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The Patriarch: a Canary Islands juniper that has survived human pressure and volcanic activity for a millennium

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Could a tree survive for centuries on an oceanic island under strong human pressure? And what if the island is subject to the recurrent activity of several volcanoes? The Canary Islands archipelago, in the North Atlantic Ocean, meets both conditions. These volcanic islands have been inhabited by humans for the last two millennia (del Arco et al. 1997) and currently are a major tourist destination (15 million visitors in 2016). Surviving here for centuries is certainly a real challenge for any tree, because in addition to usual volcanic activity, human arrival triggered extinctions of endemic species and disappearance of whole ecosystems. But unexpected things sometimes happen. The Teide National Park, in Tenerife Island, was declared in 1954 and includes several active volcanoes, the highest of which is named Teide and peaks at 3,718 m above sea level, just 15 km away from the shoreline in the midst of the island. Park managers, concerned with preserving and recovering Teide's native flora and fauna (Olano et al. 2017), are now directing their efforts to study the population dynamics and longevity of remaining Canary Islands junipers (*Juniperus cedrus* Webb. & Berthel.). Their aim is to discern whether these large shrubs, or small trees, were once able to form forests that could have covered the currently treeless landscape.

In October 2018, we spent 1 week in the Teide National Park sampling wood cores from Canary Islands junipers with the help of park managers and rangers. Our targets were junipers located at the foot of escarpments or in flat areas at higher elevation, but in any case, accessible by foot. One of these individuals was an apparently old tree located in a barren landscape on the edge of a lava flow, out of sight from roads and walking trails, and completely isolated from other junipers (Fig. 1). The tree has an extremely irregular and twisted trunk, with large dead portions and clear signs of wood rot. However, lateral sides still keep bark from ground to the top, allowing the tree to sustain a healthy canopy despite the large amount of rotten wood. Because of the venerable look of this tree, local people named it "The Patriarch," although it is actually a female with surprisingly prolific seed cone production. Given its potential fragility, we collected a single 5-mm-diameter core of 12.5-cm length with an increment borer from one of the alive sides, just until we found rotten wood. But since the trunk was much larger (up to 95 cm diameter), and we and the park managers were curious about how old that tree would be given its particular location, isolation and look, we also collected a small piece of wood from the central part of the stem to determine its age as exactly as possible by using ^{14}C. Dating was corrected considering the atmospheric $\delta^{14}C$ variations during the last millennium, and uncertainty in dating was estimated accordingly (Appendix S1: Figure S1).

We counted 329 growth rings in the 12.5-cm core, but radiocarbon dating from the central part indicated that the tree was much older, just as much as 1,050 $\pm$ 30 yr BP (Poznan Radiocarbon Laboratory, Poznan, Poland, Appendix S1: Figure S1). This means that "The Patriarch" probably germinated by the second half of the 10th century, when the aboriginal Guanches people had already been living in the island for a millennium. During the first half of its life, the tree had to survive livestock from aboriginal Tenerife's tribes, who shared the highest part of the island (that is, the current territory of the National Park) for summer rangelands (Lorenzo 1991). Aboriginal people also used *Juniperus cedrus* as firewood (Machado and Galván 2012), and introduced the use of prescribed fire management, reducing the forested area in the Canary

FIG. 1. 'The Patriarch', a 1,050-yr old female *Juniperus cedrus* living in the Teide National Park in Tenerife, Canary Islands. Photo: Manuel Suárez.

Islands (de Nascimento et al. 2016). Later, and along with recurrent earthquakes and eruptions of nearby volcanoes (Fig. 2), "The Patriarch" witnessed the European colonization by the end of the 15th century and the subsequent land-use changes and landscape transformations linked to the introduction of agriculture, which enhanced human pressure on natural ecosystems (Parsons 1981, Fernández-Palacios et al. 2016). Our observation is in line with the exceptional longevity recorded for juniper species in other mountain regions across the world, such as North America[6] or central Asia (Esper et al. 2007), and stands out among recent dating of other millennial conifers in continental Europe (Mathaux et al. 2016, Piovesan et al. 2018, Camarero and Ortega-Martínez 2019) in the sense that those conifers live in cliffs or remote mountainous areas away from human pressure. Our tree, instead, lives in an easy-access area that was under high pressure of domestic herds for a long time, and where juniper trees were exploited by aboriginal people and later by Europeans because of their high-quality wood. This finding points to the hypothesis that Canary Islands junipers were once abundant in the National Park (Machado and Galván 2012), but the species was eradicated from flat areas due to human activity and confined to cliffs and off-limits places for humans and cattle. Why and how "The Patriarch" survived the deforestation process is still an enigma.

