inspected and quarantined (for 4-6 weeks) before integration into plant collections.
Large specimen plants	Very high	These plants, especially if in leaf and with large rootballs, are a significant pathway for the introduction of plant pests and diseases and other non-native species.	It is crucial to know where plant material originated – it may originally have come from countries outside your region and could be accompanied by unwelcome biodiversity. Ideally this type of material should only be aquired after rigorous risk assessment. Quarantine for at least 6 weeks.
Wood, timber, bark samples	Medium to very high	Can carry nematodes, insect pests and diseases, as well as other non-native species. Wood with bark attached is considered particularly high risk.	Under International Standards for Phytosanitary Measures (ISPM) 15, woody packaging material (including pallets) should be marked to show it has been treated by chemicals or heat, ensuring it is not infested with live beetle larvae (e.g. Asian longhorn beetle), nematodes and other plant pests. ispm15.com/ISPM15_Revised_2009.pdf
Soil and growing media	Medium to very high	Can harbour a range of invertebrates, including flatworms, nematodes, insects and microorganisms such as fungi and bacteria.	Avoid importing/exporting plant material with soil and growing media. If unavoidable, quarantine for at least 6 weeks.

6.8.4 Biosecurity Best Practice

- **Field work**

  A large proportion of notifiable pest species not only cause damage in their own right but can be vectors for other pests and diseases, e.g. nematodes, viruses and fungi (for instance, *Ophiostoma ulmi*, the fungus responsible for Dutch elm disease, is vectored by the Scolytus beetle). Where botanic garden staff are involved in fieldwork, careful preparation, planning and good hygiene measures should be followed to avoid the introduction and/or spread of invasive alien species.

- **Sourcing**

- When sourcing plants from commercial sources, use reliable suppliers with a proven track record of providing healthy/pest-free plants – if possible, visit nurseries and look at how they manage their plants;
- Contact with suppliers, for example visiting storage sites;
- Specify exact requirements on purchase order forms;
- Seek to purchase plants propagated within country; avoiding large container-grown plants, where possible;
- Avoid plants which have been treated with pesticides, as these can mask symptoms of infection.

- **Plant arrival**

  Botanic gardens acquire material from many sources (Chapter 3, Sections 3.4.3 and 3.4.4; and Section 6.3) and it is recommended that all plant material is inspected and monitored, as cultivated material often presents as many issues as that from natural sources:

- Inspect all plants carefully on arrival;
- Only accept delivery if happy that plants are free from unwanted organisms;
- Check all necessary documentation where applicable (for instance, if in Europe or sourcing European plants, check the plant passport number – EC Plant Passport UK/EW 12345).

- **Export**

  Equally, plant material leaving *ex situ* collections, especially when intended for (re)introduction purposes and population reinforcement programmes *in situ*, needs to be carefully screened for any pests and diseases it might carry. Plants should only leave the nursery if they are healthy and pest free. Useful protocols have been developed for this by the Royal Botanic Garden Edinburgh with particular reference to plants used for reintroduction programmes (Frachon, 2013).

Tuberous plants ready for shipping. (Image: Royal Botanic Garden Edinburgh)

- **Disinfection**

  This is particularly important when entering or leaving infected sites or quarantine areas where all staff (and visitors) should disinfect/clean footwear, hands, equipment and vehicles. Make disinfecting kits available which could include; brush for scrubbing footwear, bucket, water container (and source of clean water), disinfectant (differs dependent on country), hand sanitizer and associated consumables including paper towels, gloves and safety glasses.

- **Reducing risk**

  General careful management of plants within collections will greatly reduce the risk of the establishment and spread of any pests and diseases. This includes:

- **Practice good husbandry** – a healthy plant is less likely to succumb to disease;
- **Not over-fertilising plants** – overuse of nitrogen results in 'soft' growth which may be more vulnerable to attack by pests and diseases;
- **Not overplanting, and pruning trees and shrubs carefully** – to ensure good airflow to reduce the likelihood of disease outbreaks;
- **Good infrastructure** – well-maintained paths, fences and signs can not only restrict visitor movement through the botanic garden (thus reducing spread of organisms), but also stop breeding grounds for harmful organisms (muddy paths, rotting wood etc.);
- **Good irrigation and drainage** – stops the spread of organisms and generally maintains the health of plants;
- **Careful waste disposal** – all known infected plant material should be burnt to stop spread; correct composting will kill most organisms though;
- **Continuous monitoring for pests and diseases** – helps the quick identification and subsequent treatment of any outbreaks, and increases the success rate of any management measures; special attention should be paid to nursery and production areas; staff should be encouraged to observe plants carefully while caring for them, noting any significant changes in health, and using tools such as sticky, pheromone and light traps to monitor what pests are present.

