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Short Communication

Conservation of *Ptilostemon greuteri* (Asteraceae), an endemic climate relict from Sicily (Italy): State of knowledge after the discovery of a second population

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ABSTRACT

Ptilostemon greuteri is one of the most endangered and poorly studied woody vascular plant species of the Mediterranean Basin, endemic to Sicily (Italy). Several peculiar traits confer to *P. greuteri* a character of uniqueness and an enigmatic attractiveness. In fact, at first glimpse the largest individuals of this species remind the most remarkable and peculiar cases of herbaceous genera (e.g., *Echium*, *Senecio*) turned woody on insular or insular-like mountain ecosystems. Following the discovery of a second population of this rare species, a project aiming at the study and conservation of *P. greuteri* was set up. We present here updated information on the distribution, conservation status, biology and ecological requirements of this species. Field surveys supported by drone imagery were carried out to estimate the current range of the two populations. The data obtained allowed to refine the conservation status assessment of the species and to update the distribution pattern of *P. greuteri* by means of detailed digital maps of each population. Ongoing field investigations currently provide valuable information about the ecological requirements of the species and point out the impact of wildfires on population size and structure. Our research has also highlighted several knowledge gaps that need to be filled to apply more effective conservation measures. Preliminary results suggest that local topographic and mesoclimatic factors (air humidity and shade) are key variables explaining the persistency and survival of *P. greuteri* in the area.

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1. Introduction

Fifteen *Ptilostemon* species are known worldwide (Greuter, 1973; Vilatersana et al., 2010). All occur in the Mediterranean Basin, from Crimea and Transcaucasia in the East, and Spain and Morocco in the West (Greuter, 2006). According to Herrando-Moraira et al. (2013), *Ptilostemon* represents a basal taxonomic unit of the Tribe Cardueae (incl. *Carduus* spp. and *Cynara* spp.). Unlike the other members of the tribe, this genus shows a high rate of endemism, and most species have narrow distribution ranges (Greuter, 1973). The centre of origin of the genus is assumed to be the Eastern Mediterranean area. The westward gradual colonisation of the whole Mediterranean Basin may have occurred following a complex path during the Pleistocene. Southern Spain and Northern Africa probably played a key role as refugial areas during Pleistocene glacial events, as they host the most ancestral species within the Western Mediterranean Basin (Vilatersana et al., 2010).

The species of the genus *Ptilostemon* are traditionally separated into two subgenera, namely subgenus *Lamyra* which includes a single annual species: *P. stellatus* (L.) Greuter, and subgenus *Ptilostemon* with 14 perennial species (Greuter, 1973; Ferrauto et al., 2017; Raimondo and Domina, 2006). This separation is also supported by aneuploidy, with 2 n = 32 in all the species of the subgenus *Ptilostemon* (Brullo et al., 1991; Fernandes and Queiros, 1971; Moore and Frankton, 1962; Renzoni-Cela, 1963; Salmeri, 2019; Tzanoudakis, 1986) and 2 n = 24 for *P. stellatus* (Bartolo et al., 1977). However, Vilatersana et al. (2010) debated on the small relevance of keeping *P. stellatus* in a separate monospecific subgenus, since annuality is a common trait in the Cardueae tribe and is subject to frequent reversals (García-Jacas et al., 2002). All species except *P. stellatus* grow predominantly on nutrient-poor habitats such as rocky slopes, screes or cliffs (Greuter, 1973). To date, only little and mostly general knowledge is available about the ecology of the majority of the perennial species of the genus, except for *P. leptophyllus* (Pau and Font Quer) Greuter studied by Deil (2006), and *P. casabonae* (L.) Greuter studied by Angiolini et al. (2005) and Picciau et al. (2018).

In recent years, increasing attention has been given to *P. greuteri* Raimondo and Domina (Fig. 1), one of the rarest vascular plants endemic to the island of Sicily, Italy. Unlike the other members of subgenus *Ptilostemon*, which are mostly perennial (spiny) herbs or subshrubs (Greuter, 1973), *P. greuteri* is a tall shrub. This woody thistle was first discovered in the 1980s from a single location (hereafter referred as POP1) at Cappellone Valley (Municipality of Castellammare del Golfo, Province of Trapani) in north-western Sicily, where ca. 250 individuals were recorded (Raimondo and Domina, 2006).

Among the many distinctive traits of *P. greuteri* with respect to the entire genus, the most remarkable are the size that adult plants can reach (up to 3.5 m) and the average leaf area (usually >30 cm^2 and up to 80–90 cm^2 according to Raimondo and Domina, 2006), which is far larger than all the other *Ptilostemon* species (Greuter, 1973). It took 25 years since its discovery to share the existence of *P. greuteri* with the scientific community. Different reasons can be evoked to explain the considerable time elapsed between its finding in the 1980s and the publication of the species in 2006: i) its location close to a forest road and inside an artificial pinewood probably made the discoverers suspect that it was just an escaped exotic species, and ii) its unique and puzzling anatomical characteristics (general habit, leaf size and shape) made it rather problematic to relate this unknown plant to any of the genera of vascular plants known for the Italian and Mediterranean flora.

