THE ROLE OF GARDENS IN INTEGRATED CONSERVATION PRACTICE: THE CASE OF CONSERVING *QUERCUS BRANDEGEEI* IN BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

Gardens and horticulturists play an increasingly important role in plant conservation, both *in situ* and *ex situ*. Integrated research and conservation of species intends to work across fields to connect science to conservation practice by engaging actors from different sectors, including gardens. The case of integrated conservation of *Quercus brandegeei*, a microendemic oak species in Baja California Sur, Mexico, is presented as an example of a collaboration between gardens and academic researchers to create a species-specific conservation plan that incorporates horticultural knowledge.

INTRODUCTION

There are many niches to be filled in the world of environmental conservation. Different organisations dedicate themselves to different missions, such as protecting land, preserving biodiversity and community engagement, among others. On top of this complexity, the conservation landscape is constantly changing and evolving, making it a dynamic field of study and practice. Although they are not always viewed as conservationists, gardeners and horticulturists play a direct and important role in plant conservation, not only in collections within their own walls, but also globally, through contributions to fundamental research and *in situ* conservation.

Species-specific plant conservation is a niche of environmental conservation that is particularly suited to gardens and horticulturists. Other conservation practitioners often focus on entire ecosystems or landscapes; if an organisation does focus on a particular species, it usually gravitates towards charismatic flagship species, which are almost always animals (although notable exceptions include the Global Trees Campaign, a programme dedicated to *in situ* conservation of threatened trees). This work is undoubtedly valuable; often work to protect one flagship species implies the

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conservation of the whole ecosystem upon which it relies. However, it is often the case that plant species continue to face risks, even within protected ecosystems, due to species-specific threats, like selective harvesting, plant diseases, inbreeding depression or regeneration problems, and solutions to these problems require actors with botanical and horticultural expertise. Overall, plant species conservation is under-represented in global conservation efforts, despite being equally vital to the protection of global biodiversity (Havens *et al.*, 2014). Gardens can contribute to such conservation collaborations that extend beyond their borders.

THE IMPORTANCE OF THE CONSERVATION OF PLANTS AND PLANT DIVERSITY

Plants provide essential environmental services that hold up entire ecosystems. For example, they filter pollutants from the air and water, stabilise hydrological systems, prevent soil erosion, and provide food and shelter for animal wildlife. Furthermore, plants are essential to human wellbeing by providing food (crops) and medicines, giving us a direct anthropocentric interest in conserving plants for our own welfare. Beyond the importance of plants in general, there is also an imperative to preserve diversity of plant life. We know that a high diversity of species increases the health of a system by strengthening its resilience to loss (Chapin *et al*., 1997; Folke *et al*., 2004). For example, an agricultural monoculture that relies on one species or one variety of crop puts a food system at high risk of loss from specialised pests or pathogens, whereas higher crop diversification increases a system's resilience to that same type of loss (Lin, 2011).

While a lot of conservation money and attention should be paid to protecting landscapes and ecosystems, there are some instances where simply protecting land does not necessarily protect the biodiversity within that land. Often, there are still ecological processes and threats that can drive species to extinction within protected lands. Climate change is a good example of this phenomenon. A changing climate may cause the loss of suitable habitat within a species' current range. Since plants, especially trees, are (relatively) immobile, they cannot quickly move to suitable habitat that is far away. The movement of plants happens over generations as they reproduce and disperse seeds. Thus, even when land is protected, if habitat is being lost to climatic shifts, then biodiversity is still at risk of extinction within that landscape.

THE ROLE OF GARDENS

The work of gardens and horticulturists is especially relevant to plant species conservation – whether they are directly conserving species in *ex situ* collections or engaging in research that can inform *in situ* conservation.

Ex situ conservation in gardens is vital for the security of reserves of species that may be becoming extinct in the wild. While *in situ* conservation is the ultimate goal of most species conservation, the elements of *in situ* conservation are often much more complex and harder to control than those of *ex situ* conservation. For example, if a forest is losing biodiversity due to illegal logging, then a conservation approach must involve understanding the policy failures, economic incentives and cultural factors at play – a task that is exceedingly complex. Furthermore, any viable solutions must consider what is politically feasible, socially responsible and ecologically valid. This type of work can take years, which is time that some species do not have before they become extinct. Gardens provide secure locations for species that are at risk of extinction because of larger social or ecological factors, and gardens can ensure the survival of these species while long-term habitat restoration work is being implemented. Moreover, plant material from gardens can be used in eventual *in situ* restoration efforts.

