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SHORT COMMUNICATION

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Characterization of the Spanish juniper population of El Peñón de Alamedilla (Granada, Spain): conservation status and protection proposal

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Abstract

Aim of study: To characterize the southernmost Spanish Juniper (*Juniperus thurifera* L.) population in Europe, a relict species of the tertiary flora.

Area of study: El Peñón de Alamedilla, Los Montes region (Granada, Spain).

Materials and methods: A census and geo-referencing of the individuals in the population was carried out, together with the determination of the population structure, inference of the potential extension of the population, and discussion of the risk faced by the population.

Main results: A total of 899 individuals were located in mainly 128 ha from 806 to 888 m a.s.l. We found 50.6% adults, 35.7% saplings and 13.6% juveniles. Sexing on the adults showed a 60% of male feet compared to 39.1% of females (0.9% undifferentiated). 47% of the population has a basal diameter less than or equal to 50 mm. A 74.11% of the population was in grasslands + scrubs, and only 5.3% of the specimens were in arable lands. All individuals are on privately owned land.

Research highlights: The characterization of this southernmost Spanish Juniper population suggests a good viability and resilience, though there is also a high risk of inbreeding, with the population being able to go into genetic drift, which is critical for successful reproduction and may easily jeopardize its conservation efforts. This species is not protected enough in Andalusia and conservation measures should be taken.

Keywords: *Juniperus thurifera*, SE Iberian Peninsula, relict population, Natura 2000 Network.

Authors' contributions: FB Navarro and MN Jiménez devised the work. JA Vílchez and JM Marruecos carried out the fieldwork. FB Navarro, MN Jiménez, and JA Vílchez reviewed and wrote the manuscript.

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Introduction

The Spanish juniper (*Juniperus thurifera* L.), is a long-life evergreen species belonging to the Cupressaceae family, with a height between 4 and 12 meters and a diameter measured at breast height (DBH) that rarely exceeds 1 m (López, 2001). The species is unisexual dioecious and shows alternate bearing, although monoecious individuals can be found (Montesinos, 2007). Pollination is anemophilic and the seeds are wrapped in fleshy galbules or arcestids mainly dispersed by birds. It is an endemic species of the western Mediterranean with a wider distribution during the cold stages of the Pleistocene. The most abundant populations are found in the Iberian Peninsula (Appendix A1 [suppl.]) spreading throughout the North Plateau, the Iberian System, the mountains of the southeast of the South Plateau and the northeastern section of the mountains of the Iberian southeast, usually between 800 m and 1600 m above sea level. Towards the Iberian southeast, the populations become scarce and composed by small groups of individuals or even isolated trees in the mountains and highlands of Albacete, Murcia, Jaén, Granada, and Almería provinces (Gómez Manzaneque *et al.*, 2000; Lorite *et al.*, 2000; Ferrández, 2003; Alonso *et al.*, 2010; Caudullo *et al.*, 2017). In the province of Granada there are populations and individuals scattered to the NE (Huéscar and Puebla de Don Fadrique Municipalities), in addition to the population that concerns us in this work, El Peñón de Alamedilla located in the region of Los Montes. The latter turns out to be the southernmost population in Europe, only surpassed to the South by a splendid and isolated male individual, the