According to the last IUCN Red List assessment, due to its narrow range and the single known location, *P. greuteri* is classified as Critically Endangered (CR), following criteria B1ab(iii)+ 2ab(iii) of the IUCN guidelines (Rivers, 2017). Although the number of

Fig. 1. General habit (a), capitules (b) and seeds with pappus (c) of *Ptilostemon greuteri*.

individuals was reported as stable, the quality and extent of its habitat have been stated to be declining due to wildfires and the abandonment of traditional grazing practices (Raimondo and Domina, 2006; Rivers, 2017). Protection and habitat management were already listed by Rivers (2017) as a requisite for the long-term conservation of the species. However, no monitoring scheme was previously set up to accurately assess threats and the evolution of the only known population.

A second population (hereafter referred as POP2) was discovered in the same area by one of the authors (Scuderi, 2006) in the valley between the peaks of Cozzo Monaco and Pizzo Branco, around 2.2 km south of POP1. Highlighting the finding of this new population and considering that most life traits of the species are still poorly understood, this article aims at reviewing and updating the available knowledge on the ecology, biology, population size and distribution of *P. greuteri* in order to outline the investigation priorities for conservation purposes. In addition to reassessing its classification on the IUCN Red List of threatened species, altogether, the increasing bulk of information may be helpful in decision making and address the conservation planning of this extremely rare, narrow ranged and endangered endemic species.

2. Material and methods

2.1. Population features and distribution range

The classification and taxonomic treatment of the plants mentioned throughout the text follow Pignatti et al. (2017–2019).

Regular and seasonal (spring and autumn) monitoring and surveys have been taking place in both populations since 2019. The main phenological phases of *P. greuteri* were recorded in 100 flowering individuals (50 from each population) by adopting the criteria and the data sheet proposed by Puppi and Zanotti (1989). Additionally, the health of the plants, the evidence of disturbance factors (e.g., wildfire scars, pathogens) and the possible range variations have been regularly recorded. Moreover, the average seed weight of four lots of 100 seeds from each population was measured using an analytical balance Vetek Ohaus Adventurer and statistically compared with t-student test.

A number of reference points all along the borders of each population were recorded through high resolution GPS device (Trimble GEO 7X) in order to obtain a reliable measure of the currently known distribution range of *P. greuteri* populations and to update the Extent of Occurrence (EOO) and the Area of Occupancy (AOO) (IUCN Standards and Petitions Committee, 2022). Additionally, a drone flight in both populations was carried out in autumn 2021 to improve the accuracy of *P. greuteri* distribution in the least accessible

