Zelkova – an ancient tree

Global status and conservation action

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BOTANIC GARDEN OF THE UNIVERSITY OF FRIBOURG (BGF), Switzerland, is a main centre for the scientific study of Tertiary relict trees. BGF also leads a number of basic and applied national and international research projects on conservation biology, biogeography of aquatic and alpine plants and urban ecology. BGF is the initiator of the global Project *Zelkova*.

BOTANIC GARDENS CONSERVATION INTERNATIONAL (BGCI), is an international nonprofit organisation linking botanic gardens and affiliated institutions in over 120 countries in a shared commitment to the conservation of plant diversity, sustainable use and environmental education. BGCI provides the Secretariat for the IUCN/SSC Global Tree Specialist Group and is a partner of the Global Trees Campaign, a joint initiative among Fauna and Flora International, BGCI and a wide range of other organisations to safeguard the world's most threatened trees and their habitats for future generations.

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Zelkova sinica. Colchic Botanic Garden in Kutaisi, Georgia (gk)

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Summary

A Tertiary relict tree genus, *Zelkova* comprises six extant species (*Z. sicula*, *Z. abelicea*, *Z. carpinifolia*, *Z. serrata*, *Z. schneideriana* and *Z. sinica*). Serving as a model taxon to illustrate modern-day conservation challenges, the genus also holds the potential to inform biodiversity management solutions based on insights into evolutionary processes affecting species distribution and differentiation. Against this backdrop, Project *Zelkova* was launched in 2010 by an international group of experts to review existing information and gather new data for the development of an integrated strategy for the safeguard of the species in the genus *Zelkova*. Over a period of three years, this initiative has generated a number of findings that are key to the establishment of this conservation framework.

Molecular analyses performed to corroborate the phylogeny and phylogeography of all *Zelkova* species establish a clear, southwest Eurasian (Sicily, Crete, Transcaucasus) and East-Asiatic (China, Korean Peninsula, Japan) division. On the other hand, similarities between the two groups suggest linkages during earlier geological periods that later, in the Middle Miocene (18-12 million years BP), became fragmented following climatic and other environmental changes. Fossil evidence confirms that there was once a much wider distribution of closely related taxa across the entire Northern Hemisphere.

Today, the rarity of *Zelkova* in the wild, especially of the two westernmost species in the Eurasian group (*Z. sicula* and *Z. abelicea*), calls for swift conservation action. While durable fencing of extremely small populations to impede grazing pressure is the most pragmatic measure for immediate protection in the wild, long-term *in situ* conservation endeavours need to be developed 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 habitats. This is especially urgent for *Z. sicula*, which is known to exist only in two very small populations.

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. Further, the most threatened species (*Z. sicula*, *Z. abelicea* and *Z. sinica*) require priority attention as they are also least represented in *ex situ* collections.

Shared scientific interest in related species in disjunct regions provides an excellent common ground to foster regional and international collaboration, exchange of expertise and joint research programmes. Capitalising on this potential, an increase in coordinated, global field surveys is vital to verify out-of-date or unclear records and to work towards a comprehensive overview of the entire distributional range of the genus.

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, as well as specimens planted in public parks and other amenity venues, play a critical role in enhancing environmental awareness and education. Linking reports of fossil finds and anecdotes with their extant relatives and new population discoveries, *Zelkova* and relict plants in general can provide compelling stories to develop a range of outreach programmes, including informational materials and interactive exhibitions targeted at the general public.

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.

1. C. Christe, L. Fazan and J. Gratzfeld looking for *Z. abelicea* in the Thripti mountains, Crete (gk)

2. J. Gratzfeld, G. Kozlowski and G. Garfi investigating the *Z. sicula* population of Bosco Pisano, Sicily (fc)

3. Y. Song collecting *Z. schneideriana* in Lushan, China (ek)

4. E. Gerber and G. Parolly documenting relict trees in Hyrcan National Park, Azerbaijan (gk)

5. H. Safarov presenting the herbarium at the headquarters of Hyrcan National Park, Azerbaijan (eg)

6. D. Frey investigating *Z. carpinifolia* in Rokiti, Georgia (gk)

7. Coordination meeting with E. Alirzayeva, D. Aghayeva, V. Ali-zade, E. Gerber and G. Kozlowski at the Institute of Botany in Baku, Azerbaijan

8. E. Kozlowski documenting relict trees in Yunnan, China (gk)

9. T. Kamikawa, S. Bétrisey and S. Fujioka in the Kamagase Gorge, Japan

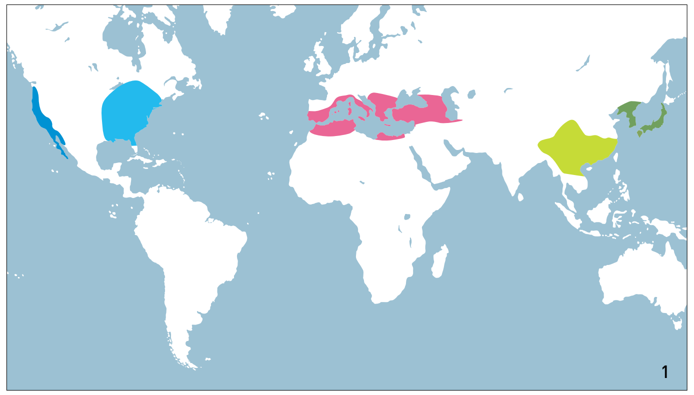
10. R. Keller, A. Mutallimov and E. Maharramova collecting *Z. carpinifolia* in Xanbulan, Azerbaijan (eg)

Project *Zelkova* – an overview

In 2010, the Botanic Garden of the University of Fribourg (Switzerland), in collaboration with the Natural History Museum in Fribourg (Switzerland) and Botanic Gardens Conservation International (United Kingdom), initiated an interdisciplinary project to undertake a scientific review of the relict tree *Zelkova* aimed at the development of a global conservation action plan for all species in this genus. Further research partners and botanic gardens worldwide joined Project *Zelkova* during the implementation phase, including the Conservatory and Botanic Garden of Geneva (Switzerland), Laboratory of Dendrogeomorphology of the University of Bern (Switzerland), Institute of Botany of the Azerbaijan National Academy of Sciences, Baku (Azerbaijan), Institute of Plant Genetics of the National Research Council, Palermo (Italy), Botanic Garden and Botanic Museum, Berlin (Germany), Botanic Garden and Department of Biology of the University of Crete, Heraklion (Greece), Institute of Dendrology of the Polish Academy of Sciences, Kornik (Poland), Chenshan Botanical Garden and Plant Science Research Center, Chinese Academy of Sciences, Shanghai (China), and Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xishuangbanna (China).

To establish this integrated conservation action plan, Project *Zelkova* addressed three main objectives:

- Review of conservation status assessments and global survey of *ex situ* collections.
- Basic and applied research, including molecular phylogeny, phylogeography, population genetics and structure, and genetic analyses of wild *Zelkova* populations compared with *ex situ* collections.
- Public awareness and outreach, including development of exhibitions and organisation of national and international seminars to exchange knowledge and share individual conservation expertise.



An ancient treasure – Tertiary relict trees

During the Tertiary period, the global climate slowly cooled, beginning with tropical to moderate temperatures some 65 million years BP and ending prior to the first extensive glaciation at the beginning of the Quaternary (approximately 2.5 million years BP). As a result, plants, including Tertiary relict trees, migrated southward, while progressive cooling increasingly fragmented the ancient woody flora. Extant Tertiary relict trees therefore comprise genera adapted to warm, wet climates that were once circumboreal in distribution but are now confined to disjunct, refugial regions.

Generally, five main refugia of Tertiary relict trees have been identified (Milne and Abbott 2002, Milne 2006): (1) the Pacific Coast of western North America, (2) southeastern North America (mainly Florida), (3) northern East Asia (Japan, the Korean Peninsula and northeast China), (4) southern East Asia (central and southern China and the Himalayas), and (5) southwest Eurasia (including the Macaronesian, Mediterranean and Transcaucasian regions). Some relict tree genera are still present in all refugial zones; one such example is *Aesculus* (Sapindaceae), with extant species adapted to mild and humid areas in the Mediterranean, Asia and North America. Many other relict trees and shrubs exhibit a similar pattern of distribution, with closely related members of the same genus occurring in several, disjunct refugia, e.g., *Liquidambar* (Hamamelidaceae), *Rhododendron* (Ericaceae), *Gleditsia* (Fabaceae) or *Castanea/Castanopsis* (Fagaceae).

Due to climatic and topographic conditions, the southern East Asia refugium is the region that houses the richest and most diverse Tertiary relict flora. In contrast, refugia in southwest Eurasia, especially in Europe, were highly affected by recurring glaciations, as the east – west oriented mountain chains and the Mediterranean Sea stopped many species from migrating southward. As a result, several prominent genera of the Tertiary tree flora entirely disappeared from the European continent or survived only in isolated and disjunct refugia in the Transcaucasian region, the Balkan Peninsula and/or in Mediterranean islands (e.g., *Albizia*, *Diospyros*, *Gleditsia*, *Hamamelis*, *Juglans*, *Liquidambar*, *Parrotia*, *Pterocarya* and *Zelkova*).

Tertiary relict trees represent ancient organisms that have been able to outlast changing environmental conditions for millions of years. They provide a unique opportunity to understand past and recent biogeographical and evolutionary processes. Despite their continued existence over an enormous geological time span, today, various relict trees retain a very restricted distribution; for many species only a few highly threatened populations remain. Unprecedented, rapid global transformations in recent history, specifically demographic and climatic changes, could irreversibly threaten the survival of numerous unique relict taxa. Conservation of this significant evolutionary heritage for future generations requires targeted action to prevent detrimental human actions from supplying "the last nail in the coffin for ancient plants" (Connor 2009).

1. Five main refugia of Tertiary relict trees. Dark blue: Pacific Coast of western North America. Light blue: southeastern North America. Red: southwest Eurasia. Light green: southern East Asia. Dark green: northern East Asia

2. *Castanea sativa* (Fagaceae), Vionnaz, Switzerland (eg)

3. *Castanea seguinii* (Fagaceae), Huangshan, China (ek)

1. *Diospyros kaki* (Ebenaceae), the Asian persimmon, widely cultivated in China, Korea and Japan (ek)

2. *Diospyros lotus* (Ebenaceae) has a disjunct distribution and naturally occurs in the Hyrcanian region and China (ek)

3-4. *Parrotia persica* (Hamamelidaceae), widely distributed across the Northern Hemisphere during the Tertiary period, survived the last glaciations only in the Hyrcanian forests in Azerbaijan and Iran (ek, eg)

5-6. *Parrotiopsis jacquemontiana* (Hamamelidaceae), a member of the monotypic genus and closest relative of *Parrotia*, naturally occurs in Afghanistan and the Himalayas (ek)

Resilient but not invulnerable – *Zelkova*, a global view

THE GENUS

Zelkova, a member of the Ulmaceae family, represents one of the most emblematic relict tree genera of the Tertiary. Its taxa were an important component of vast forests that prevailed in the Northern Hemisphere during much of that geological period. One possible origin of *Zelkova* is the northern Pacific area, from where it would have spread later throughout the entire Northern Hemisphere to North America and North Africa, where it is now extinct. Notably, the oldest known fossils attributed to *Zelkova* found in western North America date from the Early Cenozoic, 55 million years BP.

Today, the genus comprises six extant species with a distinctive disjunct distribution: the Mediterranean Basin with *Z. sicula* and *Z. abelicea*, the Transcaucasian region with *Z. carpinifolia*, and eastern Asia with *Z. serrata*, *Z. schneideriana* and *Z. sinica*. The disjunction between the East-Asiatic and west Eurasian taxa may have occurred during the Tertiary's Middle Miocene, 18-12 million years BP, as a result of increasing aridity.

In western Eurasia, *Zelkova* became restricted to refugia during the Quaternary's Pleistocene ice ages. An evolving summer dry climate in the Mediterranean region in that period suggests an important impact on further range fragmentation of *Zelkova*. As a result, the genus disappeared from continental Greece in the Middle Pleistocene, some 400,000 years BP, but persisted longer (to some 30,000 years BP) in central Italy. The two Mediterranean species in Sicily (*Z. sicula*) and Crete (*Z. abelicea*) appear to have remained secluded in very small, isolated refugia with recurring cold periods and limited seed dispersal that likely impeded migration northwards during interglacial periods.

1. Global distribution of the genus *Zelkova*

2. *Z. carpinifolia*, Ajameti Nature Reserve, Georgia (gk)

3. *Z. sicula*, Ciranna, Sicily (gk)

4. *Z. abelicea*, Levka Ori, Crete (gk)

5-6. Fossil leaves of *Zelkova zelkovifolia* from the Pliocene (5, Willershausen, Germany) and the Miocene (6, Brezanky, Czech Republic) (hrs)

ECOLOGICAL, SOCIO-ECONOMIC AND CULTURAL VALUES

The role of *Zelkova* species and populations in the maintenance of ecosystem processes and functions has not been thoroughly studied to this day. However, their ability to outlast millions of years of geological history and changing environmental conditions, suggests that *Zelkova* and other Tertiary relict species possess an exceptional adaptive potential. While understanding of their degree of resilience and adaptive capacity requires further investigations, relict species may take a central research position in a rapidly transforming environment, that will ultimately lead to species combinations that have not occurred before and emerging, novel ecosystems.

