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Ecological assessment of *Juniperus turbinata* Guss. forest on the Strofades Islands, Ionian Sea, Greece

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Abstract

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The Strofades Islands form part of the National Marine Park of Zakynthos. *Juniperus turbinata* Gussone (syn. *Juniperus phoenicea* Linnaeus) forests are one of the few remaining high forest forms in Mediterranean. Here, the ecological status and the state of forest regeneration on the Strofades were evaluated to contribute information to their preservation. Seventeen sampling sites were established in the most representative locations. Fourteen sites were dominated by *J. turbinata*, while the predominant species was *Quercus coccifera* Linnaeus, accompanied by *Phillyrea latifolia* Linnaeus and *Pistacia lentiscus* Linnaeus, in the remaining three sites. Our results showed the presence of poorly formed juniper populations dominated by individuals with multiple trunks and rotting heartwood. Various factors contributed to the absence of regeneration, including poor soil, rocky substrate and grazing activity by a large number of free ranging goats. The broadleaf evergreen species dominated over *J. turbinata* along the juniper forest boundaries. Our results demonstrate that broadleaved shrubs are favoured, limiting the regeneration of juniper, stressing the importance for implementing forest conservation measures and expanding our knowledge about juniper regeneration processes.

Keywords: protected area; ecological status; growth trees; regression model

Ecological significance and distribution of *Juniperus phoenicea* Linnaeus forests. *J. phoenicea* is a small evergreen tree or shrub with a maximum height of 12 m (You et al. 2016) that is widely distributed across the Mediterranean region, from the Canary Islands and Atlas Mountains of Africa in the west, to Jordan and Saudi Arabia in the east (Dzialuk et al. 2011; Sanguin et al. 2016). This species is also abundant in the Balkan Peninsula, including Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Romania and Greece, as well as Cyprus (Tsiourlis et al. 2016). Despite its wide distribution in the Mediterranean (Alrababah et al. 2007), it is absent in Syria, Lebanon and Palestine (Zohary 1973).

This helio-thermophilous species is native to the Mediterranean basin, exhibiting tolerance to dry and warm climates and extreme adverse conditions (Mathaux et al. 2016). It is mostly found at low to mid elevations and south-facing slopes (Hammi et al. 2010). The co-occurrence of Juniper with other thermo-Mediterranean forest taxa (*Pinus sylvestris* Linnaeus, *Pinus pinaster* Aiton, and *Quercus* spp.) dates back to the Pleistocene in the Iberian Peninsula (Marreiros, Bicho 2013). Fruit and leaf fragments of juniper were identified from the Bronze Age in the extreme insular environment of the Balearic Islands (Formentera islet) probably belonging to the *J. phoenicea* subsp. *turbinata* (Gussone) Nyman (Sureda et al. 2017).

In Spain, this species is found in a variety of states, including isolated patches (Gómez-Rodríguez et al. 2010), natural forests with *Quercus ilex* Linnaeus and *Pinus nigra* J.F. Arnold at 1,400–1,800 m a.s.l. (Miralles et al. 2009) and chaparral-like bushlands with *Q. ilex* subsp. *rotundifolia* (Lamarck) Tab. Morais at 900 m a.s.l. It is usually found on limestone (Miralles et al. 2007) or in Mediterranean matorral at 500–600 m a.s.l. It is a typical species of the continuously grazed garrigues of eroded soils and semi-arid Mediterranean climate (López-Bermúdez et al. 1998). In Portugal, it is found at elevations of 280 m in plant communities of evergreen sclerophyllous species and drought-tolerant semi-deciduous species (Werner et al. 2001).

In Israel, it is found in remnants of the Mediterranean climax maquis of the *Pistacio palaestinae-Quercetum calliprini*, at high elevations of 1,400 to 1,600 m a.s.l. (Zohary 1973; Weinstein-Evron 1987). In Sardinia, it is a component of maquis vegetation at low elevations (Morillas et al. 2017).