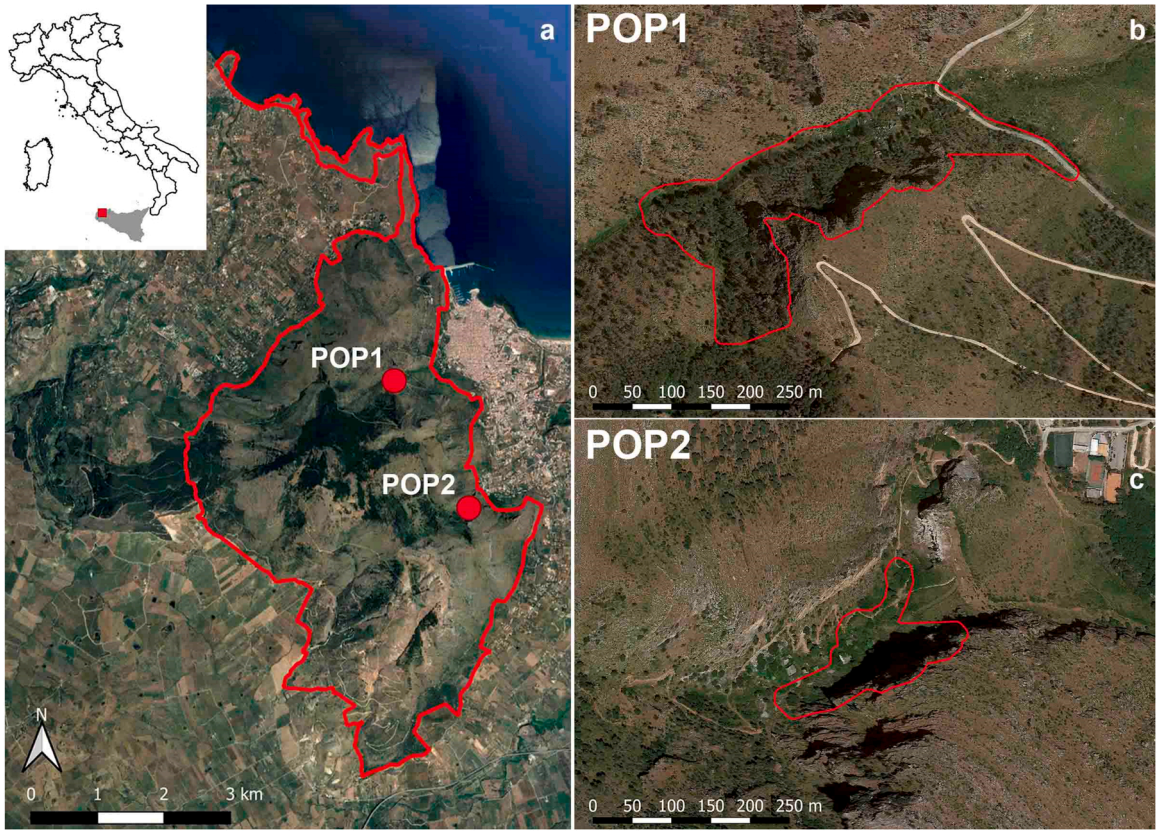

Fig. 2. General location of Mt. Inici within the Natura 2000 Special Area of Conservation ITA010015 "Complesso Monti di Castellammare del Golfo" outlined in red (a), and contour in red of the two populations (b-c) of *P. greuteri* on Mt. Inici.

locations (e.g., ledges and cliffs). The data collected where subsequently processed through QGIS v.3.16.1 software and a buffer area of 10 m radius was added around each population perimeter. The resulting geometries were then layered on the digital elevation model (DEM) of Sicily with a 2 m spatial resolution provided by the Sicilian Regional Department of Territory and Environment (http://www.sitr.regione.sicilia.it/geoportale/). Georeferenced data were also used to automatically determine EOO and AOO through the geospatial conservation assessment tool GeoCAT (http://geocat.kew.org/) (Bachman et al., 2011).

2.2. Wildfire history and life cycle

The recent history and impact of wildfires in both sites were reconstructed by means of two different data sources, i.e., the written reports of the Forest Agency of Trapani and the thematic maps available at the Forest Information System of the Sicilian Region (2022). Additionally, available Google Earth imagery was used to visually evaluate to which extent POP1 and POP2 were affected by recent wildfire events. To confirm the estimated date of last fire occurrence, the annual shoot growth units of ten large *Fraxinus ornus* trees living in the surroundings of each *Ptilostemon* population were counted.

In order to assess the longevity of *P. greuteri*, stem disks from 13 individuals were analysed. To avoid destructive sampling, the disks were collected from the largest individuals that did not survive the wildfire of 2017 in POP1. The disks were taken from the base of each stem and prepared for ring analyses according to standard procedure (Fritts, 1976). To minimise bias in estimating the growth dynamics in the tree-ring time-series and to assess the most probable age of each individual, a qualitative cross-dating was performed through the visual comparison of the individual ring-width graphs (skeleton plot; see Stokes and Smiley, 1968) drawn with the aid of a stereomicroscope (up to 32× magnification). In addition to ring counting, the mean diameter of each cross section was recorded by averaging the minimum and maximum values recorded for each stem disk. Spearman's rank correlation (Hollander and Wolfe, 1973) was computed in R (version 4.2.0., R Core Team, 2022) in order to assess the relationship between stem diameter and age.

3. Results

3.1. Abiotic and biotic characteristics of the two populations

Both populations of *P. greuteri* fall within the Special Area of Conservation (SAC) ITA010015 "Complesso Monti di Castellammare del Golfo" on the eastern flank of Mt. Inici (maximum elevation: 1064 m a.s.l.), near the coast of NW-Sicily. (Fig. 2a). Both populations are mostly located on NNE-facing calcareous cliffs (Catalano et al., 2011) and ledges as well as in the bottom of narrow, steep and shaded gorges1 (Fig. 2b-c), distant approximately two kilometres one from each other.

In POP1 most (about 90%) *P. greuteri* individuals currently grow on a steep talus slope under the cover of a *Pinus pinea* afforestation stand, established ca. 50 years ago in a valley that was previously used as rangeland. The S-SW-facing side of the valley is characterised by a patchy plant community dominated by tussock grasses such as *Ampelodesmos mauritanicus* and perennial herbs like *Charybdis pancration*, *Ferula communis*, *Thapsia garganica*, *Asphodelus ramosus*, *Asphodeline lutea* and *Brassica villosa*, whereas several woody species such as *Fraxinus ornus*, *Pistacia terebinthus*, *Rhus coriaria* and *Teucrium flavum*, are rather common on the NE-facing slope. The last severe wildfire that affected the area happened on July 2nd, 2017 and strongly impacted the *P. greuteri* population, causing the sudden death of all plants (not a single adult individual survived, *Authors' obs*). However, after this event numerous seedlings germinated, and the population is currently dominated by 3 or 4-year-old saplings (Fig. 3) which are very abundant and form dense patches that can spread over several hundred square metres. The frequent fall of the *P. pinea* trees killed during the most recent wildfire contributes to create gaps in the tree canopy, giving back to the slope its pre-afforestation open landscape physiognomy.

