Authors: Joachim Gratzfeld, Gregor Kozlowski, Laurence Fazan, Stéphane Buord, Giuseppe Garfì, Salvatore Pasta, Panagiota Gotsiou, Christina Fournaraki, Dimos Dimitriou

WHITHER RARE RELICT TREES IN A CLIMATE OF RAPID CHANGE?

Conservation challenges of *Zelkova sicula* and *Z. abelicea* – two Mediterranean narrow endemics

Zelkova serrata. *Buddhist shrine, Hita, Japan. (S. Bétrisey)*

Shepherd's crooks ('Katsouna') made from Zelkova abelicea. *Omalos, Crete. (G. Kozlowski)*

Introduction

Specimens of *Zelkova* spp., which may be up to 1,000 years old, found in places of worship and contemplation in eastern Asia, give evidence to the ancient and close relationship of people with these trees. Likewise, traditional herbal medicine, household items and other objects made from various parts of the tree, are testimony to the strong cultural and socio-economic values and customs associated with this genus.

Relict trees

Zelkova species form part of the Arcto-Tertiary relict flora that covered large parts of the northern hemisphere during the Caenozoic Era (some 55 – 2.5 million BP). Fossil discoveries attributed to the genus, dating back more than 50 million years, give proof of the plant's once wider, circumboreal occurrence. Today the highly disjunct distribution of the six extant species – *Z. sicula, Z. abelicea, Z. carpinifolia, Z. schneideriana, Z. sinica* and *Z. serrata* – from the Mediterranean over to the Caucasus and East Asia, make this genus a fascinating subject for phylogenetic and biogeographic studies to advance the understanding of evolutionary processes.

Zelkova zelkovifolia. *Pliocene. Willershausen, Germany. (H. R. Siegel)*

Global distribution of Zelkova *spp. Map by Natural History Museum Fribourg, Switzerland*

Unfortunately, the relict nature of the genus is no recipe for survival in a rapidly transforming environment. As elsewhere in the world, habitat loss, overexploitation, fast changing climatic conditions and many other drivers of change exert high pressure on remaining natural *Zelkova* populations, especially the two Mediterranean species, *Z. sicula* and *Z. abelicea*. These species occur in exceptionally isolated and fragmented locations. Among the rarest trees in the world, they require specific management approaches combining a set of integrated *in* and *ex situ* conservation measures.

Zelkova sicula – one of the rarest trees in Sicily and in the world

Within the genus, *Z. sicula* Di Pasq., Garfì & Quézel has a particularly remarkable position. Discovered in 1991 (Di Pasquale *et al*., 1992), this narrow endemic is known from only two locations. Both populations cover an area of occupancy of less than one hectare and include a few hundred small trees each. Occurring between 350 and 450 m above sea level on the north-eastern slopes of the Iblei Mountains (south-eastern Sicily), the populations are found in open forest communities with other tree species such as *Quercus suber, Q. virgiliana, Olea europaea* var. *sylvestris, Pyrus spinosa* and *Calicotome infesta*.

Z. sicula. *Population of Ciranna, Sicily. (G. Garfì)*

Distribution of Z. sicula *(red colour). Map by Natural History Museum Fribourg, Switzerland*

Staying alive in a changing climate

Several of the morphological and life traits of *Z. sicula* can be interpreted as the result of a long-lasting process of adaptation to a rather suboptimal environment. Unlike the other *Zelkova* species, *Z. sicula* is a shrub or a small tree. Characteristic for plants at the limit of their distribution range, this habit is most likely a response to water shortage in the current habitat. The location of both populations restricted to the bottom of gullies and along narrow streams, suggests that these micro-habitats play a key role in enabling the species to withstand drought. Nonetheless, extreme environmental hazards, such as prolonged drought can cause moderate to severe damage, ranging from withering of leaves to dieback of branches and stems. What is more, rising habitat fragmentation and livestock grazing represent major further threats to both populations. Due to its rarity, *Z. sicula* has been included as Critically Endangered (CR) on the IUCN Red List of Threatened Species.

Z. sicula *micro-habitat.(G. Garfì)*

Z. sicula *leaf withering. (G. Garfì)*

Two populations – two clones: two individuals?

