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One hundred and eighty years of *Saga pedo* (Pallas, 1771) (Orthoptera, Tettigoniidae) findings in Italy diachronically revisited

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Abstract

According to the most recent updates on the occurrence of *Saga pedo* in Italy, including observations from San Marino, 92 findings have been reported. Of these, 12 were recorded between 2000 and 2020, 26 between 1971 and 1999, and 44 were before 1970 (1855–1969). The observations of this Saginae, listed in the annexes of the Habitat Directive, referred to 18 regions (excluding Emilia Romagna and Marche) and 42 provinces. Through this work, utilizing web searches and recently published or unpublished data, we have collected information on the species' occurrence across all Italian regions, adding 11 more provinces and 81 new findings. We put together 174 occurrence records of this insect in Italy between 1855 and 2023, dividing them into three periods: (1) before 1970; (2) 1971–1999; and (3) 2000–2023. Here, we present its diachronic distribution. Moreover, we identified an interesting relationship between limestone or dolomite bedrocks and the distribution of *Saga* across Italian territory, suggesting a strong calciphily in this orthopteran. Over the past 180 years, the elevation of sampling sites has also increased. The mean altitude of *Saga* records rose from less than 400 m to about 540 a.s.l. with its maximum known altitude in Italy increasing from 950 to over 1,200 m a.s.l. This research provides additional insights into the importance of Citizen Science in collecting ecological data, particularly for threatened species and those listed under the Habitat Directive.

Keywords: *Saga pedo*, Tettigoniidae, distribution, citizen science, Italy, altitude

Introduction

Geographic data on species distribution are important for various scientific and management purposes, including by governments, companies, agencies involved in land management and biodiversity conservation (Jetz et al. 2012). Anthropogenic disturbances, along with biotic and abiotic factors, significantly impact the diversity and community composition of insects. However, little information is available about how insect communities respond to disturbance and land-use changes (Samways 1989). Orthoptera play a key role in food webs (Samways 1997) because they are a food source for both vertebrate and arthropod predators (Parr et al. 1997). Additionally, several have been used as bioindicators because they respond to the conditions of

ecosystems and are sensitive to habitat changes (Kati et al. 2004).

The genus Saga Charpentier 1825

The genus *Saga* includes 17 species distributed throughout the Palaearctic that inhabit grasslands and semi-open habitats (Lemonnier-Darcemont et al. 2009; Cigliano et al. 2024). *S. pedo* is the only species known to occur in the Italian fauna, as the records of *S. hellenica* Kaltenbach 1967 and *S. natoliae* Serville 1839 in Italy are considered erroneous (Galvagni & Prosser 2004; Massa et al. 2012). Consequently, considering the extremely peculiar morphology of this orthopteran, we

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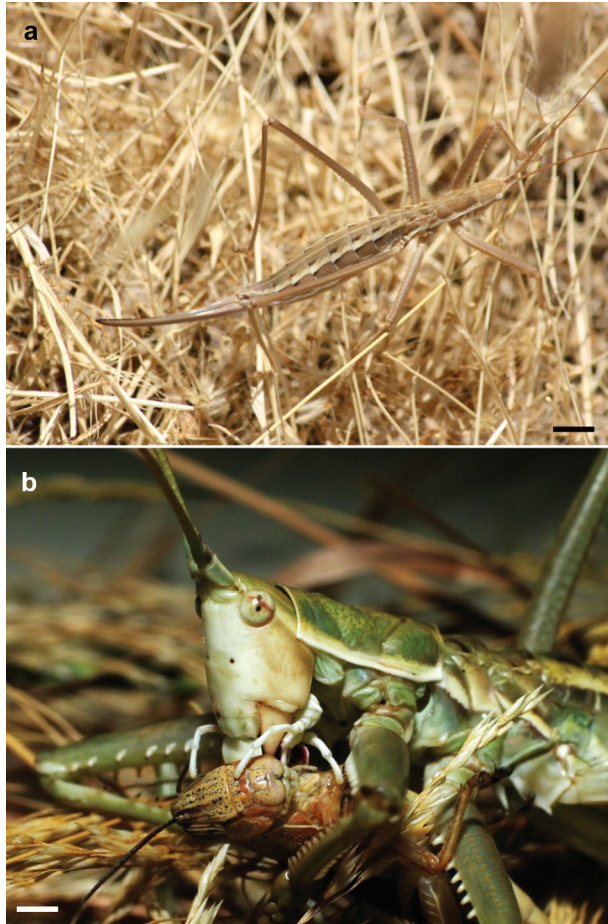