Tertiary relict tree species also contribute to human welfare and can provide a significant part of the total economic value derived from biodiversity in a given area. The genus *Zelkova* plays an important role in forestry, the provision of timber, paper production and construction. Its wood is also valued by local communities in the manufacture of traditional furniture, decorative items and other craft work. *Zelkova* and other Tertiary relict trees including *Gleditsia* and *Parrotia* are planted to stabilise slopes against erosion and landslides (e.g., in Iran). Some species have also proven beneficial in the detoxification of soil and water (e.g., *Pterocarya fraxinifolia*).

In traditional Chinese medicine, leaves and other parts of the East-Asiatic *Zelkova* species are used in the preparation of remedies to treat colds, headaches and diarrhoea, and in drugs with tocolytic effects. Further, *Zelkova* species may hold the key to combating plant pests in their genes. Experiments have shown that *Z. abelicea* remains unaffected by the Dutch elm disease. It may therefore lend itself as a vital taxon to breeding programmes designed to enhance resistance to plant pathogens in the Ulmaceae family.

The characteristic and impressive vase-shaped crown of older specimens has made *Zelkova* species very popular in Asia, where they are often planted in parks, near temples and around homes. Koreans value *Zelkova* trees as a symbol of tolerance, patience, peace and harmony.

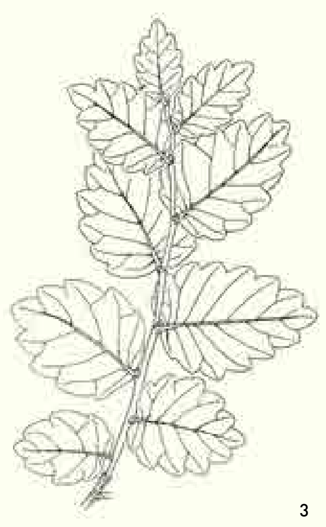
People's close association with and relative dependence on *Zelkova* and other relict trees may represent both a challenge and an opportunity to develop and implement conservation action. Integrating the specific ecological, socio-economic, cultural, religious and spiritual values and dimensions of these species in ecosystem management decisions in a given area will be central to the success of maintaining relict plant populations for future generations.

1. *Z. carpinifolia* often planted in hedgerows. Vani, Georgia (gk)

2. Large and old *Z. carpinifolia* trees around Martvili monastery. Western Georgia (gk)

3. Old tree of *Parrotia persica* (Hamamelidaceae), a species often managed through pollarding and used for the production of timber. Hyrcan National Park, Azerbaijan (eg)

4-5. *Alnus subcordata* (Betulaceae), an endemic relict tree in the Hyrcanian forests, commonly used by the local timber industry. Talysh mountains, Azerbaijan (gk)



CLASSIFICATION AND MORPHOLOGY

The family Ulmaceae, in the order Urticales, used to include some 15 genera, with a division into two subfamilies: Ulmoideae (ulmoids) and Celtidoideae (celtoids, e.g., *Celtis*). However, recent molecular analyses place the celtoids in the family Cannabaceae, while the core family Ulmaceae newly comprises only eight genera (*Ampelocera*, *Chaetachme*, *Hemiptelea*, *Holoptelea*, *Phyllostylon*, *Planera*, *Ulmus* and *Zelkova*). Although genetically very closely related to the typical ulmoid genera of *Ulmus* and *Planera*, the genus *Zelkova* has intermediate characteristics of both of the former subfamilies. Secondary leaf veins run directly to the teeth (craspedodromous venation), which is typical in the ulmoids. The fruit, in contrast, is much more similar to the drupaceous fruits of the celtoids, while the majority of ulmoids display winged, samara-shaped fruits.

All species in the genus *Zelkova* form deciduous trees, rarely shrubs. Generally, leaves are simple, distichous, with a serrate to crenate margin and pinnate venation; in addition, they include two stipules that are linear-lanceolate, free, and caducous, causing a short transverse scar on each side of the leaf base. The secondary veins extend to the margin and end in a tooth. However, *Zelkova* leaves exhibit an impressive morphological variability and a distinct dimorphism, depending on the type of twig and its position in the crown. On fertile and fruiting shoots, leaves are generally smaller and show a shallower dentation, while they are usually larger with a coarser dentation on vegetative shoots. Flowers appear at the same time

1-3. Young branchlets of *Zelkova* with typical leaf polymorphism: proximal leaves are very small with an asymmetric base; central leaves are usually large; distal leaves are regular and smaller than the central ones. (1) *Z. serrata* from Mitaka, Japan; (2) *Z. carpinifolia* from the Talysh mountains, Azerbaijan; (3) *Z. abelicea* from Levka Ori, Crete (hrs, ml)

4. Fruits of *Z. carpinifolia*. Hyrcan National Park, Azerbaijan (eg)

5. Fruits of *Z. sinica*. Botanic Garden Lyon, France (ek)

1. Young leaves of *Z. sinica*, still with stipules. Swiss National Arboretum, Vallon de l'Aubonne, Switzerland (eg)

2. Male flowers of *Z. carpinifolia*, clustered in proximal leaf axils. Botanic Garden Lyon, France (ek)

3. Female and bisexual flowers of *Z. sinica*, clustered in distal leaf axils. Botanic Garden Lyon, France (ek)

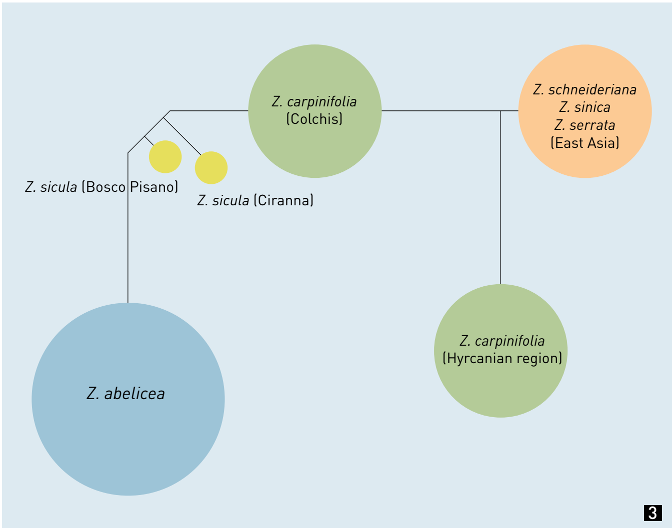
4. *Z. carpinifolia* leaf dimorphism of sterile (left) and fertile (right) shoots. Baghdati, western Georgia (gk)

5. Exfoliating bark of *Z. sinica*. Botanic Garden Lyon, France (ek)

6. Typical vase-shaped crown of *Z. carpinifolia*. Botanic Garden Dublin, Ireland (gk)

as the leaves. Male flowers are clustered in a proximal leaf axil of young branchlets. Their perianth is campanulate with 4-6 or a maximum of 7 lobes. The number of stamens is equal to the number of perianth lobes. Female and bisexual flowers are usually solitary or, rarely, clustered in groups of 2-4 and occur in a distal leaf axil of young branchlets. Their perianth is 4-6-parted with imbricate tepals. Fruits are oblique, dorsally keeled, with persistent beak-shaped stigmas. *Zelkova* species are diploid (2n = 28) with the exception of *Z. sicula*, which is triploid (2n = 42).

An interesting characteristic of the genus is the small production of pollen and low germination rate. Mature fruits usually fall with the entire twig, and the leaves that are still attached function as a parachute, carrying the seeds a few metres away from the parent tree (decurtation). While seed dispersal is very limited, vegetative propagation by means of suckers, which is very common in the family Ulmaceae, is another important reproduction strategy in this genus.



1. *Z. sicula* from Ciranna (Sicily), displaying morphological and genetic similarities with *Z. carpinifolia* (gk)

2. *Z. carpinifolia* from Babaneuri (eastern Georgia), genetically very close to the Hyrcanian populations (gk)

3. Schematic phylogeny of the genus *Zelkova*

4. *Z. carpinifolia* from the Colchic region. Ajameti Nature Reserve, western Georgia (gk)

IT'S IN THE GENES – PHYLOGEOGRAPHY

The biogeographical history of *Zelkova* and differentiation within its species is not fully resolved, and new genetic analyses are needed to understand the complex pattern of evolution and migration of this genus. Until recently, limited phylogenetic and phylogeographic research had been carried out for *Zelkova* species. Most of these studies suffered from a small sample size and/or too little plant material from wild populations. *Z. sinica*, occurring in China, had almost never been included in any analysis.

Based on the findings from chloroplast and nuclear DNA analyses, the genus was found to be divided into two main sections: a southwest Eurasian cluster with *Z. sicula*, *Z. abelicea* and *Z. carpinifolia*, and an East-Asiatic group with *Z. serrata*, *Z. schneideriana* and *Z. sinica*. This division is in accordance with leaf morphology: the teeth of leaves of the East-Asiatic *Zelkova* species exhibit shallow sinuses, while those of the Eurasian taxa are coarser. However, some findings demonstrate a strong association between *Z. schneideriana* and *Z. carpinifolia*. This linkage could be interpreted as the footprint of a species that was once more widely distributed throughout most of the Northern Hemisphere during the Tertiary, but became fragmented in a later period following changes in climate. The differentiation between the East-Asiatic and southwest Eurasian groups is likely to have occurred during the Tertiary's Middle Miocene (18-12 million years BP). This division may have been deepened by the growing aridity in Central Asia that acted as a barrier against reunification.

Although the Mediterranean species *Z. abelicea* covers a relatively small area (endemic to Crete), it is almost certainly the most genetically diverse among the southwest Eurasian species: each mountain massif where the plant occurs, represents a separate genetic unit. As regards *Z. carpinifolia*, two main clades were identified: an eastern clade of the Hyrcanian region (Azerbaijan and Iran), including the highly isolated population in eastern Georgia (Babaneuri), and a western clade, including populations of the Colchis (western Georgia and northeastern Turkey). As for *Z. sicula* (endemic to Sicily), the species is genetically impoverished in each of the two known populations. Likely of hybrid origin, the parents of this taxon are suggested to be close to *Z. abelicea* and *Z. carpinifolia* ancestral species. This makes *Z. sicula* fundamentally important to the understanding of the complex evolution of the genus.

The situation between and within the East-Asiatic *Zelkova* species remains particularly unclear. More work is needed, including genetic analyses based on large-scale collection of plant material from natural populations throughout the entire range of these species. This especially pertains to China and the Korean Peninsula, to clarify the phylogenetic and phylogeographic position of the related species.

1-2. *Z. abelicea* exhibits a very high genetic diversity within and between populations. The population of Thripti (1) in eastern Crete is very distant from the one of Kedros in the Psiloritis mountains (2). This separation may have happened several million years ago (gk)

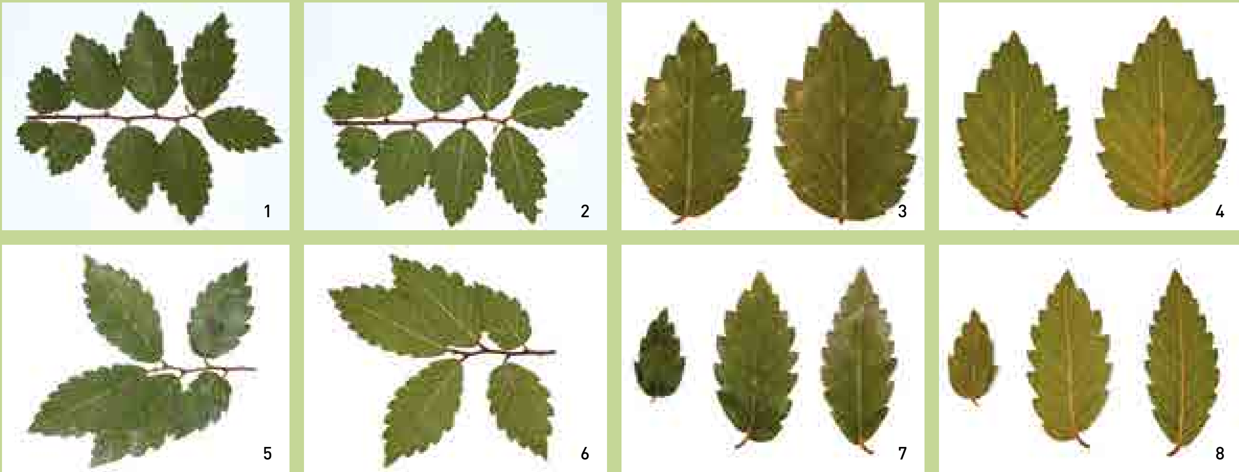
Zelkova species – individual profiles and recommended priority actions

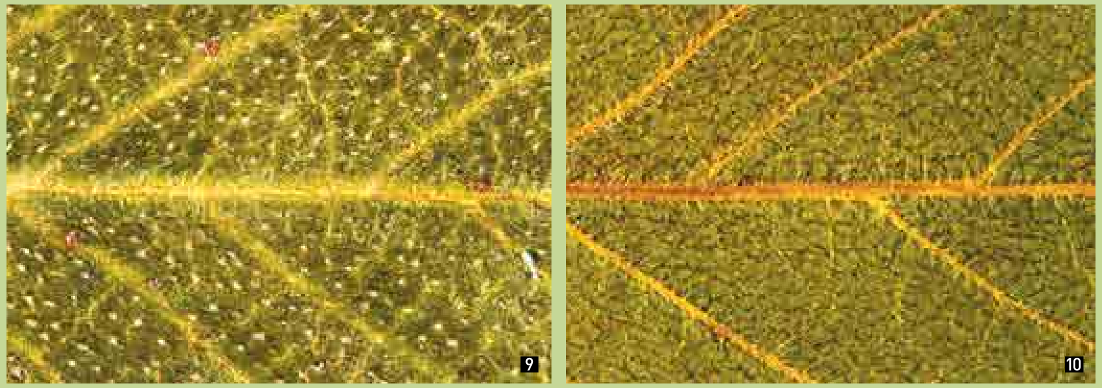
Zelkova carpinifolia. Talysh mountains, Azerbaijan (gk)

Zelkova sicula Di Pasq., Garfì & Quézel

Sicilian Zelkova/Zelkova siciliana (Italy)
IUCN Red List of Threatened Species: Critically Endangered

Zelkova sicula was discovered in 1991 in eastern Sicily in the Iblei mountains. A second population was found in relative proximity to the former in 2009. With only two populations known to this day, *Z. sicula* is one of the rarest and most endangered trees worldwide. Due to its geographical and phylogenetic position, this species is the key taxon for understanding the evolution and biogeography of the genus *Zelkova* in western Eurasia.





