

THE OMAN BOTANIC GARDEN (3): A REVIEW OF PROGRESS
(2010–2016) WITH EMPHASIS ON HERBARIUM AND SEED BANK
COLLECTIONS, PROPAGATION CHALLENGES AND GARDEN
DESIGN PRINCIPLES

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ABSTRACT

This article follows two others published in *Sibbaldia* in 2008 and 2009 about the development of Oman Botanic Garden (OBG) and highlights the subsequent progress of key elements of the collection. Significant revisions to the design of OBG are discussed, as are developments in landscape design principles and aspirations. The growth and management of the OBG herbarium and seed bank collections and propagation department are described, with a focus on operational challenges and achievements. Numerical data are presented to demonstrate the growth in all three departments, and images of facilities and species in the collections are shown. The overarching challenges, achievements and ambitions for the future of OBG are conveyed throughout.

INTRODUCTION

The Oman Botanic Garden (OBG) project was initiated in 2006 with the aim to collect, conserve, cultivate and showcase the indigenous flora of Oman across a range of carefully created native habitats constructed within the garden site. The details of the OBG concept and aims are described in detail in two earlier publications (Patzelt *et al.*, 2008; Patzelt *et al.*, 2009). These articles presented a general overview of OBG and provided details on collection policies, strategies, nursery construction, plant production and propagation.

Before the start of the project the vast majority of the native plants of Oman had never been cultivated. Since then, the OBG team has continued to work hard to increase the knowledge required to understand the botany and ecology of Oman's native plants

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while increasing the practical experience needed to propagate, grow and nurture this diverse group of plants.

In recent years OBG has been involved with, or directly responsible for, significant advances in botanical and horticultural knowledge of the wild plants of Oman. Knowledge of Oman's flora has progressed rapidly with the publication of several key texts, including the *Synopsis of the Flora of Oman* (Patzelt, 2015a) and *Flora of the Sultanate of Oman* vol. III (Ghazanfar, 2015), *A Photographic Field Guide to The Plants of the Western Hajar Mountains* (Patzelt, 2015b), and *The Flora of Ru'us al-Jibal* (Feulner, 2011). When Patzelt *et al.* (2009) was published the flora of Oman was thought to contain c. 1,200 taxa. Patzelt (2015a) revised this figure with the flora now containing 1,407+ taxa. Coupled with the additions and revisions to Oman's flora there have also been important advances in the understanding of rare plants and potential threats to their survival and conservation. For a full quantitative list of Oman's endemic, near-endemic, regionally endemic and threatened plant species see Patzelt (2014). The *Oman Plant Red Data Book* (Patzelt, 2014) provides the most up-to-date statistics relating to Oman's rare and threatened species.

Advances in national botanical knowledge have been matched by significant gains in horticultural knowledge and practices at OBG. Starting from a low level of experience in 2006 the team at OBG has made enormous advances in seed collection and storage techniques, plant propagation and cultivation, integrated pest management, translocation and maintenance of mature trees.

The challenges and achievements of OBG have permeated the project's ethos and aspirations from the beginning. Flexibility, change and adaptability prove to be key to the Garden's enduring success. As with all institutions and organisations, botanic gardens operate in an environment of change. Periodic review of existing strategic documents, including master plans, is required for the institution to remain relevant. Successful reviews are highly valuable, and give an opportunity to all interested parties and individuals to comment on development intentions and design solutions (Patzelt & Anderson, 2015).

This was exemplified in 2012 when a review of the existing master plan resulted in significant revisions to the design and operations of key project components, including the garden habitats, amenity areas, visitor services and buildings, site circulation and interpretation. In addition to conducting field work and building up the living collection, the OBG team has worked very closely with a multidisciplinary team of design consultants – including landscape architects, architects, engineers, interpretation designers, soil scientists and irrigation designers – throughout all stages of the design process following the master plan review, from concept design through to technical design (Fig. 1). The final result of this unprecedented collaboration between designers, horticulturists and scientists is driven by elegant design, environmental sustainability, innovative engineering, detailed landscape design principles (see below) and practical operational considerations. The new landscape design for the garden is the result of years of detailed research, development, creativity and, most importantly, consistent communication between the OBG team and the landscape design team. Sharing knowledge and

expertise has been key and continues to be the single most important element of the OBG refinement and development phase.