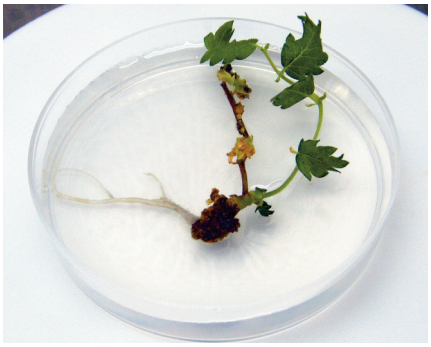
Recent studies (Christe *et al*., 2014b) suggest that *Z. sicula* has been subject to severe isolation and genetic impoverishment. Fructification is irregular and seeds are most probably sterile due to its triploidy. Regeneration relies on vegetative mechanisms such as root suckering and layering; as a result, individuals in both genetically impoverished but distinct populations are assumed to be of clonal origin; hence, each population could be regarded as a single individual. This, in addition to the extended geographic isolation, has most likely caused a sharp decline in gene flow and a decrease in intra-specific genetic variability. On the other hand, clonality and vegetative reproduction are adding a further trait of uniqueness to this species in the genus *Zelkova*; as with *Lomatia tasmanica* (Proteaceae) – known from a single, clonal population estimated to be several ten thousands of years old (Lynch *et al*., 1998), each *Z. sicula* population could potentially represent a many thousand year-old genetic unit.

Young tree of Z. sicula *developing by root suckering. (G. Garfì)*

Rescue trials in progress

Since 2011, a major project funded through the European Commission EC Life Programme (http://www.zelkovazione.eu/) is implementing a range of integrated *in* and *ex situ* conservation actions in the areas of knowledge and monitoring, active conservation, expertise, and education/awareness and communication. To date, a number of key milestones have been achieved, including the exclusion of grazing through fencing and a sustainable management plan involving formal agreements with local stakeholders, as well as the legal protection of the target species through the enactment of a Councillor's Decree by the Regional Department of Environment.

The recent successful development of protocols for *in vitro* and *in vivo* vegetative multiplication is a further major step towards effective *in* and *ex situ* conservation, with the poor intra-specific variability in the species facilitating the establishment of the field collections.



Z. sicula in vitro *rooted plantlet. (A. Carra)*

Introduction to other ecosystems?

Securing viable populations *in situ* nevertheless remains the main conservation challenge. Introduction to other ecosystems is being studied to establish further populations in new locations. These have been identified using the guidelines for 'assisted colonisation' (Brooker *et al.*, 2011), and build on paleo-ecological data and observations of specimens grown under different *ex situ* conditions which reveal the growth potential of *Z. sicula* into actual trees (Garfì *et al.*, 2011; Garfì and Buord, 2012). These findings suggest that more humid and cooler climatic conditions typical to montane mixed deciduous forests with *Fagus, Acer*, deciduous *Quercus*, etc. may offer a

Bosco Pomieri, Madonie Mountains, 1340 masl, a potential introduction site. (G. Garfì)

better match for the ecological requirements of *Z. sicula*. This conservation approach is applied as the 'last resort' for narrow endemics confined to very specialised habitats and increasingly encroached upon by unfavourable environmental conditions.

Zelkova abelicea – a Cretan persisting against all the odds

Zelkova abelicea (Lam.) Boiss. is the only endemic tree of the east-Mediterranean island of Crete. The species is found in open, mountain forest communities between 900 and 1,800 m above sea level, where it grows in mixed stands with *Acer sempervirens, Quercus coccifera* and occasionally *Cupressus sempervirens*. Populations of *Z. abelicea* occur in all four main mountain ranges including Levka Ori, Psiloritis, Dhikti and Thripti. Primarily, they occupy north-facing slopes and areas around dolines (sinkholes) with adequate and relatively constant water supply, but the species is also found near river beds and gullies, where moisture tends to remain close to the surface during the dry summer period.

Threatened and fragmented populations

More than 40 populations of *Z. abelicea* are known, mainly in Levka Ori (ca. 30) and in the Dhikti Mountains (ca. 10). Only two populations occur in the Psiloritis Mountains, and one small population in the Thripti Mountains. This fragmented distribution occurred already prior to the modern, botanical exploration of Crete (ca. 300 years ago) and forms part of a lively debate whether Crete was ever dominated by continuous woodland

Z. abelicea*, Omalos, Crete. (J. Gratzfeld)*

Distribution of Z. abelicea *(red colour). Map by Natural History Museum Fribourg, Switzerland*

before the arrival of man. To date, it is not resolved if the fragmented pattern of *Z. abelicea* populations is the result of anthropogenic habitat transformation or if its occurrence always consisted of a patchy distribution (Kozlowski *et al.*, 2014).

Recent studies confirm however, that all populations are subject to threats from overgrazing and browsing (goats and sheep), as well as from soil erosion, drought and fires. As a result, all stands of *Z. abelicea* are dominated by dwarfed and heavily browsed individuals. This habit is especially pronounced in relatively small and isolated populations (e.g. in Thripti where there are no large trees at all). This is of great concern to conservation as only fully developed trees are able to flower and produce fruits (Fazan *et al.*, 2012; Kozlowski *et al.*, 2014). *Z. abelicea* has been included as Endangered (EN) on the IUCN Red List of Threatened Species.