In Greece, its populations belong to *Juniperus turbinata* Gussone (Adams et al. 2013; Dimopoulos et al. 2016; Mazur et al. 2016, 2018). *J. turbinata* (syn. *J. phoenicea*) individuals are mainly found scattered or in small assemblages on the rocky slopes of open woods in pure or mixed populations (Milios et al. 2007) and on sandy areas with degraded and shallow soils (Quézel et al. 1992), which are considered too hostile for the establishment of more competitive forest species. Arboreal formations of *J. turbinata* are rare in Greece, as it forms mainly bushes (Quézel, Médail 2003). This species is distributed across an altitudinal range of 0 to 400 m a.s.l., usually in Central Greece, the Peloponnese, the Aegean Islands (Tzanopoulos, Vogiatzakis 2011), Crete and, to a lesser extent, the Ionian Islands. When *J. phoenicea* occurs in protected areas, it serves as an indicator species of changing environmental conditions (Kabiel et al. 2016), providing information for addressing ecological questions, especially in remote, small island ecosystems (Hegazy et al. 2008; Tzanopoulos, Vogiatzakis 2011), particularly when knowledge on landscape dynamics is sparse.

J. turbinata (syn. *J. phoenicea*) only occurs in its natural forest form (6–11 m tree height) in a few areas in Greece, including the Strofades Islands in the Ionian Sea. The Strofades is a remote ecosystem of oceanic type, which is of particular ecological interest. In particular, long-term land use, mainly in the form of grazing, along with forest thinning and clearing, have been practiced there, leading to the existence of a forest remnant within an insular National Park. Today, this remnant is composed of *J. turbinata* habitat.

Aims of the study. The present study aimed to assess the ecological state of *J. turbinata* (syn. *J. phoenicea*) present in the isolated mixed forest of the Strofades Islets and to contribute to the conservation of this forest remnant that is of high ecological value. We focused on the growth rate of juniper individuals and the mapping of forest cover to provide preliminary data in relation to the landscape dynamics of the studied islands.

Thus, the objectives of this study included: (*i*) high resolution mapping of the land cover categories of the islets to identify the current distribution of *J. turbinata* forest patches in relation to other coexisting evergreen broadleaved tree species, (*ii*) assessing the structure and ecological status of the forests on the islets, with particular emphasis on *J. turbinata*, (*iii*) evaluating the relationship between tree growth (diameter and height) and the age of the species.

MATERIAL AND METHODS

Study area. The Strofades Islands (37°14'4596'', 21°0'4788'') are situated 27 miles south of Zakynthos Island and 27.5 miles west of the Peloponnese peninsula (Fig. 1). These islands encompass many islets, but two are the largest: Stamfani Island or Large Strofadi, with an area of about 1.2 km^2, and Harpie Island, covering approximately 0.165 km^2 (Fig.1). Nine land cover categories are mainly distinguished for these islands (Fig. 1), the built area, areas covered by juniper forest (*Juniperus* Linnaeus), areas covered by broadleaved species (broadleaves), areas covered by brushwood-

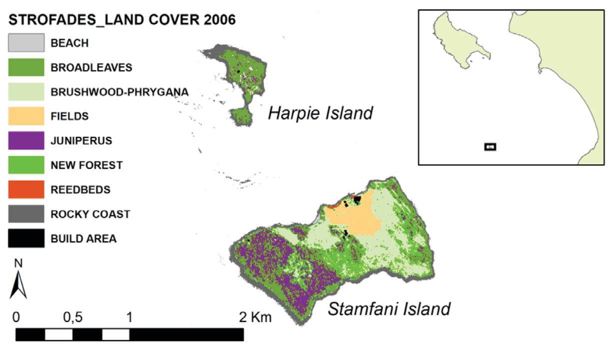

Fig. 1. Location of the Strofades Islands in the Ionian Sea; land cover is categorised as build area, *Juniperus* Linnaeus, broadleaves, brushwood-phrygana, new forest, fields, reedbeds, beach, and rocky coast

phrygana, areas of forest regeneration (new forest), fields, reedbeds, beach, and finally rocky coast.

The highest altitude of the islands is approximately 20 m a.s.l. The climate is Mediterranean, with the wet season lasting from October to March and the dry season from April to September. The Strofades Islands have been part of the National Marine Park of Zakynthos since 1999, because they contain valuable terrestrial and marine biotopes of high biodiversity.

Field recording. To analyse the structure of the *Juniperus* forest, 20 sampling plots (of 10 m radius) were initially delineated on the Island of Stamfani "Megalo Strofadi" only, where the forest forms more old structures. Plots were randomly selected in the vegetation class with a minimum distance of 100 m among plots, with the exclusion of the regions in the New Forest category. Finally, 17 sampling plots were surveyed, as for 3 plots was not possible to be accessed due to very dense vegetation. 14 sampling plots were surveyed in the central and western part of Island of Stamfani, where the Juniper forest dominates and 3 in the eastern part of the island, where *Quercus coccifera* Linnaeus and *Phillyrea latifolia* Linnaeus are the predominant species. Field data were collected according to a specific protocol designed for this study.