HABIT

The majority of *Z. sicula* individuals in both populations are shrubs, 2-3 m in height, with a few specimens growing larger, to 6-8 m. However, the natural size of the species when mature is unknown, as all wild specimens are heavily affected by unfavourable dry climate conditions, severe browsing and other anthropogenic effects. Both populations exhibit remarkable differences in leaf shapes. Those of plants from the Bosco Pisano population are morphologically very close to *Z. abelicea* (small size, oval shape, entire leaf base, 3-6 secondary veins). The leaves of individuals from the population of Ciranna are generally longer and more lanceolate, resembling *Z. carpinifolia* to some degree.

1-4. *Z. sicula* from Bosco Pisano, upper surface and underside of branchlets and leaves, respectively (hrs)

5-8. *Z. sicula* from Ciranna, upper surface and underside of branchlets and leaves, respectively (hrs)

9-10. *Z. sicula* from Bosco Pisano, closer view of the upper surface and underside of a leaf (hrs)

11. Flowering branchlet (ml)

12. Bark of a small tree from Bosco Pisano (gk)

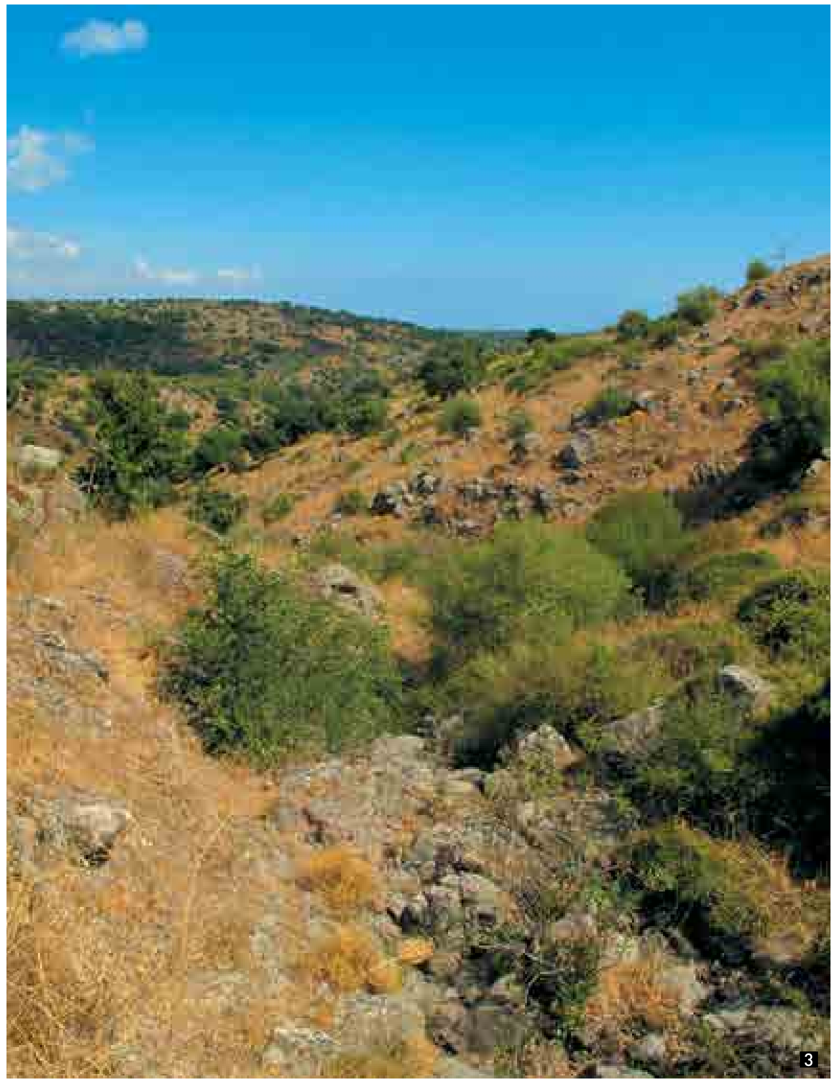
13. Pseudogalls of *Zelkovaphis trinacriae*, an Eriosomatinae aphid relict, living on *Z. sicula*. *Z. trinacriae* has a dioecious life cycle with *Z. sicula* as its primary and most likely *Carex* sp. as its secondary host. Another species in this aphid group, *Zelkovaphis caucasica*, has been described from Georgia as a parasite of *Z. carpinifolia*. Bosco Pisano (gk)

14. Fruiting branchlet. Cultivated tree in Buccheri (gk)

15. The majority of *Z. sicula* individuals grow as 2-3 m tall shrubs. Population from Ciranna (gk)

DISTRIBUTION

Z. sicula is endemic to the Mediterranean island of Sicily (Italy) and is the westernmost taxon in the genus. Both known populations occur in the province of Syracuse on the northern slopes of the Iblei mountains, separated from each other by a distance of only 17 km. The population of Bosco Pisano discovered in 1991 and comprising some 230 individuals over an area of 0.4 ha, is established in a basaltic hollow trail (thalweg) that extends nearly 200 m at an altitude of 450-550 m a.s.l. The other population, found in 2009 near Ciranna, includes some 1,500 individuals covering an area of 0.8 ha. Its habitat is similar to that of Bosco Pisano but is lower in altitude (310-350 m a.s.l.).



ECOLOGY

Z. sicula is the only member in the genus that occurs within a typical Mediterranean habitat comprising thermophilous, evergreen and semi-deciduous oak wood communities, with trees of *Quercus suber*, *Q. virgiliana* and *Olea europea* subsp. *sylvestris*, and shrubs of *Pyrus spinosa*, *Calicotome infesta*, *Sarcopoterium spinosum* and *Phillyrea latifolia*. However, the present vegetation pattern in both locations where *Z. sicula* occurs, is the result of long-lasting anthropogenic impact (coppicing, fire and grazing). In addition, the two populations are almost entirely restricted to the bottom of the thalwegs. This suggests that the species does not meet its bioclimatic optimum in both sites, while thousands of years ago, it may have been a typical representative of more mesic communities, such as mixed woods dominated by summergreen, broadleaved deciduous trees. This assumption is supported by a remarkably well-developed specimen planted in 1993 in Buccheri (820 m a.s.l. with meso-Mediterranean climatic conditions): this plant exhibits a regular tree habit at some 7 m in height (in 2012); its mean growth rate is of the order of 40 cm/year.

1. General view of the Bosco Pisano population (lf)

2. View of the basaltic hollow trail (thalweg) in Ciranna (gk)

3. General view of the Ciranna population (gk)

1. *Pyrus spinosa* (Rosaceae). Bosco Pisano (gk)

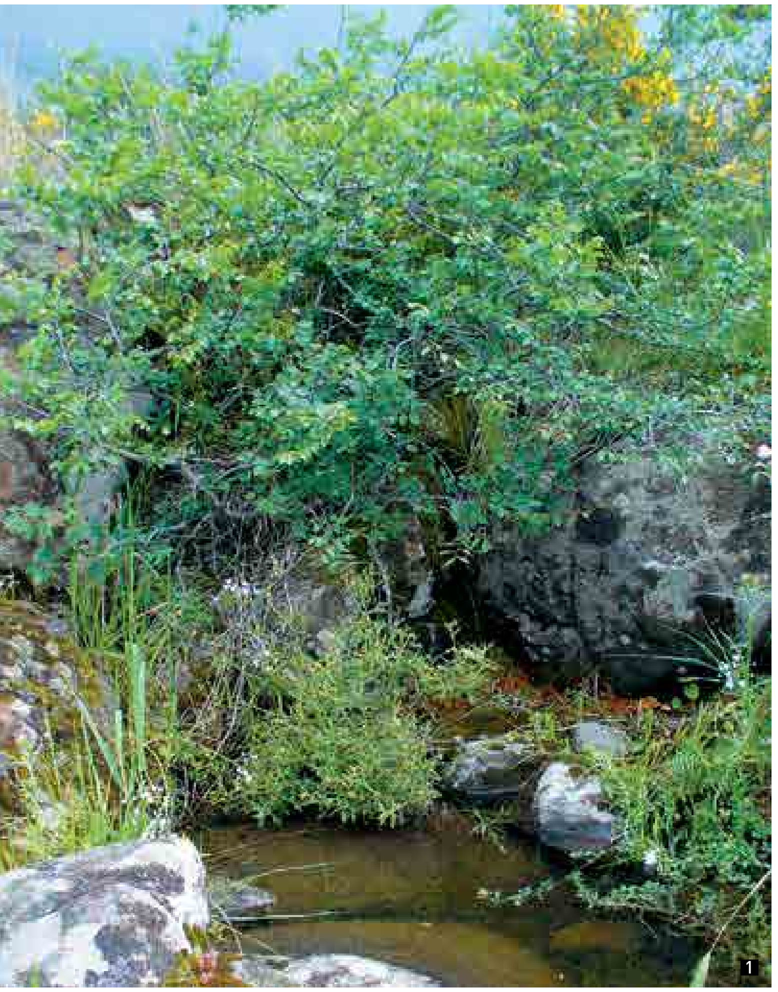
2. In both known populations, *Z. sicula* reproduces exclusively vegetatively. Bosco Pisano (gk)

3. Individuals growing under a large *Quercus suber* tree fare better during severe drought periods (gk)

4-5. Cultivated tree of *Z. sicula* in Buccheri (planted in 1993). Note the regular tree habit, not observed in the natural populations (gk)

THREATS

Z. sicula is recorded as Critically Endangered in the IUCN Red List of Threatened Species. While grazing, mainly by cows, exerts a significant pressure on the species, extreme climatic fluctuations in recent years have accelerated the process of degradation in both populations. In 2007, some 10% of *Z. sicula* individuals at Bosco Pisano were lost to severe drought. The already limited total area covered by the species and small number of plants further increase the vulnerability of *Z. sicula* to accidental hazards, such as fire. What is more, unlike the other members in the genus which are all diploid, *Z. sicula* is triploid and exhibits pollen anomalies. This may explain why, to date, only sterile fruits and vegetative propagation in *Z. sicula* have been observed. In conclusion, the geographic isolation combined with the small population size and asexual reproduction strongly reduce the genetic variation of *Z. sicula*, which in turn diminishes the ability of the species to face rapid environmental and/or biological changes.



1. In spring, thalwegs are often filled with water, which is most likely one of the main reasons why *Z. sicula* has survived in these sites. Bosco Pisano, end of April 2011 (lf)

2-3. Severe drought poses the main threat to *Z. sicula*. Bosco Pisano, September 2011 (gk)

4-5. To prevent grazing by livestock, both populations have been fenced. Ciranna (4) and Bosco Pisano (5) (gk)

6. Both populations are thoroughly studied and monitored by the Institute of Plant Genetics of the National Research Council in Palermo, Sicily (gk)

7-8. Potential introduction sites of *Z. sicula*, with relictual occurrences of *Taxus baccata* in the Nebrodi mountains, northern Sicily (gk)

RECOMMENDED PRIORITY ACTIONS

Enhance immediate measures for *in situ* conservation: In collaboration with local farmers, as an urgent measure to prevent livestock from further grazing and trampling on the vegetation, fences previously established at both sites need to be reinforced. This would also pave the way for further in-depth research on the impact of complete browsing elimination on the performance and competitive ability of *Z. sicula* compared to associated species.