Spanish juniper from the Llanos de Olivares (reported by J. Del Río in 2007) in the Municipality of Gorafe (Granada) (Appendix A1 [suppl.]). This scattered distribution in the Iberian SE may be due to several factors: competition with other more resilient species (Quercus spp. or Pinus spp.), the historical human pressure due to its prized wood, and especially the successive changes in the climate since it can be considered a relict species of the tertiary flora (Costa *et al.*, 1987; Gómez Manzaneque *et al.*, 2000; Ferrández, 2003; García & Allué, 2005; Montesinos, 2007). Modeling made with MaxEnt by CIFOR-INIA [Adecuación y distribución de especies forestales españolas (inia.es)] evidence that the potential distribution of this species is mainly relegated to the surrounding mountains (Sierra de Mágina, Sierra de Baza, North Sierra Nevada, Sierra de María, etc.) leaving the current populations of the Iberian SE completely outside the phytoclimatic area of 'high viability' showed for the Iberian Peninsula by García & Allué (2005). Also, the climatic projections made by Felicísimo *et al.* (2012) show migrations of these potential areas towards refuges in the north of the Iberian Peninsula at the end of this century. The population of El Peñón de Alamedilla was already known by technicians and researchers (Gómez Manzaneque *et al.*, 2000; Lorite *et al.*, 2000), but there is no characterization study of the southernmost relict Spanish-juniper grove of the Iberian Peninsula and Europe. Its importance lies in constituting a genetic reservoir of the species in the south of the Iberian Peninsula with unknown local adaptations, which could be useful for the conservation of the species in the climate change scenarios. The objectives were determining the population size and structure, including sex and ages ratios, and proposing management practices facing the protection and conservation of this singular population.

Material and Methods

Description of the study area

The Spanish juniper grove of El Peñón de Alamedilla is located in the Las Cañadas area, located in El Peñón, a dispersed nucleus of the Alamedilla municipality, Los Montes Region, Granada province (Spain) (Fig. 1). The area is a temporary hydrological basin with an altitude range between 750 m and 1000 m. Soils are calcareous lithosols and regosols, the average annual temperature 14.9ºC, and average annual rainfall is 355 mm (Appendix A1 [suppl.]). The area is located in the Guadiciano-Bacense biogeographic sector (Guadiciano-Bastetano District) of the Baetic province, Mediterranean region, and the bioclimate is the semi-arid mesomediterranean (Rivas-Martínez & Loidi, 1999). Two series of potential vegetation converge in this area, the Mediterranean basophilic holm oaks serie (*Paeonio coriaceae-Querceto rotundifoliae Sigmetum*) and the semi-arid pine groves-kermes oak serie (*Rhamno lycioidis-Querceto cocciferae S.* faciation with *Ephedra fragilis*) (Valle, 2004). The current vegetation at the area is based on a mixture of species from both series, with a predominance of *Pinus halepensis-Quercus coccifera* forests with scattered *Quercus ilex* subsp. *ballota* and *Juniperus thurifera*. Ancient land uses had been cereal crops with associated grazing, continuing with no major changes to date. We can find also degraded areas that were previously cultivated lands, which were progressively abandoned since the 1950s. For a few decades, the cultivation of the olive tree has become important, and recently the almond and pistachio.

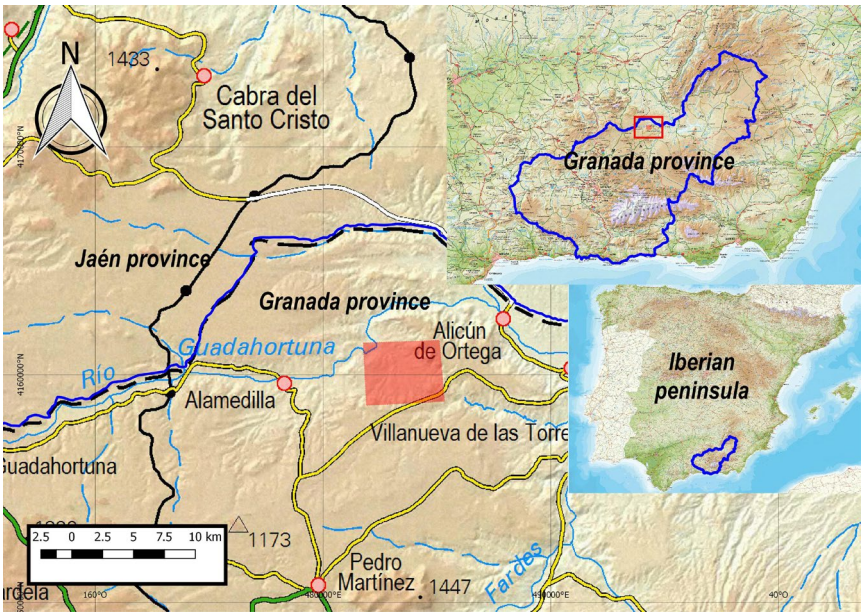

Figure 1. Demarcation of the geographical location of the study area (red box), and Granada provincial boundary (blue).