Not only do gardens provide species reserves, they also conduct scientific research that can inform *in situ* efforts. Experts at gardens across the world conduct research on how different species grow, reproduce, defend themselves against disease and respond to environmental changes (Cavender *et al*., 2015). The data from this research gives conservationists information on the best growing conditions for species both *in* and *ex situ*. Breeding programmes at gardens can help create resistant varieties of species that are threatened by pests or pathogens. Moreover, genetic and taxonomic research helps guide conservation dollars in order to maximise the amount of gene or species diversity being conserved. For example, genetic research can provide recommendations for plant collection in order to maximise genetic representation (i.e. do not collect all seeds from one population), and taxonomic discoveries of new species can point conservation actions towards rare and endangered species that had been previously unaccounted for in conservation work (Hoban & Schlarbaum, 2014; Hoban & Strand, 2015).

Integrated conservation, or conservation that works across fields of study to combine *in situ* and *ex situ* conservation, and which connects research to conservation action by creating scientifically informed strategies, is especially important for saving plant species. Moreover, it is a strategy that allows for collaboration between gardens and other conservation practitioners. Here we present a case study of the integrated research and conservation of *Quercus brandegeei*, an endangered microendemic oak species in Baja California Sur, Mexico. This case study demonstrates how integrated conservation works in action, and it highlights the importance of horticulture in the overall conservation of this species. This project is a collaboration between gardens and universities for the research and conservation of this species, and the lessons learned in the propagation of this species *ex situ* will benefit conservation of this species both in gardens and in the wild.

INTEGRATED RESEARCH AND CONSERVATION OF *QUERCUS BRANDEGEEI*

Quercus brandegeei is an endemic Mexican oak species found only within an approximately 3,000 km^2 distribution around the Sierra La Laguna mountain range in Baja California Sur, Mexico (Figs 1 & 2). It is an evergreen tree that averages between 10 and 12 m in height, although larger trees approach 20 m, and individuals commonly

