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INTEGRATED CONSERVATION ACTIONS FOR THE RELICT AND ENDEMIC CRETAN TREE *ZELKOVA ABELICEA* (ULMACEAE)

Fazan, Laurence[1]*; Fournaraki Christini[2]; Gotsiou Panagiota[2]; Sklavaki Polymnia[3]; Dimitriou Dimos[3]; Kargiolaki Hariklia[4]; Kehagiadaki Eleftheria[4]; Aspetakis Ioannis[5]; Arvanitis Pantelis[5]; Silligardos Emmanouil[6]; Koudoumas Emmanouil[6]; Kozlowski Gregor[1,7]

[1]Department of Biology and Botanical Garden, University of Fribourg, Chemin du Musée 10, CH-1700 Fribourg, Switzerland, laurence.fazan@unifr.ch, gregor.kozlowski@unifr.ch
[2]CIHEAM Mediterranean Agronomic Institute of Chania, MAICh, Alsyllio Agrokepiou, Chania 73100, Crete, Greece, flora@maich.gr, yiota@maich.gr
[3]Forest Directorate of Chania, FDC, Chrissopigi, Chania 73100, Crete, Greece, p.sklavaki@apdkritis.gov.gr, d.dimitriou@apdkritis.gov.gr
[4]Forest Directorate of Rethymno, FDR, Komvos Amariou 74100, Rethymno, Crete, Greece, harkargio@gmail.com, kexele@gmail.com
[5]Forest Directorate of Heraklio, FDH, Dasiko Fytorio Foinikias, 71410 Heraklio, Crete, Greece, i.aspetakis@apdkritis.gov.gr, p.arvanitis@apdkritis.gov.gr
[6]Forest Directorate of Lassithi, FDL, P. Kapetanaki 8, 72100 Agios Nikolaos, Crete, Greece, e.silligardos@apdkritis.gov.gr, e.koudoumas@apdkritis.gov.gr
[7]Natural History Museum Fribourg, Chemin du Musée 6, CH-1700 Fribourg, Switzerland

Abstract

Zelkova abelicea is an endangered, relict and the only endemic tree species of the island of Crete. This rare species is threatened mainly by browsing and trampling by flocks. We present here a project initiated in 2014 for the conservation of *Z. abelicea* which includes specific in situ and ex situ conservation actions such as fencing of small natural stands, seed and vegetative material collection for seed bank or ex situ plantations, as well as public sensitization actions. *Z. abelicea* individuals reacted positively in most fenced areas by growing fast and producing long shoots directly after fencing took place, and plant species richness and coverage were found to be higher than in areas still subject to browsing. Regarding ex situ conservation actions, definitive results are still expected in the following years. Finally, numerous local people have been informed about this threatened and rare tree and the project actions through environmental education programs and local public events.

Keywords

Plant conservation, Threatened tree, Browsing pressure, Crete, Zelkova abelicea

Introduction

The genus *Zelkova* (Ulmaceae) diversified and evolved during the Paleogene ca. 55 Ma ago, in subtropical-temperate forests of the North Pacific region between eastern Asia and North America, and later spread towards western Eurasia. Species of the genus *Zelkova* were important elements of the vast forests that prevailed throughout the Northern Hemisphere during much of the Cenozoic Era (Mai 1995, Wang et al. 2001, Fineschi et al. 2002, 2004). The oldest fossils attributed to *Zelkova* date from the early Eocene (55 Ma) in western North America, where the genus is extinct today (Burnham 1986). The climatic oscillations during the Quaternary, and notably the glaciations that occurred in Europe, had dramatic effects on the distribution of the local flora, with species becoming extinct, dispersing in new areas or surviving in glacial refugia and possibly recolonizing areas during warmer phases (Comes and

Kadereit 1998, Hewitt 2000). This was also the case with the ancestral *Zelkova* species, which survived throughout the Quaternary climatic oscillations only in specific refugial areas (Wang et al. 2001). The genus now comprises six extant species, with disjunct distribution patterns (Zheng-Yi and Raven 2003, Denk and Grimm 2005): three in eastern Asia (*Z. serrata, Z. schneideriana* and *Z. sinica*), one in southwestern Asia (*Z. carpinifolia*), and two species endemic to the Mediterranean islands of Sicily (*Z. sicula*) and Crete (*Z. abelicea*).

