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E. N. Daskalakou, S. Oikonomidis, S. Boutsios, K. Ioannidis, & C. A. Thanos

Population characteristics of *Juniperus drupacea* (*Cupressaceae*) at the westernmost marginal area of its world distribution (Mt. Parnon, Greece)

Abstract

Daskalakou, E. N., Oikonomidis, S., Boutsios, S., Ioannidis, K. & Thanos, C. A.: Population characteristics of *Juniperus drupacea* (*Cupressaceae*) at the westernmost marginal area of its world distribution (Mt. Parnon, Greece). — Fl. Medit. 32: 305-316. 2022. — ISSN: 1120-4052 printed, 2240-4538 online.

Juniperus drupacea Labill. is a relict, dioecious tree/shrub found in Turkey, Syria, Lebanon and Israel, while in Europe it is native only in Greece (on Mt. Parnon and in a restricted area of Mt. Taygetos). According to the IUCN Red List criteria, *J. drupacea* has been assessed as endangered (EN) for Europe, with major threats being grazing of saplings, overexploitation of its wood and climate change. For the first time to our knowledge, the structure of the diverse stands of *J. drupacea* across its entire population range on Mt. Parnon is being studied. Thirteen monitoring plots (20 × 25 m) have been selected and established to cover fully both the species' geographic distribution on Mt. Parnon as well as the heterogeneity of its habitats. The morphometric traits (gender, canopy height, canopy base height, diameter at breast height and number of trunks) for each individual within the plots were recorded during the monitoring periods of 2020 and 2021. The Female / Male individual ratios, in both the northern and the southern area of the species' range deviate significantly from the expected ratio 1:1 of the evolutionary stable strategy, it should be noted that from the 729 individuals recorded 254 were juveniles. Canopy height may reach 11.5 m with a DBH up to 132 cm whereas individuals are usually multi-trunked (1-9 trunks were recorded). The average tree density was 1121.5 ± 139.8 individuals per hectare for the entire mountainous population range.

Key words: biodiversity, conservation, Syrian juniper, sustainable management, population structure.

Introduction

Junipers are slow-growing and long-lived evergreen small trees or shrubs, well adapted to dry environments and found in a variety of habitats, from sea level to above the timberline (Adams 2014). *Juniperus* (*Cupressaceae*) is one of the most diverse genera of conifers and includes ca. 75 species (Adams 2014; Dörken 2019), which are widely grown in temperate and subtropical regions of the Northern Hemisphere south to tropical Africa (Bonner 2008), with ca. 20 taxa distributed in Europe, Canary Islands, Azores, Asia Minor and Africa (Adams 2014).

Caryocedrus is one of the three, putatively monophyletic *Juniperus* sections and it is represented exclusively by *Juniperus drupacea* Labill. This species is well separated from its congeners on the basis of both molecular data and its unique morphological features, i.e. the unusually large seed cones [(up to 3 cm in diameter), with three ovules fused and forming a hazelnut-like "stone" at maturity], in addition to the inflorescence-like structure of male reproductive units (Dörken 2019).

Juniperus drupacea is a relict tree/shrub species, with distinct male and female individuals (dioecious). Its global geographical distribution is relatively limited and fragmented, mostly in SE Turkey, Western Syria, Israel and Lebanon (Boratynski & al. 1992). In Europe, it is found exclusively in SE Peloponnese, Greece, in Mt. Parnon and in a restricted area of Mt. Taygetos, where it forms small patches (Tan & Iatrou 2001; Bergmeier 2002; Dimopoulos & al. 2013). Greece is a well known hotspot for plant diversity in Europe and the Mediterranean area, showing impressively high endemism (Georghiou & Delipetrou 2010; Dimopoulos & al. 2013); in particular, the Peloponnese area is considered one of the 10 Mediterranean Basin hotspots, on the basis of plant endemism and richness (Médail & Quézel 1999). All over the country, junipers are represented by 8 taxa: *Juniperus communis* L., *J. drupacea, J. excelsa* M. Bieb., *J. foetidissima* Willd., *J. macrocarpa* Sm., *J. oxycedrus* L., *J. phoenicea* L. and *J. sabina* L. (Arabatzis 1998; Dimopoulos & al. 2013).