6.8.5 Preventing Future Introductions of Pests – Sentinel Research

Preventing the introduction or establishment of a pest is the most cost effective management tool available in the protection of plant species from invasive alien pests (MacLeod *et al*., 2002). A significant issue in safeguarding against the introduction of such organisms is that the majority of the most damaging pests introduced into temperate forests in recent years are not considered pests in their native regions or were unknown to science before widespread damage was recorded (Kenis *et al*., 2006).

Botanic gardens and arboreta are in a unique position to aid in the identification of such 'unknowns' (Case study 6.9). Within their collections they play host to plant species that are growing outside their natural ranges. These plants can be used as so-called sentinels, and can be monitored for damage by pests and diseases. Subsequent information recorded can be reported back to the plant's country of origin, and incorporated into efforts concerning plant protection. Sentinel plants within botanic gardens can not only help identify future threats, but also provide relevant information on a particular pest as illustrated in Case study 6.7. This information can be used to determine the risk a pest poses and potentially aid in the development of appropriate eradication and/or containment programmes. It also demonstrates the value of collaboration between different institutions – botanic gardens, research institutes and governmental regulatory organisations as in the case of the International Plant Sentinel Network (IPSN) (Box 6.4).

CASE STUDY 6.9

A role for botanic gardens in plant health – the example of Charles University Botanic Garden Prague, Czech Republic

Ellie Barham, York, United Kingdom

In recent years the Czech Republic has been plagued by a non-native sawfly, *Nematus lipovskyi*. The sawfly was first recorded in the Charles University Botanic Garden in Prague in 2010; before this, *N. lipovskyi* had only been recorded in the United States. The botanic garden not only played an important part in its identification in a new geographical range, but also aided research to increase knowledge of its general biology and potential implications for the local environment. This information was subsequently used in suggesting appropriate country-wide phytosanitary measures.

The presence *N. lipovskyi* in the botanic gardens was highlighted after larvae caused extensive defoliation to *Rhododendron molle*, the insect's major host. Samples of both adults and larvae were collected and sent to the Entomological Department of the National Museum in Prague for identification. Despite being found in 2010, problems with rearing the larvae meant that it was not formally identified until 2013 after further specimens were collected from the botanic garden. Morphological diagnosis of adult insects is essential in making a positive identification, though the use of molecular analysis is increasing. Similarly, often, even if adults are found within close proximity, only rearing larvae to adults will ensure they are one and the same. In the case of *N. lipovskyi*, the larvae had not been previously described.

Once identified, Charles University Faculty of Science set up a preliminary monitoring programme in collaboration with the State Phytosanitary Administration. Field observations were carried out in the botanic garden, monitoring particular behaviours including occurrence, damage on host plants, oviposition behaviour etc.

This work has greatly increased the knowledge of the hosts for the pest, and has allowed extensive study of the insect's biology and life cycle. This information is valuable in creating effective, integrated management programmes to prevent, control or eradicate outbreaks.

A larva of Nematus lipovskyi feeding on rhododendron leaves. (Image: Martina Juraskova)

Box 6.4 The International Plant Sentinel Network (IPSN) – a novel approach to combating invasive alien pests and diseases

The International Plant Sentinel Network (IPSN) is a novel approach contributing on a global scale to the protection of plant species from invasive alien pests and diseases by increasing capacity and capability within botanic gardens and arboreta. The network provides access to a host of IPSN resources through its 'members-only area', including in-depth guides to good biosecurity practise, diagnostic sampling and an introduction to the structure of plant health governance around the world. It also provides training on what could be causing particular types of damage and a form (the Plant Health Checker) to help record signs/symptoms in a standard format whilst familiarising users with key plant health terms. In addition, links to resources from around the world, discussion forums and information on current/new and emerging threats are provided. The IPSN also runs workshops and training sessions for contributing institutions around the world, bringing botanic garden staff together with representatives from government and institutes working on plant health. The IPSN is free to join, and gardens do not have to be BGCI members to do so.