Figure 1. *Saga pedo* greyish form, Sicily, Rocca Busambra 2009 (a) (scale bar = 1 cm); green form preying on *Eyprepocnemis plorans* (Charpentier, 1825), Sicily, Etna 2008 (b) (scale bar = 0.5 cm).

refer directly to the morphological diagnosis of the species *Saga pedo* (Figure 1) for its generic identification.

Morphological diagnosis and conservation status of Saga pedo

Adult. Total length: 100–120 mm, including the ovipositor. It is an apterous species and the largest European parthenogenetic orthopteran, of which only the female was known until 2006; the male was discovered and described in Switzerland (Baur et al. 2006). The species is easily recognized by its large size, elongated head with markedly hypognathic chewing apparatus, and downward-facing mandibles, as well as robust spiniform formations on the anterior and median femora and tibiae (Fontana et al. 2002; Buzzetti & Fontana 2004). The body is uniformly light green or greyish, including the legs, and a lighter yellowish-white stripe is visible along both lateral margins of the thorax and

abdomen. The antennae are long, filiform, and very slender; the ovipositor is long, stout, and saber-shaped. The legs are extremely well-developed and slender (Fontana et al. 2002; Buzzetti & Fontana 2004).

S. pedo is listed among the species protected by the Bern Convention (Appendix II), and is mentioned in the European Community Habitat Directive 92/43/EEC (Annex IV). It is also recognized by the Tuscany Regional Law (April 6, 2000 n. 56) and is included among the species particularly protected by Regional Law 15/2006, ‘Provisions for the Protection of Minor Fauna in Emilia-Romagna. Furthermore, it is designated as a species deserving immediate and absolute protection (source: Regulation of the President of the Italian Republic for the implementation of the Community Directive 92/43/EEC - OJ 248 23/10/1997 suppl. ord. 219). The Saginae is included in the European Red List, classified as ‘‘VU-B1/2 db’’, which indicates that it is vulnerable due to a particularly fragmented environment and continuously declining populations (Hochkirch et al. 2016). The main threats of the species include overgrazing, the use of chemicals, fires and afforestation (Lemonnier-Darcemont et al. 2009).

Ecology, biology, phenology and geographical distribution

S. pedo feeds on other invertebrates, mainly other orthopterans and Mantodea (Kaltenbach 1970; Fontana & Cussigh 1996; Massa et al. 2012; Lemonnier-Darcemont et al. 2016). Aggressive and intimidating behavior has been reported for the species (Galvagni & Prosser 2004). It is a xerothermophilous species of medium altitudes (in Italy, it is known not to exceed 950 m altitude: Fontana et al. 2002; Galvagni & Prosser 2004), showing both diurnal and nocturnal habits, and is associated with natural and semi-natural grasslands (Holuša et al. 2013). The species prefers relatively open environments with herbaceous vegetation and bushes, where it moves with limited agility and does not make particularly long jumps. Eggs hatch in spring, and the nymphs undergo nine molts before reaching the final adult image (Fontana et al. 2002). Some of the eggs may hatch a couple of years after being laid (Massa et al. 2012; Hochkirch et al. 2016). This strategy allows the species to overcome difficult years.

Among the species of the genus *Saga*, *S. pedo* has the widest range, occupying an area that extends from the central part of the Iberian Peninsula to southern France, Corsica, peninsular Italy, Sicily,