Zelkova abelicea (Lam.) Boiss. is the only endemic tree species of Crete. This species was supposedly widespread in the past and may have formed a forest belt in the Cretan mountains (Søndergaard and Egli 2006). It is currently found in scattered and isolated stands within the five main mountain ranges of Crete distributed from 900 m a.s.l. to the upper tree limit at approximately 1800 m a.s.l. (Egli 1997). In some areas, *Z. abelicea* may form mixed stands with *Acer sempervirens*, *Quercus coccifera* and occasionally *Cupressus sempervirens* (Fazan et al. 2012). Most frequently however, the species has a scattered distribution with few to no arborescent individuals in a more or less degraded phrygana with numerous dwarfed individuals. The species does not tolerate very xeric conditions and is therefore preferentially found on north-facing slopes in and around dolines where moisture and water supply is most adequate. The species is also found growing on scree slopes and in or around river beds that are active only during extreme precipitation events as well as at high elevations on south-facing slopes (Egli 1997, Søndergaard and Egli 2006, Fazan et al. 2012). *Zelkova abelicea* is most frequent in the Levka Ori and Dikti mountains, with only one known population in the Psiloritis and Thripti mountains, and a very scattered but widespread population on Mt. Kedros (Egli 1997, Fazan et al. 2012).

The large majority of *Z. abelicea* stands show an asymmetric population structure, possessing individuals with two distinct morphological types: few arborescent individuals and numerous dwarfed shrubs (Figure 1). Large arborescent trees of 5-20 m in height with a well-developed crown and bearing fruit are very rare and may represent only 5% of all known individuals (Kozlowski et al. 2014). All other individuals are present in a dwarfed, bushy, shrub-like form with multiple stems, dense growth and leaves < 2 cm (Fazan et al. 2012, Kozlowski et al. 2014). This morphology is mainly due to the extreme pressure of browsing by goats, which prevents young individuals from developing into fully shaped trees. Arborescent trees are able to produce fruits and can reproduce sexually, whereas dwarfed individuals never flower and only propagate clonally through root suckers, which the species produces abundantly in disturbed or eroded areas (Kozlowski et al. 2012). Interestingly, dwarfed and heavily browsed individuals grow extremely slowly, with an average growth rate of 0.24 mm/yr and can be very old (> 600 yr), and may surpass in age normally-growing arborescent trees (Fazan et al. 2012). Furthermore, vegetative propagation may have allowed dwarfed individuals to propagate and persist for centuries (perhaps even millennia) in disturbed (e.g. browsed) or degraded areas.

High levels of genetic variability were found in chloroplast markers within *Z. abelicea* (33 haplotypes), and as well as a strong phylogeographical structure, as each of the mountain ranges of Crete represents a separate genetic unit (Christe et al. 2014).

Pastoral activities (ovine and caprine) seem to pose the most important threats to the species. Browsing by goats but also trampling and erosion of soil due to the presence or passage of numerous sheep or goats in the areas where *Z. abelicea* individuals grows prevent seedlings and saplings from establishing and dwarfed shrubs from growing tall and fructifying (Fournaraki and Thanos 2006, Kozlowski et al. 2012). The very dry summer climatic conditions as well as future climate change may also pose threats to the species, as seeds germinate very slowly and require cold stratification for several months in order to germinate (Fournaraki and Thanos 2002), and seedlings germinate late in the spring and are thus very sensitive to drought conditions. Fire, as well as altered water regimes resulting from the

construction of reservoirs, land-use changes, road construction and changes in the dynamics and seasonality of pastoral activities may also pose further threats to the species. Although soil erosion is detrimental to seedling establishment, it may facilitate asexual propagation of the species by exposing roots and promoting suckering (Fazan et al. 2012, Kozlowski et al. 2012). Moreover, sexual regeneration is hindered also due to the low percentages of viable seeds (Fournaraki and Thanos 2002, Fournaraki 2010, Thanos et al. 2010). Furthermore, Z. *abelicea* has a strong cultural value on Crete, as traditional shepherd sticks (κατσούνες) are made preferentially from its hard, light and durable wood (Fournaraki and Thanos 2006). However, the pruning of plants and illegal collection of wood hinders the growth and development of fruiting trees.