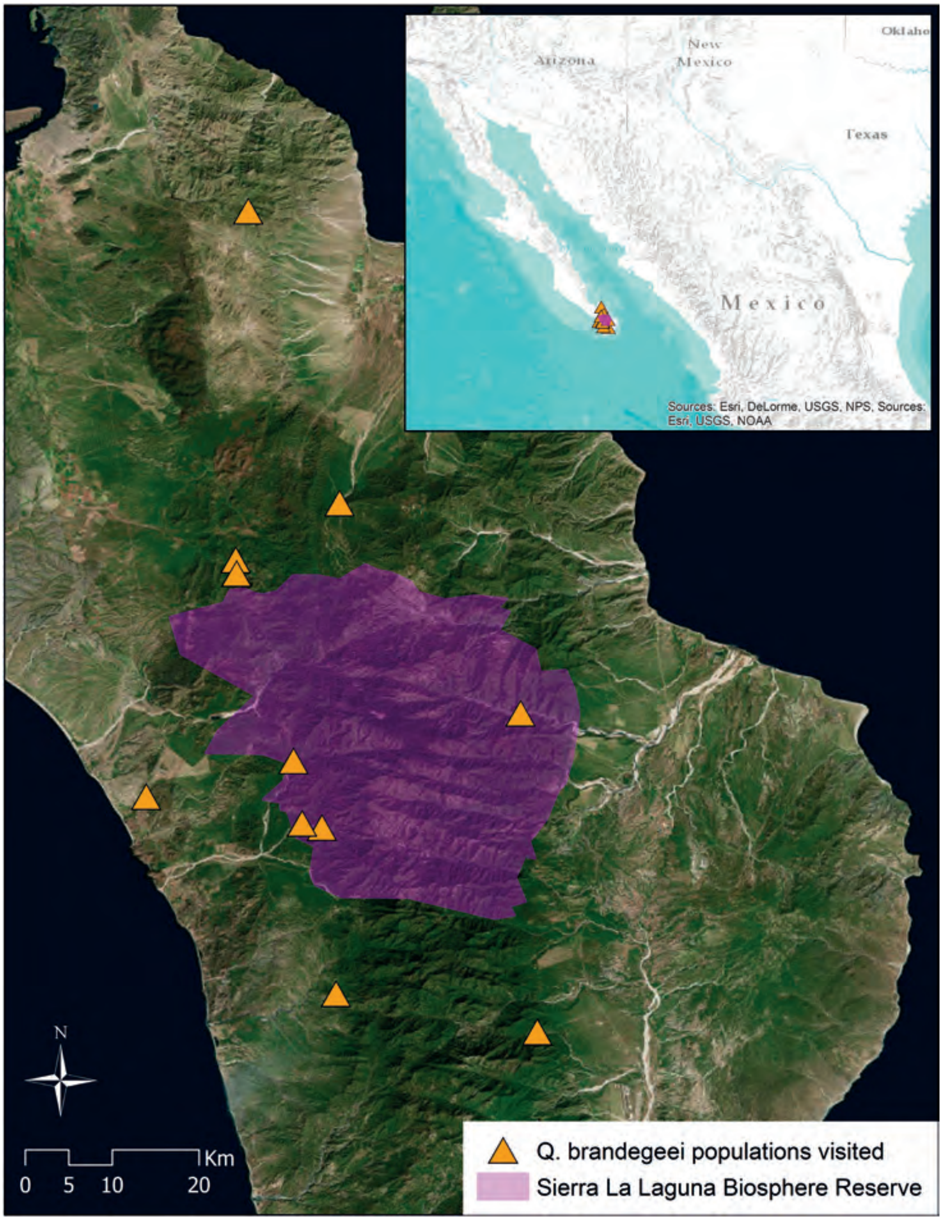

Fig. 1 Location of *Quercus brandegeei* populations and the Sierra La Laguna Biosphere Reserve. Map drawn by Emily Beckman.

Fig. 2 *Quercus brandegeei* on the south-western side of the Sierra La Laguna. Photo: A. González-Rodríguez.

have multiple trunks resulting from regenerative sprouting. The tree has small, glabrous, elliptical leaves, usually 40–65 mm long, sometimes with smooth edges and sometimes with a few pointed teeth. The acorns are elongate and range from 30 to 37 mm in length; they mature in November and December, after the rains of autumn hurricanes (Goldman, 1916).

Within the dry landscape of the Sierra La Laguna, *Quercus brandegeei* is found along the edges of sandy streambeds that fill up after hurricanes (Fig. 3). No regeneration from seed has been observed for the species in the past 30 years, and we estimate that there are no individuals less than 100 years old. This lack of regeneration, along with the small number of individuals left, puts this species at high risk of extinction. There are two working hypotheses addressing the lack of regeneration: (1) lack of water due to a dropping water table as seasonal dry periods get longer with long-term climate change, and (2) herbivory from livestock grazing (Fig. 4), as cattle ranching is an important local economy in that region (Díaz *et al*., 2001; León-de la Luz & Breceda, 2006; Comisión Nacional De Áreas Naturales Protegidas, 2003). An interaction between long-term climate change and livestock grazing is proposed.

The Sierra La Laguna mountain range holds an impressive amount of biodiversity due to the number of microhabitats present within a relatively small area. These microhabitats are created due to variability in altitude (the region ranges from sea level to 2,090 m), aspect (there are mountainsides facing all four cardinal directions) and latitude

Fig. 3 *Quercus brandegeei* surrounded by cacti. Photo: Neil Gerlowski.

(the Tropic of Cancer crosses the mountain range) (León-de la Luz & Breceda, 2006). The high biodiversity and high level of endemism warranted the creation of the Sierra La Laguna Biosphere Reserve within the mountains. An inventory of the flora within the Reserve published in 1999 found 974 species in total and 79 endemic species (Comisión Nacional De Áreas Naturales Protegidas, 2003; León-de la Luz, 1999). Within the tropical dry forest systems of the Reserve, where *Quercus brandegeei* occurs, there are 520 species and 33 endemic species, including *Q. brandegeei* (Comisión Nacional De Áreas Naturales Protegidas, 2003). Both climate change and human activity have been noted to be driving certain species to extinction in the area, including within the protected area (Comisión Nacional De Áreas Naturales Protegidas, 2003; Díaz *et al*., 2001; León-de la Luz & Breceda, 2006).