Sardinia, and then across central Europe, Russia, and northwestern China (Galvagni & Prosser 2004; Massa et al. 2012). The species is absent in Greece and Anatolia, where it is replaced by other species of the genus (e.g., *S. naotoliae*, *S. hellenica*, *S. ephippigera*, etc.). Lemonnier-Darcemont and Darcemont (2007) report a case of hybridization between *Saga pedo* and *Saga rammei*. In Italy, the species occurs sporadically and rarely in almost all regions, including the major islands (Fontana & Cussigh 1996; Galvagni & Prosser 2004). Along the alpine arc, *S. pedo* is mainly found in populations of very few individuals in foothill refuge areas characterized by xerothermal microclimates and Mediterranean-type blooms (referred to as “xerothermal oases”: Fontana & Cussigh 1996; Galvagni & Prosser 2004; Iorio et al. 2019; Brandmayr et al. 2020; Di Pietro & Maioglio 2022; Maioglio & Repetto 2022). Being a predator, *S. pedo* is uncommon; in Italy, it is quite rare, and its habitat is often threatened (Fontana & Cussigh 1996). The primary threat factor is the degradation of the xeric areas where it typically lives. It is generally more common in regions with rich orthopteran populations (Mazzei et al. 2012; Castiglione et al. 2019). In the last two decades, the number of localities where it occurs has increased significantly, suggesting that ongoing climate change may be affecting the distribution and density of its populations, which are still relatively inconsistent. Species protection and greater attention towards invertebrate species may have contributed to an increase in the number of records of this species in Italy. More recently, Ancillotto & Labadessa (2024) reported the species as recently extinct in the urban area of Rome, Italy.

Several distributional data points for *Saga pedo* have been reported on platforms and social media linked to the citizen science. Citizen science is a method of science communication that involves non-scientific stakeholders in scientific researches (Newman et al. 2017). This approach facilitates and supports the economical collection of data (Haklay et al. 2021). Recently, citizen science has become extremely popular due to a rise in the number of papers and research projects (Oliveira et al. 2021). Our work aims to investigate the current distribution and ecological preferences of *Saga pedo* in Italy, in both protected and non-protected areas, using citizen science as a means to detect new and useful data.

Materials and methods

To ensure the most efficient and comprehensive data collection, we employed a mixed-methods approach that included literature review, data-mining, and

dedicated websites. Photographs of *S. pedo* taken in Italy were sourced from various online platforms. First, we utilized the web application Morphic (Leighton et al. 2016), which allows users to specify search terms and retrieve photographs from the Google images® search engine. This free and open-source web application (<http://morphs.io>), is based on a perpetual hashing algorithm (Niu & Jiao 2008) that removes duplicate photographs and avoids geographical biases by using Google’s Hummingbird relevance algorithm (Chauntelle & Yazdanifard 2014). To further reduce the number of duplicates and identify the original photographic sources, we utilized the Tineye reverse image search application (<https://tineye.com>). We then supplemented our Morphic searches with manual searches on various naturalist websites and social media platforms, including Facebook (<https://www.facebook.com/>; and Twitter (<https://twitter.com/>) (Figure 2). The Facebook groups we investigated included: “Fauna Siciliana”; “Ortotteri: biologia, identificazione ed allevamento”; “SagaPedo”; “Entomologia, Insetti e altri Artropodi”; “Insetti e Aracnidi Italiani”; “AFNI Sezione Sicilia”; “Insetti e altri artropodi - un fantastico mondo da scoprire”; “Insetti e Aracnidi Italiani”; “Insetti e aracnidi; Identificazione ragni e insetti”; “Riconoscimento Insetti”; “Aracnidi e Insetti: Official Group”; and “Centro di Educazione Ambientale ODV”. These sites were not accessed through Morphic tools, as they are not indexed by search engines (Leighton et al. 2016). However, we chose to include them in our manual search because they are very popular within the entomological community. Data were also mined from national entomological and naturalists’ online forums, such as Forum Entomologiitaliani, Forum NaturaMediterraneo and Forum Acta Plantarum, as well as from national and international citizens science websites (iNaturalist.org, Ornitho.it). All data collected are updated to December 2023.

The data were categorized as follows: (1) before 1970; (2) between 1971 and 1999; and (3) between 2000 and 2023 (Figure 3).

In the final database, we included only records verified by the authors through photographs, specifying the exact locality, date and other relevant information. For each observation, we recorded the date, locality (name), GPS coordinates (if available), number of observed specimens (if specified), data source and elevation in meters above sea level (if available). All collected data are available upon request from the corresponding author.