Yorkshire Arboretum learning to use molecular diagnostic testing techniques for the needle blight fungus, Dothistroma septosporum. (Image: Ellie Barham)

6.9 ENHANCING HORTICULTURAL CAPACITY

Leigh Morris,
Royal Botanic Garden Edinburgh

For a botanic garden to deliver its mission, people with specific skills and knowledge are required in the horticultural team. Some skills and knowledge may be fundamental to the daily operation of the botanic garden, whereas others may only be required to meet targets or ambitions over a shorter period of time. This section is about the skills and training that need to be considered for the botanic garden team to ensure that the staff members have the capacity to deliver the mission.

It is important that the botanic garden management team recognises the importance of training and development of staff to keep the institution progressing and to maintain staff engagement. Therefore staff need to be given time to pursue training. In addition resources must be allocated to other forms of staff development such as travel to other botanic gardens, conferences or plant collecting. There are benefits to the botanic garden not only of increased knowledge of the team, but increased morale and engagement with the aims of the institution. A number of elements should be considered:

Key questions

- What skills and knowledge are required within the botanic garden for it to deliver its mission?
- What skills and knowledge exist in the staff team already?
- Is there potential to develop and build capacity within your existing team?
- Can the skills be sub-contracted (bought in) when required?
- Are staff with different skill sets required?
- How to ensure continued training for staff?

1. Training needs analysis

It is recommended that an objective appraisal of the capacity required within the botanic garden is carried out early in planning or review processes. This can be approached in different ways, but all can be termed a Training Needs Analysis (TNA). A TNA requires a critical analysis of the training needed and the best ways to get the required support and knowledge. In its simplest format, a TNA is simply writing down a list of the skills and knowledge required to operate the garden, appraising that of the current staff and identifying any gaps. A decision then needs to be made on whether the gaps are significant enough to justify employing new staff or to build up the capacity of the existing team using one or more of the approaches described below.

2. Capacity building options

A diverse range of training opportunities is offered by various botanic gardens (Box 6.5). However, it may be relevant for staff to attend courses or internships in other institutions such as commercial nurseries, forestry organisations and agricultural colleges. These operate many areas of activity which have cross overs with the horticultural activity of botanic gardens and are worth considering as sources of capacity building. Whether financial resources are well-allocated for training and travel or means are more limited (Case study 6.10), these numerous options enable tailor-made exchange programmes and staff development to ensure that the botanic garden is able to meet its aims within the context of the resources available.

CASE STUDY 6.10

Capacity building at the Oman Botanic Garden, Oman, and at the Nezahat Gökyiğit Botanik Bahçesi, Turkey

Leigh Morris, Edinburgh, United Kingdom

The Oman Botanic Garden (OBG) aims to be a showcase for Omani and Arabian flora and a model of sustainability in the Gulf region. Since the formation of the initial botanic garden team in 2006, the building of their collective capacity was identified as a key priority and a number of capacity building activities have been carried out to develop the team. OBG signed a Memorandum of Agreement with the Royal Botanic Garden Edinburgh (RBGE). This resulted in the following exchanges:

- A number of RBGE staff spent time in Oman delivering bespoke training and development for the OBG team in an extremely wide range of topics. These ranged from field collection and plant identification to horticultural skills, and from tractor driving to plant database set up and operation. RBGE staff were also in Oman to assist with, and work alongside Omanis, during key milestones early in the botanic garden's development. These included native habitats assessment and mapping, nursery construction, initial tree translocation operations and the planting of the first collections in the botanic garden.
- RBGE delivered their Certificate in Practical Horticulture (CPH) course in Oman to 16 members of the OBG team, including four senior botanists and horticulturists. Three of these senior staff then completed the RBGE Instructor Assessor programme at the Queen Sirikit Botanic Garden in Thailand. The CPH was further developed by staff of the Oman Botanic Garden and successfully taught in Arabic by adapting the course to local conditions and knowledge.
- A number of OBG staff have completed bespoke internships at RBGE alongside botanists and horticulturists to acquire in-depth knowledge of RBGE protocols, systems and techniques. In addition, many of the Omani interns joined the RBGE BSc study tour annually, to view horticulture in other areas of the UK.
- An Omani botanist successfully completed the MSc in Biodiversity & Taxonomy of plants, with their research dissertation focusing on an important Omani tree species.