Z. abelicea is listed as vulnerable in the first version of the Red Data Book of Greece (Egli 1995), and is classified as endangered on the IUCN Red List of Threatened Species (Kozlowski et al. 2012). The species is protected under Greek law (presidential Decree 67/81), forbidding the collection and export of any plant material without a specific permit. Most populations fall within NATURA 2000 sites. Moreover, it is also included in the Bern Convention and in Annexes II and IV of the European Habitats Directive 92/43/EEC.

The fragmentation of *Z. abelicea* populations as well as its specific genetic structure requires considering each mountain range where the species occurs as a separate conservation unit, with locally adapted conservation strategies. Each of these isolated, and in some cases small populations is at risk of being lost as a result of an accidental, deliberate or stochastic event. However, until recently, there were no particular management and conservation actions taken for the conservation of *Zelkova abelicea*, apart from some very local actions such as fencing of a small population in the Rouvas forest (Psiloritis, Rethymno) in the framework of an old LIFE project (LIFE99 NAT/GR/006497, 1999-2001), or the fencing of a small stand on Katharo plateau (Lassithi) in 2000 in the framework of the ARCHIMED project as well as collection of seeds coming from some populations of the Levka Ori (Chania) for ex situ conservation in the seed bank of the Mediterranean Agronomic Institute of Chania (MAICh).

In 2013 and 2014, two Greek National Programs of the Ministry of Environment for monitoring species and habitat types of the European Habitats Directive were initiated (one particular for the area of Samaria National Park in the Levka Ori, and the other for all other Cretan areas), and *Z. abelicea* populations started to be systematically inventoried and monitored but without implementing concrete measures to improve the conservation status, or the protection of the species.

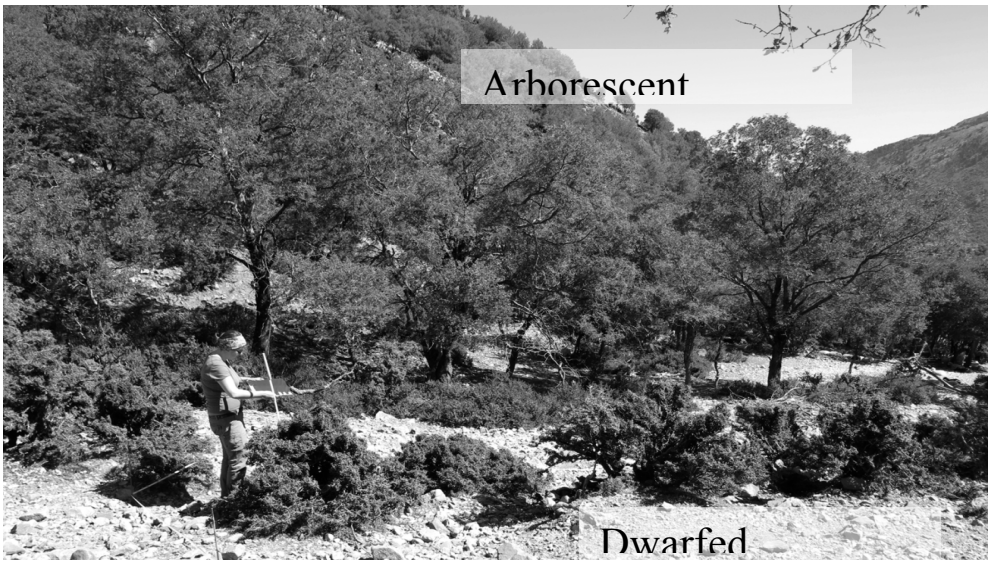

Figure 1. The two morphological types of *Z. abelicea*: arborescent trees in the background, and