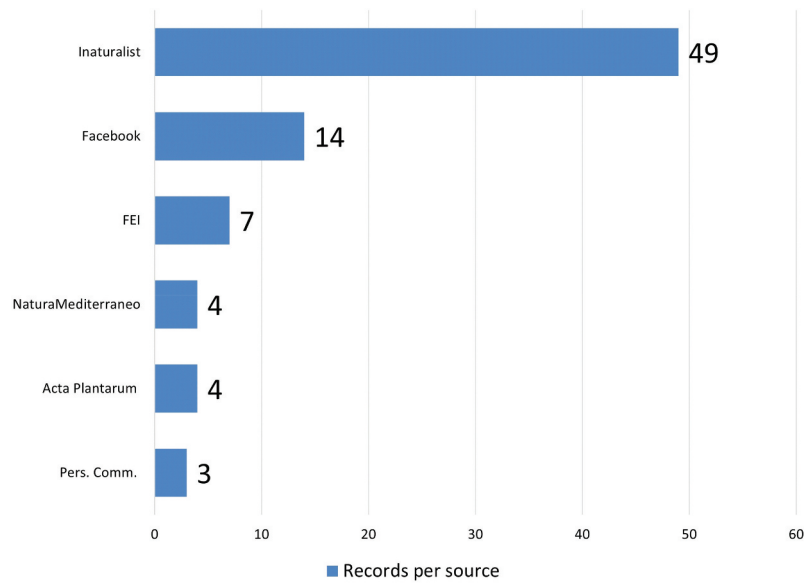


Figure 2. Records collected via manual searches from different sites of naturalists and social media sites.

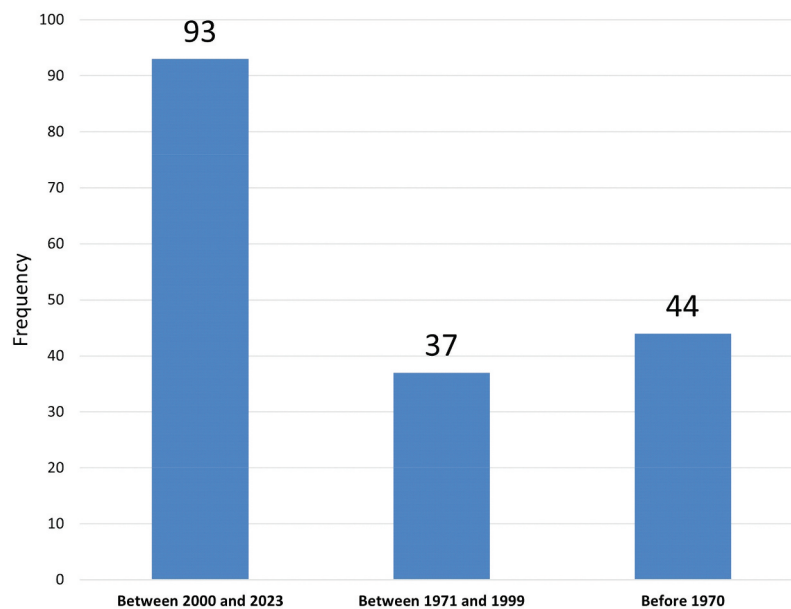


Figure 3. Number of records of *Saga pedo* by year, before 1970, between 1971 and 1999 and between 2000 and 2023. An observation is missing because the year is vaguely indicated as the interval between 2000 and 2004.

Distribution maps and relationships with the bedrock

The maps were created using the open source QGIS (v. 2.12, New York, USA). The database reports the elevation (if given by the author); however, in many cases this value was inferred from the location itself. Generic locations such as “Etna” were excluded from the elevation statistics, and the relationship between year and elevation was calculated as a regression line using only

reliable data, specifically 167 out of 174 records. To explore a possible relationship between bedrock type and the occurrence of *Saga*, all 167 locations were plotted against the distribution of calcareous and dolomite substrates in Italy, using code 11 of the Geolithologic Map of the “Geoportale Nazionale”. The distribution map of *Saga pedo* was performed using the QGIS program, incorporating the new records.

Results and discussion

We report here the updated distribution of *Saga pedo* in Italy, including the maximum altitudes reached by the species and other useful data for future monitoring on its phenology and ecology. As of 2023, there are 174 reports of *Saga pedo* across 92 localities: 44 before 1970, 37 between 1971 and 1999, and 93 between 2000 and 2023 (considering published journal data and/or unpublished data). Literature and other data sources indicate that the species is absent in many regions of Italy. However, our new reports show that *S. pedo* is a much more widespread species than previously known, perhaps merely elusive (Figures 4 and 5).