Monitoring and characterization

The population has been recorded by foot on a series of field trips undertaken from 11/04/2018 to 06/09/2019. Sampling areas were delimited and checked to locate all the individuals. In addition, a search for individuals outside the main group of El Peñón de Alamedilla by interviews with residents of the area was carried out. The individuals were georeferenced to know their location using UTM coordinates in the WGS84 Datum. For this, the UTM GeoMap software was used. The obtained coordinates were digitized in a digital cartography using Quantum GIS software (QGIS). The basal diameter of the trunk was measured as an indicator of the age of the individuals, and although the relationship will not be completely linear since the juniper species have a very irregular growth in semi-arid environments, we can assume diameter as an indicator of growth throughout the life of the individual, and therefore its longevity (Génova & Sadornil, 2020). A forestry caliper with a range of 0 to 600 mm was used for basal diameter measurements and a digital caliper with a range of 0 to 15 mm was used for smaller individuals. Two perpendicular measurements were taken and the average was used in the analyses. Measurements recorded were divided into diameter classes of 50 mm. The shape, arrangement and changes in these classes will indicate disruptions in population recruitment and its conservation status. During the development of the fieldwork a subsample composed of 490 adult individuals randomly selected were sexed (Fig. S1 [suppl.]). In this subsample the individuals were also classified by vegetative states (juveniles, saplings, and adults) following the criteria of Garitacelaya *et al.* (2006). Finally, we characterized the current land use in which the entire population settled, and the altitude above sea level of each individual was recorded. For this, we used the information layer of the Geographic Information System of the Common Agricultural Policy (SIGPAC) and the Digital Elevation Model (Instituto Geográfico Nacional, Gobierno de España, www.ign.es). Also, kriging analyses were carried out with the GIS software SAGA v. 2.3.2 (http://saga-gis.org), to identify the areas of origin of the current population (Appendix A1 [suppl.]).

Results and Discussion

Location and extension

The census resulted in 890 individual distributed in an area of approximately 128 ha (Fig. 2), plus 9 scattered