In 2014, a project was initiated for the conservation of *Zelkova abelicea* in collaboration between the University of Fribourg (Switzerland), the Mediterranean Agronomic

Institute of Chania and the four Forest Directorates (Chania, Rethymno, Iraklio, Lassithi) of Crete, with actions aiming at i) the implementation of in situ measures (fencing of small plots) for protecting and studying the effect of browsing and grazing exclusion on the growth of *Z. abelicea* and the general vegetation, ii) the ex situ conservation of all known populations of the species (with both seed banking and ex situ cultivations), as well as iii) increasing public awareness through various dissemination and public sensitization actions. The first phase of the project ended in 2016, and the project continues for a second phase from 2017 to 2020. We present here an outline of the project actions and some preliminary observations and results from the in situ and ex situ conservation actions from the first phase (2014-2016) of the project.

Materials and Methods

In situ conservation actions

In the first phase of the *Z. abelicea* conservation project, the main objectives of the in situ project actions were the protection of selected stands of *Z. abelicea* from browsing and trampling in all mountain ranges of Crete by fencing as well as monitoring the effect of the protective measures on plant growth and on vegetation regeneration within the selected fenced pilot plots. In total, 32 fenced plots were established in 12 sites throughout the mountains of Crete in areas in which there are natural populations of *Z. abelicea* (with the exception of the *Z. abelicea* population of Mt. Psiloritis for which no agreement could be made with local land users, and of Thripti Mountain in Eastern Crete which was fenced during the 2nd phase of the project in early 2017). See Table 1.

Table 1. Number of fenced plots and area fenced in each mountain range.

Mountain	No of fenced plots	Total area fenced (m^2)
Levka Ori	18	1128
Kedros	4	115
Psiloritis	0	0
Dikti	10	338
Thripti	0	0
Total	32	1581

The main criteria for plot selection were presence of *Z. abelicea* individuals, morphology of individuals (dwarfed trees with nearby fruiting individuals when available), feasibility of installing fencing due to natural elements (slope, rock outcrops), accessibility of the site (for material transport), natural hazard possibility (e.g. rockfall), as well as contact with and motivation of local land users. Plot size varied between 2.25m^2 and 360m^2 with a median size of 25m^2. It was decided to have mostly small sized plots, to avoid deliberate destruction as well as minimize their impact on local land user activities. Within each fenced plots, the position of every *Z. abelicea* individual was mapped, and growth parameters (e.g. tree height, diameter, crown diameter, number of trunks) were measured. This was also done on other tree species growing within the plots. These measurements were taken in autumn (i.e. at the end of the growing season) of every year (T1, T2, etc.), starting with the year before fencing occurred (T0) for reference purposes.

Additionally, the vegetation of each fenced plot was monitored, in May of every year (i.e. when the majority of plants are flowering or setting fruit), and presence and number of plant species as well as vegetation cover (in percentage of total surface) for each species were recorded, and compared with an adjacent non-fenced plot subject to browsing. Number of species was recorded in a 16m^2 area in every plot in order to be able to compare number of species between plots of various sizes (for the plots smaller than 16m^2, the whole plot surface was recorded).

Ex situ conservation actions

One of the main objectives of the project is to create ex situ collections of *Z. abelicea* using plant material (seeds and vegetative material) collected from all the mountain regions where *Z. abelicea* occurs in order to preserve as much of the genetic diversity of the species as possible. Until the start of the project in 2014, ex situ collections of *Z. abelicea* did not exist in Greece apart from some seed collections of *Z. abelicea* coming from the Levka Ori and preserved since 2000 in the Seed Bank of MAICh following international standards (initially acc. FAO/IPGRI 1994, and revisions and later acc. ENSCONET 2009a,b,c). Germination protocols and experiments to test seed variability have already been developed and undertaken for the previously collected *Z. abelicea* seeds by the Seed Bank of MAICh in collaboration with the Department of Botany of the University of Athens since 2002 (Fournaraki and Thanos 2002). These protocols and experiments were used and adapted if necessary in the *Z. abelicea* conservation project to the different seed collections acquired throughout Crete.