Isolated, shrub habit population of Z. abelicea *in the Thripti Mountains, Eastern Crete. (G. Kozlowski)*

Each mountain chain represents a separate genetic and conservation unit

Because of the extreme fragmentation, gene flow between distant populations is highly unlikely, mainly because of the limited dispersal capacity of seeds. This was confirmed by recent genetic studies demonstrating that *Z. abelicea* populations are highly genetically diverse within and between the four mountain regions (Christe *et al*., 2014a). This indicates on the one hand that the colonization of Crete by *Z. abelicea* is very ancient (probably before the early Miocene, some 25 million years ago), and, on the other hand, that each mountain chain with *Z. abelicea* populations should be considered as a separate genetic unit.

Ex situ conservation challenges

In comparison with other *Zelkova* species, especially those from Eastern Asia, *Z. abelicea* is underrepresented in botanic garden collections (Kozlowski *et al*., 2012). In addition, only a very small portion of the genetic variability in natural populations is found in *ex situ* collections (Christe *et al*., 2014b). In fact, all investigated individuals cultivated in botanic gardens and arboreta, originate from one single region of the Omalos Plateau (Levka Ori), while the other genetically distant populations do not appear to be in *ex situ* collections.

Future *ex situ* conservation efforts will need to consider the entire genetic diversity of the species, whilst avoiding genetic mixture of differentiated populations from the four mountain chains, especially when establishing field living collections (Kozlowski *et al*., 2012, 2014). Furthermore, dwarfed and heavily browsed populations do not produce seeds. Vegetative propagation is the only option to establish collections of these populations, enhancing the complexity and costs of *ex situ* conservation measures.

In situ conservation challenges

Conventional measures of protection and management, including effective methods to limit and/or completely prevent livestock grazing and browsing should be implemented by means of fencing, and should comprise the entire range of the genetic diversity of the species. Such measures require to be developed in close collaboration with

Seed collections for ex situ *conservation of Z.* abelicea *at the Mediterranean Agronomic Institute of Chania, Crete. (G. Kozlowski)*

shepherds and other stakeholders (e.g. local administration, municipalities, national park administration), and accompanied by long-term scientific surveys to monitor progress and allow adaptive management.

Ongoing conservation action

Based on the thorough research work undertaken in recent years, an international, interdisciplinary and integrated conservation programme for *Z. abelicea* has been initiated. The implementation of the project is assumed by the Mediterranean Agronomic Institute of Chania (MAICh) in collaboration with the Forest Directorate of Chania (FDC) as well as with forest agencies from other administrative regions of Crete. International coordination and scientific support is assured by researchers and conservationists from the Universities of Fribourg (Switzerland) and Athens (Greece), Botanic Gardens Conservation International (BGCI, United Kingdom) and the Institute of Biosciences and BioResources of the National Research Council in Palermo (Sicily, Italy). Amongst others, new and genetically representative *ex situ* collections (field living collections as well as seed banks) are being established using seeds and vegetative plant material sampled from all mountain regions where *Z. abelicea* occurs. Additionally, selected pilot plots have been fenced and are regularly monitored by the team of MAICh and researchers and students of the University of Fribourg. What is more, a range of local and international campaigns and public

Fenced pilot sites with Z. abelicea*. On the left: non-fenced and heavily grazed area. Xeropotamos, Crete. (M. Beffa)*

outreach events have been realized, including scientific seminars, conferences and exhibitions, accompanied by a series of first-rate public outreach materials.

Conclusions

The conservation challenges presented by *Zelkova* spp. have attracted the attention of researchers, conservation practitioners and horticulturalists in a joint endeavour to secure the remaining genetic diversity in the genus. Inspired by this shared concern, since 2010, a highly interdisciplinary and international research group represented by partners from Europe, the Caucasus and East Asia have been participating in the development and implementation of an integrated conservation action plan for *Zelkova* spp. (Kozlowski G. & Gratzfeld J., 2013).

The isolated occurrence and rarity of *Z. sicula* and *Z. abelicea* provide an ideal context to practise integrated conservation action and serve as models for safeguarding other threatened species. While the exclusion of grazing pressure such as through fencing is the most pragmatic measure for immediate protection in the wild, long-term *in situ* conservation efforts need to be implemented in close collaboration with local stakeholders and anchored in national legislation and policy. Systematic scientific evaluations to monitor progress and allow adaptive management will in turn, inform the nature of population reinforcement programmes and options for potential introduction to other analogous environments in situations where the original habitat has been lost, or no longer provides a viable option for the species survival. This is especially urgent for *Z. sicula*, known from only two locations.