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CASE STUDY 6.10 (CONT.)

In addition to the support of RBGE, OBG has acquired capacity building from a number of other partners including Botanic Gardens Conservation International (BGCI). OBG staff have attended international conferences, undertaken a number of study tours and carried out internships at other botanic gardens. Senior staff have completed Masters and PhD programmes at other UK universities. The vision for OBG is to become a 'world class' botanic garden and it was immediately recognised that building the capacity of their team in a number of ways was key to achieving this vision.

At the Nezahat Gökyiğit Botanik Bahçesi (NGBB) in Istanbul, Turkey, capacity building was aimed at a small number of personnel to enable them to deliver a practical horticultural course to other staff. This was carried out on-site, reducing the requirement for travel and ensuring that development was relevant to the local conditions:

- The RBGE Certificate in Practical Horticulture (CPH) programme was delivered in Istanbul to the NGBB horticulture team (Morris, 2010). Three of their horticulture team subsequently completed the Instructor Assessor course in Edinburgh. NGBB are now an RBGE Accredited Centre delivering the CPH to their own staff, and to members of the public.

- One of the NGBB staff completed the BSc in Horticulture with Plantsmanship at RBGE on a full-time basis over four years and has now returned to a senior post at NGBB.

- A number of NGBB staff completed bespoke internships within the horticulture team at RBGE.

- A number of RBGE staff spent time at NGBB delivering bespoke training and development for their team on an extremely wide range of topics.

Training in plants record management, Oman Botanic Garden. (Image: Leigh Morris)

Training module on soil texture for NGBB's horticulture team as part of the RBGE's Certificate in Practical Horticulture. (Image: Leigh Morris)

Box 6.5 Capacity building options

Training on-site: Trainers are contracted to come to the botanic garden to deliver tailored training in specific areas of operation. Such capacity building is typically un-certificated. However, as much time as necessary (or that can be afforded) can be devoted to specific areas and individuals. Such delivery of skills and knowledge can be extremely focused and make good use of external expertise. This can be useful for highly specific skills and knowledge, for example a herbarium expert or plant propagator from another botanic garden coming to work alongside your own to develop a curation system or propagation protocols. Bespoke training can often be delivered by external botanic garden consultants, or by staff of another established botanic garden with which a collaborative relationship has been established.

Training off-site: Staff visits to other botanic garden(s) for an internship period. This can be highly focused, or more general. Many large botanic gardens offer an internship programme. However, within the global botanic garden network, the vast majority of institutions host staff for training only if their expenses can be met by the employer. In such a relationship, the visiting staff will simply be placed in the appropriate team and will work alongside the staff of the host botanic garden, learning through experience. Such capacity building is not as focused and therefore a longer training period is required; however, the embedded learning gained by such an immersive placement can be highly significant and can expand the learning in other unexpected ways.

Formal training programmes: Some large botanic gardens offer training courses specifically aimed at building capacity for staff of botanic gardens in development. In this model, staff typically travel to the host botanic garden where they undertake a formal courses. In the 1980s, the Royal Botanic Gardens Kew recognised the need for specialised horticultural and botanical training, and began to establish a series of international diploma courses for people working in botanic gardens, herbaria, arboreta and other plant conservation organisations, including the International Diploma in Botanic Garden Education and the International Diploma in Botanic Garden Management delivered over a period of 5 weeks. A different model in formal education is offered by the Royal Botanic Garden Edinburgh (RBGE). Practical Horticulture and Field Botany are certificated programmes specifically aimed at delivering key practical skills. The RBGE certificates are delivered as a two-week block course in Edinburgh, or within the botanic garden where the skills are required. The advantage of these programmes is that they can be tailored specifically to the host botanic garden according to its resources. It can also be more economical for one or two trainers to travel to one botanic garden, than for several staff to travel to Edinburgh. The RBGE Certificate in Horticulture is endorsed by BGCI and has now been successfully delivered in a number of botanic gardens around the world (Morris and Cohen, 2010; 2013)

In-house training: For long-term success, a botanic garden needs knowledgeable staff who can pass on their skills to new and developing personnel. In order to communicate their knowledge to others effectively these individuals need to have capacity building and teaching skills.