Secure *Z. sicula* by means of *ex situ* cultivation: The rarity of *Z. sicula* calls for a major *ex situ* conservation effort to support the survival of the species in the long run. As established by the global survey carried out under Project *Zelkova*, the provenance of the *Z. sicula* plant material in all reported collections originates from the population that was discovered first in 1991. Future *ex situ* holdings therefore should represent plants from both currently known locations, to capture as much of the species' genetic variation as possible. Detailed propagation and cultivation protocols will contribute to the long-term viability of newly established *ex situ* collections despite propagation options being limited at present to vegetative reproduction only.

Scale up field surveys: After the discovery of a second population in 2009, it seems probable that further *Z. sicula* populations at other locations in Sicily may be found. Building on recent ecological research on *Z. sicula*, additional field surveys should focus not only on habitats similar to the sites where the species is presently known to occur but also on more mesic forest communities, including deciduous, broadleaved forests and woody, alluvial communities in creeks and along streams and rivers.

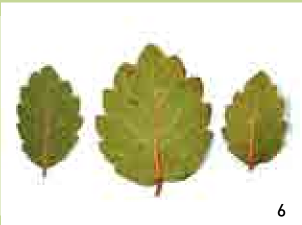
Trial the establishment of new populations: Increasing the number of populations is likely to contribute to enhancing the species' survival chances in the long-term. Strategies include the introduction of *Z. sicula* into neighbouring and/or similar sites in the province of Syracuse, and experimental planting in entirely new locations of Sicily with favourable climatic conditions. Such introductions and/or assisted relocation, however, would require further research, especially pertaining to the species' reproductive biology and its interaction with other physical and biotic elements in a given ecosystem, to support and enhance its development performance.

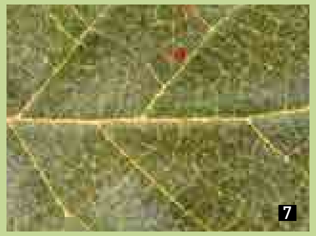
Recognising the conservation significance of this unique species, the European Commission and a number of Italian and international partners are supporting a major initiative launched in 2011 to safeguard *Z. sicula* from extinction (www.zelkovazione.eu). In particular, measures include the development and implementation of an integrated *in situ* and *ex situ* conservation strategy supported by scientific research and public outreach activities. The ultimate goal of this ambitious venture is to attain wide recognition of *Z. sicula* as a species of national and global interest in need of strict legal protection.

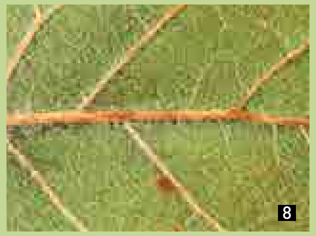
Zelkova abelicea (Lam.) Boiss.

Cretan Zelkova/Ambelitsia (Greece)
IUCN Red List of Threatened Species: Endangered

Although *Zelkova abelicea* attracted the attention of naturalists for nearly three centuries, many of its conundra were resolved only recently, assisted by modern molecular and dendrochronological methods. *Z. abelicea* represents without doubt one of the main biological treasures of the Mediterranean island of Crete, where the species is endemic. Isolated from the mainland for millions of years, Crete is of high importance to research and conservation of relict flora. It is probable that *Z. abelicea* escaped extinction in part due to the complex topography of Crete and the suitable climatic conditions, including high precipitation in the island's mountainous areas.







HABIT

Z. abelicea is a medium-sized tree or shrub, reaching a height of 10-15 m (maximum 20 m) under favourable conditions. However, due to intensive grazing and browsing, the species is most often encountered in a dwarfed habit, representing 95% of its total population. Generally, *Z. abelicea* is a long-lived tree, with some individuals thriving for several hundred years. Dwarfed specimens often surpass larger trees in age, occasionally reaching more than 500 years. Populations with a higher proportion of large trees are rare and are found mainly in the Levka Ori. Like *Z. sicula* in Sicily, the leaves of *Z. abelicea* are small and rounded with few pairs of secondary veins. High levels of evapotranspiration during the growing season may explain these morphological adaptations and the evolutionary trend toward sclerophylly (in contrast to the larger and softer leaves of the East-Asiatic *Zelkova* species in subtropical, more humid environments). Moreover, *Z. abelicea* is the only member in the genus with a needle-like wax ornamentation covering the leaf surface, a strategy to reduce evaporation during the dry and hot Mediterranean summer.

1-2. Upper surface and underside of a sterile branchlet (hrs)

3-4. Underside of a fertile branchlet (hrs)

5-6. Upper surface and underside of leaves (hrs)

7-8. Closer view of the upper surface and underside of a leaf (hrs)

9. Flowering branchlet (ml)

10. Browsed branches with small leaves (ml)

11. Large trees in the Omalos Plateau, Levka Ori (gk)

12. Heavily browsed and dwarfed tree in Rouvas Forest, Psiloritis (gk)

DISTRIBUTION

Z. abelicea is endemic to Crete. In the middle of the 19th century, the species was also described from northern Cyprus by the Austrian botanist Theodor Kotschy. However, this record is considered to be the result of misidentification. Although all main Cretan mountain chains (Levka Ori, Psiloritis, Dhikti and Thripti) host populations of *Z. abelicea*, the distribution of the species is extremely fragmented. Currently, some 42 stands of *Z. abelicea* are known, the majority of which occur in the Levka Ori (ca. 30) and Dhikti ranges (9). Two populations are found in the Psiloritis mountains, on the northern slopes of Mount Kedros and in the Rouvas Forest. Only one small population is recorded from the Thripti range. *Z. abelicea* reaches almost 1,800 m a.s.l. in the Levka Ori; in the Dhikti mountains it can grow at up to 1,600 m a.s.l., whereas the isolated populations of Psiloritis and Thripti are located between 1,150 and 1,350 m a.s.l. It is estimated that over a million dwarfed *Z. abelicea* individuals and as many as 20,000 normally developed and fruiting trees occur across Crete.






ECOLOGY

Z. abelicea is found in supra- and oro-Mediterranean open and discontinuous mountain forests, often accompanied by *Acer sempervirens*, *Quercus coccifera* and occasionally *Cupressus sempervirens*, as well as by a variety of shrubs (e.g., *Euphorbia acanthothamnos*, *Berberis cretica*, *Phlomis cretica*, *P. lanata*, *Prunus prostrata*, *Rhamnus oleoides*, *R. alaternus*, *Daphne sericea*, *Crataegus monogyna*, *Verbascum spinosum*, *Sarcopoterium spinosum*). Representing one of the highest-elevation trees in Crete, *Z. abelicea* almost exclusively occurs on north-facing slopes. However, it can also be found around dolines and in, or close to, rocky river beds and gullies, where moisture tends to remain near the surface during the dry summer period. The dwarfed habit is associated with numerous factors, the most important being intensive browsing and water stress, as well as fire, coppicing and pollarding, and low nutrient availability. Only large trees with branches unaffected by browsing appear to be able to produce flowers and fruits.



1. *Berberis cretica* (Berberidaceae). Omalos Plateau, Levka Ori (gk)

2. *Acer sempervirens* (Sapindaceae). Mount Kedros, Psiloritis (gk)

3. *Cupressus sempervirens* (Cupressaceae). Rouvas Forest, Psiloritis (gk)

4. Northern slopes of Mount Kedros, Psiloritis (gk)

5-6. Forest fragments with large *Z. abelicea* trees are very rare and are found mainly in the Omalos Plateau, Levka Ori (jg, gk)

7. *Quercus coccifera* (Fagaceae). Rouvas Forest, Psiloritis (gk)

8. Typically associated with *Z. abelicea* in severely grazed sites: *Sarcopoterium spinosum* (Rosaceae), *Euphorbia acanthothamnos* (Euphorbiaceae) and *Phlomis lanata* (Lamiaceae). Thripti mountains (gk)

9. Under ideal conditions, *Z. abelicea* can reach a height of 20 m. Omalos Plateau, Levka Ori (gk)

THREATS

Recorded as Endangered in the IUCN Red List of Threatened Species and protected under Greek national law, *Z. abelicea* faces a number of threats. The most important pressure originates from overgrazing by livestock. In contrast to *Z. sicula* and *Z. carpinifolia*, which are browsed almost exclusively by cows, *Z. abelicea* incurs intensive ovine and caprine grazing, with a major impact on tree habit and vigour. Soil erosion, related to high browsing pressure, as well as water stress and fire, represent additional threat factors. As with many other tree species in Crete, *Z. abelicea* has been logged since ancient times for its valuable timber. To the present day, the species provides fodder for livestock, and its branches are often cut by means of pollarding and are used by local people for the production of traditional walking sticks (katsouna).

The species' fragmented distribution plays an important role in restraining gene flow between populations and thus could potentially reduce the plant's capacity to adapt to new stress, diseases or pests. The dominance of mainly non-flowering, severely browsed populations is another major concern for the long-term genetic viability of the species. Finally, more frequent drier climate conditions in recent history, in particular in the eastern part of Crete, may prove particularly detrimental to the survival of *Z. abelicea* in the long run.

THRIPTI: A UNIQUE BONSAI FOREST

A singular population of *Z. abelicea* is known from Thripti, Crete's easternmost mountain range. Its genetic and geographic isolation and unique structure provide it with an exceptional status among the other *Z. abelicea* populations in Crete.

LOCATION

Situated between Ierapetra in the southwest and Sitia in the northeast, Thripti (also Thripiti, Thrypti or Thriptis Ori) is Crete's easternmost mountain range in the province of Lassithi, with Afendis Stavromenos (1,476 m a.s.l.) being the highest summit. Established at some 1,150 m a.s.l. and extending over an area of 5,135 m^2, *Z. abelicea* forms a unique population in this area that is confined to the northeast side of a limestone doline. No further *Z. abelicea* plants are found on the surrounding slopes or in adjacent sinkholes.

DOMINANCE OF DWARFED TREES

A field survey established a total of 964 browsed and dwarfed *Z. abelicea* individuals. Only five plants were recorded to have grown tall enough to partially escape browsing (more than 2 m with an average stem circumference at breast height at or below 30 cm), while most other individuals were small, exhibiting the characteristic bonsai habit. Their stem circumference at ground level generally measuring less than 30 cm, some 100 specimens however were found with bigger girth rates.

1. Geographical position of the *Z. abelicea* population in the Thripti mountains

2-4. General view of the doline and its vegetation structure (gk)

5. The population is composed almost entirely of non-flowering and dwarfed individuals (gk)

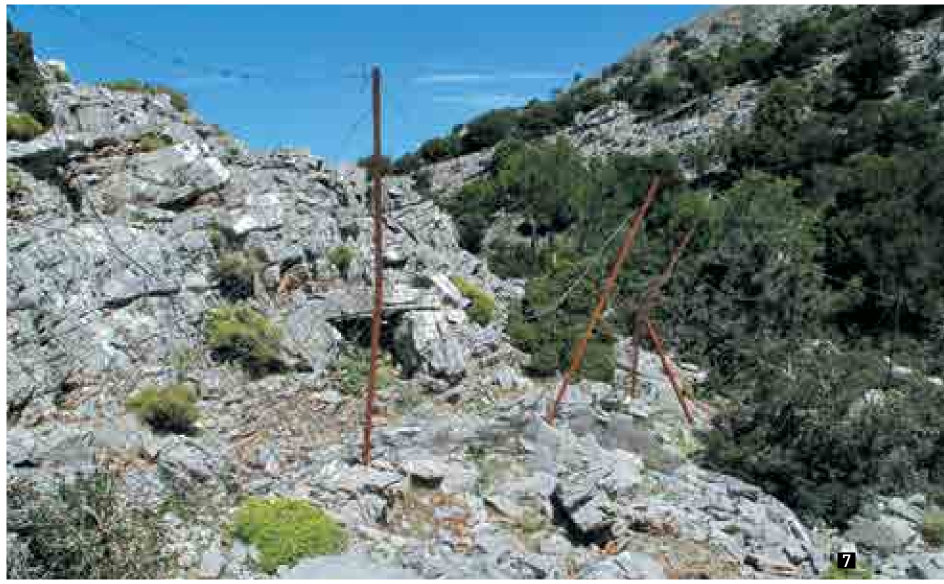
6. According to a recent survey (2012), only five individuals partially escaped browsing (gk)

ASSOCIATED TREES AND SHRUBS

Thripti's *Z. abelicea* population is interspersed by a small number of trees of *Pyrus spinosa* and *Acer sempervirens*. More commonly, however, they associate with *Z. abelicea* as browsed specimens too, along with *Rhamnus oleoides*. The undergrowth is mainly composed of *Berberis cretica*, *Euphorbia acanthothamnos*, *Phlomis lanata* and *Sarcopoterium spinosum*.

SPECIFIC THREATS

This population occurs in an area that is used as open pasture for goats and sheep during the summer season, resulting in a lasting browsing impact. Although this is not a major resting place for livestock due to its remoteness and lack of road access, grazing is the main pressure and impedes the sexual reproduction of the species. Fire constitutes another factor with a major bearing on Thripti's *Z. abelicea* population, as pastures are burned periodically to induce regrowth of more palatable vegetation for livestock.