On the contrary, POP2 currently hosts several hundreds of large, mature individuals. Only relatively few seedlings were noticed

Fig. 3. Dense recruitment of *P. greuteri* seedlings (lanceolate, shiny leaves in the lower part of the picture) recorded in POP1 two years after the last wildfire.

during the latest surveys carried out in autumn 2021. More than half of the entire population is restricted to rocky ledges and NE-facing cliffs, and *P. greuteri* is found in association with many chasmophytic plants such as *Euphorbia bivonae*, *Iberis semperflorens*, *Lomelosia cretica*, *Seseli bocconei*, etc. and with woody sclerophylls like *Rhamnus alaternus* and *Chamaerops humilis*. Nevertheless, the largest individuals occur in the lowest part of the stand, concentrating in the loose rock debris located between the base of the cliff and the bottom of the valley. Very common throughout the whole surface of the lower part of the stand are *Rubus ulmifolius*, *Centranthus ruber*, *Lavatera olbia* and many shade-tolerant plants that are frequently found under the canopy of dense evergreen *Quercus ilex*-dominated forests, such as *Acanthus mollis* and lianas like *Hedera helix*, *Smilax aspera* and *Clematis cirrhosa*. Altogether, they form a very thick and almost impenetrable community.

Recent fire history is also different than in POP1. Since 2010, two large wildfires affected POP2 and the surrounding area, respectively on July 15th, 2012, and June 16th, 2016. However, the comparison with available Google Earth imagery (August 26th, 2012, and July 30th, 2016), suggests that POP2 was partially (2012) or entirely (2016) spared by these two events. Additionally, the age of *Fraxinus ornus* trees occurring in the site confirms that the last destructive wildfire might have occurred ca. 10 years ago. The absence of further burning events in recent years is consistent with the presence of many living mature individuals of *P. greuteri* herein.

The lowest part of the site hosting *P. greuteri* in POP2 was cultivated, probably until the Second World War, as testified by the occurrence of wild vines (*Vitis* sp.), *Rhus coriaria*, *Ceratonia siliqua*, *Amygdalus communis* and *Fraxinus ornus* and the diffuse presence of (currently collapsing) dry-stone walls and terraces, while the upper part of the site hosts several introduced woody species (e.g., *Pinus pinea*, *Eucalyptus camaldulensis*, *Quercus suber*) as a result of afforestation activities carried out since the 1960s.

3.2. Life cycle and reproductive biology

Based on the regular observations carried out during the years 2020 and 2021 (data not shown), the flowering period of both populations extends from mid-April to May and is perfectly simultaneous in the two populations. The capitula are ripe in June. The monitoring activities carried out in POP1 showed that wild individuals are reproductive starting from the second or third year of age, but seed production becomes abundant after the fourth year. Seeds have a functional pappus, but they are rather large and heavy. The average weight of each seed was found to be around 0.04 g (Table 1) and appears to be significantly different between the two populations ($p = 0.0006$).

As for woodiness, the stem and the branches of *P. greuteri* exhibit the same features as most woody species, and seasonally produced growth rings are perfectly detectable. Growth is rhythmic and since *P. greuteri* is an evergreen species, the formation of multiple rings per year, i.e. the so-called false rings, was recorded (Fig. 4). False rings were found in two different years on three stem disks, and in one year on another disk. One of the 13 samples was discarded because extensive rotten wood in the cross-section made ring counting unreliable. The analysis of the remaining stem disks showed that plants of *P. greuteri* can live up to at least 12 years. The minimal age of the analysed stem disks was 7 years, whereas half of the samples were 9-years old when they died due to the fire that occurred in 2017 (see Table 2). Moreover, scars probably caused by fire injuries were observed on two cross-sections, both dating back to a wildfire that occurred in 2013. Stem diameter values are quite variable, ranging from 17 to 49 mm, and age proved to be positively correlated with diameter (rho: 0.53, p-value 0.08).

3.3. Field mapping and conservation status assessment

Intensive field surveys in the whole area of Mt. Inici to check for possible additional populations were unsuccessful and, to our knowledge, no further populations have been found elsewhere. The drone images allowed to assess the exact location of the plants of the two existing populations and to calculate more precisely their actual distribution area. Currently, POP1 and POP2 cover 0.061 km^2 and 0.019 km^2, respectively. A precise distribution map of both populations can be found in Fig. 2b-c.

The finding and area measurement of POP2 allowed updating both the AOO and EOO of the species. Using the standard 2 × 2 km grid cells following IUCN guidelines (IUCN Standards and Petitions Committee, 2022), the AOO raised from 4 km^2 to 12 km^2, increasing threefold with respect to the assessment of Rivers (2017). Concerning the EOO, based on GeoCAT calculations, it decreased from 4 km^2 to 0.913 km^2, but following the recommendations of IUCN guidelines, indicating that EOO should not be less than AOO to ensure consistency with the definition of AOO as an area within EOO (IUCN, 2022), its value was also assessed to as 12 km^2.