The *Juniperus drupacea* populations in Mt. Parnon are of particular ecological interest as they represent more than 95% of the species distribution in Greece (Constantinidis & Kalpoutzakis 2015). Mt. Parnon juniper forests grow on limestone soils, at an altitude of 700-1600 m a.s.l., and form either pure or mixed stands with black pine (*Pinus nigra* JF Arnold subsp. *nigra*) and the endemic Greek fir (*Abies cephalonica* Loudon) (Maerki & Frankis 2015).

According to the International Union for the Conservation of Nature (IUCN), *J. drupacea* is globally classified as 'Least Concern' (LC) (Gardner 2013); however, in Europe, it is considered Endangered (EN) (Gardner 2017; Rivers & al. 2019), as it is represented only by the Greek populations; at national level, the species is protected by the Presidential Decree 67/1981. Moreover, the species is the main structural plant of the subtype 42.A5 (Syrian juniper woods) of the priority habitat "9560* - Endemic forests with *Juniperus* spp.", according to the Directive 92/43/EEC (Anonymous 2007). The greater area of Mt. Parnon has been included (GR2520006) in the European Natura 2000 Network of protected areas, a testimony of the importance of these natural juniper stands and their protection. Furthermore, the species seems to be threatened by climate change and the adoption of specific strategies is suggested for the conservation of its genetic and morphological diversity in the future (Walas & al. 2019).

The discontinuous geographical distribution of the species and the long isolation between the mountainous populations of SE Asia areas and the European ones, separated by the Aegean Sea and an estimated distance of almost 800 km (Tan & al. 1999), is also reflected to the genetic and morphological differentiation among the disjunct populations of the species (Sobierajska & al. 2016).

Therefore, taking into consideration the fragmented natural distribution and the predicted reduction of the species worldwide distribution (Walas & al. 2019), as well as the limited knowledge for the Greek populations, this study aims to describe the current *J. drupacea* population and its structure on Mt Parnon.

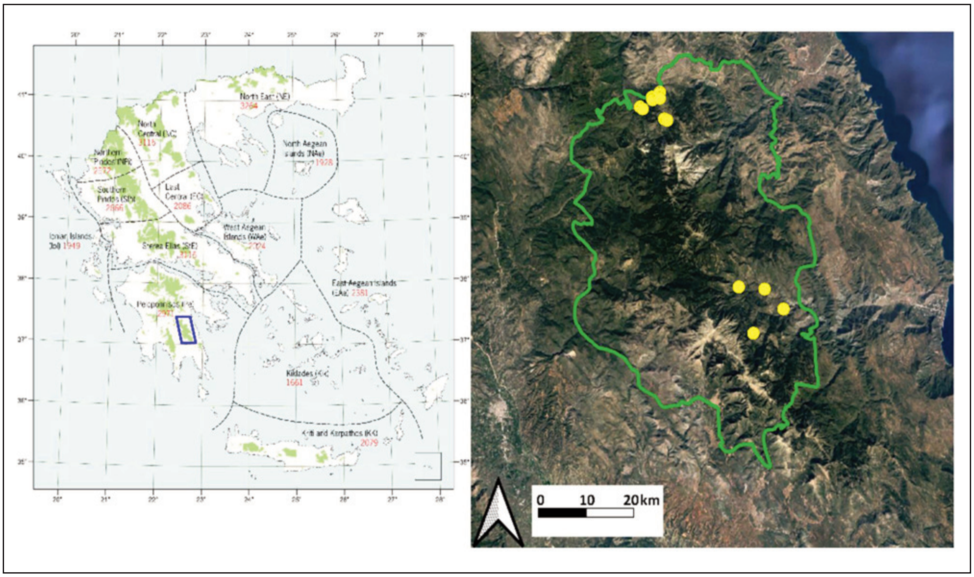

Fig. 1. Map of Greece (with the 13 phytogeographical regions, Dimopoulos & al. 2013) with the study area highlighted in blue (left). Map with *Juniperus drupacea* monitoring plots in the northern and southern areas of Mt. Parnon (right) within the boundaries of the NATURA 2000 site (green line).