1. Fenced population in Rouvas Forest, Psiloritis (gk)

2. Burnt ground surface. Mount Kedros, Psiloritis (gk)

3. Katsouna, the traditional walking stick, often made from *Z. abelicea* branches. Thripti mountains (gk)

4-5. Caprine and ovine grazing pressure is a major driver of change of the natural vegetation in Crete. Mount Kedros, Psiloritis (lf, gk)

6. Heavily browsed *Z. abelicea* individual. Mount Kedros, Psiloritis (gk)

7. Fencing of populations needs regular control and repair. Rouvas Forest, Psiloritis (gk)

RECOMMENDED PRIORITY ACTIONS

Ensure *in situ* conservation of the species' entire range of genetic diversity: The strong genetic differentiation of *Z. abelicea* populations calls for each mountain massif where the species occurs, to represent a separate conservation unit with locally adapted conservation strategies. Core populations of immediate conservation concern, identified on the basis of genetic variation, geographic isolation, area covered and browsing pressure, include the sole population in the Thripti mountains, and Mount Kedros and Rouvas Forest populations in the Psiloritis range. Effective methods and measures to limit and/or completely prevent livestock grazing by means of fencing need to be developed in close collaboration with shepherds and other local stakeholders, and accompanied by long-term scientific surveys to monitor progress and allow adaptive management.

Enhance *ex situ* conservation: As highlighted by the global assessment carried out in 2010, *Z. abelicea* is underrepresented in *ex situ* living collections, both in number and degree of genetic representativeness. A major coordinated effort is required to establish viable, representative and well-documented collections at botanic gardens, arboreta and other affiliated institutions in collaboration with forest services in Greece and especially Crete. As the bulk of *Z. abelicea* cultivated in botanic gardens almost exclusively originates from the Levka Ori region (the most accessible area and the best-known occurrence of the species), new collections based on plants from all other regions would significantly enhance the *ex situ* conservation value. In particular, this would include the small, highly isolated and threatened populations of Psiloritis, Dhikti and Thripti, from where plant material has rarely, if ever, been collected for *ex situ* cultivation.

Foster public awareness of the national botanical riches: Endowed with a diverse flora, including unique, endemic and relict species such as *Z. abelicea*, there is tremendous potential to sensitise the public in Greece and Crete to this national biological wealth. Botanic gardens, especially in or near major urban centres, represent ideal venues for developing a range of environmental campaigns and outreach activities, supported by informational materials in layman's terms and interactive exhibitions.

Zelkova carpinifolia (Pall.) K. Koch

Caucasian elm, Caucasian Zelkova/Dzelkva (Georgia)/Dzelkva grabolistnaia (Russia)
IUCN Red List of Threatened Species: Near Threatened

Zelkova carpinifolia is one of the most iconic relict trees in the Transcaucasus, between the Black and Caspian Sea. The generally warm and humid environmental conditions in this region since the late Tertiary provided a shelter for relict species during the ice ages. As a result, the Transcaucasian forests, especially those in the Colchis and Hyrcanian regions, are among the oldest, most diverse and richest habitats housing endemic, woody species in west Eurasia.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HABIT

Z. carpinifolia is a large tree, attaining an average height of 20-35 m, and measuring up to 2 m in diameter. In climatically and edaphically favourable locations of the Talysh (Azerbaijan) and Alborz (Iran) mountains however, trees can reach up to 40 m with a diameter of 3-4 m. *Z. carpinifolia* is a long-lived tree; 800 to 850-year-old individuals have been reported from the Ajameti Nature Reserve (western Georgia) and Talysh mountains (southern Azerbaijan). The vase-shaped crown and short, broad trunk dividing into numerous nearly erect, strong branches, give the species its characteristic and distinctive form. The leaves, especially on young shoots, are generally much larger than those of the Mediterranean *Zelkova* species: they can measure more than 10 cm in length and 6 cm in width, with a dentate leaf base, and 7-12 secondary veins.


8


9


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13


14

1-2. Upper surface and underside of a sterile branchlet (hrs)

3-4. Upper surface and underside of leaves (hrs)

5-6. Closer view of the upper surface and underside of a leaf (hrs)

7. Underside of a fertile branchlet (hrs)

8. Flowering branchlet (ek)

9. Fruits (hrs)

10. Large trees in the Ajameti Nature Reserve, western Georgia (gk)

11. *Z. carpinifolia* shrub at some 1,200 m a.s.l in the Talysh mountains, Azerbaijan (gk)

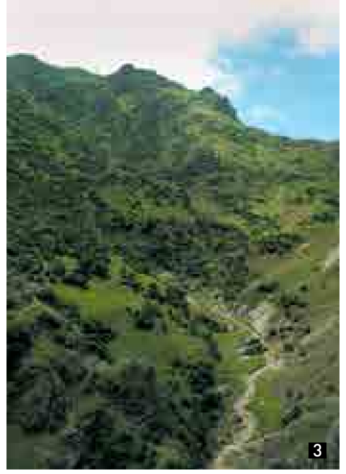
12. Exfoliating bark of a medium-sized tree. Baghdati, western Georgia (gk)

13. Fruiting branchlet. Güneshli, Talysh mountains, Azerbaijan (eg)

14. Female, bisexual and male flowers of *Z. carpinifolia* (ml)

DISTRIBUTION

Z. carpinifolia occurs in Azerbaijan, Georgia, Armenia, Iran and Turkey. Two population centres, the eastern Hyrcanian (Talysh and Alborz mountains) and the Colchis (western Georgia), can be distinguished. According to recent molecular studies, the significant genetic differentiation between these two groups is indicative of the many million years gone by since these populations fragmented into their current distributional ranges. A few isolated *Z. carpinifolia* locations are also known outside the two main areas of distribution, including northwestern and eastern Georgia, southeastern Anatolia in Turkey, western Azerbaijan and the Iranian part of Kurdistan. These isolated occurrences and recent palaeobotanical studies suggest that at various periods in the past, but especially between 6,000 and 5,500 BP, *Zelkova* forests were widespread in the Transcaucasian region.



ECOLOGY

Generally favouring moist, humus-rich soils but not tolerating waterlogged or swampy conditions, *Z. carpinifolia* is a light-demanding canopy tree. The species occurs mainly between 100 and 600 m a.s.l., an elevational range at which plants easily reproduce from seed. In some regions, however, *Z. carpinifolia* can grow at 1,200-1,500 m (e.g., in the Talysh mountains) or even above 1,550 m a.s.l. as in Anatolia, where multi-branched shrubs are found on stony soils. Usually on sunny south- and west-facing slopes, *Z. carpinifolia* can form almost pure stands under optimal conditions, but is also often admixed with oak and hornbeam species. In the largest remaining *Z. carpinifolia* forest fragments of the Talysh and Alborz mountains, where the annual precipitation is over 1,500 mm and average July temperatures are in the order of 22-25°C, the species is accompanied by other emblematic, broadleaved Tertiary relict trees including *Acer velutinum*, *Albizia julibrissin*, *Alnus subcordata*, *Diospyros lotus*, *Gleditsia caspica*, *Parrotia persica* and *Quercus castaneifolia*.

1. Mixed forest with large *Acer velutinum* (Sapindaceae) trees in Hyrcan National Park. Dashtatük, Azerbaijan (gk)

2. Fruits of *Acer velutinum*. Xanbulan, Azerbaijan (eg)

3. Slopes with *Z. carpinifolia* in the Talysh mountains close to Lerik, Azerbaijan (gk)

4. Mixed forest in Hyrcan National Park (gk)

1. Forest with *Z. carpinifolia* and *Phyllitis scolopendrium*. Xanbulan, Azerbaijan (gk)

2. Alluvial forest dominated by *Pterocarya fraxinifolia* (Juglandaceae) between Istisu and Bandasar. Hyrcan National Park, Azerbaijan (gk)

3. *Parrotia persica* (Hamamelidacae). Xanbulan, Azerbaijan (eg)

4. Crowns of *Quercus castaneifolia* (Fagaceae). This impressive oak species can grow up to 50 m in height. Xanbulan, Azerbaijan (eg)

5. *Pterocarya fraxinifolia* (Juglandaceae). Botanic Garden Lyon, France (ek)

6. *Albizia julibrissin* (Fabaceae). Botanic Garden Lyon, France (ek)

THREATS

Prior to the advent of agriculture thousands of years ago, the Transcaucasian region included large areas with woody vegetation, particularly in the alluvial lowlands. Today, only small forest fragments remain, such as in the Colchis where more than 90% of the original lowland and foothill forests were eliminated. *Z. carpinifolia* has been extensively logged for its valuable timber, very popular because of its attractive, light, supple and rot-resistant wood. An ever-expanding timber need poses the greatest threat to the remaining forest areas containing *Z. carpinifolia*. Even relatively well-preserved forests in the Talysh and Alborz mountains have lost 40% of their cover to agriculture in the last 50 years. By and large, in all regions where *Z. carpinifolia* occurs, severe grazing (mainly bovine), expanding mass tourism and related road and infrastructure development in areas of scenic beauty, are major drivers of change. Although numerous natural reserves and parks have been created in Georgia, Azerbaijan and Iran, pressure on the forests is steadily rising.

RECOMMENDED PRIORITY ACTIONS

Review existing distribution records and scale up field surveys: For a number of cited occurrences, only out-of-date and/or imprecise information concerning the number and status of *Z. carpinifolia* populations is available. To prioritise important sites for *in situ* conservation, new field surveys are particularly recommended for the very isolated and small population stands in Turkey (regions of Trabzon and southeast Anatolia) and Armenia as well as those in western Azerbaijan and the Iranian part of Kurdistan to develop locally adapted protection measures. While the most important population in the east of Georgia at Babaneuri (some 170 km east of Tbilisi) enjoys protection by law following the establishment of a nature reserve explicitly dedicated to the conservation of *Z. carpinifolia*, new field assessments are also required in virtually all regions of Georgia where *Z. carpinifolia* had been described previously. This is especially pertinent to isolated populations in Abkhazia (northwest Georgia) and the Colchis (regions of Guria, Adjara and Imereti in western Georgia) with the highest occurrences of *Z. carpinifolia*.

1. View from the foothills of the Talysh mountains over the Lenkaran towards the Caspian Sea lowlands in southern Azerbaijan (eg)

2. Highly grazed, open forests with isolated large trees of *Acer velutinum* in the Talysh mountains. Dashtatük, Azerbaijan (eg)

3. Browsed and dwarfed *Z. carpinifolia* individual. Baghdati, western Georgia (gk)

4. In the Transcaucasian region, cows are the main livestock that browse on *Z. carpinifolia*. Talysh mountains, Lerik, Azerbaijan (gk)

1. Hyrcan National Park is one of the most important protected areas in Azerbaijan. Entrance at Burcali (eg)

2-3. Botanic gardens in the Transcaucasian region could play an important role in *ex situ* conservation of *Z. carpinifolia*: (2) National Botanic Garden in Tbilisi and (3) Colchic Botanic Garden in Kutaisi, Georgia (gk)

4. *Z. carpinifolia* populations are found scattered in the Colchis region of western Georgia. Ajameti Nature Reserve (gk)

5. Babaneuri Nature Reserve was established to protect the most important population of *Z. carpinifolia* in eastern Georgia (gk)

6. Old monasteries and other sacred sites play an important role in protecting the last remaining forest fragments. Martvili monastery, western Georgia (gk)

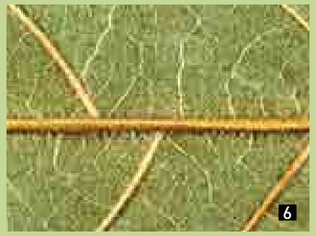
Enhance the conservation value of *ex situ* collections: While *Z. carpinifolia* is a very popular species in botanic gardens worldwide, only two collections are recorded in the countries of its origin, with incomplete provenance information. Large-scale genetic analyses are required for nearly all collections to clarify and confirm the specific origin of the cultivated plants. Of immediate *ex situ* conservation concern are the highly isolated *Z. carpinifolia* populations in Turkey, Abkhazia and the Colchis.

Strengthen regional collaboration: While national coordination is a fundamental prerequisite to define and implement conservation priorities, the transboundary distribution of *Z. carpinifolia* across Azerbaijan, Georgia, Armenia, Iran and Turkey, similarly calls for collaboration at Transcaucasian level. Inspired by a common research and conservation interest, such regional specialist networks would inform the development of a long-term, integrated *in situ* and *ex situ* conservation strategy for *Z. carpinifolia* throughout its entire geographic range based on specific management experience gained locally.

Zelkova serrata (Thun.) Makino

Japanese Zelkova/Keyaki (Japan)/Ju shu (China)/Neutinamu (Korea)
IUCN Red List of Threatened Species: Not Evaluated

Zelkova serrata exhibits the largest geographical range among the members in the genus. Its densely grained and rot-resistant hardwood is widely sought after in construction and shipbuilding, and for the production of tool handles and superior quality furniture. The recent discovery of compounds in twig extracts of this species that are relevant to cancer treatment, may offer new opportunities for *Z. serrata* to become a major medicinal plant in the future.