Repeated field observations concerning the demographic and spatial patterns of *P. greuteri* and recent information about the persistence and frequency of threat factors allowed to provide more accurate evaluations on the conservation status of the species. The severe fragmentation of the population (*sensu* IUCN), the observed/inferred decline of the habitat and the fluctuation of the number of mature individuals (both due to frequent wildfires), in addition to the recalculation of EOO and AOO led to a new conservation status

Table 1
Weight of four lots of 100 seeds (g) from POP1 and POP2.

POP1	POP2
4.42	4.17
4.47	4.09
4.30	4.07
4.46	4.02

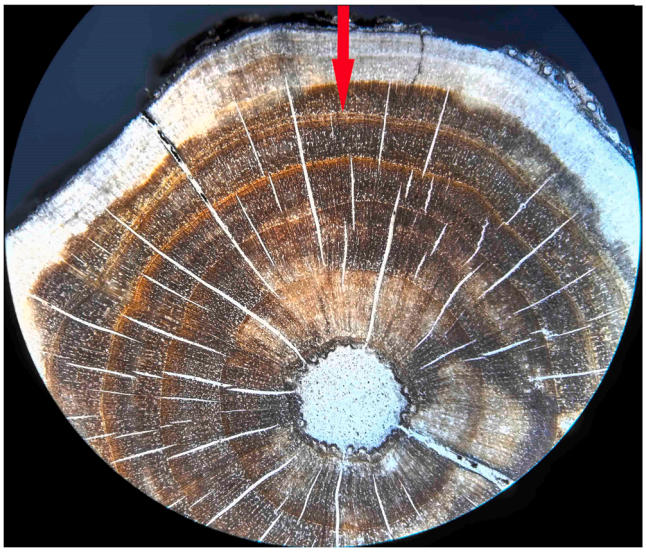

Fig. 4. Cross-section and growth rings of a large individual of *P. greuteri*. The arrow highlights the presence of a second ring very close to a first ring corresponding to a false ring.

Table 2
Stem disks analysis.

Plant n.	Age (yrs)	Diameter (mm)
PG1	9	52
PG2	9	45
PG3	11	33
PG4	9	49
PG5	9	45
PG6	9	37
PG7	7	26
PG8	7	31
PG9	12	46
PG10	7	17
PG11	10	40
PG12	9	34

assessment. Accordingly, *P. greuteri* is confirmed to be Critically Endangered (CR), but with updated criteria, i. e. B1ab(iii)c(iv) (IUCN Standards and Petitions Committee, 2022).

4. Discussion

4.1. Life trait peculiarities and reproduction

Within the genus, *P. greuteri* is undoubtedly the largest species, being able to exceed 3.5 m in height, and among the most long-living representatives. Woody stem ring-analysis revealed that it can live up to 12 years at least, consistently to the estimates reported by Di Gristina et al. (2020). However, it must be underlined that all the investigated stem material issued from individuals that died in the last wildfire of 2017, hence their actual longevity could be strongly underestimated. Additionally, the observed occurrence of false growth-rings indicates a possible polycyclic growth resulting from differential growth response of the species to seasonal climatic fluctuations (e.g., summer dormancy during drought stress, regrowth along with autumnal precipitation), a frequent pattern in tropical woody species (Rozendaal and Zuidema, 2011) which is common also among Mediterranean shrubs or trees (e.g., Cherubini et al., 2003). Moreover, the detection of synchronous germination (i.e., half of the collected stem disks had the same age) suggests that single events (e.g., climatically favourable seasons, wildfires, etc.) may trigger more conspicuous recruitment, though the age range (from 7 to 12 years) detected in our samples suggests that recruitment rates may be rather uniform and continuous through time.

Based on our observations, individuals in the wild are reproductive starting from the second or third year of age, contrarily to what was reported in Di Gristina et al. (2020), who stated that plants are reproductive only when they reach 4–5 years of age, whereas cultivated *P. greuteri* plants are able to reproduce already in the first year after germination (S. Brullo, *pers. comm.*). Furthermore, we found that the flowering period of both populations occurs between April and May. This is in disagreement with the findings of

Raimondo and Domina (2006) who report that *P. greuteri* blooms between May and June. Differences in seed weight among the two populations will need further investigation to test whether seed size/weight is differently correlated with seed dormancy and germination velocity (Delgado et al., 2008).