Key landscape design principles at OBG are as follows:

Variety of experiences	Use existing landform
Immersive habitats	Retain existing habitats
Shade and shelter	Cultural landscape integration
Reasonable walking distances	Integrated wayfinding
Day and night landscape	Natural play
Sense of anticipation	Clutter free design

The changes to the built and landscape design elements at OBG have resulted in a considerable shift in the strategy and operations of the botany and horticulture departments. Revisions to the planting designs have led to significant changes in the Nursery Production List (Patzelt *et al.*, 2009). The Production List, which lists the species and their numbers and sizes required for all habitat and amenity planting plans and is the driving force behind all plant collecting and production strategies, has been modified to reflect and support these changes.



Fig. 1 One of thousands of landscape and habitat sketches produced during the OBG design review process. Photo © A. Anderson.

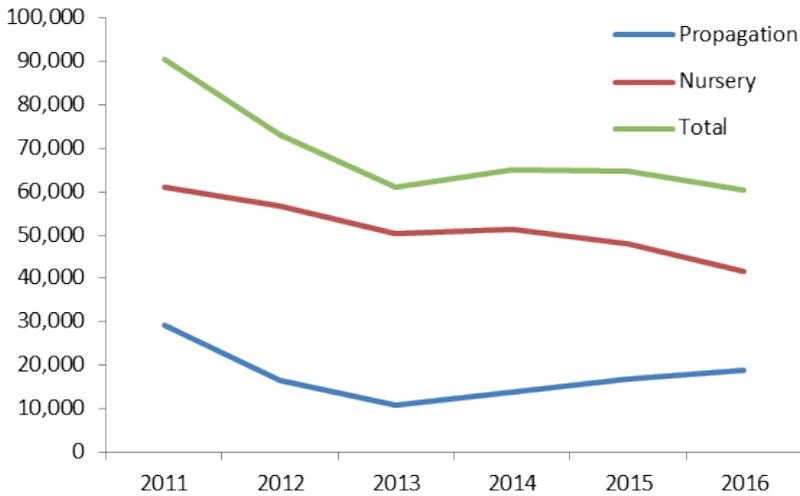


Fig. 2 Plant numbers in propagation, nursery and total plant numbers in cultivation in OBG 2011–2016. The sharp fall in numbers from 2011 to 2013 coincides with a significant review of the design of the project and associated changes in plant production strategies and targets.

The new planting designs for OBG precisely locate and quantify each species for the habitat areas and the amenity areas of the garden. Armed with this information, the OBG field, propagation and nursery teams now have an exact target list for all plants that need to be produced. This has led to a huge change in the makeup of the plant collections. In 2012 the collection shifted from high plant numbers to lower numbers and higher species diversity. The propagation department now only propagates according to the precise production target numbers, which are driven by the planting design numbers. In early 2012 the propagation and nursery plant numbers dropped (Fig. 2), however renewed propagation efforts, based on the targeted production of priority species in 2015 and 2016, have seen plant numbers and diversity of plants increase. The new strategy is streamlined and on target for the planting phase of the project.

The following sections examine OBG's progress in developing several key plant collections. Focusing on the herbarium, seed bank and propagation sections, this article outlines the breadth of experience, knowledge and resources that OBG has so successfully developed in recent years and sets out the direction in which the project is heading.