HABIT

Z. serrata is a large tree that can grow up to 30 m and reach 1 m in diameter, and produces an exfoliating grayish white to grayish brown bark upon ageing. Elliptic to ovate-lanceolate, leaves can measure up to 10 cm in length and 5 cm in width, with a serrate to crenate margin and 9-15 secondary veins. In contrast to the similar *Z. schneideriana*, young branchlets of *Z. serrata* are brownish purple to brown, and glabrous (rarely lightly pubescent). The smooth and glabrous leaf blade abaxially is sparsely pubescent but only along the veins. The drupes, 2,5-3,5 mm in diameter with an irregular network of low ridges, mature from September to November.

1-2. Upper surface and underside of a sterile branchlet (hrs)

3-4. Upper surface and underside of leaves (hrs)

5-6. Closer view of the upper surface and underside of a leaf (hrs)

7. Underside of a fertile branchlet (hrs)

8. Fruits (hrs)

9-10. Young branches of *Z. serrata* are brownish purple and glabrous (eg, gk)

11. Seedlings of *Z. serrata* on the forest floor. Chichibu, Honshu Island, Japan (sb)

12. Stem of *Z. serrata*. Chichibu, Honshu Island, Japan (sb)

13. Large *Z. serrata*. Hita, Kyushu Island, Japan (sb)

DISTRIBUTION

In Japan, *Z. serrata* naturally occurs from the south of Kyushu Island (Kagoshima) through Shikoku Island to the extreme north of Honshu Island (Aomori). For centuries, this species has been widely planted as an ornamental tree in parks, near homes and along streets and alleys. In China, *Z. serrata* is described from numerous provinces (Anhui, Fujian, Gansu, North Guangdong, Guizhou, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Liaoning, Shaanxi, Shandong, Sichuan and Zhejiang). The species is also distributed in Taiwan, South and North Korea. There are also unverified records from Russia (e.g., Kuril Islands).

ECOLOGY

Z. serrata favours a mild climate, growing particularly well in limestone valleys on rich, moist soils, although it can also develop in drier environments and under poorer soil conditions. Its deep and laterally extended root system makes the species highly wind-resistant. Occurring from lowland to mountain forests (mainly between 500 and 2,000 m a.s.l.), *Zelkova serrata* is usually encountered in riparian habitats, in ravines and on shady slopes. In Japan, *Z. serrata* is often found in association with *Acer japonicum*, *A. mono*, *Aesculus turbinata*, *Castanea crenata*, *Celtis jessoensis*, *Juglans ailanthifolia*, *Pterocarya rhoifolia*, *Quercus serrata*, and a variety of shrubs comprising *Callicarpa japonica*, *Cornus controversa*, *Kerria japonica*, *Wisteria floribunda* and *Sasa senanensis*. In Taiwan, in the southernmost part of its range, woody plants occurring with *Z. serrata* include *Carpinus kawakamii*, *Quercus variabilis*, *Q. tarokoensis*, *Ulmus parvifolia*, *Dodonaea viscosa*, and various species of *Acer*.

1-2. Natural forests with *Z. serrata*: (1) Kamagase Gorge, Kyushu Island; (2) Chichibu, Honshu Island, Japan (sb)

3. *Pterocarya rhoifolia* (Juglandaceae). Alluvial forests of Tataoki River, Kyushu Island, Japan (sb)

4. In Japan, *Z. serrata* is one of the most popular trees planted in parks. Tokyo (sb)

1. *Aesculus turbinata* (Sapindaceae). This species is very closely related to the Balkan endemic *A. hippocastanum*. Tataoki River, Kyushu Island, Japan (sb)

2. *Z. serrata* growing along Tataoki River. Kyushu Island, Japan (sb)

3. *Wisteria floribunda* (Fabaceae) climbing on *Z. serrata*. Tataoki River, Kyushu Island, Japan (sb)

4. *Cornus controversa* (Cornaceae). Tataoki River, Kyushu Island, Japan (sb)

5. Plantation of *Cryptomeria japonica* (Cupressaceae). Chichibu, Honshu Island, Japan (sb)

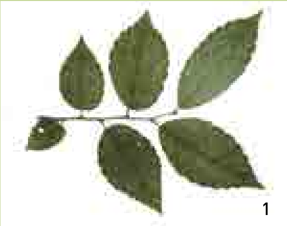
THREATS

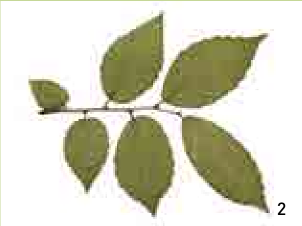
Natural *Z. serrata* populations remain preserved to the present day only in remote and inaccessible areas, including steep mountain slopes and ravines. Although widely planted as an ornamental tree in Japan, the summergreen, broadleaved forests in which *Z. serrata* naturally occurred had been largely replaced by monocultures comprising *Cryptomeria japonica*, *Larix leptolepis* and *Chamaecyparis obtusa* by the middle of the 20th century. On the other hand, large areas with *Z. serrata* are being planted today for timber production. Plant material sourced for plantations is often of unknown provenance and comprises predominantly fast-growing cultivars with limited genetic variability that are bred mostly for quality timber. Recent studies have confirmed the very low levels of genetic diversity of *Z. serrata* plantations, especially in northern Japan (Fukatsu et al. 2012). Limited data are available regarding the threats to and conservation status of *Z. serrata* in China. Its relative rarity however suggests that wild populations are at great risk of being lost, especially as a result of increasing habitat degradation and transformation.

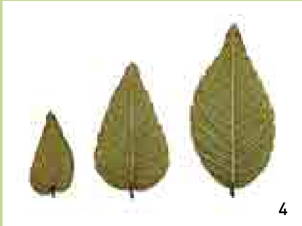
Zelkova schneideriana Hand.-Mazz.

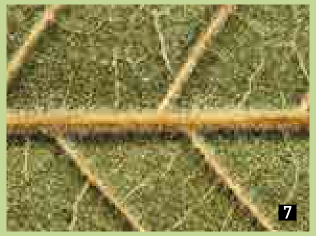
Schneider's Zelkova/Da ye ju shu (China)
IUCN Red List of Threatened Species: Not Evaluated

Very important in forestry and landscaping due to disease and wind resistance, wild populations of *Zelkova schneideriana* have been intensively harvested in the past for quality hardwood timber. Today, as a result of uncontrolled logging and habitat loss, *Z. schneideriana* is rare and considered to be threatened across its distributional range in China.









HABIT

Attaining a height and diameter of up to 35 m and 80 cm, respectively, the bark of *Z. schneideriana* is grayish brown to dark gray, often exfoliating. Ovate to elliptic-lanceolate and up to 10 cm long and 4 cm wide, leaves are serrate to crenate with 8-15 secondary veins. Unlike the similar *Z. serrata*, young branchlets are gray to grayish brown and densely covered with white pubescence. Abaxially, the leaf blade is also densely pubescent. *Z. schneideriana* displays accentuated seasonal changes in leaf colour: red in spring, and dark red, brown, beige or green in autumn. The drupes, 2,5-3,5 mm in diameter with an irregular network of low ridges, mature from October to November.

1-2. Upper surface and underside of a sterile branchlet (hrs)

3-4. Upper surface and underside of leaves (hrs)

5. Underside of a fertile branchlet (hrs)

6-7. Closer view of the upper surface and underside of a leaf (hrs)

8. Young branchlets are densely pubescent (hrs)

9. Red to brown autumn coloration. Chenbu, China (xy)

10. Flowering branches. Zhejiang, China (yz)

11-12. Large *Z. schneideriana*. Chenbu, China (xy)

13. Fruiting branchlet. Lushan, China (ek)

DISTRIBUTION

Endemic to China, *Z. schneideriana* has the widest distributional range in this country among the three East-Asiatic species. However, its populations are very fragmented and usually small. Described from 16 provinces including Anhui, Fujian, south Gansu, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, south Shaanxi, southeast Sichuan, southeast Xizang, Yunnan and Zhejiang, the largest *Z. schneideriana* populations have been reported from Zhejiang, Hunan, Hubei and Guizhou. Mainly found between 100 and 1,100 m a.s.l., in Yunnan and Xizang, where *Z. schneideriana* has the western- and southernmost distribution of all Chinese members in the genus, the species can also occur at much higher altitudes (1,800-2,800 m a.s.l.).

ECOLOGY

Favouring a mild climate, *Z. schneideriana* grows on fertile, slightly acidic to calcareous soils. However, it can tolerate saline and alkaline conditions. The species' growth performance is reduced under drier conditions and on barren soils. As with *Z. serrata*, the deep and laterally extended root system of *Z. schneideriana* provides this tree with a remarkable wind resistance. Like the other East-Asiatic *Zelkova* species, *Z. schneideriana* very often grows in ravines along streams and rivers. In these environments, the species is often associated with tree genera known also from habitats of *Zelkova* in western Eurasia: *Pterocarya stenoptera*, *Acer buergerianum*, *Alnus trabeculosa*, *Albizia kalkora*, *Diospyros lotus* and *Gleditsia sinensis*. In addition, various other families and genera not found in the Transcaucasian or Mediterranean regions, are very common here: *Broussonetia papyrifera* (Moraceae), *Camptotheca acuminata* and *Alangium chinense* (Cornaceae), *Liriodendron chinense* (Magnoliaceae), *Vernicia fordii* (Euphorbiaceae), *Ailanthus altissima* (Simaroubaceae) and *Wisteria sinensis* (Fabaceae). *Z. schneideriana* is also a typical element of China's unique temperate to subtropical humid forests, dominated by deciduous trees but intermixed with a relatively large proportion of evergreen species. Key woody plants in these forests include, amongst others, *Liquidambar formosana*, *Ulmus parvifolia*, *Celtis sinensis*, *Cinnamomum chekiangense*, *Machilus thunbergii*, *Phoebe sheareri*, *Rhus chinensis*, *Ilex purpurea*, and various Fagaceae genera, e.g., *Quercus, Lithocarpus*, *Cyclobalanopsis*, *Castanopsis* and *Castanea*.

1. *Z. schneideriana* can propagate vegetatively. Nanyang, China (nz)

2. In many regions of central China, *Z. schneideriana* survived only in or near sacred sites. Huangshan (md)

3. *Cyclobalanopsis glauca* (Fagaceae). Huangshan, China (ek)

1. *Lithocarpus hancei* (Fagaceae). Shuhe, Yunnan, China (ek)

2. *Castanopsis delavayi* (Fagaceae). Shuhe, Yunnan, China (ek)

3. *Vernicia fordii* (Euphorbiaceae). Hangzhou, China (ek)

4. *Liquidambar formosana* (Hamamelidaceae). Xian Yushan, China (ek)

5. *Diospyros lotus* (Ebenaceae). Hangzhou, China (ek)

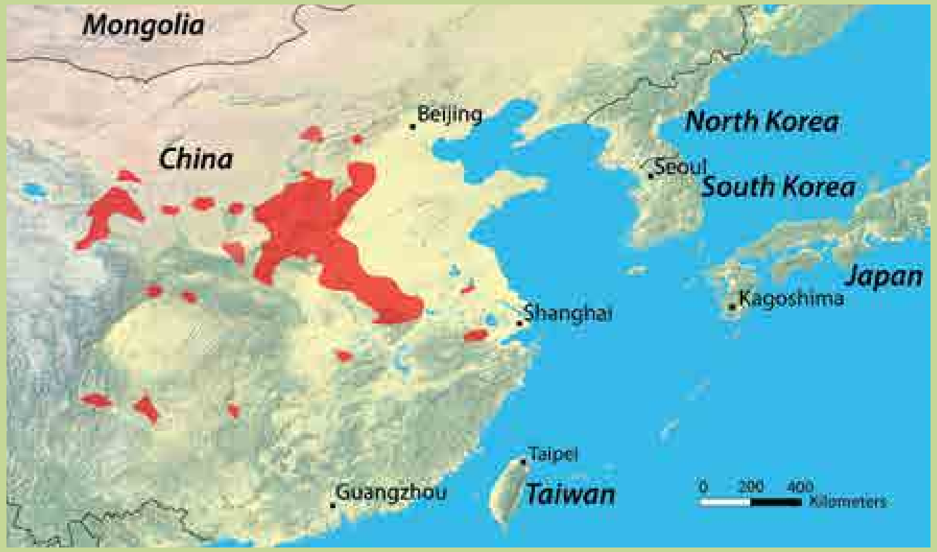
THREATS

Although *Z. schneideriana* is still relatively common in China, and single trees are often found in the vicinity of sacred sites and ancient temples, natural populations have significantly diminished in number and size in recent history due to habitat loss, agricultural expansion and human settlements. As with the other East-Asiatic *Zelkova* species, wild *Z. schneideriana* stands mostly remain conserved in remote, inaccessible areas including steep slopes and ravines in nature reserves and national parks. Detailed threat and conservation status assessments for *Z. schneideriana* are presently not available. Studies carried out in Hubei (Dabieshan, Wujiashan) and Zhejiang (Jiaxing, Tianmushan) confirm however, that the species is endangered due to uncontrolled commercial logging, expanding urbanisation and agricultural intensification. Whether herbivory by rhesus macaques (*Macaca mulatta*) – for which *Z. schneideriana* is a major source of food during the winter months – has a negative impact, especially on small populations, remains to be established.

Zelkova sinica C. K. Schneid.