As elsewhere in the world, *ex situ* conservation of *Zelkova* faces the challenge of ensuring genetically representative collections, preferably in the countries of the species' natural distribution, where current *ex situ* holdings are still largely inadequate. The complexity of capturing the whole range of a species' genetic variation for *ex situ* conservation is well illustrated by the distinct genetic diversity of *Z. abelicea* found in each of its four main locations of occurrence. While the remoteness and inaccessibility of some of the last remaining natural *Zelkova* populations prevent the broader public from appreciating their grandeur in the wild, *ex situ* collections at botanic gardens and associated scientific institutions, play a critical role in enhancing environmental awareness and education. Linking reports of fossil finds with their extant relatives and new population discoveries, *Zelkova* and relict plants in general, can provide compelling stories to reach out to the wider society. Relict species from ancient times not only function as storehouses of information of the Earth's transformations over millions of years but also deliver a diverse range of ecosystem services. Though ultimately a matter of societal choice, their conservation may therefore present a vital element in the development of future ecosystem management approaches, especially in a period of unprecedented, rapid global change.

References

- Brooker, R., Britton, A., Gimona, A., Lennon, J. & Littlewood, N. 2011. *Literature review: species translocations as a tool for biodiversity conservation during climate change.* Scottish Natural Heritage Commissioned Report No.440, 68 pages.
- Christe, C., Kozlowski, G., Frey, D., Bétrisey, S., Maharramova, E., Garfì, G., Pirintsos, S. & Naciri Y. 2014a. *Footprints of past intensive diversification and structuring in the genus* Zelkova *(Ulmaceae) in south-western Eurasia*. Journal of Biogeography. **41**: 1081-1093.
- Christe, C., Kozlowski, G., Frey, D., Fazan, L., Bétrisey, D., Pirintsos, S., Gratzfeld, J. & Naciri Y. 2014b. *Do botanic garden collections capture the genetic variation of wild populations? A molecular analysis of two relict tree species* Zelkova abelicea *and* Z. carpinifolia. Biodiversity and Conservation **23**: 2945-2959.
- Di Pasquale, G., Garfì, G. & Quézel P. 1992. *Sur la présence d'un* Zelkova *nouveau en Sicile sudorientale (Ulmaceae)*. Biocosme Mésogéen, **8-9**: 401-409.
- Fazan L., Stoffel M., Frey D., Pirintsos S. & Kozlowski G., 2012. *Small does not mean young: age estimation of severely browsed trees in anthropogenic Mediterranean landscapes.* Biological Conservation **153**: 97-100.
- Garfì G., Carimi F., Pasta S., Rühl J. & Trigila S., 2011. *Additional insights on the ecology of the relic tree* Zelkova *sicula di Pasquale, Garfì et Quézel (Ulmaceae) after the finding of new population*. Flora, **206**: 407-417.
- Garfì G. & Buord S., 2012. *Relict species and the challenges for conservation: the emblematic case of* Zelkova sicula *Di Pasquale, Garfì et Quézel and the efforts to save it from extinction*. Biodiversity Journal, **3** (4): 281-296.
- Kozlowski G., Frey D., Fazan L., Egli B., Bétrisey S., Gratzfeld J., Garfi G. & Pirintsos S., 2014. *Tertiary relict tree* Zelkova *abelicea (Ulmaceae): distribution, population structure and conservation status*. Oryx **48**: 80-87.
- Kozlowski G., Gibbs D., Huan F., Frey D. & Gratzfeld J., 2012. *Conservation of threatened relict trees through living* ex situ *collections: lessons from the global survey of the genus* Zelkova (Ulmaceae). Biodiversity and Conservation, **21**: 671-685.
- Kozlowski G. & Gratzfeld J., 2013. Zelkova – *an ancient tree. Global status and conservation action*. Natural History Museum Fribourg, Switzerland, 60 pages.
- Lynch A.J.J., Barnes R.W., Cambecèdes J. & Vaillancourt R.E., 1998. *Genetic Evidence that* Lomatia tasmanica *(Proteaceae) Is an Ancient Clone*. Australian Journal of Botany **46**: 25-33.

Joachim Gratzfeld
Botanic Gardens Conservation International,
199 Kew Road, Richmond,
Surrey, TW9 3BW, United Kingdom,
joachim.gratzfeld@bgci.org

Journal of Botanic Gardens Conservation International

BGjournal

Volume 12 • Number 2 • July 2015

Tree conservation and the role of botanic gardens

BGCI
Plants for the Planet