Seedlings that develop after the germination experiments are cultivated at the nursery of MAICh and two nurseries of the Forest Directorates of Crete (Chania and Iraklio) in order to be used for ex situ plantations of *Z. abelicea* and/or for restoration projects. These ex situ plantations will contain genetic material coming only from neighboring natural populations to avoid genetic pollution and will serve for several purposes: conservation of the genetic diversity, environmental education and public awareness and in the long term will also give the possibility to provide material (wood) for the making of the traditional walking sticks of shepherds, with certified origin of cultivation and not from natural populations.

Z. abelicea has a masting cycle producing massive amounts of fruit every ca. 3 yr, and almost no fruit in the unfavourable years. The species also has a very low percentage of sound seed (Egli 1997, Fournaraki and Thanos 2006, Søndergaard and Egli 2006) and some stands contain no fruiting individuals. Therefore, there is also the aim to develop a protocol for the vegetative propagation of the species, particularly for the conservation of *Z. abelicea* populations in which few or no fruiting individuals are found, and which cannot give accessions for seed banking. Experiments using different concentrations of rooting hormones in summer and winter cuttings as well as shoot and root-stolon cuttings are still under way.

Results

In situ conservation actions

Out of the 32 fenced plots, 27 were still standing in autumn 2016. Four plots were destroyed by people for unclear reasons (possibly land-use conflicts), and one by heavy snowfall during the winter 2014-2015 and not rebuilt. Several plots also sustained considerable damage due to heavy snowfall during the winter 2014-2015, and one was impacted by rockfall in early spring 2015, but all were subsequently repaired. Furthermore, three plots were "visited" by goats after having being fenced.

In most cases, as soon as fencing occurred, *Z. abelicea* individuals, started to grow, and shoots to elongate (Figure 2). On average, individuals were 15 cm taller one year after fencing (T1) compared to the reference year (T0), and one year later (T2) they had grown on average 14 cm more. Average maximal elongation of the longest shoot was of 28 cm for the first year (T1) after fencing and 30 cm for the second year (T2) after fencing, while absolute maxima was 120 cm for the first year and 57 cm for the second year.

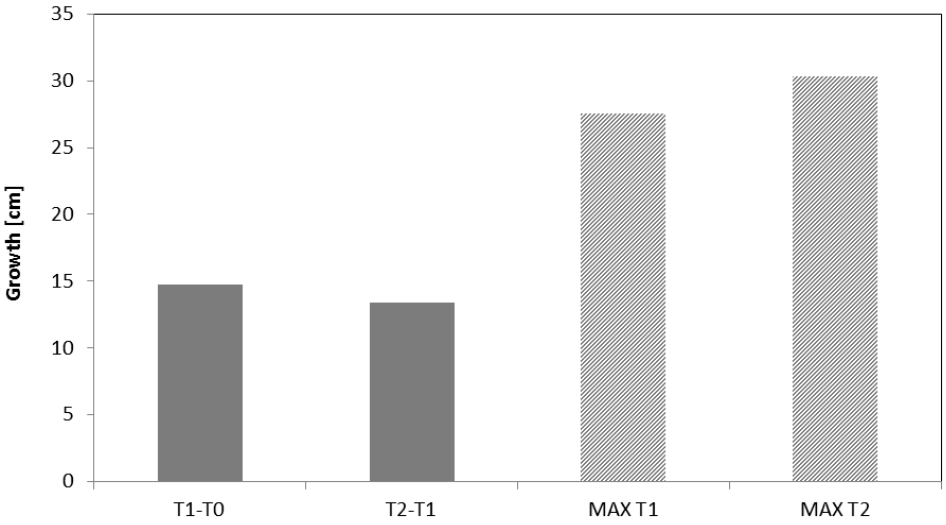

Figure 2. Average elongation of *Z. abelicea* trees between different time periods as well as average maximum shoot elongation.T0 is the reference year before fencing, T1 the first year after fencing and T2 the second year after fencing.