Little previous work has been published on *Quercus brandegeei*, including basic demographic information. A larger study on the evolutionary history of the *Virentes* 'live oak' lineage within the genus *Quercus*, to which *Q. brandegeei* belongs, noted the species' narrow habitat, low genetic diversity and highly limited gene flow with the rest of the *Virentes* group, indicating genetic isolation that corresponds to its geographic isolation (Cavender-Bares *et al*., 2015). The authors noted a complete lack of regeneration from seed – small vegetative resprouts were sometimes noted clustered at the base of adult trees – during their collection work in 2007. Their observations correspond

Fig. 4 Livestock browsing on *Quercus brandegeei.* Photo: Audrey Denvir.

to Kevin Nixon's conclusion of no regeneration in the species' Red List Assessment in 1998 and our own observation of the same a decade later in 2017 (Denvir & Westwood, 2016). These recurring observations suggest that regeneration has not been successful in at least 30 years, and likely much longer than that given the size structure of the population.

We visited the Sierra La Laguna in spring 2017 to conduct a demographic study of *Quercus brandegeei*; the study intended to find most or all populations, obtain a reasonable estimate of total population size and collect data on size structure. The project team talked to local experts and consulted herbarium records to locate 11 wild populations of *Q. brandegeei* – what may be most, if not all, populations of the species. The demographic study revealed that the total species population is most likely fewer than 1,000 individuals, its extent of occurrence is less than 465 m^2 and there is no regeneration in the wild, qualifying the species as Endangered on the International Union for the Conservation of Nature's Red List of Threatened Species (Denvir & Westwood, 2016).

Fundamental size information (height, diameter, basal area) was collected for individuals in each population to obtain a basic understanding of age structure. Admittedly, size is a poor proxy for age since growth rates vary widely based on a number of genetic and environmental factors. As such, it is often the case that small trees can be deceptively old. For our purposes, we aimed to understand whether there was any new growth (juvenile trees) within these populations, and since no small (juvenile) trees were observed, we conclude there is likely no wild regeneration for this species. Additional demographic and ecological data were also collected on the presence of flowering, the surrounding vegetation and the soil conditions in which the species grows.

In order to increase *ex situ* conservation (this species had previously only been recorded in three gardens worldwide), we returned to all known populations of *Quercus brandegeei* in November 2017 to collect mature acorns for distribution to Mexican botanical gardens. We found prolific fruiting in 8 of the 11 populations and collected around 2,000 acorns in total. Half were dispersed among 11 gardens, most in Mexico and one in Los Angeles, and the other half were sent to the Universidad Nacional Autónoma de México (UNAM) campus in Morelia, Michoacán to conduct propagation experiments. The results of these studies will directly inform both *in situ* and *ex situ* plantings in the future.

The propagation experiments will compare the growth, survival and physiological responses between seedlings subjected to regular watering and those under chronic drought (i.e. permanently receiving very limited amounts of water). In this way, it will be possible to evaluate the resistance levels of the species and to study its adjustment mechanisms to cope with the harsh environment. A second set of experiments will test for different soil concentrations of nitrogen (N) and phosphorus (P). Preliminary soil analysis from *Quercus brandegeei* populations indicates that these nutrients are, in general, very low, but concentrations vary in the soils across the sites where the species grows. In the experiments the amount of nutrients will be varied, simulating for each one (N and P) the low, intermediate and high concentrations found naturally in the distribution of the species. The growth, survival and physiological responses of the seedlings will be monitored for three months. In this way, it will be possible to identify the sites within the natural range of the species that have the best soil nutrient conditions to introduce seedlings for reforestation purposes.

In addition to studies conducted at UNAM, we are also collecting information more informally from the gardens to whom we sent acorns in November in order to collate propagation recommendations that can be used to the same end – informing both *in situ* and *ex situ* plantings.

LESSONS LEARNED FROM PROPAGATION EXPERIENCE AND RECOMMENDATIONS

The acorn collection and subsequent garden propagation has given us a number of lessons learned for growing this species successfully (summarised in Table 1):

Acorns germinate immediately. We spent a week collecting acorns, and like other species within the *Virentes*, the acorns exhibited precocious germination, with many beginning to germinate as soon as one day after collection. This posed a challenge for distribution to gardens as acorns began germinating even before shipment. For some gardens, shipping acorns took too long (more than a couple of days) and this severely impacted their ability to plant and germinate the seeds. Interestingly, however, some of the less mature seeds did not germinate immediately and in fact took four to six weeks to germinate once planted.