An interesting correlation has been observed between the presence of *Saga pedo* and the distribution of calcareous or calcareous-dolomitic substrates, as indicated by code 11 of the Geolithological Map from the National Geoportal (MATTM). As shown in Figure 5, nearby all the occurrences of *Saga* are concentrated on carbonate bedrocks or on the basic lava beds of the Etna volcano. However, it is important to note that the presence of this orthopteran is also influenced by climate and habitat factors (Lemonnier-Darcemont et al. 2009). In the Gargano and Triestine Karst most records go back to the last century, when such areas were severely deforested and covered by thermophilic pastures; spontaneous reconstruction of the forests has now been accomplished and *Saga* have become rarer here once again (Repetto et al. 2024). However, in other areas, such as the Ligurian Apennine or the Alta Murgia National Park (Apulia), the presence of this species has remained stable due to the well-preserved conditions of the Mediterranean open lands. A similar situation occurs in the “Petrosa” SAC of the Pollino National Park in northern Calabria, where extensive pastures with *Stipa austroitalica* are well conserved (Ancillotto & Labadessa 2023).

Regarding the elevation of the findings, recent data seem to show a trend of increasing altitude, which could correspond to the known phenomenon of global warming ($R = 0.0243$); however, the slope of the curve did not result in statistical significance (Figure 6).

Over approximately 180 years, the mean altitude of *Saga* records has risen from less than 400 meters to about 540 meters above sea level, an upward shift comparable to similar trends observed in other insect groups (Konvicka et al. 2003; Scalercio et al. 2014). The Orthoptera community has been observed shifting in response to climate change in Central Europe (Poniatowski et al. 2018; Löffler

et al. 2019). Additionally, the maximum known altitude of *Saga pedo* in Italy has increased from 950 to over 1,200 meters above sea level.

Unfortunately, population studies on this species are also rare and scattered. An interesting project aimed at monitoring *Saga pedo* was conducted in Slovakia between 2003 and 2006 at 36 sites considered suitable for the species' occurrence (Křístin & Kaňuch 2007). Monitoring was conducted using the count-and-release method, where individuals were counted and then released within transects, each 2 hectares in size. Each site was inspected 2 to 6 times per year, between May and October, from 11 a.m. to 6 p.m. Within the transects, the species was searched using various methods: entomological netting, both for mowing (500 mowings per site) and beating shrub branches (50 beating per site), direct visual search and listening for Orthoptera acoustic calls. Captured individuals of *S. pedo* were measured, weighed using a field scale and immediately released without any marking. The species was found at 20 out of 36 sites (13 of which were previously known), with maximum densities of three adults and 12 nymphs, both observed in early July.

A two-year study was carried out by Anselmo (2019, 2022) in the middle and upper part of the Susa Valley (Piedmont, Italy), where 34 individuals were counted in meadows, pastures and even vineyards, with grassy vegetation primarily composed of *Stipa pennata* L., 1753, *Bromus erectus* Huds., 1762, *Festuca ovina* L., *Chrysopogon gryllus* (L.) Trin., 1820, on a bedrock of marble and calcschists. Additionally, Ancillotto and Labadessa (2023) found that areas with Eastern sub-Mediterranean dry grasslands positively influence the presence of *Saga pedo*. Repetto et al. (2024) reported that most individuals were found in small, isolated xeric grasslands surrounded by a predominantly wooded matrix. They identified a clear correlation between the presence of *S. pedo* and open, unmanaged grasslands. Due to forest expansion in the north Apennines, they considered the current presence of the species in the area to be ecologically suboptimal.

Overall, this orthopteran was found to inhabit all regions of Italy. Only recently was this large Tettigoniidae recorded in Tuscany (Vergari et al. 2017) and it was reported again in Lombardy 141 years since its first discovery. Additionally, Nerozzi et al. (2022) documented *Saga pedo* as prey for the European Roller *Coracias garrulus* (Aves, Coraciidae) and highlighted the degradation of xeric grasslands, along with fires, as one of the main currently threats facing *Saga pedo*. Further,



Figure 4. Updated distribution of *Saga pedo* at 2023. Note that the species has been recorded after 2000 in nearby all regions of Italy, with the exception of the Val D'Aosta. Pentagon symbol: records before 1970; star: records between 1971 and 1999; triangle: records between 2000 and 2023.