HERBARIUM – PROMOTING PLANT SYSTEMATICS AND CONSERVATION IN ARABIA

The OBG herbarium was established in 2006 with the aim of building up and preserving a complete archival collection of the flora of Oman. The herbarium currently holds 2060 voucher specimens from 98 plant families (86 per cent of Oman's total). The herbarium strives to fulfil its obligations towards promoting national, regional and global

plant conservation through collaboration, research and international best practice. The goals of the herbarium are driven by Targets 1, 2, 15 and 16 of the Global Strategy for Plant Conservation (GSPC, 2011–2020). The collection will be available to scientists, researchers, designers, gardeners and educational institutions to nurture a better understanding and conservation of Oman's wild plants.

Under the guidance and tutelage of OBG's Director of Science and Research, Dr Annette Patzelt, the herbarium collection is curated by Zawan Al Qassabi. The herbarium and voucher collections are managed to the highest standards and follow the latest APG III (Stevens, 2001–) revisions. To ensure the collection is kept to the highest standards a clear set of closely monitored guidelines are followed (see below).

Starting from nothing in 2006, the existing voucher collection has rapidly and consistently expanded due to the focus of Dr Patzelt and the Botany and Conservation Department. The herbarium now houses an impressive archival collection of Oman's native plant species.

The OBG herbarium functions and guidelines are as follows (Oman Botanic Garden, 2011):

- Collect, process, mount and label examples of all Omani native plants.
- Maintain the herbarium collection according to the most recent taxonomic revisions.
- Regularly inspect and clean the collections to prevent pest problems.
- Manage requests for loans from other herbaria and requesting loans.
- Generate herbarium data including distribution maps and species.
- Digitise all Oman Botanic Garden herbarium voucher specimens.
- Develop a virtual online herbarium.

Two herbarium staff members work closely with the field work team members from the Botany and Conservation Department to ensure that fresh herbarium vouchers are collected on all plant collecting trips (Fig. 3). When plants arrive from the field they are dried and their identification is verified. Collection details are entered in the database and a unique accession number is assigned to each plant (Patzelt *et al.*, 2008). A voucher label detailing the collection data for each plant is prepared, and then the specimen and label are mounted and secured to the sheet. Vouchers are placed in a freezer at -20°C

	2011	2012	2013	2014	2015	2016
Taxa	571	677	701	766	814	849
Families	84	90	90	98	98	98
Vouchers	1,147	1,433	1,520	1,711	1,930	2,060

Table 1 Numbers of collections in the OBG herbarium 2011–2016. Consistent data prior to 2011 are not available. The herbarium holds 61 per cent of all taxa in Oman and 86 per cent of all plant families.



Fig. 3 Ghudaina Al Issai, Abdulrahman Al Hinai and Mohammed Al Balushi collecting herbarium specimens. Dhofar, 2014. Photo © D. Lupton.

for five days to kill any potential pests or diseases, then the specimens are placed in their cabinets and arranged by family. Specimens are routinely inspected for possible pest infestation every three months. Vigilant monitoring by OBG staff has ensured that the herbarium has remained free of serious pest outbreaks since it began.

The international standing of the OBG herbarium has advanced significantly in 2016 through the commencement of a voucher digitisation programme coupled with joining the JSTOR Global Plant Initiative and registering with *Index Herbariorum* (Fig. 4). The OBG herbarium will soon include an online virtual herbarium and will thus be in a position to open its significant collection to interested parties around the world. The OBG herbarium continues to grow in size and importance and is poised to become a key resource for international plant taxonomy and conservation programmes in the coming years.

SEED BANK – FROM PLANT PROPAGATION TO *EX SITU* CONSERVATION

The OBG seed bank houses the largest documented collection of Arabian plant seeds in the world. With 647 plant taxa (46 per cent of the national total) and 90 plant families (80 per cent of national total) currently in storage, the seed bank is the heart of the OBG project. The collection and management of this vast array of genetic and geographic diversity is an enormous and ongoing task involving thousands of hours of field work,



Fig. 4 *Cyperus longus*, OBG's first digitised voucher specimen. Photo © Z. Al Qassabi.

plant identification, data recording, seed cleaning and processing. The seed bank fulfils an essential role, providing the seed for propagation and making regular updates on gaps or low numbers in the OBG plant collection. The review of this data allows for the ongoing refinement of collection targets and species lists for plant collection field trips across the country. The mid- to long-term aim for the seed bank is to implement and develop a genetically diverse collection of Oman's wild plants, with a particular focus on endemic, rare and threatened plants.