Forest structure was analysed based on forest inventory methods and analysis (Forest Inventory and Analysis – FIA) and ForestBIOTA, with some modifications. In the field, 14 variables were recorded: geographical coordinates of the area, soil condition, erosion and depth – soil depth categories were assigned based on a three-fold scale: surface/shallow (< 2 cm), medium (2–10 cm) and deep (> 10 cm) (FAO 2006), rock and vegetation coverage, vegetation layers, coverage of main species, DBH, tree height, increment cores (to estimate the annual growth and the age of trees) and regeneration. Furthermore, the effects of grazing or other anthropogenic activities were assessed (Jovellar Lacambra et al. 2013). The density of coexisting species was estimated in each quadrat of each plot.

To estimate the age of the trees, an increment borer (Pressler, Sweden) was used, and increment cores were taken from three *J. turbinata* trees nearest to the centre of the plot, at breast height. The increment cores were processed and the annual rings were measured using a stereoscope in the laboratory, to determine the annual growth and the age of the trees.

Analysis of field-recording data. To evaluate the health of the forest, growth parameters (diameter and height) and age were analysed using the R environment. The Age variable was reclassified into three age classes (class 1: < 100 years, class 2: 100–150 years, class 3: > 150 years) to evaluate the differences of height and breast diameter among age classes using ANOVA at 0.05. Means were separated by using the Tukey-Kramer honestly significant difference (HSD) test. In addition, the relationship between the age and diameter of *J. turbinata* was evaluated with a linear model to generate an allometric equation between the age of juniper trees and their diameter.

RESULTS

Analysis of forest status

Analysis of vegetation shows that the forests of the Strofades (Stamfani Island) have two forms: (*i*) in which *J. turbinata* is dominant, with a mean cover of 64% and broadleaved species covering 36%, (*ii*) in which juniper is entirely absent and broad-leaved evergreen species are dominant. The juniper forest is located on the south-western and western sides of the island of Stamfani, and the percentage of juniper cover within the 14 plots studied in this area ranged from 30 to 70%. In almost all plots, *P. latifolia* and *Pistacia lentiscus* Linnaeus were present with a high percentage of cover (over 20%), while species like *Myrtus communis* Linnaeus and *Olea europea* var. *sylvestris* (Miller) Lehr were rare with lower (5–10%) percentage cover. In three sampling plots (14, 15, 16), *Q. coccifera* (50%), *P. latifolia* (20%) and *P. lentiscus* (20%) were recorded. In these sampling plots, *J. turbinata* had 5% cover. A significant percentage of climbing species *Smilax aspera* Linnaeus was recorded in all sampling plots (Table 1).

The absence of regeneration or low abundance of saplings was recorded in the juniper forest. In 12 out of the 17 plots, regeneration was completely absent. In comparison, in four plots (2, 3, 6, 7), regeneration did not exceed 5%. All other broadleaved evergreen species that coexist with juniper appear to exist in a better state, with higher rates of regeneration (Table 2). Based on three-fold scaling, the soil was shallow or medium in depth. Dead trees of *J. turbinata* were measured in all sampling plots (Table 3), and a very significant correlation was found between the mean diameter of juniper trees and the number of dead trees – dead trees standing or fallen on the ground ($r = 0.646$; $P < 0.01$). Overgrazing was evident in all sampling plots.

Table 1. Species cover (%) in the sampling plots

Plot	*Juniperus turbinata* Gussone	*Quercus coccifera* Linnaeus	*Phillyrea latifolia* Linnaeus	*Pistacia lentiscus* Linnaeus	*Olea europea* var. *sylvestris* (Miller) Lehr	*Myrtus communis* Linnaeus	*Rhamnus alaternus* Linnaeus	*Smilax aspera* Linnaeus
1	70	0	25	20	0	0	0	20
2	65	0	20	15	0	0	0	5
3	40	0	50	15	0	0	0	15
4	35	0	60	10	0	0	0	5
5	60	0	20	20	0	0	0	5
6	40	0	20	15	10	10	5	10
7	70	0	25	20	0	15	0	5
8	40	0	25	50	0	20	0	10
9	40	0	20	4	0	0	0	40
10	50	0	30	5	0	10	0	5
11	30	0	40	25	0	10	0	20
12	45	0	40	20	0	0	0	30
13	30	40	30	15	0	0	0	5
14	0	50	20	20	10	5	0	10
15	0	60	0	20	0	0	0	20
16	5	50	20	25	0	5	0	20
17	70	5	10	25	0	10	0	5