Materials & Methods

Study area

Monitoring was carried out on Mt Parnon (Arcadia prefecture, southeast Peloponnese), Greece (Fig. 1). The majority of the monitoring plots were established on the protected area of the Natura 2000 European Network "Mount Parnon (and Malevi area)" - code GR2520006. In the particular area around the Malevi Monastery, juniper trees appear as the dominant species (Maerki & Frankis 2015). The above forest is a unique and extremely sensitive ecosystem at national level and has been declared as a Preserved Monument of Nature (Government Gazette 121/D/21-2-1980) while the wider area has been designated as an Area of Absolute Nature Protection [(Government Gazette 353/6-9-2010) and amendments, according to Government Gazette 60/A/31-3-2011)].

Monitoring

Thirteen (13) monitoring plots, of 500 m^2 area each (20 × 25 m), were established in October 2020 (Table 1): nine (9) plots in the northern and four (4) in the southern area of Mt. Parnon. The plots were located at varying altitudes, exposures and slopes in order to cover the entire geographic range of the species as well as the heterogeneity of its habitats. A total of 729 *J. drupacea* individuals were recorded in all 13 monitoring plots; 550 and 179 trees were tagged in the northern and southern areas of Mt. Parnon, respectively. The morphometric traits, i.e. tree gender, individual height, diameter at breast height (DBH) and the number of trunks for each individual were recorded during the years 2020-2021.

Table 1. Summary table of the individual characteristics of *Juniperus drupacea* for each monitoring plot, including mature and juvenile individuals. Mean values are drawn from the total number of individuals of each monitoring plot and are accompanied by the standard error of the mean. For the calculation of the mean DBH of each site, firstly, we calculated the mean DBH for all the trunks of each individual and then the DBH of the site was calculated.

Location	**Site code**	**DBH, cm**	**Canopy Height, m**	**Canopy base height, m**	**Trunks /individual**	**Individual s /plot**	**Density (individuals/ha)**
N. Parnon	A1	4.7 ± 0.7	4.1 ± 0.3	0.0 ± 0.0	1.4 ± 0.1	49	980
N. Parnon	A2	7.1 ± 0.4	6.2 ± 0.3	0.0 ± 0.0	1.8 ± 0.1	87	1740
N. Parnon	A3	4.8 ± 0.3	3.5 ± 0.1	0.0 ± 0.0	1.8 ± 0.1	89	1780
N. Parnon	A4	4.7 ± 0.4	3.3 ± 0.2	0.0 ± 0.0	1.4 ± 0.1	76	1520
N. Parnon	A5	5.9 ± 1.0	4.0 ± 0.3	0.0 ± 0.0	1.3 ± 0.1	34	680
N. Parnon	A6	4.7 ± 0.7	4.1 ± 0.2	0.1 ± 0.0	3.8 ± 0.3	55	1100
N. Parnon	A7	5.0 ± 0.8	4.4 ± 0.5	0.0 ± 0.0	1.3 ± 0.2	20	400
N. Parnon	A8	3.7 ± 0.4	2.7 ± 0.1	0.0 ± 0.0	1.7 ± 0.2	69	1380
N. Parnon	A9	5.5 ± 0.5	3.3 ± 0.2	0.0 ± 0.0	1.6 ± 0.1	71	1420
S. Parnon	J1	65.8 ± 8.4	6.6 ± 0.4	1.7 ± 0.1	1.0 ± 0.0	12	240
S. Parnon	J2	20.9 ± 3.4	3.0 ± 0.3	0.1 ± 0.0	1.0 ± 0.0	56	1120
S. Parnon	J3	18.1 ± 1.8	3.4 ± 0.2	0.0 ± 0.0	1.0 ± 0.0	33	660
S. Parnon	J4	28.1 ± 3.2	5.1 ± 0.4	0.9 ± 0.2	1.1 ± 0.1	78	1560

The datasets, corresponding to the northern and southern parts of the mountain, were compared and the observed differences of individual growth traits and gender distribution between the two study areas are presented and discussed.