Sprouting is very common in the wild and is seemingly the only current strategy for regeneration in the wild. This form of regeneration is not ideal for promoting genetic heterogeneity; if individuals of this species in *ex situ* collections are not producing seed for some reason, they could regenerate themselves through sprouting in the event of tree damage. More research is needed to know if sprouts can be cut and rooted elsewhere. It should be noted that live oak seeds are desiccation intolerant and do not undergo dormancy (Klemens *et al.*, 2011; Center *et al.*, 2016). As a consequence, they lose viability in the seed bank fairly rapidly. As such, all *ex situ* collections must be living.

Germination and viability rates are relatively high. A float test was conducted for all acorns upon collection (sinkers are known to be viable), and this test revealed a viability rate close to 100 per cent, with only a handful of acorns failing out of 2,000. For the gardens that received the acorns sufficiently quickly after collection so that they had not desiccated, germination rates ranged from 43 to 50 per cent.

Quercus brandegeei grows in dry, sandy soils. The natural range of this species occurs in xeric habitat; many populations can be found at the edges of streambeds that are almost 100 per cent sand. As such, sand should be added to the potting soil for *ex situ* propagation of this species, and the soil should be aerated, porous and allowed to dry out completely on a regular basis. Gardens who received acorns have found success watering once or twice a week, employing cycles of watering to saturation and drying completely. All of the receiving gardens have used some mixture of peat moss and sand, with some also adding vermiculite and perlite.

Lesson learned	Propagation recommendation
Seeds are desiccation sensitive but need to respire to remain viable.	During transport and short-term storage, seeds need to be aerated but not allowed to desiccate.
Acorns germinate immediately.	Plant seeds as soon as possible after collection.
Immature seeds germinate after four to six weeks.	If collected acorns are immature, plant them immediately after collection, and be patient for a much later germination.
Sprouting is very common.	Sprouting occurs after planting from seed, and these new sprouts can be used as a propagation strategy in *ex situ* collections.
Quercus brandegeei grows in dry, sandy soils.	Compost should contain a mixture of peat moss and sand, with the option of vermiculite or perlite additives. Water once or twice per week; allow soil to dry completely between watering.

Table 1 Propagation recommendations for *Quercus brandegeei.*

NEXT STEPS

The next steps for this project include the development of reforestation plans for the species within its current range. These are informed by the data gathered from the aforementioned greenhouse experiments and the gardens' propagation experiences. There is also potential to employ strategies of assisted migration for this species. Ecological niche modelling (ENM) was executed for this species for its current temperature and precipitation niche and for a number of different climate change projections. The ENM analysis revealed that there may be suitable habitat for *Quercus brandegeei* in mainland Mexico (Denvir *et al*., 2017). Here, again, gardens in these areas will play an important role in developing an assisted migration programme by: (1) ground-truthing the validity of the computer models (i.e. testing whether the species can grow successfully in these areas); (2) providing *ex situ* and near *situ* land where trees can be planted; and (3) developing partnerships with land managers who can execute horticulturally informed *in situ* planting and monitoring.

GARDEN COLLABORATION IN INTEGRATED CONSERVATION

Integrated conservation plans for plant species are designed to incorporate species-specific biology. As demonstrated with the research and conservation of *Quercus brandegeei*, horticulturists' knowledge is essential to knowing how best to grow a particular species both in gardens and in the wild. Gardens are already set up to incorporate a scientific approach to horticulture and, importantly, gardens can help raise funding to support the implementation of conservation action that is based on their own research. Furthermore, many gardens have the advantage of being public-facing, which provides opportunities for environmental education and raising awareness of locally important species that are at risk of extinction.

Gardens are also unique in that they are equipped to approach conservation with a taxonomic focus. Our work with oak conservation demonstrates not only the importance of horticulture in integrated conservation, but also a model of global conservation efforts based around taxonomic groups. The Integrated Research and Conservation of *Quercus brandegeei* Project is part of a larger effort to study and conserve all of the world's oaks – a collaboration between the Global Trees Campaign and the Morton Arboretum. We chose to focus on oaks because they are ecologically important to forests across the world, both temperate and tropical. Moreover, oaks are exceptional in that they cannot be preserved in seed banks. Thus, since all *ex situ* conservation must occur in living collections, gardens are especially important to this group. Through our network and collaborations, we aim to connect gardens, researchers and conservation practitioners across international borders in order to protect this important group of trees across the world.

Of course, beyond oaks, there are many more taxonomic groups that could benefit from a similar integrated, global approach, and it is gardens that are poised to provide leadership for this type of conservation.

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