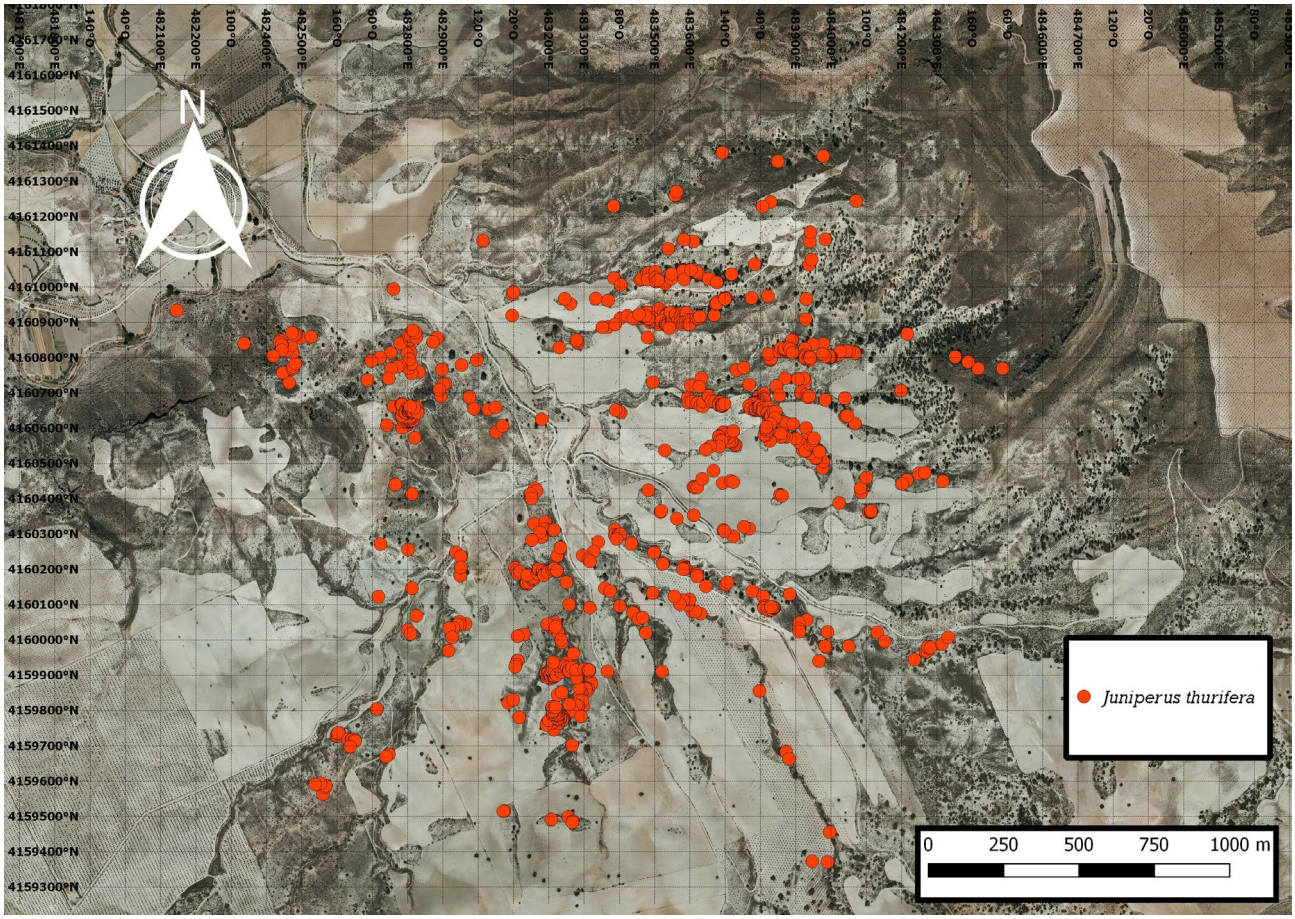

Figure 2. Distribution of the 890 specimens surveyed in the Cañadas del Peñón (Alamedilla, Granada).

Figure 3. Adult individuals 33, 53 y 747 inside or in the border of arable lands.

individuals in the Barranco del Molino, belonging to El Peñón, La Ronca, and a mature specimen with a group of saplings in Las Agüillas (Fig. S2 [suppl.]). These scattered individuals indicate a more extensive prior distribution, vestige of a larger population how it runs in other cases (Santos & Tellería, 2006). A percentage of 74.11% of the population was found in spaces categorized in SIGPAC as grasslands + scrubs (Fig. S3 [suppl.]), and only 5.3% of the specimens were in agricultural spaces (arable lands) (Fig. 3). All individuals are on privately owned land.