Statistical analysis

The Shapiro – Wilk normality test revealed, for all the continuous variables, a deviation from the normal distribution and henceforth we used non-parametric tests for assessing the significance of our hypothesis. The Mann-Whitney test was used for the relationship between the continuous variables, while for the gender structure a chi-square test was performed to test the deviation from the value 1:1 (Female : Male), the evolutionary stable strategy (Fisher 1930). Pearson's correlation index was calculated for the continuous variables in order to discover any potential relationships among the biotic variables and two additional abiotic ones, altitude and shadiness of the habitat, where the values for each of the abiotic variables were extracted from raster data of forest cover (Hansen & al. 2013) and from the Copernicus DEM (2016).

Finally, a factor analysis for mixed data (FAMD) was performed with gender, canopy height, mean DBH and number of trunks as its parameters. For the comparison of the DBH data in multi-trunked trees, the mean DBH of all trunks for each individual was used.

For the handling of the entire dataset, the statistical tests and the drawing of diagrams, we used R version 3.6.3 (R Development Core Team 2005).

Results

The number of juniper trees i.e. all individuals including saplings in each monitoring plot ranged from 12 to 89, with a mean value of 56 ± 7 individuals. Therefore, tree density ranged from 240 to 1780 individuals per hectare and by combining all data we obtain an average value of 1121.5 ± 139.8 individuals per hectare, for the entire mountainous population range (Table 1).

A significant proportion (30%) of the individuals examined were found to have multiple trunks (Electronic Supplementary File 1: Fig. S1) and the number of trunks observed ranged up to 9 (only 1 individual with 9 trunks was recorded). The number of trunks per tree was found to differ statistically significantly (Mann-Whitney test: p-value   0) between the southern and the northern part of the Mt. Parnon. Individuals in the southern part are usually single-trunked (<10% multi-trunked) compared with the population of the northern part where a significant proportion of trees (40%) are multi-trunked.

The Female/Male individual ratios (Fig. 2), in both the northern (F/M = 0.67 ± 0.11 - chi-square test: p-value < 0.001) and the southern (F/M = 1.84 ± 0.81 - chi-square test: p-value <0.05) plots, deviate significantly from the evolutionary stable strategy ratio 1:1. Male individuals outnumber significantly the female ones in the north and vice versa in the south. It should be also noted that in the northern population, where the individuals are fre-