Besides dating the tree, we measured ring widths in the core, recording an average increment rate of 0.219 ± 0.009 mm/yr (mean $\pm$ SE) for the last three centuries (Fig. 2). This rate is low compared to the other individuals we had sampled, which were much younger (38.7 ± 1.9 yr, maximum age of 63 yr, $n = 20$) and showed ten-fold average increments (2.855 ± 0.071 mm/yr, *unpublished data*). Our observations agree with expectations in open-canopy forests, where young trees produce wider rings that narrow as they age until they approach an asymptote (Biondi and Qeadan 2008*a*). Tree rings also indicated that "The Patriarch" was sensitive to climate fluctuations, because we observed width differences between successive growth rings (mean sensitivity = 0.427; see Biondi and Qeadan 2008*b*, Fig. 2) and the last decades cross dated relatively well with the young trees' chronology ($r = 0.351$, $P = 0.011$; Appendix S1: Figure S2). In fact, correlations between ring width indices and monthly climatic variables showed that this tree produces wider rings when July is rainy ($r = 0.483$, $P = 0.001$; data between

[6] http://www.rmtrr.org/oldlist.htm

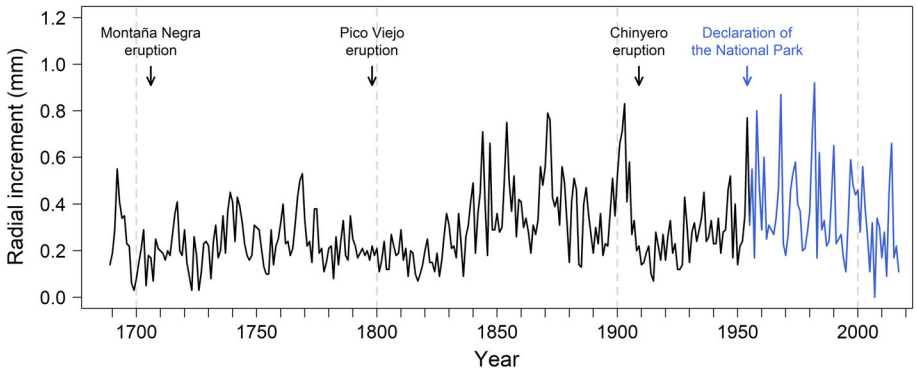

Fig. 2. Radial increments for the last three centuries in the old female *Juniperus cedrus* tree sampled at the Teide National Park in Tenerife, Canary Islands. Note that annual increments are in all cases lower than 1 mm. The ring-width series showed good cross dating with our juniper robust chronology from the park for 1978–2017 (Appendix S1: Figure S2).

1970 and 2015). The combination of sensitivity to water availability, sustained radial-increment rates, and strong seed cone production indicates that "The Patriarch" is still a healthy tree, which may eventually live for years as long as human pressure and volcanic activity do not disturb it (Peñuelas and Munné-Bosch 2010).

Our observation supports the idea that, combined with current drivers of global change such as climate warming or invasive species, the impact of human pressure in oceanic islands has been so strong that, in many cases, we are still beginning to decipher what island ecosystems looked like before human arrival. Archeological (Machado and Galván 2012) and ecological (Nogales et al. 2014) evidences suggest that the Teide National Park was once covered by open juniper woodlands, and so may have been other high areas across the archipelago. Because Canary Islands junipers seem to be much more resistant to drought than the current dominant species, Teide broom (*Spartocytisus supranubius* (L. f.) Christ ex G. Kunkel, Olano et al. 2017), promoting its recovery might increase the resilience of this ecosystem to global warming. Further research should therefore (a) ascertain the ages of Canary Islands junipers that were confined to cliffs and inaccessible places (. . .are they also millennial?), (b) evaluate how climate warming is affecting young individuals that have established at the foot of escarpments since the declaration of the National Park 65 yr ago, and (c) discern whether recovering former juniper woodlands would be possible through restoration efforts and by controlling populations of introduced herbivores such as wild sheep and rabbit.

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