Table 2. Regeneration of the forest sampling plots

Plot	Regeneration (%)						Tree height (m)	Herbaceous plant (%)	Total vegetation cover (%)
	Juniperus turbinata Gussone	*Quercus coccifera* Linnaeus	*Phillyrea latifolia* Linnaeus	*Pistacia lentiscus* Linnaeus	*Myrtus communis* Linnaeus	*Smilax aspera* Linnaeus			
1	0	0	0	5	0	0	8	5	90
2	5	0	5	5	0	5	7.5	10	70
3	5	0	5	5	0	5	7	5	80
4	0	0	1	0	0	0	7.5	0	85
5	0	0	10	5	0	5	11	5	70
6	5	0	15	5	10	10	6.5	70	80
7	5	0	10	12	8	10	6	60	75
8	0	0	5	10	10	5	6	5	80
9	0	0	0	0	5	50	8.5	5	60
10	0	0	0	0	5	7	7.2	5	80
11	0	0	0	25	15	30	9	5	100
12	0	0	0	5	0	5	10.5	5	80
13	0	25	5	5	5	0	8	20	80
14	0	40	5	5	0	5	7.5	50	90
15	0	40	0	5	0	10	6.5	30	70
16	0	35	5	5	0	10	6.4	10	70
17	20	0	0	3		10	5.2	20	80

The analysis of the height and diameter of trees showed that tree height ranged from 6 to 11 m (mean = 7.45 m, standard deviation = 1.34 m), while the DBH ranged from 14 to 49.8 cm (mean = 28.05 cm, standard deviation = 9.51 cm) (Table 4). The height of *Q. coccifera*, *P. lentiscus* and *P. latifolia* ranged from 5.2 to 7.5 m, with *P. lentiscus* species being mainly recorded in the high-shrub form.

Tree age and annual tree growth (DBH)

Overall, the age of 28 *J. turbinata* trees was estimated using tree ring analysis, which showed a mean age of 121.3 ± 38.5 (standard deviation) years, ranging from 30 to 180 years. A relatively constant decreasing trend of annual tree growth was observed, with the first four decades of aver-

Table 3. Variables measured in the forest plots

Plot	Ecological state (%)			Soil depth	Soil erosion	No. of dead trees	Grazing
	cover dead leaves	moss	rock				
1	70	10	15	S	Mo	9	Mo
2	70	10	55	S	Mo	15	Mo
3	60	15	45	S	Mo	17	Mo
4	40	5	0	M	Mo	15	Mo
5	65	5	55	M	Mo	12	Mo
6	80	20	20	S	L	12	N
7	60	70	5	M	Mo	1	Mo
8	80	0	5	D	L	8	Mo
9	70	0	15	M	L	4	Mo
10	60	10	30	S	Mo	8	Mo
11	80	10	10	D	L	14	Mo
12	90	5	10	M	L	9	Mo
13	60	10	40	M	Mo	9	Mo
14	50	10	30	M	Mo	0	Mo
15	50	5	20	M	Mo	8	Mo
16	70	15	35	M	St	7	Mo
17	80	15	10	D	L	1	St

S – surface/shallow (< 2 cm), M – medium (2–10 cm), D – deep (> 10 cm), Mo – moderate, L – low, St – strong, N – none

age annual growth ranging from 0.8 to 1.4 mm for juniper, declining to 0.7 to 0.9 mm in the 5th decade. In the 7th and 8th decades, the average annual increase was 0.6 and 0.7 mm, respectively. Almost all individuals of 120 to 130 years had rotting heart wood, with it not being possible to estimate the age of trees older than 130 years (Fig. 2).