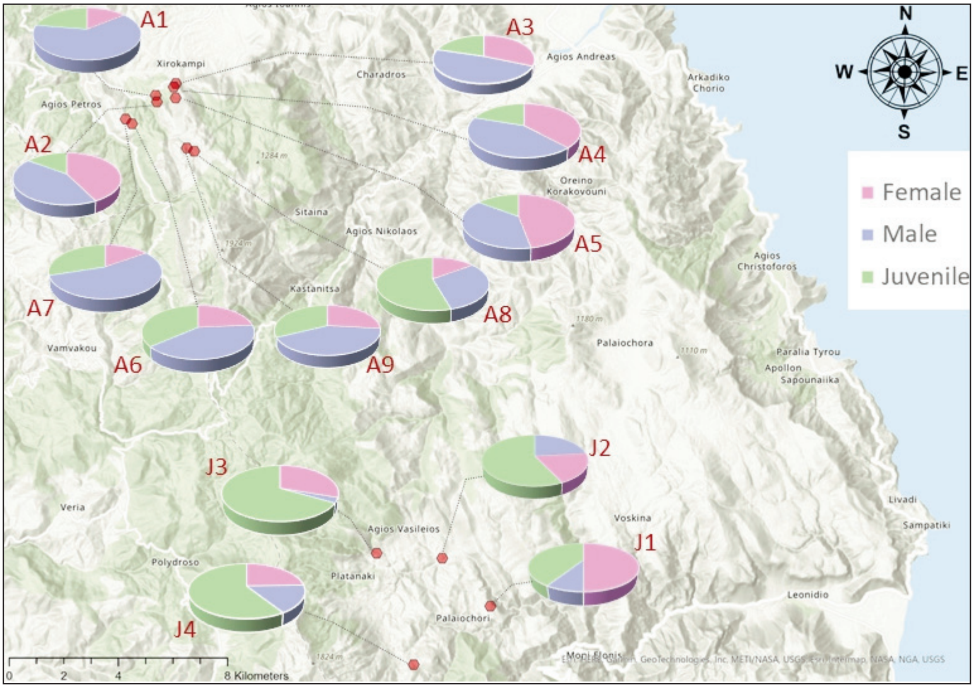

Fig. 2. *Juniperus drupacea* gender contribution (%) amongst the monitoring plots established in the northern and southern areas of Mt. Parnon.

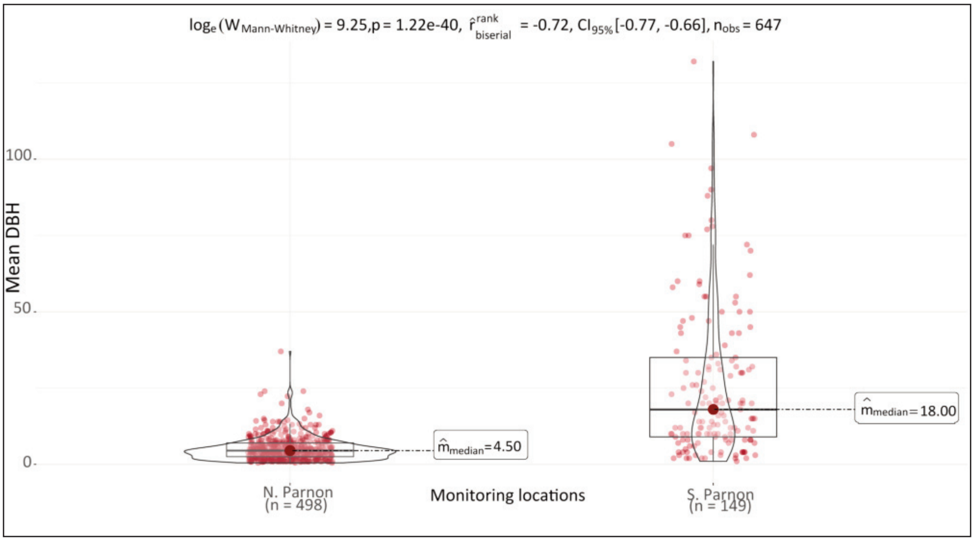

Fig. 3. Statistic plot representing the mean DBH between North and South Parnon along with the results of the non-parametric statistical test.

quently multi-trunked, there are no differences regarding the number of trunks for male and female individuals, while the juveniles are mostly single-trunked (Kruskal-Wallis p-value < 0.001, Dunn-test p-values < 0.001 for both male-juvenile and female-juvenile).

In regard to DBH (Fig. 3), by comparing the values between the northern and the southern monitoring plots a statistically significant difference (Mann-Whitney test: p-value $\simeq$ 0) was observed. Moreover, the DBH of the individuals of the southern plots was notably about twice as large as that of the northern part of the mountain. On the other hand, the canopy height comparison between the two areas returned a much lower statistical difference (Mann-Whitney test: p-value = 0.044).

The starting lowest level of the canopy (foliage) was also found to differ statistically between southern and northern *J. drupacea* populations (Mann-Whitney test: p-value $\simeq$ 0). Specifically, in most individuals recorded in the northern plots the canopy was starting from the very basis of the trunk. The same phenomenon was rarely seen in the southern monitoring plots, where the canopy was observed to start from a much higher point of the trunk.