The seed bank is currently housed in a temporary space, consisting of an air-conditioned (16°C) processing and storage room and an adjoining seed bank manager's office. Seed cleaning and processing is done by hand and adheres to the following closely managed procedure:

1. Newly arrived seeds are dried at room temperature and cleaned using an aspirator.
2. Fruits are squashed gently using a rubber bung and wood ash is used to remove any sticky residues.
3. Seeds are washed under running water and dried at room temperature.
4. Seeds are sieved through a variety of aperture sizes to remove debris.
5. All seeds are inspected for insects and infested seeds are discarded.

6. Processed seeds are counted and weighed.
7. Accession numbers are assigned to each individual collection, and all data associated with an accession are entered into the database.
8. Seeds are packaged into labelled envelopes and placed in sealed boxes for storage and supply to propagation when required.
9. Seed collections are regularly inspected for possible insect or pathogen problems.

	2010	2011	2012	2013	2014	2015	2016
No. of taxa	460	506	562	579	610	634	647
No. of families	85	90	84	86	85	87	90

Table 2 Increase in numbers of taxa and families in the OBG seed bank 2010–2016. The seed bank holds 46 per cent of all taxa in Oman and 80 per cent of all plant families.

The seed bank is in a transitional phase in terms of both physical location and role in the garden. As the current primary function of the OBG seed bank is to provide seed for the propagation of plants for the garden there is a relatively quick turnover of seed and, as a result, seed viability has not been seriously impacted. Germination trials are carried out each year on selected taxa to assess seed viability after a number of years in storage. Many of the seeds in the OBG collection are orthodox, meaning that they can be dried and remain viable when stored at lower moisture and temperature levels than would be experienced in nature (Fig. 5). Levels of viability therefore remain reasonably high, at least in the short term.

With higher than recommended temperatures and relative humidity, the present temporary location and physical conditions of the seed bank are not ideal for seed



Fig. 5 Seed processing at the OBG seed bank. Photo © D. Lupton.

processing and storage. Despite the accomplishments of the OBG seed bank staff members, the current facility is not suitable for the effective long-term conservation of wild plant germplasm. A new seed bank facility is being developed and will incorporate state-of-the-art equipment and storage facilities, which will allow the long-term storage of seed and the conservation of significant proportions of Oman's plant germplasm.

Following guidelines and advice from the Millennium Seed Bank (MSB, 2001), the OBG collection, treatment and storage techniques will follow best international practice and will make a significant contribution to *ex situ* plant conservation in Oman. Preliminary discussions have taken place between staff from the MSB and OBG about developing mutually beneficial links and research projects in the future. The OBG seed bank hopes to foster and support seed conservation research and training within Oman and promote a collaborative approach to plant conservation in the region.

PROPAGATION – CHALLENGES AND ACHIEVEMENTS

The propagation team at OBG is part of the Living Collections Department and has been leading an intensive programme of native Arabian plant propagation in the state-of-the-art OBG nursery since 2008. Prior to the initial production work at OBG, the vast majority of Oman's native plants had never been propagated before, so the team embarked on what was, and remains, a steep learning curve of experimentation and innovation. For details on the principles and general strategies of plant propagation at OBG see Patzelt *et al.* (2008).