Chinese Zelkova/Da guo ju (China)
IUCN Red List of Threatened Species: Not Evaluated

Zelkova sinica has recently attracted growing interest from foresters and landscape architects because of the species' economic and ornamental potential, e.g., high quality hardwood, large crown, reddish bark and autumnal leaf coloration. However, distribution, biology and ecology of *Z. sinica* are by far the least established in the entire genus.



HABIT

Attaining a maximum height of 30 m and diameter of 60 cm, the bark of *Z. sinica* is grayish white to green-yellow, and reddish when exfoliating. Ovate to elliptic, and 3-6 cm long and up to 3 cm wide, the leaves are predominantly glabrous, with a crenate margin and 6-10 secondary veins. Fruiting of *Z. sinica* occurs earlier than in the other two East-Asiatic *Zelkova* species (August to September). The most distinctive morphological characteristics of the species are its smooth, large drupes, which are 5-7 mm in diameter. They are also the heaviest among the members of the genus *Zelkova*: 1000 fruits weigh some 27 g (in comparison: 13 g in *Z. serrata* and 16 g in *Z. schneideriana*).

1-2. Upper surface and underside of a sterile branchlet (hrs)

3-4. Upper surface and underside of leaves (hrs)

5-6. Closer view of the upper surface and underside of a leaf (hrs)

7. Underside of a fertile branchlet (hrs)

8. Flowering branches. Botanic Garden Lyon, France (ek)

9-10. Fruiting branchlets. Botanic Garden Lyon, France (hrs, ek)

11-12. *Z. sinica* in *ex situ* collections: (11) Botanic Garden Poznan, Poland; (12) Colchic Botanic Garden in Kutaisi, Georgia (gk)

DISTRIBUTION

Endemic to China, *Z. sinica* has the smallest distributional range of the East-Asiatic *Zelkova* species. Its occurrence is very fragmented, with many small and isolated populations. Described from seven provinces, mainly in central China, including north Gansu, Hebei, Henan, northwest Hubei, Shaanxi, south Shanxi and north Sichuan, the distribution of *Z. sinica* overlaps in a number of locations with *Z. schneideriana* and *Z. serrata*. However, these species have only rarely been found together in the same forest fragments (e.g., in Henan with *Z. schneideriana*).

ECOLOGY

Z. sinica favours a warm climate and fertile, deep soils (with a pH from slightly acidic to highly calcareous). Growing mainly in valleys along rivers between 300 and 2,500 m a.s.l., *Z. sinica* is the least drought-tolerant of all *Zelkova* species. It is an element of the humid, subtropical deciduous forests of central China. Co-occurring species comprise numerous trees in the Fagaceae family, including *Castanea mollissima*, *Quercus dentata*, *Q. aliena* and *Q. variabilis* as well as *Celtis koraiensis*, *Ulmus pumila*, *Diospyros lotus*, *Carpinus cordata*, *Albizia kalkora*, *Pistacia chinensis*, *Platycarya strobilacea*, *Maclura tricuspidata*, *Broussonetia papyrifera* and *Grewia biloba*.

1. Young tree of *Z. sinica* (zl)

2. Young leaves with stipules. Swiss National Arboretum, Vallon de l'Aubonne, Switzerland (eg)

3. Sterile branches in summer. Botanic Garden Lyon, France (ek)

4. Exfoliating bark. Botanic Garden Poznan, Poland (ek)

1. *Broussonetia papyrifera* (Moraceae). Lushan, China (ek)

2. *Quercus dentata* (Fagaceae). Huangshan, China (ek)

3. Rhesus macaque (*Macaca mulatta*). Lushan, China (ek)

THREATS

As with *Z. serrata* and *Z. schneideriana*, only incomplete information is available pertaining to specific drivers of change that threaten wild populations of *Z. sinica*. Generally, these relate to overexploitation of forest resources, unsustainable woodland management, habitat loss and an ever-expanding urbanisation. As in the case of *Z. schneideriana*, the impact of rhesus monkeys feeding on *Z. sinica*, is presently unknown.

RECOMMENDED PRIORITY ACTIONS (EAST-ASIATIC SPECIES)

Scale up field surveys: As highlighted in the species profiles, biogeographical, biological and conservation status knowledge of the East-Asiatic *Zelkova* species is still very fragmentary. While a few studies have been carried out locally, a global and analytical synthesis for each of the three species remains to be established. This will require a considerable increase in field surveys in all countries and regions where East-Asiatic *Zelkova* species are known, reported or likely to occur. For instance, further investigations are needed to determine the situation of *Z. serrata* in the heavily urbanised regions of Kyushu and central Honshu in Japan, and to establish and validate the presence and conservation status of the species in Russia and North Korea. As the main country of occurrence of all East-Asiatic taxa, China's *Zelkova* populations will require a major focus of attention including a thorough review of herbaria specimens and literature, followed by further field surveys. This information will serve as a vital resource for assessing the species' global conservation status in accordance with the categories and criteria of the IUCN Red List of Threatened Species, and for developing targeted conservation actions.

Advance research in phylogeny and phylogeography: Of major relevance to the understanding of the evolution of the entire genus of *Zelkova*, much of the phylogeny and biogeography of the East-Asiatic taxa remains still in the dark. Comprehensive phylogenetic and phylogeographic studies are required to clarify the relationship among the three species based on analyses of plant material collected from a wide range of locations where populations are known to occur.

Designate priority sites for *in situ* conservation: Field surveys, conservation status assessments and information gained from molecular analyses inform the establishment of a priority list of populations of conservation importance. While prioritisation for *in situ* conservation would include wild populations with highest genetic diversity, the inventory would also need to consider small, geographically and genetically isolated stands of East-Asiatic *Zelkova* species. The ultimate status of designated conservation areas, including necessary management measures will require consideration of all stakeholder needs and interests, particularly those of local communities, who directly depend on the natural resources in a given area.

1-4. Accelerating development, urbanisation, large-scale agriculture and plantations in China, a nation that is home to the richest Tertiary relict flora worldwide: (1 and 4) Shanghai; (2) Lijiang, Yunnan; (3) the Yangtze River in northern Yunnan (ek)

5. Rice plantation in Lushan, China (ek)

6. Cultural landscape of Chichibu mountains in Kyushu Island, Japan (sb)

7. Tea plantation in Xian Yushan, China (ek)

8. Growing infrastructure for tourism development in China's mountainous areas. Lijiang, northern Yunnan (ek)

9-10. Intensive forestry in Japan: (9) *Z. serrata* plantations in Chichibu, Honshu Island; (10) Clear-cutting in Kamagase Gorge, Kyushu Island (sb)

Enhance the conservation value of *ex situ* collections: While additional, genetically representative conservation collections of all East-Asiatic *Zelkova* species are necessary in all countries where they are native, enhanced *ex situ* conservation measures are needed especially for *Z. sinica* which is least represented in Chinese living collections. Geographically and/or genetically isolated populations, subject to in-depth surveys, will be of primary concern for *ex situ* conservation. Further large-scale genetic analyses are essential to verify and clarify the origin of existing East-Asiatic *Zelkova* collections, which frequently lack detailed provenance information.

Strengthen regional collaboration: As with *Z. carpinifolia*, enhancing regional exchange of knowledge and expertise in the management of *Z. serrata*, *Z. schneideriana* and *Z. sinica* is particularly vital to devising integrated conservation strategies. Stronger scientific collaboration among experts from China, North and South Korea, Japan and Russia to fill knowledge gaps in the East-Asiatic division of *Zelkova* would also contribute to fostering our general understanding of the evolutionary processes and changes at work in Tertiary relict species.

1. *Z. sinica*. Botanic Garden Poznan, Poland (gk)

2. *Z. carpinifolia*. National Botanic Garden in Tbilisi, Georgia (gk)

3-4. So-called Cut-leaf Zelkova (*Z. x verschaffeltii*), a cultivar of hybrid origin, most likely between *Z. serrata* and *Z. carpinifolia*. Botanic Garden Dublin, Ireland (gk)

5-6. *Z. serrata*. Botanic Garden Poznan, Poland (gk)

7-8. *Z. carpinifolia*. Botanic Garden Dublin, Ireland (gk)

More than Jurassic Park – *ex situ* conservation of *Zelkova* species

STATUS OF *EX SITU* COLLECTIONS

The Global Strategy for Plant Conservation (GSPC) of the Convention on Biological Diversity (CBD) provides a comprehensive framework for plant conservation action from global to local levels. Addressing 16 conservation objectives, first adopted by the Conference of the Parties to the CBD in 2002, the GSPC calls on the parties to attain *at least 75% of threatened plant species in ex situ collections, preferably in the country of origin, and at least 20% available for recovery and restoration programmes* by 2020 (GSPC Target 8).

Against this backdrop, a survey was undertaken in 2010 to assess the conservation status of *Zelkova* species in *ex situ* holdings worldwide (Kozlowski et al. 2012). This study revealed major gaps, both in the extent and the quality of the collections. While all *Zelkova* taxa are found in botanic gardens and arboreta, few collections exist in the countries of the species' natural occurrence. Botanic institutions in nations with a strong horticultural tradition, including the United States, Germany, United Kingdom and France, hold the majority of related collections; however, they are not in locations of the species' origin. More importantly, *Zelkova* species that are most at risk are also least represented in botanic garden collections and are thus inadequately safeguarded through *ex situ* conservation. Only 10% of all known *ex situ* collections in the genus are made up of the acutely threatened Mediterranean *Z. sicula* and *Z. abelicea*, while the more common Transcaucasian *Z. carpinifolia* is generally well represented in *ex situ* holdings at the global level. A similar situation applies to Chinese *Zelkova* taxa held in collections in China: *Z. sinica*, which has the smallest distributional range of all East-Asiatic *Zelkova* species, is least represented in Chinese *ex situ* collections. Likewise, *Z. serrata*, the species with the widest natural distribution, is also the most common *Zelkova* in botanic garden collections in China.

Limited information on the provenance of the cultivated material adds a further challenge to research and *ex situ* conservation. More than 80% of all *Zelkova ex situ* collections are not well documented. Not only is the origin of the plant material unknown, but its taxonomic status and/or the cultivation history are often uncertain too. These collections are inappropriate for scientific study (e.g., phylogeny and phylogeography) and are also unsuitable for practical conservation based on wild plant material. What is more, *Zelkova ex situ* collections are generally small, with some 90% holding either one individual, or two to ten trees at most. These limited numbers have a major bearing on the collections' genetic diversity and representativeness.

GENETIC DIVERSITY AND REPRESENTATIVENESS OF *EX SITU* HOLDINGS

Project *Zelkova* uncovered tremendous differences in the genetic structure and origin of *ex situ* collections in botanic gardens. An initial, detailed study was carried out for *Z. carpinifolia* and *Z. abelicea* based on molecular analyses using chloroplast and nuclear DNA markers.

As regards within-species genetic variability of the Transcaucasian *Z. carpinifolia*, it is generally fairly accurately represented in *ex situ* holdings. Genetic analyses have revealed that the gene pool of both phylogeographically distant regions is found in *ex situ* collections: the majority of the sampled trees (69%) originate from the eastern cluster (Iran, Azerbaijan and eastern Georgia), while 31% derive from the western cluster (Turkey and Georgian Colchis).

In contrast, the Cretan species *Z. abelicea* is underrepresented in botanic garden collections. Although this species has an extraordinarily high genetic variability within and between natural populations, only a minute part of this diversity is found in *ex situ* holdings. The overwhelming majority of related *ex situ* collections is representative of a single region, the Omalos Plateau in the Levka Ori, an area most visited for collection of *Zelkova* plant material. The other three mountain chains (Psiloritis, Dhikti and Thripti), which house genetically very distinctive *Z. abelicea* populations, have most likely never been sampled for *ex situ* conservation. It is hence argued that the genetic diversity of the threatened *Z. abelicea* is inadequately secured in living collections.

In general, the molecular studies have demonstrated that *Zelkova ex situ* collections by and large exhibit a lower genetic diversity than that of *in situ* polymorphic populations. What is more, an important level of misidentification in botanical collections was recorded. No less than 10% of *Zelkova* trees in *ex situ* holdings were incorrectly identified and belong to different Ulmaceae genera (e.g., *Ulmus* spp.) or even to other families (e.g., Betulaceae, *Carpinus betulus*).

RECOMMENDED PRIORITY ACTIONS

Consolidate international collaboration among botanic gardens, arboreta and affiliated institutions to prioritise conservation needs of relict species in the framework of GSPC Target 8.

Strengthen coordination and research in the countries of origin of *Zelkova* and other relict taxa to establish and manage documented *ex situ* conservation collections representative of the genetic diversity found in wild populations.

Capitalise on the high potential of *Zelkova* and other relict taxa held in *ex situ* collections to enhance public outreach and education in biodiversity conservation by means of connecting the species' past, present and future in narratives, displays and other means of interpretation.