Table 4. Mean and standard deviation (SD) of DBH and height

Species	DBH (cm)		Height (m)	
	mean	SD	mean	SD
Juniperus turbinate Gussone	28.05	9.51	7.45	1.34
Quercus coccifera Linnaeus	27.58	8.63	6.15	1.24
Phillyrea latifolia Linnaeus	17.95	8.08	6.26	0.91

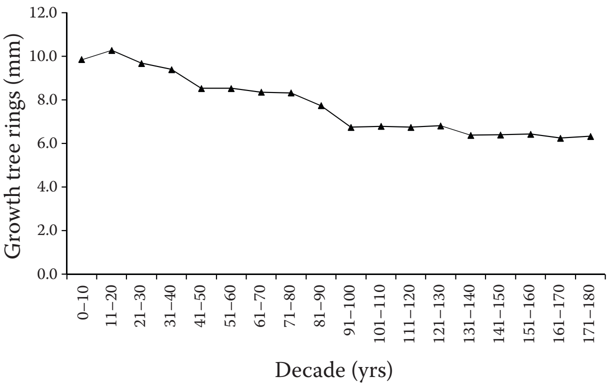

Fig. 2. Average growth rate of *Juniperus turbinata* Gussone per decade in the study area

Relationship between diameter and age

Three age classes (class 1: < 100 years, class 2: 100–150 years, class 3: > 150 years) were created to evaluate forest growth with age (diameter and height). The DBH of the trees significantly differed among age classes ($F_{2, 25}$ = 30.62, P < 0.001), with a highly significant difference being observed among all classes, showing a constant increase with age (Fig. 3). The main difference was observed between the 1st and 3rd class (Tukey HSD = 17.6, P < 0.001), followed by the difference between the 1st and 2nd class (Tukey HSD = 8.9, P < 0.001) and the2nd and 3rd class (Tukey HSD = 8.7, P < 0.01). Tree height changed significantly with the age ($F_{2, 25}$ = 12.02, P < 0.001). The height in the 1st class was significantly lower than that in the 2nd class (Tukey HSD = 19.5, P < 0.001) and the 3rd class (Tukey HSD = 26.45, P < 0.001), while the height of the 2nd and the 3$_{rd}$ class did not differ significantly (Tukey HSD = 6.95, P > 0.05) (Fig. 4).

The linear regression of age versus diameter produced a significant model ($F_{1, 26}$ = 128.9, P < 0.001, R^2_{adj} = 0.88257), with the form: age = 26.8546 + 4.1143 × diameter. The residuals of the model were close to the fitted model (median value = 1.6, 1st quantile = –9.8 and 3rd quantile = 8.9 years), while three outliers of residuals (–20.8, –29.6 and 47.8) were found in trees that were more than 150 years old (Fig. 3).

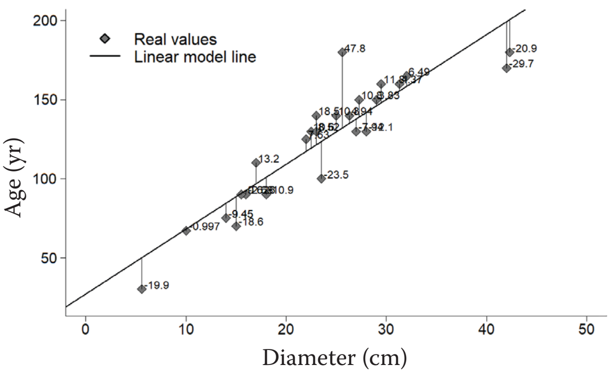

Fig. 3. Regression model of age versus diameter of *Juniperus turbinata* Gussone

numbers – residuals from the fit model line

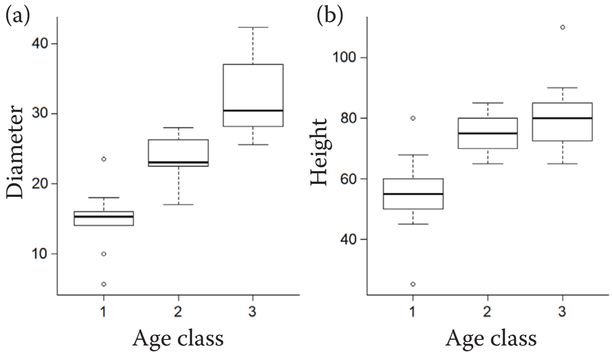

Fig. 4. Box plot of the distribution of *Juniperus turbinata* Gussone diameter (a) and height (b) for the three age classes (1: < 100 years, 2: 100–150 years, 3: > 150 years)