4.2. Disturbance factors, resilience and recovery

As cited previously, the whole Mt. Inici area is renowned for having been affected in the last decades by recurrent and oftentimes catastrophic fire events, therefore wildfires are to be considered as the most important disturbance factor and threat for *P. greuteri*. The entire POP1 was destroyed during the last wildfire that occurred in summer 2017. Not a single adult plant survived, suggesting that the species is totally unable to resprout after burning and is an obligate seeder. Though not recorded in any official written document nor detectable in Google Earth imagery, probably another event of low, rapid fire but of mild intensity, unable to kill the plants, partially affected this population in 2013, as inferred by the scars detected on only two out of the 13 sampled stem disks. Although POP2 has not suffered from fire disturbance during at least the last ten years yet, as shown by Google Earth imagery, it is permanently under the threat of a possible wildfire. Nevertheless, as already reported by Pignatti et al. (2017–2019) and Di Gristina et al. (2020), the impact of fire on the survival of *P. greuteri* may be less detrimental than what is usually observed in other strictly chasmophytic species (Hopper, 2012; Michael and Lindenmayer, 2012; Speziale and Ezcurra, 2014). Indeed, *P. greuteri* seems to be relatively well adapted to fire, as seedlings are found to germinate massively, but not exclusively, after burning events. In fact, in POP1, some diffuse recruitment not so evidently related to fire occurrences is inferred by the age distribution of the investigated plants. However, thousands of seedlings were recorded in spring 2019 (Fig. 4), i.e., two years after the last wildfire, also highlighting the marked pioneer behaviour of *P. greuteri*.

Our observations agree with previous knowledge about the ability of Cardueae to develop long-lasting soil seed banks (Häffner and Hellwig, 1999). However, as demonstrated by experimental studies on the sclerophyllous vegetation of Australia, where frequent high-intensity fires promoted sprouters against obligate seeders (Keith, 1996), the capability of *P. greuteri* to respond effectively after fire events is likely to depend on fire frequency and intensity. In fact, intense fires proved to be able to destroy the whole set of reproductive individuals, while too frequent fire events may cause a critical depletion of soil seed bank, with severe implications for the conservation of the species (Di Gristina et al., 2020).

Additional disturbance factors relate to biotic interactions, but up to present they are still overlooked and probably underestimated. For instance, seed predation by Diptera has already been detected and mentioned by Raimondo and Domina (2006), but its impact on dispersal and recruitment has never been assessed. Also, some fungal diseases have been newly recorded during recent field surveys and seem to promote diffuse decline and many casualties, especially in the lowermost range edge of POP1. Very preliminary analyses

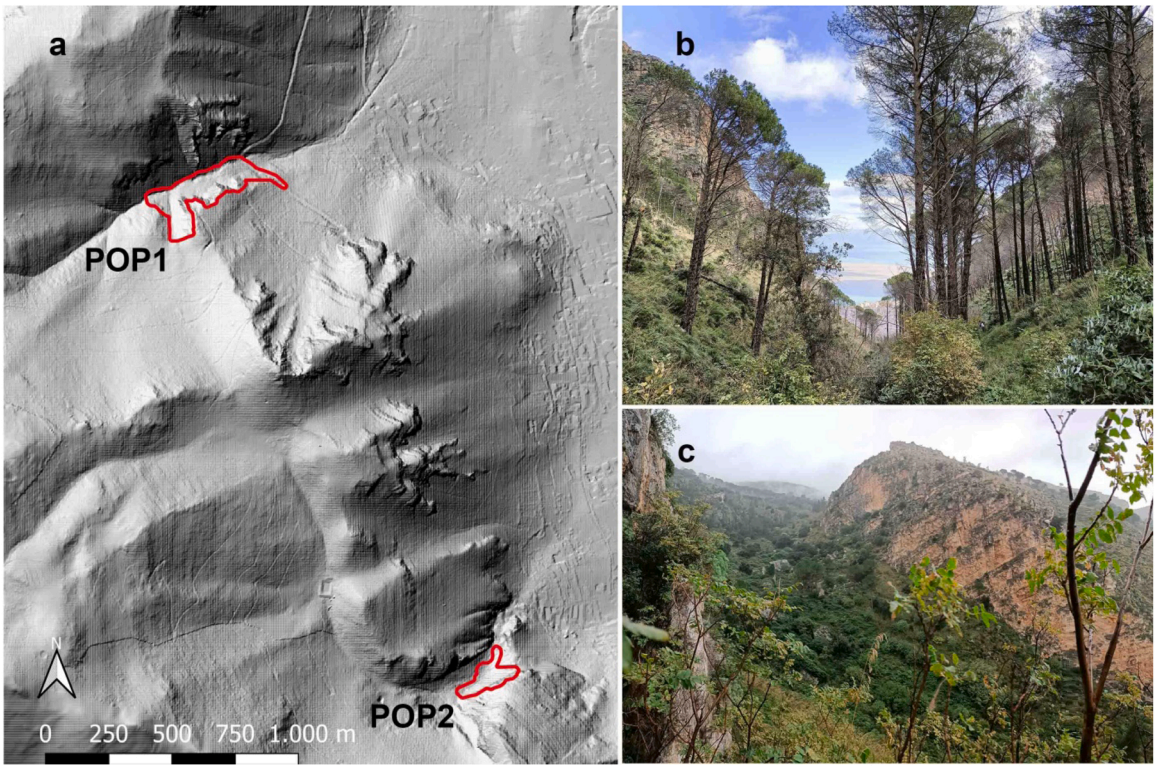

Fig. 5. Digital Elevation Model (2 m spatial resolution) of the eastern slopes of Mt. Inici highlighting the SW-NE oriented narrow valleys (a) and general view of the sites (b - POP1 and c - POP2) hosting the two populations of *P. greuteri*.

from still ongoing research highlighted infections in the root system and stem collar triggered by more than a dozen different fungal pathogens, including *Phoma* sp., *Fusarium* sp. and *Alternaria* sp. (L. Torta, *pers. comm.*). Since these fungi usually act as weakness parasites, it is likely that their insurgence turned into pathogenicity due to the extreme drought and high temperature that occurred in summer 2021, which caused severe stress to *P. greuteri* plants.