In regard to the possible relationships (Fig. 4) between the continuous variables and the two abiotic factors (altitude, canopy shadiness), we observed a significant positive correlation between the shadiness of the monitoring plots and the height of the individuals (Pearson's R = 0.37, p-value < 0.001). Negative correlations were observed between the altitude of the plots on the one hand and the canopy height and the DBH on the other (Pearson's R = -0.15 and -0.26, p-value < 0.001, respectively). Interestingly, positive correlations were also observed between the number of trunks on the one hand and the canopy height (Pearson's R = 0.27, p-value < 0.001) and the canopy base height (Pearson's R = 0.30, p-value < 0.001) on the other.

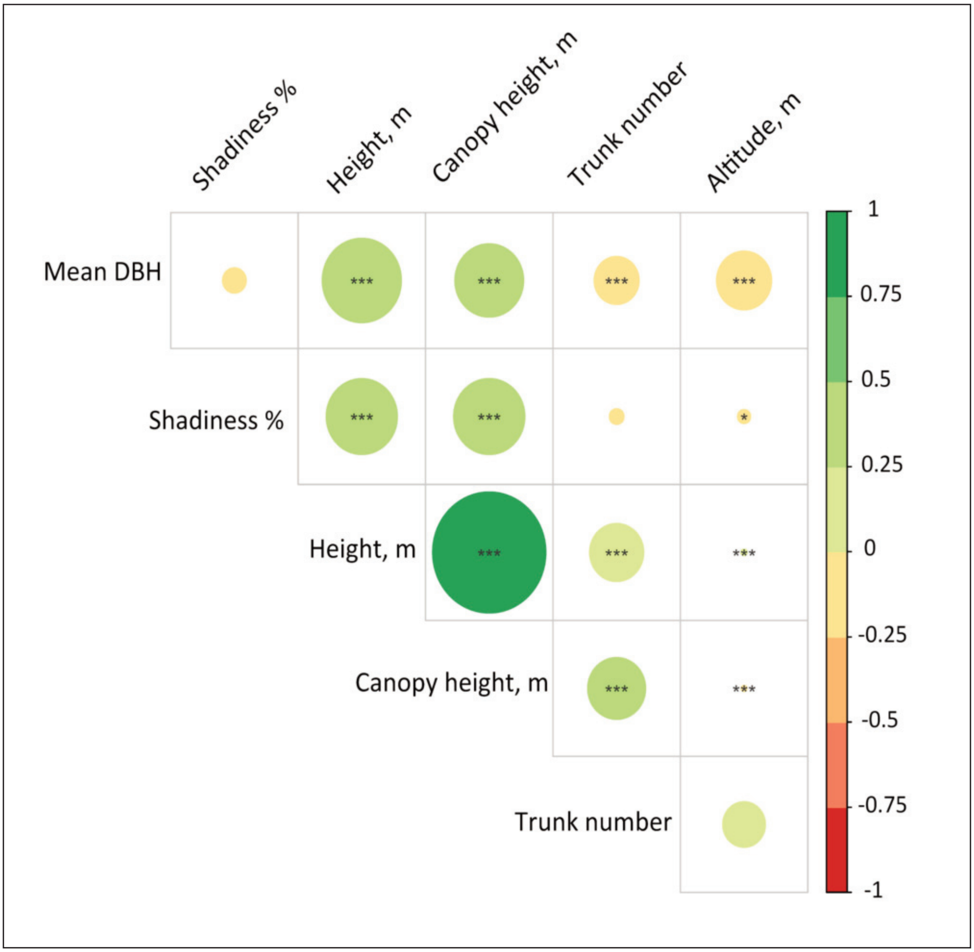

Fig. 4. Correlation plot for the individual characteristics of *Juniperus drupacea* and for two abiotic parameters (altitude and shadiness). The stars inside the circles represent the significance level, while the size of the circles represents the absolute value of the Pearson index.