Characterization of the population

The distribution of individuals with altitude (Fig. A4 [suppl.]) is mainly concentrated from 826 m to 875 m above sea level, with a total range from 806 to 888 m a.s.l. and a mean value of 852 m a.s.l. The basal diameter indicates that 47% of the population has a diameter less than or equal to 50 mm (Fig. A5 [suppl.]). The values range from 0.6 mm to 750 mm, the mean value being 123 mm. We found a small fraction of individuals with a high diameter (and probably a high age), followed by individuals with intermediate diameters in a moderate abundance, and finally a very high group of individuals with smaller diameters. This distribution indicates a foundational effect from a small group of individuals (Bertaudière *et al.*, 1999; Bayo, 2003; Alonso & Pérez, 2003). The size of the first class diameter group (0-50 mm) may indicate successful recruitment events in recent times, possibly motivated by a change in environmental conditions, competition with other species or human pressures (Alonso & Pérez, 2003). In view of the data we can consider that this population, being at the limits of its distribution, maintains an adequate recruitment (Gastón, 2006). The population size registered is relatively high. In the southeast Iberian, populations rarely exceed one hundred individuals and regeneration is limited or non-existent. Therefore, we are faced with a population with a volume of individuals that suggests a good viability and resilience (Ferrández, 2003; Alcalde & Génova, 2006; Montesinos *et al.*, 2012). Regarding the classification of individuals by vegetative state, we found 50.6% adults, 35.7% saplings and 13.6% juveniles. Sexing on the adults of the subsample shows a 60% of male feet compared to 39.1% of females (0.9% undifferentiated). That generates a population structure skewed towards the male sex. The proportion of female feet found may be because females show a greater need for resources to generate the seeds (Roques *et al.*, 1984; Gauquelin *et al.*, 2002; Rozas *et al.*, 2009; Montesinos *et al.*, 2012). The deviation of the sex ratio 1:1 causes the seed production of the population to decrease, there is a higher rate of seed predation by arthropods, and therefore there is a reduction in dispersal and regeneration (Gauquelin *et al.*, 2002; El Alaoui El Fels & Roques 2006). This can also pose a high risk of inbreeding, with the population being able to go into genetic drift, which is critical for successful reproduction and may easily jeopardize its conservation efforts. In this sense, the sex ratio should be monitored over time in coming years. However, the results of sex ratio and population structure found can be considered antagonistic. The sex ratio indicates low recruitment rates due the few females while the diameter classes indicate that there is a good recruitment of individuals. This could be explained because this population is located at the distribution limit of the species, or because stochastic phenomena have taken place (Montesinos *et al.*, 2012). Based on the presence/absence of kriging analysis (Appendix A1 [suppl.]) we found 10 main nuclei. The kriging analysis based on the basal diameter indicates the areas with the highest concentration of individuals

with a high basal diameter, assuming that this diameter is approximately proportional to the age of the individuals. Therefore, it indicates the areas with the highest probability to be source areas. This is in accordance with the analysis of diameter classes related to a foundational effect from a small group of individuals.

Conservation status

Spanish juniper is not included in the Andalusian List of Threatened Species (CAEA) (Anonymous, 2012) despite that it is not an abundant species in this Region. It is relatively widespread in near Regions such as Murcia and Castilla-La Mancha, where it is protected. However, the species is included in the Red List of the Vascular Flora of Andalusia (Cabezudo *et al.*, 2005) as a Vulnerable species (VU B2ab (ii, iii, iv, v)) and in the geographic information system of the List of Endangered Flora of Andalusia (FAME), without category, considering this a step prior to be included as a protected species in the CAEA or in the Andalusian List of Wild Species in Special Protection Regime (LAESPE). No special plans are focused on its protection, beyond being considered a taxon of special interest by administrative technicians and scientists (Alonso *et al.*, 2010). In fact, this relict species of high geo-botanical interest shows similar status in terms of individuals or populations than other species, which are included in LAESPE, such as *Taxus baccata*, *Sorbus aria*, *Prunus mahaleb*, etc. (see more details about the conservation status in Appendix A1 [suppl.]).

Management proposal

The population of Spanish juniper can be considered a genetic reservoir to recover the species throughout the southeast of the Iberian Peninsula, whose potential distribution area is quite wide (Guadix-Baza-Huéscar plateaus, Vélez plateau in Almería and nearby xeric mountains). This population has potential to be recognized as a Genetic Conservation Unit (GCU) of the EUFORGEN programme (Lefevre *et al.*, 2013; Rudow *et al.*, 2020) and a 'seed source' for afforestation or translocation to other Spanish juniper areas where their local adaptations may be successful (Lorite *et al.*, 2000; Montesinos *et al.*, 2012). For all these reasons, it is proposed i) the inclusion of this population within a protection figure of the Network of Protected Natural Spaces or as SCI within the Natura 2000 Network, ii) collect enough and varied genetic material for its conservation in seed banks, iii) nursery grow of seedlings for their reintroduction in the area or the creation of new expansion areas, iv) acquisition of land for the protection of this juniper or establishment of contracts or agreements with private landowners to protect this juniper population, v) put in value the Alamedilla Spanish juniper population as a local resource, vi) include the Spanish juniper as a protected species in the List of Endangered Species of Andalusia or, failing that, in the Andalusian List of Wild Species under the Special Protection Regime.

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