4.3. Macroclimate and microrefugia

Following the bioclimatic classification criteria proposed by Rivas-Martínez (1994), both populations of *P. greuteri* are subject to Thermo-Mediterranean climatic conditions (Bazan et al., 2015). However, as it happened for the narrow endemic *Zelkova sicula* (Garfì et al., 2011), the discovery of a second population resulted in a rather close replication of the micro-topographical and environmental traits of the already known POP1. This allowed to better understand the ecological requirements of the species and to outline a more reliable ecological niche (Garfì et al., 2021a). In fact, both POP1 and POP2 are restricted to narrow valleys (Fig. 5a-c) and the largest individuals occur in the lower part of the stands, i.e., on rock debris located between the cliff base and the valley bottom. This pattern could be related to more favourable microclimatic conditions provided by micro-depressions or sheltering boulders, where *P. greuteri* plants probably benefit from short-lasting water runoff during the rainy season (Ashcroft et al., 2012; García et al., 2020).

As a rule, during the interglacial optima, macro- and mesoclimatic conditions may have favoured the spread of many woody species and the recovery of entire forest ecosystems (e.g., Nieto Feliner, 2011). Nonetheless, increasing evidence points out that particularly favourable microclimatic and micro-topographic conditions have played a major role, allowing many climate relicts to overcome glacial events "hiding" in microrefugia in the Mediterranean Basin (Cheddadi and Bennett, 2020; Garfì et al., 2021b; Médail and Diadema, 2009; Pasta et al., 2022). Though a chasmophytic syndrome has been observed in both *P. greuteri* populations (Gianguzzi et al., 2022), the fact that the largest plants are mostly concentrated in the valley bottom, especially in POP2, corroborates the assumption that localised micro-environmental conditions are crucial to support plant growth and long-term persistence against the surrounding adverse climate. Water availability, especially groundwater, is probably the key abiotic driver explaining the current distribution pattern of the species (Hampe and Jump, 2011; McLaughlin et al., 2017). Moreover, although research is still on-going, it is hypothesised that plants in both sites may take advantage of exceptionally high amount of moisture condensation triggered by the close vicinity of the sea and the steep profile of Mt. Inici. These elements are thought to favour intense overnight dew accumulation and cause frequent fogs. In fact, *P. greuteri* belongs to a very small group of warm-loving evergreen broadleaved plants (e.g., *Laurus nobilis*, *Viburnum tinus*, *Bupleurum fruticosum*) enjoying very peculiar tropical-like warm-humid sites and surviving in the Mediterranean Basin only where they can avoid the "true" (i.e. seasonally very dry and very warm) Mediterranean-type climatic conditions (Mai, 1991). Therefore, consistently to what was observed for the relict populations of *Z. sicula* (Garfì et al., 2021b) it is assumed that also for *P. greuteri* the narrow and steep valleys play a key role as microrefugia in arid environments. Ongoing measurements of the main macro- and micro-climatic parameters (rainfall, air temperature and humidity, leaf wetness, as well as soil temperature and humidity in both populations) will help to validate these assumptions.

4.4. Woodiness, gigantism and other "insular" traits

Several peculiar traits confer to *P. greuteri* a character of uniqueness and an enigmatic appeal. At first glimpse, the largest individuals of this species remind the most remarkable and weird cases of herbaceous genera (e.g., *Echium*, *Senecio*) turned woody on insular or insular-like mountain ecosystems (Lens et al., 2013; Whittaker and Fernández-Palacios, 2007). Indeed, *P. greuteri* is not the only shrub of its genus. In fact, it shares the woodiness trait with two congeneric species living in the eastern Mediterranean countries, i.e., the tall shrubs *P. chamaepeuce* (L.) Less and *P. gnaphaloides* (Cirillo) Soják, in addition to the dwarf shrub *P. diacantha* (Labill.) (Greuter, 1973).