From modest beginnings, the propagation team has worked diligently to broaden their experience and understanding of the challenges associated with the propagation of wild plants. The team experiments with a wide range of propagation factors including soil mixes, seed treatments, sowing techniques, breaking dormancy, timing of seed collection and sowing, pest and disease control, optimum temperature and moisture levels, vegetative propagation methods and the use of rooting hormones. The methods used and the results gathered throughout the propagation trials are carefully documented and entered in the OBG database (see Patzelt *et al.*, 2009 for details).

Seed propagation

The propagation team has had many successes (Fig. 6) and results have for the most part improved each year (Table 3). However it continues to encounter challenges and frustrations with difficult species. Examples include *Ochradenus arabicus* (Resedaceae) and *Heliotropium calcareum* (Boraginaceae), which have not germinated despite thousands of seeds being sown. Seeds of these and other challenging species (Table 4) have been collected from different locations at varying times of the year, the seed has been treated in numerous ways and sown in a range of media, yet germination rates remain at zero. While this can be frustrating and perplexing, it is fundamentally a part of life when undertaking such pioneering work. There are a number of factors that consistently

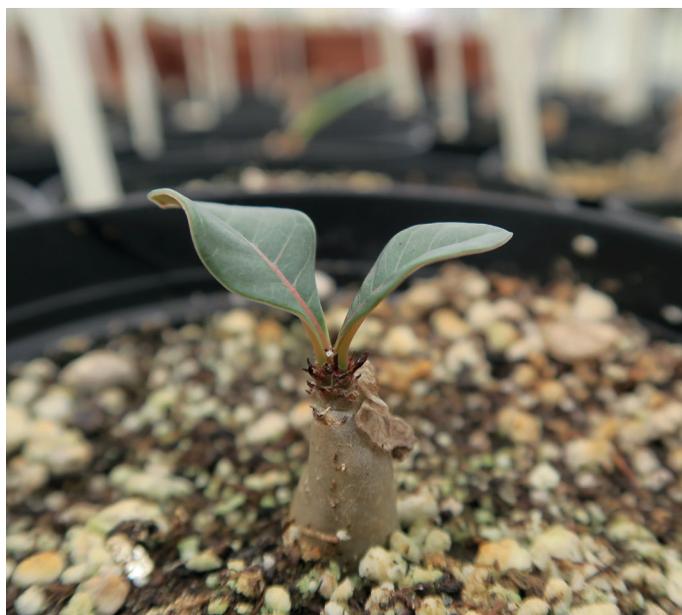


Fig. 6 *Adenium obesum* seedling. Photo © D. Lupton.

	Total taxa in prop.	Total plants in nursery and prop.	Total taxa in nursery	% of Oman taxa (1,407)	Total plant families	% of Oman plant families (113)	Total Red List taxa (261)	% of Oman Red List taxa
2008	no data	51,851	327	23	68	60	85	32
2011	29,342	90,388	663	55	101	86	no data	no data
2012	16,428	73,261	716	60	96	82	147	56
2013	10,762	60,982	712	59	97	83	139	53
2014	13,731	65,112	757	63	98	84	150	57
2015	16,708	64,751	804	67	100	85	152	58
2016	18,795	60,330	800	67	100	85	153	59

Table 3 Plant numbers in the propagation and nursery units in OBG. Data for 2009 and 2010 are incomplete so are therefore omitted. The drop in propagation and nursery numbers from 2012 to 2014 coincides with the review and redesign of the OBG landscape and planting plans.

challenge the team's ability to germinate seed. Through diligence, trial and error these impediments have decreased; however, they remain a consistent challenge to the staff.