Lastly, the applied FAMD (Fig. 5), using the variables: number of trunks, DBH, canopy height and gender revealed a significant difference between the northern and the southern part of the population studied. 59.3% of variance is explained by the two first components and 92.2% by the four factors used.

Discussion

Only limited ecological studies have been implemented on *Juniperus drupacea* in the Mediterranean region (Douaihy & al. 2017) and still remain open questions about phenol-

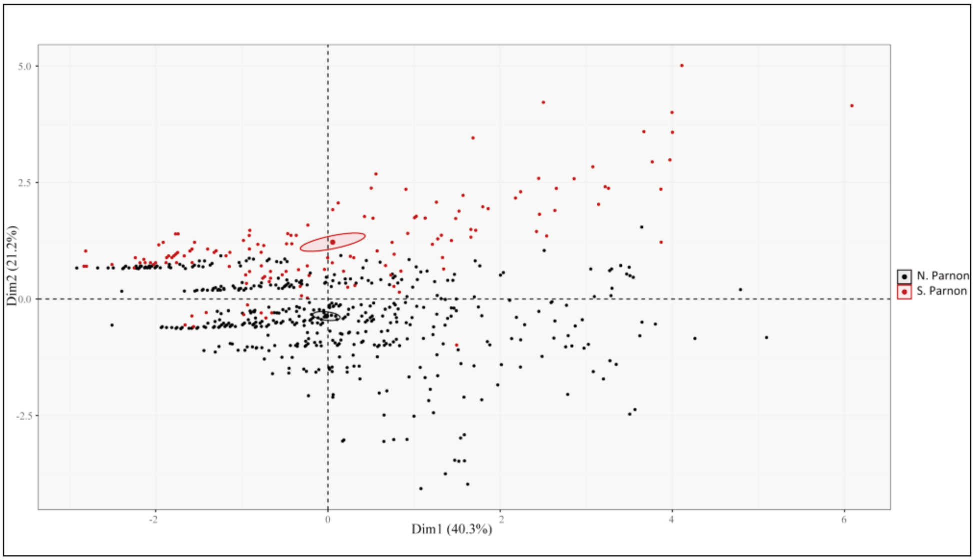

Fig. 5. FAMD plot with the variables used: 1) canopy height 2) mean DBH 3) gender and 4) number of trunks. The red dots represent the individuals on the south part of Mt. Parnon and the black dots the individuals on the north part. The 95% confidence ellipses are also presented.

ogy and regeneration that have to be answered (Maerki & Frankis 2015). In this study, for the first time to our knowledge, tree growth traits (DBH, canopy height, canopy base height, number of trunks and gender ratio) are investigated in the *J. drupacea* European populations, at the westernmost part of the species distribution range, in Mt. Parnon (Peloponnese, Greece).

On the basis of extensive field surveys, the structure of *J. drupacea* populations was revealed to follow two distinct patterns in the northern and the southern part of Mt Parnon, respectively. This clustering was confirmed by Factor Analysis of Mixed Data and shows a clear differentiation in number of trunks per individual, trunk diameter at breast height (DBH), canopy height and tree gender.

According to our analysis, *J. drupacea* individuals from the southern monitoring plots were larger in diameter (thicker) measured at breast height, when compared to the northern-recorded ones. In the former area, the majority of Syrian juniper individuals are carrying just one and single trunk, indicating that the above juniper trees are undoubtedly of older age, at least 75 years old. Based on the preliminary interpretation of the existing, old aerial photographs (1945) of the study area, we conclude that the majority of the northern monitoring plots were agricultural land in the past and have been recently forested.

The overall mean canopy height was less than 7.2 m, always a lower value compared to the upper canopy height limits, e.g. 18-25 m, reported elsewhere (Boratynski & al. 1992; Yucedag & al. 2021); taller trees were isolated and located on the underside of the Malevi Monastery. Absolute canopy height values were in agreement with earlier surveys (Boratynski & Browicz 1982; Bergmeier 2002) and quite similar to those reported for the eastern Mediterranean Syrian juniper populations (Douaihy & al. 2017).