It is recommended that key staff develop their teaching skills, and this is possible with specific training. There are a number of courses offered by colleges and training agencies to deliver this. RBGE developed a 4-day 'Train the Trainer', now known as the 'Instructor Assessor' programme, designed to teach botanists and horticulturists the key skills required to pass on their own knowledge and skills. The course is itself practical and requires participants to deliver and critique a number of micro-teach sessions, with the emphasis on improving communication techniques throughout. This course has been used to train staff at a number of botanic gardens and has also been adopted by the Royal Horticultural Society in the UK for the development of senior horticulturists.

Full-time professional courses: Professional Diplomas, Degrees and post-graduate qualifications on a full-time basis should be considered for long-term development of staff to acquire deeper knowledge and understanding in a specific area. Staff undertaking such a period of study, gain a far wider and deeper knowledge base, which then returns to their own botanic garden. While on the programme, they will usually have the opportunity to focus some of their studies and research on topics that are highly specific to their home garden needs and a strong link between the employer garden and the education provider is highly recommended. Some botanic gardens offer professional programmes in conjunction with colleges or universities, and these programmes can provide additional linkages, opportunities and benefits to the employees on the programmes. Examples of these programmes are:

- RBGE's Diploma and BSc (Hons) in Horticulture with Plantsmanship, offered with the University of Glasgow and the Scottish Rural College (SRUC); and
- RBGE's MSc in Biodiversity & Taxonomy of Plants, in partnership with University of Edinburgh.

Online learning support: The internet is becoming an increasingly important source of knowledge for botanic gardens and there is a number of on-line courses that could be highly relevant across a number of topics. The big advantage of such learning is that it can be widely accessed at a comparatively low cost to the garden. The main disadvantage is that there is no face-to-face contact with tutors, other institutions and colleagues on the programme.

A few online learning providers now offer 'blended learning', where there is some face-to-face contact with tutors and other learners, so that the studying continues beyond this via the on-line learning platform. The success of either completely on-line or blended learning hinges on several features: Learners need to be highly motivated and given the time to study remotely. The learning provider must be dynamic in their delivery methods and, most importantly, the on-line content needs to go beyond a long list of documents to be read. RBGE developed their own on-line virtual learning environment called 'PropagateLearning' which is used to support the courses and bespoke training offered (Morris, 2014).

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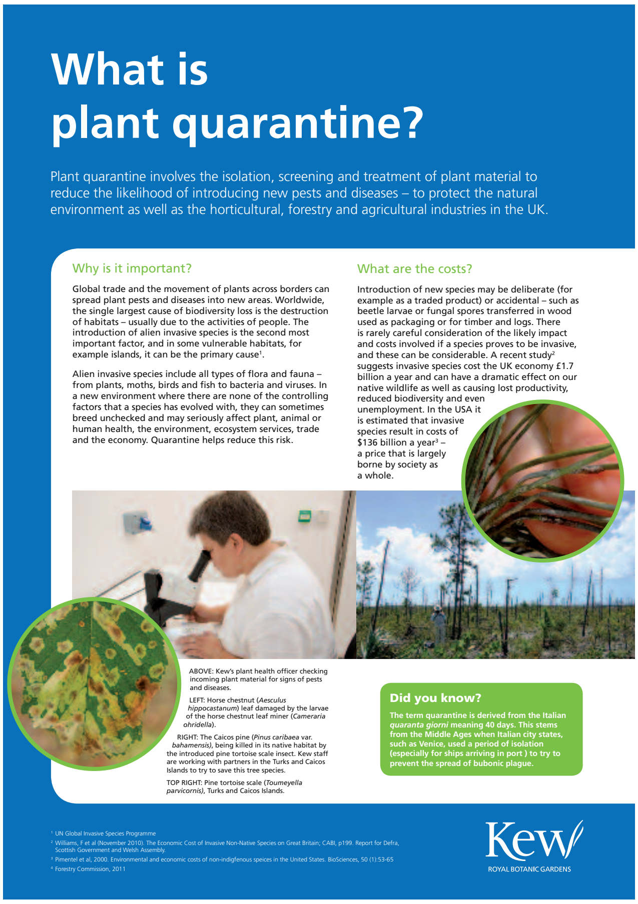

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