Factors affecting seed germination success at OBG include:

- collection of unripe/unviable seeds from the field
- understanding of the seed compost requirements for different species

Taxa	Family	No. of seed sown	% success	No. of cuttings	% success
<i>Pistacia falcata</i>	Anacardiaceae	472	0	394	0
<i>Ehretia dhofarica</i>	Boraginaceae	504	0.2	n/a	n/a
<i>Heliotropium calcareum</i>	Boraginaceae	305	0	n/a	n/a
<i>Sterculia africana</i>	Malvaceae	312	0	69	13
<i>Ochradenus arabicus</i>	Resedaceae	43,799	0.16	n/a	n/a
<i>Ochradenus aucheri</i> subsp. <i>aucheri</i>	Resedaceae	10,967	0.12	n/a	n/a
<i>Pappea capensis</i>	Sapindaceae	n/a	n/a	543	0
<i>Daphne mucronata</i>	Thymelaeaceae	5,491	1	249	0
<i>Fagonia indica</i>	Zygophyllaceae	1,535	0.07	n/a	n/a

Table 4 Species showing consistently low or zero propagation success at OBG.

- seeds infested with insects; this is common in *Acacia* and *Euphorbia* seeds
- understanding of the required pre-sowing treatments
- the length of time seeds are stored in the seed bank prior to germination

Vegetative propagation

In 2014 there was a deliberate shift towards increasing vegetative propagation at OBG, particularly in relation to the propagation of woody plants. The shift in focus was largely driven by fundamental changes in the garden planting design which led to a need for the cultivation of large amounts of mature and semi-mature trees and shrubs. In 2015 an extensive trial of vegetative propagation by cuttings was conducted, with a range of cutting techniques tested on 77 plant species. The trials were set up to examine the effectiveness of vegetative propagation, particularly in relation to plants which to date had shown poor germination rates, and to expedite the production and cultivation of large amounts of priority woody plants required for planting in the habitat and amenity spaces of the garden. The trials coincided with improvements to the efficiency of facilities in the cuttings house, including the replacement of the pad and fan system with a HVAC (heating, ventilation and air conditioning) cooling system, and the installation of new misting units and heated benches (Fig. 7).

Results for many of the species tested were positive and in some cases vegetative cuttings proved significantly more successful than propagation by seed (Fig. 8). A major benefit of the use of cuttings is that the OBG nursery collection itself can be the source for a large and diverse stock of fresh cutting material, which means cuttings can be taken in the nursery and immediately sent to the propagation unit. This significantly reduces the time between taking the cutting and inserting it, which greatly increases the chances



Fig. 7 *Croton confertus* on the misting bench December 2015. Photo © A. Anderson.

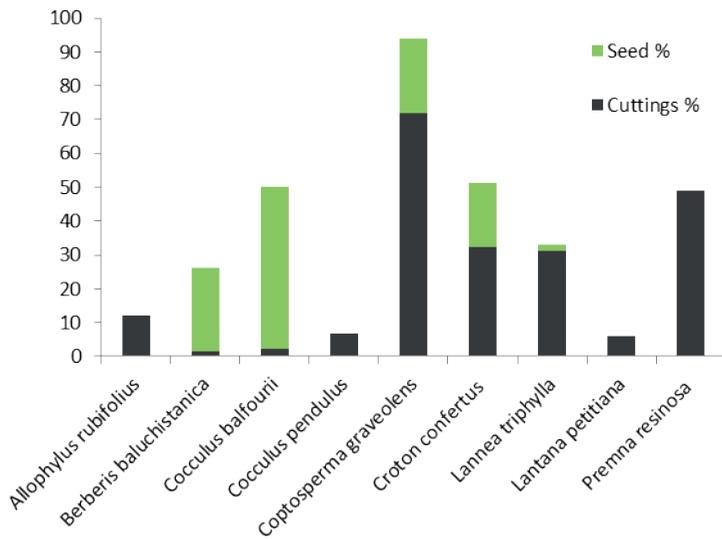


Fig. 8 Comparative percentage of success of vegetative and seed propagation on a subset of woody species at OBG. Cuttings improved propagation rates for many of the species tested. In some cases (e.g. *Berberis baluchistanica* and *Cocculus balfourii*) the opposite was true. The success of the seed germination of *B. baluchistanica* in 2015 can be attributed to sowing only freshly collected seed.

of rooting. It also lessens the pressure on the field team's collection workload and resources and reduces the need for removing cutting material from plants in the wild.