Furthermore, the number of measured trunks per individual varied between the two populations, with the multi-trunked individuals dominating the northern populations. Multiple trunks is apparently a trait inherent to *J. drupacea* (and other juniper species) and this is corroborated by the fact that the northern area has been under strict protection for over 40 years now while the southern one has been probably affected by land management history, particularly grazing (and wildfires, to a lesser extent). In addition, the number of trunks per individual affected negatively the mean diameter at breast height of the Syrian juniper trees, which probably can be explained by the allocation of individual tree growth resources into several trunks (Bui & Leoncini 2021). Plot altitude seems to affect the individual tree growth conditions; higher plot altitudes show a negative effect on both canopy height and DBH, probably due to the particular site quality, competition among plants, limited soil depth and local microclimatic conditions as well (Coomes & Allen 2007; Wu & al. 2015; Zheng & al. 2021).

The statistically significant positive correlation between the trunk number and the canopy height, as well as the canopy base height probably indicates the strong competition between the multiple trunks for light or nutrients, e.g. as proved in various understorey trees (Koop 1987; Del Tredici 2001; Tanentzap & al. 2012), without any dominant or secondary trunk clearly still observed in our surveys.

Regarding the gender ratio, more female individuals were observed in the southern monitoring plots with males being dominant in the northern part of the mountain. A deviation from the theoretical gender ratio of 1:1 was recorded in both European populations and indicated, to a lesser extent, in the Lebanese populations as well (Douaihy & al. 2017). Biased sex ratio, e.g. in other junipers, might be associated both to the greater reproductive costs by females and the past land management history as well (Ward 1982), or strongly affected by elevation, with males favored in higher altitudes (Ortiz & al. 2002). Patterns of natural selection on sex ratio may be affected by the quality and stability of the immediate habitat, as well as by life-history traits, competition and dispersal; environmental effects, both temporal and spatial, can also create a biased sex ratio (Sapir & al. 2008). The contribution of juvenile (young, non-reproductive trees without cones) or unidentified individuals varies greatly between the northern and southern plots of Mt. Parnon (27% and 59%, respectively) thus being dominant in the latter case. When all junipers recorded, i.e. both juvenile and mature individuals, the overall tree density corresponds to quite dense thickets, accounting for more than 850 trees/ha in the old, mature juniper forest, with even higher values (> 1000 trees/ha) in the abandoned but forested old fields, with slight density variations observed from north to south distribution of the species. Finally, the most part of the northern section of Mt. Parnon has been designated as a Preserved Monument of Nature (Government Gazette 121/D/21-2-1980) more than forty years ago, which probably influenced juniper tree density and regeneration. On the other hand, the strongly affected by overgrazing southern part, was much more sparsely colonized, and quite recently (since 2012) protected by the Greek Law and Authorities.

In conclusion, further scientific knowledge is necessary, enhanced by field surveys and laboratory studies, which is expected to contribute to the conservation of biodiversity on the fragile and endangered, by a number of threats, mountainous forest ecosystems of Mt. Parnon. In addition, introducing forest management plans on the Syrian juniper conservation in the Mediterranean Basin (e.g. Tahlouk & al. 2001) are of particular interest for the protected areas of the European Natura 2000 network, thus offering new knowledge for the Greek forests in the future.

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Addresses of the authors:

Evangelia N. Daskalakou[1]*, Spyridon Oikonomidis[1,2], Stefanos Boutsios[1], Kostas Ioannidis[1], Costas A. Thanos[2]

[1]Institute of Mediterranean & Forest Ecosystems, Hellenic Agricultural Organization - ELGO "DIMITRA", Terma Alkmanos, Athens 11528, Greece, E-mails: edaskalakou@fria.gr, stboutsios@gmail.com, ioko@fria.gr

[2]Department of Botany, Faculty of Biology, National and Kapodistrian University of Athens, 15784 Athens, Greece. E-mails: soikonomidis@biol.uoa.gr, cthanos@biol.uoa.gr

*Corresponding author