The "insular-woodiness hypothesis" formulated by Darwin (1859) and the plant insular "gigantism" syndrome pointed out by several island biogeographers have been among the most exciting and debated topics of last half century (Biddick et al., 2019; Burns, 2019; Carlquist, 1974; Lens et al., 2013; Olson, 2020; Pignatti, 1979). So far, documented examples of secondary woodiness, often associated with accelerated disparification of growth forms, are known from aseasonal, frost-free island climates that permit year-round plant growing (temperature) conditions, such as those found in (sub)tropical oceanic islands or tropical sky islands (Carlquist, 1974; Kidner et al., 2016; Neupane et al., 2017). Based on its woody habit, it could be assumed that *P. greuteri* belongs to a very ancient lineage, representing the last survivor of an extinct flora. However, secondary woodiness and diversification across steep environmental gradients can be the products of a relatively fast and recent (mid-Pleistocene) process, with rates comparable to remarkable adaptive radiations in plants (Kadereit and Abbott, 2021). Additionally, recent studies point out that secondary woodiness may have favoured the survival of plants on resource-poor (water, nutrients) habitats (Dória et al., 2018; Nürk et al., 2019). To this purpose, ongoing research on the chemical and physical characteristics (pH, water retention, texture, structure, nutrient content, etc.) of the soils where *P. greuteri* grows will shed light on the edaphic requirements of this species.

Finally, a hypothetical very ancient origin of *P. greuteri* is not supported by current knowledge on the palaeogeography of the island, since Sicily started its final emersion only 5 million years ago (Pasta et al., 2022). Also, the genetic analyses presented by Vilatersana et al. (2010) show that *P. greuteri* is not the most basal/ancient/isolated species within the genus. Most probably, *P. greuteri* is a "special" climate relict which managed to survive in a "very special" place to escape the Pleistocene glacial events. In fact, Mt. Inici falls within the so-called Drepano-Panormitan district (Brullo et al., 1995), including the calcareous ranges of NW-Sicily. This district is one of the most species-rich areas of the Mediterranean, and the Mountains of Trapani alone are home to over 1000 vascular plant taxa, more than 200 of them being of high biogeographic and conservation interest (e.g., extremely localised and phylogenetically isolated

endemites, see Brullo and Brullo, 2021, Guarino and Pasta, 2017, 2018, and Scuderi, 2006). For this reason, the calcareous ranges of NW-Sicily are featured among the Italian Important Plant Areas (Blasi et al., 2011).

5. Conclusions

The high-quality mapping of the current populations of *P. greuteri* allowed to update the available information on the shape and size of both populations, and this in turn helped improve and update the conservation status assessment of the species. Based on our land surveys and updated observations carried out on the two known populations, *P. greuteri* is confirmed as Critically Endangered (CR) following the new criteria B1ab(iii)c(iv). Though the risk level remained unchanged, the proposed amendments to the classification criteria, as well as the planning of effective *in-situ* and *ex-situ* conservation activities (Abeli et al., 2021) suggest the need for regular and continuous monitoring activities and in-depth studies on the reproductive biology, the effective weight of threat factors and the demographic trends of the species, as in the case of other narrow endemics of the Mediterranean flora (Pasta et al., 2016; Zaia et al., 2020). In the meanwhile, several knowledge gaps have been pointed out. It comes clear that several ecological factors which could elucidate the survival strategy, the current distribution and assemblage patterns of *P. greuteri* have not yet been adequately investigated. Once again, special attention should be given to assess the impact of climate on persistence as well as to evaluate the role of extreme climatic events as triggers for possible biological "natural" adversities (e.g., fungal diseases). It seems therefore necessary to carefully plan and carry out a detailed survey that allows to measure and compare the daily and seasonal trends of the meso- and microclimatic conditions both at the atmospheric level and in the soil to better understand which are the most important drivers of seed germination, seedling establishment and adult plant growth. Additionally, in-depth investigations on the wood and leaf anatomy as well as the physiology of *P. greuteri* could probably help to understand how this plant was able to withstand Mediterranean climatic conditions for millennia.

A rough description of the vegetation patterns of POP1 has been provided by Raimondo and Domina (2006), who considered *P. greuteri* as a chasmophilous species belonging to the cliff communities referred to the phytosociological alliance *Dianthion rupicolae* (Brullo and Marcenò, 1979). More recently, Gianguzzi et al. (2022) interpreted the plant communities hosting *P. greuteri* in both sites as a peculiar type of thermophilous lauriphyllic maquis framed into the alliance *Oleo-Ceratonion*. Ongoing vegetation surveys (Marcenò et al., 2022) will hopefully refine our knowledge on the niche of the target species.

Our findings also point out the need to further investigate micro-topographic and micro-climatic features. Such variables may play an even more important role during the key phases of the life cycle of this critically endangered species, i.e., seed germination, seedling establishment and adult development. The possible influence of extreme climatic events (e.g., drought) on the severity of damages caused by predators and pathogenic fungi should also be explored, whereas further studies on wood and leaf anatomy and plant physiology could provide new insights on the drought-tolerance of *P. greuteri*.

The results issuing from preliminary and ongoing field investigations will be useful to set up a good niche model and may help to better address future conservation efforts. Moreover, the discovery of a second population encourages to keep searching for new stands of *P. greuteri* and to look for the best suited places for future assisted translocation initiatives.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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