The average number of species found within the fenced plots was significantly higher ($p < 0.01$) compared to the external areas monitored for comparison that were still under browsing pressure both for the first year and the second year after fencing. There were on average 55 species in the fenced plots in the first year after fencing (T1) and 58 species in the second year after fencing. Comparatively, in the external areas, only 42 species were found in the first year, and 46 in the second year (Figure 3).

Investigations about vegetation cover are still ongoing, and no definitive results are yet available. However, in areas where browsing pressure was strongest, visual differences were already seen in the first spring after fencing. The vegetation cover was higher within most of the fenced plots compared to the surrounding areas still under browsing pressure (Figure 4). Only in areas where browsing pressure is thought to be less intense were visual differences not so evident in terms of vegetation cover, although in these cases, *Z. abelicea* individuals showed elongated shoots that were not found in browsed areas, and species richness was on average also higher within the fenced plots compared to external areas

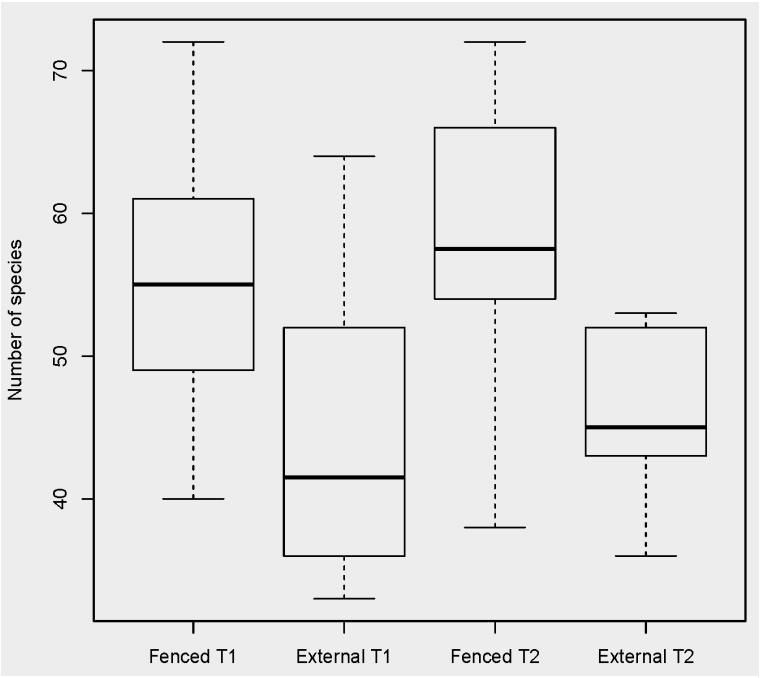

Figure 3. Average species richness within the fenced plots compared to external plots under browsing pressure for the first year after fencing (T1) and