Conclusions and perspectives

The genus *Zelkova* serves as a model relict taxon to interpret the linkages between the past, present and future. Comprising as many as six extant species occurring in disjunct regions, this genus represents one of the most telling groups of plants to research the biogeography and phylogeny of Tertiary trees. Unveiling the relationship among these species to elucidate the evolutionary processes that have affected their distribution and differentiation in the course of geological history, will inform – if not directly offer – solutions for future approaches in ecosystem conservation and management. While this potential may be revealed in its full extent only in the long-term, the conservation of relicts in a rapidly changing environment is still vital as an insurance policy for the future. Project *Zelkova* has undertaken to study the species' phylogeny and phylogeography as well as their individual ecological niches, towards the development of an integrated conservation plan. Involving numerous experts and research disciplines, an overview of the main findings of this work is provided in Tables 1 and 2.

Table 1 / Species features and conservation status

	Zelkova sicula	*Zelkova abelicea*	*Zelkova carpinifolia*	*Zelkova serrata*	*Zelkova schneideriana*	*Zelkova sinica*
Distribution	Sicily	Crete	Georgia, Azerbaijan, Armenia, Turkey, Iran	China, Japan, North and South Korea	China	China
Elevational range (m a.s.l.)	310-550	900-1,800	100-1,550	500-2,000	100-2,800	300-2,500
Main habitat type	Thermophilous, evergreen and semi-deciduous communities, with *Quercus suber*, *Q. virgiliana*, *Olea europea*, etc.	Supra- to oro-Mediterranean communities, with *Quercus coccifera*, *Acer sempervirens*, *Euphorbia acanthothamnos*, *Sarcopoterium spinosum*, etc.	Temperate forest communities, with species of *Carpinus* sp., *Acer velutinum*, *Albizia julibrissin*, *Diospyros lotus*, *Gleditsia caspica*, *Parrotia persica*, etc.	Temperate, riparian forest communities, with *Acer japonicum*, *Aesculus turbinata*, *Castanea crenata*, *Celtis jessoensis*, *Pterocarya rhoifolia*, *Carpinus kawakamii*, *Quercus variabilis*, *Ulmus parvifolia*, etc.	Temperate, riparian forest communities, with *Pterocarya stenoptera*, *Acer buergerianum*, *Alnus trabeculosa*, *Diospyros lotus*, *Gleditsia sinensis*, *Broussonetia papyrifera*, *Liriodendron chinense*, etc.	Temperate to subtropical forest communities, with *Castanea mollissima*, *Quercus dentata*, *Q. aliena*, *Q. variabilis*, *Celtis koraiensis*, *Ulmus pumila*, *Diospyros lotus*, *Carpinus cordata*, etc.
Number of populations	2	40-50	ca. 100	ca. 1000	unknown	unknown
Genetic and phylogenetic features	Triploid (2n=42), extremely low genetic diversity, phylogenetically intermediate between *Z. abelicea* and *Z. carpinifolia*	Diploid (2n=28), very high genetic diversity within and between populations, phylogenetically related to *Z. sicula* and *Z. carpinifolia*	Diploid (2n=28), strong genetic differentiation into two clades - eastern (Hyrcanian) and western (Colchis), likely to represent the link between the Mediterranean species and *Z. schneideriana*	Diploid (2n=28), no phylogenetic studies to date at global scale	Diploid (2n=28), no phylogenetic studies to date at global scale, most likely representing the closest relative of *Z. carpinifolia* in the East-Asiatic division	Diploid (2n=28), no phylogenetic studies to date, neither at the national nor global level
Utilisation	Not exploited	Pollarding of branches for livestock fodder and artisanal handicraft work	Timber for construction and furniture manufacture, important ornamental tree in landscape architecture	Timber for construction and furniture manufacture, medicinal properties	Timber for construction and furniture manufacture, important ornamental tree in landscape architecture	Timber for construction and furniture manufacture, ornamental tree in landscape architecture
Conservation status (IUCN Red List of Threatened Species)	Critically Endangered	Endangered	Near Threatened	Not Evaluated	Not Evaluated	Not Evaluated
Main threats	Overgrazing, fire, climate change (drought)	Overgrazing, fire, climate change (drought)	Excessive logging, overgrazing, tourism development	Excessive logging, habitat transformation (urbanisation and agriculture), large-scale plantations	Excessive logging, habitat transformation (urbanisation and agriculture)	Habitat transformation (urbanisation and agriculture)
***Ex situ* collections and genetic representativeness (in brackets: number of collections in countries of origin)**	5 (3), all based on one population (Bosco Pisano)	20 (2), majority based on one region (Levka Ori), poor or no representation of other populations	60 (2), representation of both phylogenetic clades (eastern and western)	110 (12), genetic representativeness not studied	47 (10), genetic representativeness not studied	33 (3), genetic representativeness not studied

Zelkova serrata. Tataoki River, Japan (sb)

With very restricted distributional ranges and few remaining populations in the wild, all six *Zelkova* species occur in distinct habitats and altitudinal zones that, in turn, shape plant habit, ecological features and reproductive mechanisms. While *Z. sicula*, *Z. abelicea* and *Z. carpinifolia* of the southwest Eurasian group are each found in clearly defined, disjunct regions (Sicily, Crete and Transcaucasus), the distributions of *Z. serrata*, *Z. schneideriana* and *Z. sinica* in the East-Asiatic division (China, Korean Peninsula, Japan) overlap in China. Although chloroplast and nuclear DNA analyses substantiate this fragmented geographic pattern, genetic similarities among *Z. carpinifolia* and *Z. schneideriana* suggest, that close linkages of these species existed during an earlier geological period that later became disconnected as a result of environmental changes.

While detailed conservation status assessments according to the IUCN Red List categories and criteria have been undertaken to date for the southwest Eurasian species only, the rarity of wild populations on the one hand (especially of *Z. sicula*, *Z. abelicea* and *Z. sinica*) as well as limited representation of the genetic diversity in *ex situ* collections on the other (such as of *Z. abelicea*), call for more robust, integrated conservation action. The only two known stands of *Z. sicula* in Sicily serve as a striking example that nationally and locally sanctioned, rigorous *in situ* protection alone, will not safeguard the species from threats posed by increasing aridity and limited reproduction. As commonly practised, *ex situ* conservation provides an essential tool to complement measures implemented in the wild and enhance species' survival. Although this approach appears comparatively straightforward, as in the case of *Z. sicula*, which has a limited gene pool, capturing the genetic diversity of *Z. abelicea* and *Z. carpinifolia*, which both exhibit large variations among their respective populations, is a major challenge. Establishing viable and representative collections will require a significant commitment and investment by conservation stakeholders to provide appropriate resources to *ex situ* conservation institutions, including botanic gardens and arboreta.

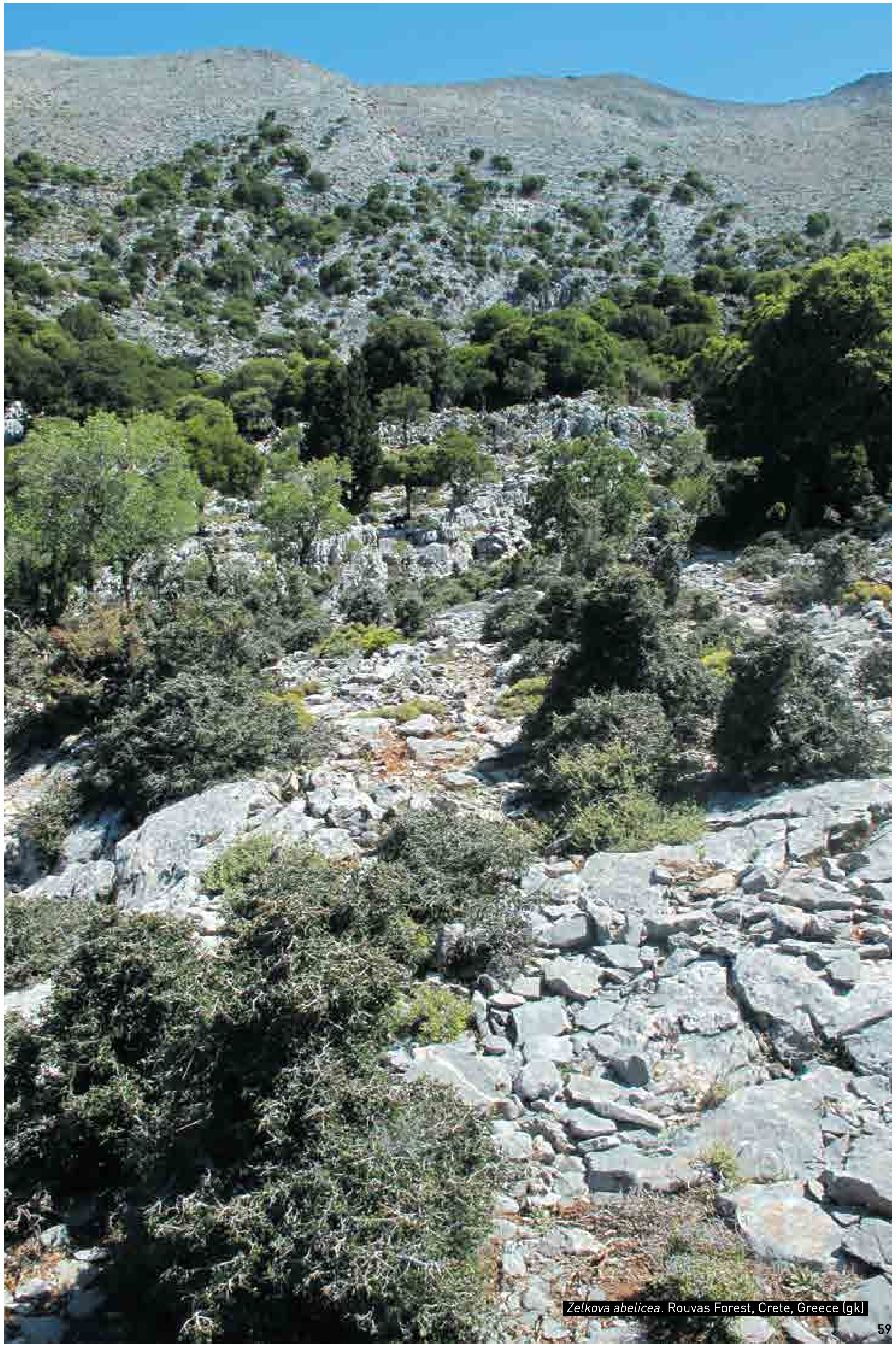
However commonplace, conservation efforts to secure the genetic diversity of target populations in the wild and in *ex situ* collections, necessitate diligent coordination at national and international levels. Relict species, especially those with relatives in disjunct regions, provide an excellent common ground to promote regional and international collaboration and joint conservation action by way of shared scientific interest.

The fascination associated with relicts from ancient times offers tremendous opportunities to attract the curiosity of the broader public. *Ex situ* collections of *Zelkova* and further Tertiary relict trees in botanic gardens, as well as specimens planted in urban parks and other public venues, present a major off-site resource for raising environmental awareness and education. Embedded in compelling stories that link reports of fossil finds with their extant relatives and new discoveries, relict plants lend themselves by their very nature and origin to the development of a variety of public outreach programmes, including interactive, target audience-oriented displays and travelling exhibitions.

In conclusion, the diverse ecological, socio-economic and cultural values related to *Zelkova* and relict trees in general, provide enormous opportunities to inform future ecosystem management approaches. Project *Zelkova* has endeavoured to compile existing information, gather and analyse new data, and recommend priority conservation actions. While ultimately a matter of societal choice, the conservation of relict species undoubtedly however presents society with the ethical challenge of preserving information stored in ancient species about the Earth's transformations over millions of years, for the coming generations.

Table 2 / Recommended priority actions

	Zelkova sicula	*Zelkova abelicea*	*Zelkova carpinifolia*	*Zelkova serrata, Zelkova schneideriana, Zelkova sinica*
Further investigations	Scale up field surveys across Sicily	Carry out additional population structure and species abundance surveys in heavily browsed populations	Review existing distribution records and scale up field surveys of populations in Turkey, Armenia, Azerbaijan, Iran and Georgia	Enhance research in phylogeny and phylogeography to clarify the relationship among the three East-Asiatic species, and scale up field surveys to consolidate distribution information from China, Japan, Russia and the Korean Peninsula as a basis for comprehensive conservation status assessments
***In situ* conservation**	Fence off wild and trial new experimental plantings in other locations with conducive environmental conditions	Fence off core zones of populations in Thripti, Mount Kedros and Rouvas Forest	Focus immediate conservation measures on isolated and threatened populations in Turkey and western Georgia	Designate priority sites for *in situ* conservation in collaboration with local stakeholders, based on comprehensive field surveys, conservation status assessments and information gained from molecular analyses
***Ex situ* conservation**	Enhance collections with plant material representing both currently known populations	Establish new collections with plant material from the isolated and threatened populations of Psiloritis, Dhikti and Thripti	Undertake large-scale genetic analyses of all collections in the countries of origin to clarify provenance information	Undertake large-scale genetic analyses to verify and clarify the origin of existing and plan new collections
Research partnerships and networking	Strengthen regional, national and global collaboration to share and capitalise on conservation and management experiences gained at the local level			
Public outreach and education	Scale up environmental campaigns supported by informational materials, interactive displays and travelling exhibitions			



Zelkova abelicea. Rouvas Forest, Crete, Greece (gk)

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