DISCUSSION

Vegetation assemblages

In our study area, pure forests of *J. turbinata* (syn. *J. phoenicea*) no longer dominate, as the species forms mixed assemblages with broad-leaved evergreen species that tend to replace pure juniper forest stands, indicating a potential gradual shift to mixed forest types. Similarly, Werner et al. (2001) and Benelli et al. (2017) reported mixed assemblages of *J. phoenicea* with broad-leaved species, such as *Q. coccifera*, *Arbutus unedo* Linnaeus, *M. communis*, *Juniperus oxycedrus* Linnaeus, *O. europaea* var. *sylvestis*, *P. latifolia*, *Phillyrea angustifolia* Linnaeus, *P. lentiscus*, *Erica* spp., *Cistus* spp. and *Rosmarinus officinalis* Linnaeus, at low elevations. Such assemblages are also described in insular ecosystems. For instance, along the southern coasts of Sardinia, *J. phoenicea* co-occurs with *O. europaea* var. *sylvestris*, *M. communis*, *P. lentiscus*, *P. latifolia*, *P. angustifolia* and *Euphorbia dendroides* Linnaeus in climax thermoxerophilous maquis formations (Kabiel et al. 2016). In the small remote island of Pianosa (Tuscany), *J. phoenicea* is dominant, along with *R. officinalis* and *Cistus* spp. (Vaccari et al. 2012).

The total mean vegetation cover and density of the juniper habitat on the Strofades Islands was 79.3%, while the mean juniper cover was 64%. Similar results were recorded in a National Reserve of northwest Sardinia, with juniper density representing 53% of the total vegetation cover of the forest area (Morillas et al. 2017).

Regeneration, tree age and degradation

The absence of natural regeneration was observed in the largest part of the area covered by *J. turbinata* forest, while at the forest edges that are exposed to light, evergreen broadleaved photophilous Mediterranean species have begun to dominate.

The poor conditions (soil-poor) for trees and the dominance of water-permeable limestone substrate might be related to the limited availability of water and the lack of regeneration (Danin 1978). In addition, in the study area, grazing activity by goats is intensive, which is an important factor that is often associated with the absence of regeneration. Goats eat the younger parts of juniper plants before consuming the older parts, and, in many cases are effective at controlling juniper. In comparison, Pritz et al. (1997) support that the presence of essential oils on *J. phoenicea* repel animals from grazing. Rogosic et al. (2009) suggested that *J. phoenicea* is largely preferred in the diet of goats, due to the high terpene content. On Stamfani Island, there are over than 150 free ranging goats, with grazing being intensively practiced in the studied area for many decades.

The data collected by this study, combined with historical data (Anetti 1842), show that forest thinning and cleaning were regularly practiced in the past, favouring the regeneration of the highly photophilous *J. phoenicea* (Kabiel et al. 2016). The degeneration of *J. phoenicea* primary forests to shrubs has also been described in Tunisia following over-exploitation, such as clearing and grazing (Ben El Hadj Ali et al. 2012).Today, the management status of the remote island cluster of the Strofades, which is part of the National Marine Park of Zakynthos, is the protection of this juniper forest without particular management measures being implemented. The only management measures concern the protection of avifauna from illegal hunting during the migration period (from spring to autumn).

In the study area, *J. turbinata* shows growth with multiple trunks. According to Magdy et al. (2010), this species presents the same form in the Desert Mountains of North Sinai, Egypt. Mature trees are not robust enough, resulting in their retaining dead branches. In many cases, individuals are stifled by *S. aspera*. Similar findings have been reported for *Juniperus excelsa* M. von Bieberstein forests by Milios et al. (2007). Concerning the regression model of age versus diameter of *J. turbinata*, a relationship between tree age and diameter was clearly identified. This model could be a useful tool because it is difficult to assess the age of junipers because this species produces discontinuous growth rings.

CONCLUSIONS

The rare ecologically-valued monument-forest of *J. turbinata* (syn. *J. phoenicea*) in the remote Strofades Islands of the Ionian Sea exhibit evidence of degradation, mainly due to grazing pressure, the existing rocky and permeable substrate, the lack of soil and, probably, the presence of more competitive species, which might hinder the natural regeneration of juniper. The results of the survey showed that, despite evidence of degradation, the juniper forest continues to grow. Therefore, further investigation is needed to develop integrated conservation management. For instance, a cohesive scheme of progressive regeneration with the partial exclusion of grazing, and monitoring of the ecological status of juniper trees with the cooperation of local and regional authorities, research institutes and local society. Future planning should focus on measures such as the establishment of permanent research sites for monitoring the regeneration potential of *J. turbinata*, and the probable expansion of broad-leaved evergreen species competing with *J. turbinata*. On the Strofades Islands, we have already installed a meteorological station to monitor and research whether the ecological status of the juniper forest is correlated with climate change.

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