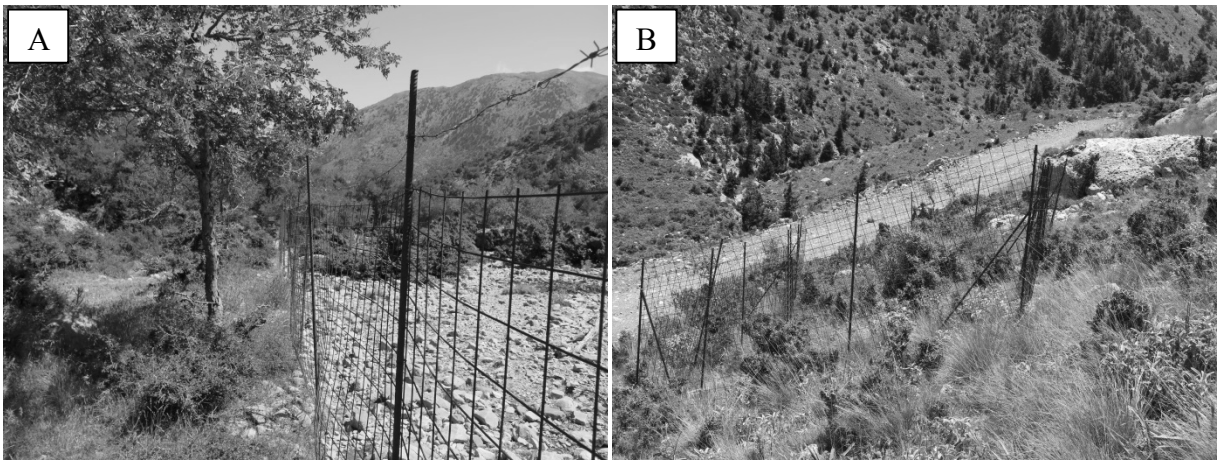

Figure 4. Visual differences in vegetation cover between fenced plots and external areas subject to browsing. A. Plot situated in an area with strong browsing pressure, with visually higher vegetation cover inside the plot (left) than outside (right). B. Plot situated in an area with supposedly little browsing pressure, with no clear visual differences between inside and outside of the plot.

Ex situ conservation actions

During the first three years of the project, only 2015 was a masting year with abundant fruit production for *Z. abelicea*, but sound seed production was extremely low (between 0-9%) and fluctuated strongly between sampled populations. So far only three accessions (all from the Levka Ori) had enough quality and quantity to be stored in the seed bank. Furthermore, the first results of the vegetative propagation of the species show very low success and further investigations are still necessary to develop more effective propagation protocols. A first ex situ plantation was established in 2016 on public land. The field was

offered by the Municipality of Platanias on the Omalos Plateau in the Levka Ori. The plantation of 50 trees was performed by pupils and teachers of the local primary school of Skine-Fourne in collaboration with the project partners. Further trees of *Z. abelicea* are planned to be planted in the same field when planting material (seedlings) from the local natural population will be available and ready for transplanting.

Discussion – Conclusions

The most important pressures on *Z. abelicea* natural populations are pastoral activities mainly through browsing and trampling by goats and sheep, inducing a domination of dwarfed, severely browsed non-flowering individuals. The protection of dwarfed individuals in the first phase (2014-2016) of the conservation project yielded promising preliminary results. Overall, *Z. abelicea* individuals reacted positively to the removal of browsing pressure by producing long shoots and elongating, both in areas of low and high browsing pressure. Both vegetation cover and species richness also showed to be higher within the fenced plots than in areas under browsing pressure. However, in some areas, the effect of fencing on both *Z. abelicea* growth or vegetation seems to be less significant, implying that other factors may be of importance (e.g. local weather and soil conditions, or a delayed reaction).

Furthermore, intentional destruction of fenced areas or intentional introduction of animals within the fences was very low, which showed how important it is to tightly collaborate with local communities and local land users, as well as the importance of public outreach and communication actions.

The very low percentage of sound seeds as well as the masting pattern of *Z. abelicea* hampered the collection of sufficient seeds to be stored in the seed bank or used for ex situ plantations or restoration purposes. Within the next years, emphasis will be made to further collect seeds. Moreover, collection of vegetative material for propagation from populations with few or no fruiting individuals is an essential part of the conservation actions. However, the first trials have showed little success, and an effective protocol still needs to be developed within the next years.

During the second phase (2017-2020) of the project, it is planned to maintain the existing fenced plots, continue the monitoring work in the fenced plots in order to follow growth and changes over several years, and to study other biotic (e.g. insect) or abiotic (e.g. weather and soil data) factors that may influence *Z. abelicea* growth and vegetation development. Further fencing of new plots is also planned, especially in areas in which no plots had been previously established or that were underrepresented. Moreover, more emphasis will also be given on more targeted actions towards local inhabitants and authorities of the areas close to natural populations of *Z. abelicea* so as to better promote the wider consensus needed for a more efficient project implementation, particularly in areas where deliberate destruction of plots has taken place.

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