Propagation by cuttings for many of the priority woody plants is continuing throughout 2016 and will continue to be an important part of plant production. Propagation by seed is still essential to build up OBG's living collection, particularly with sub-shrub and herbaceous plants. As a result of rigorous testing and good practice the propagation team have now achieved an effective balance between the use of sexual and asexual propagation methods, which has contributed to an increase in overall propagation success and a rise in species diversity and plant numbers in the nursery over the last couple of years.

The propagation team is embarking on further trials and refinements to their techniques and equipment. Later in 2016 a new autoclave will be used to sterilise soils which will allow the team to broaden their scope to include fern and orchid propagation. Trials are already underway to look at employing new pre-treatment methods and the increased use of hormones such as gibberellic acid. Building on the results of preliminary *in vitro* germination trials that were carried out in 2013 with modest success, further *in vitro* testing will take place in 2017, focusing particularly on problematic species.

CONCLUSION

The design and construction of a new botanic garden is an enormously ambitious, challenging and exciting venture that requires the input and interaction of inspired multidisciplinary teams. Critical evaluation and review of all associated processes are vital throughout the entire development and design process and a flexible, adaptive management approach is required for a successful outcome. The OBG project has embraced and learned from these challenges and continues to grow and develop its collections and staff towards achieving national and regional prominence.

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REFERENCES

- FUELNER, G. (2011) The flora of the Ru'us al-Jibal –the mountains of the Musandam Peninsula. An annotated checklist and observations. *Tribulus*, 19, 4–154.
- GHAZANFAR, S.A. (2015). *Flora of the Sultanate of Oman. Vol. 3, Scripta Botanica Belgica*. Van der Poorten, Leuven, Belgium.

- GLOBAL STRATEGY FOR PLANT CONSERVATION (2010). Targets 2011–2020. Available at www.cbd.int/gspc/targets.shtml (accessed June 2016).
- MILLENNIUM SEED BANK (2001) *A Field Manual for Seed Collectors*. Available at www.kew.org/sites/default/files/English_kppcont_035653_A%20field%20manual%20for%20seed%20collectors.pdf (accessed June 2016).
- OMAN BOTANIC GARDEN (2011). Oman Botanic Garden – Department of Botany and Conservation, Departmental Strategic Plan, 2011–2015. Internal document.
- PATZELT, A. (2014) *Oman Plant Red Data Book*. Oman Botanic Garden, Diwan of Royal Court, Muscat.
- PATZELT, A. (2015a) *Photographic Field Guide to The Plants of the Western Hajar Mountains, Sultanate of Oman*. Sultan Qaboos University, Muscat.
- PATZELT, A. (2015b). Synopsis of the flora and vegetation of Oman, with special emphasis on patterns of plant endemism. *Jahrbuch 2014 der Braunschweigischen Wissenschaftlichen Gesellschaft*, 282–317.
- PATZELT, A., AL FARSI, K., MORRIS, L. & SPALTON, A. (2009). The Oman Botanic Garden (2): Collections policy, nursery construction, expanded plant production and initial tree translocation. *Sibbaldia*, 7, 83–98.
- PATZELT, A. & ANDERSON, A. (2015). Botanic gardens – from idea to realisation. BGCi manual on planning, developing and managing botanic gardens, Chapter 1. Available at www.bgci.org/resources/2016-BGCI-botanic-garden-manual (accessed June 2016).
- PATZELT, A., MORRIS, L., AL HARTHI, L., AL RASHDI, I. & SPALTON, A. (2008). The Oman Botanic Garden (1): The vision, early plant collections and propagation. *Sibbaldia*, 6, 41–78.
- STEVENS, P.F. (2001–). Angiosperm Phylogeny Website. Version 12, 2012. Available at www.mobot.org/MOBOT/research/APweb (accessed July 2016).