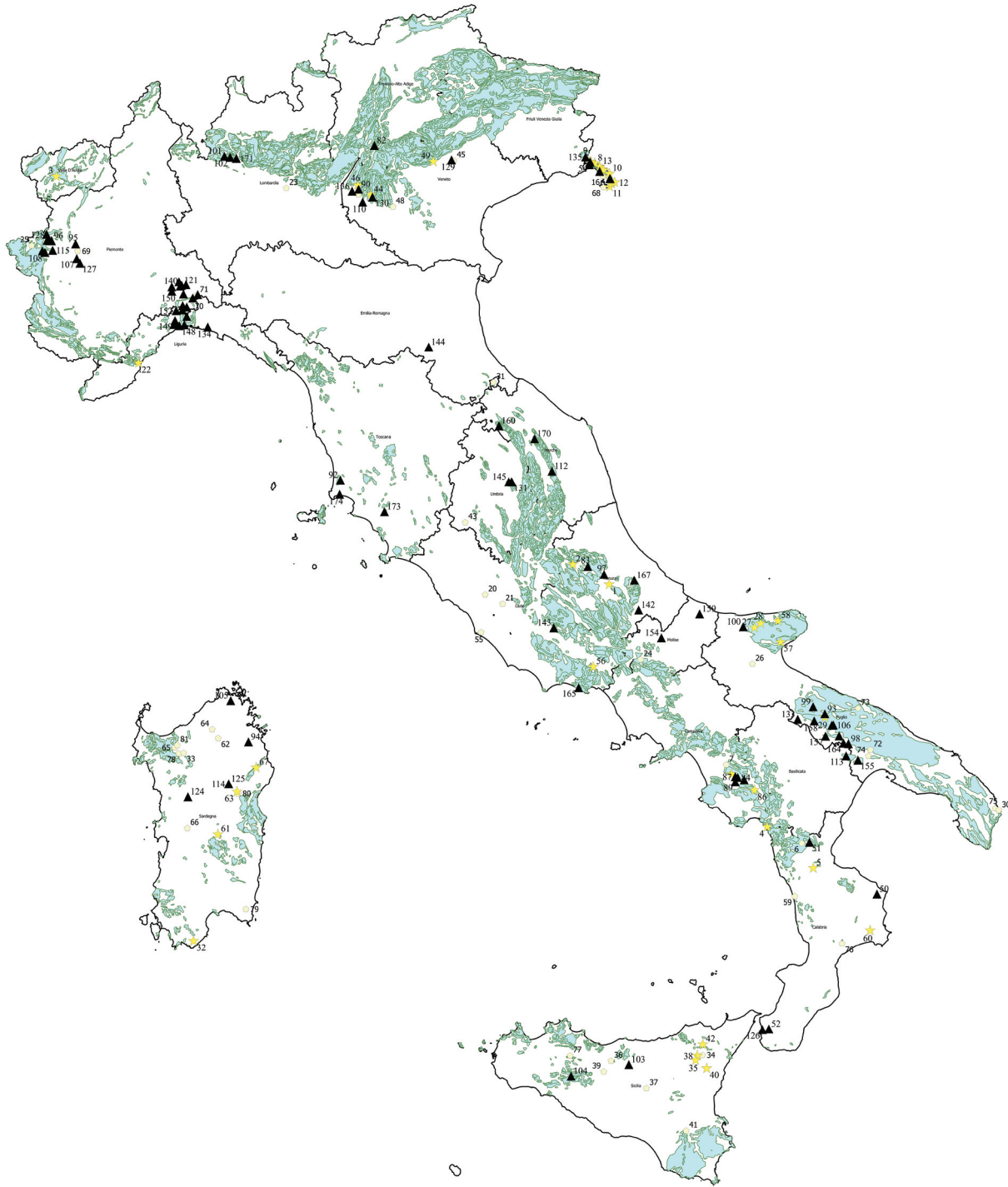


Figure 5. Distribution map of *Saga pedo* and calcareous or calcareous-dolomitic substrates, according to code 11 of Geolithological map in the national geoportail MATTM. Pentagon symbol: records before 1970; star: records between 1971 and 1999; triangle: records between 2000 and 2023.

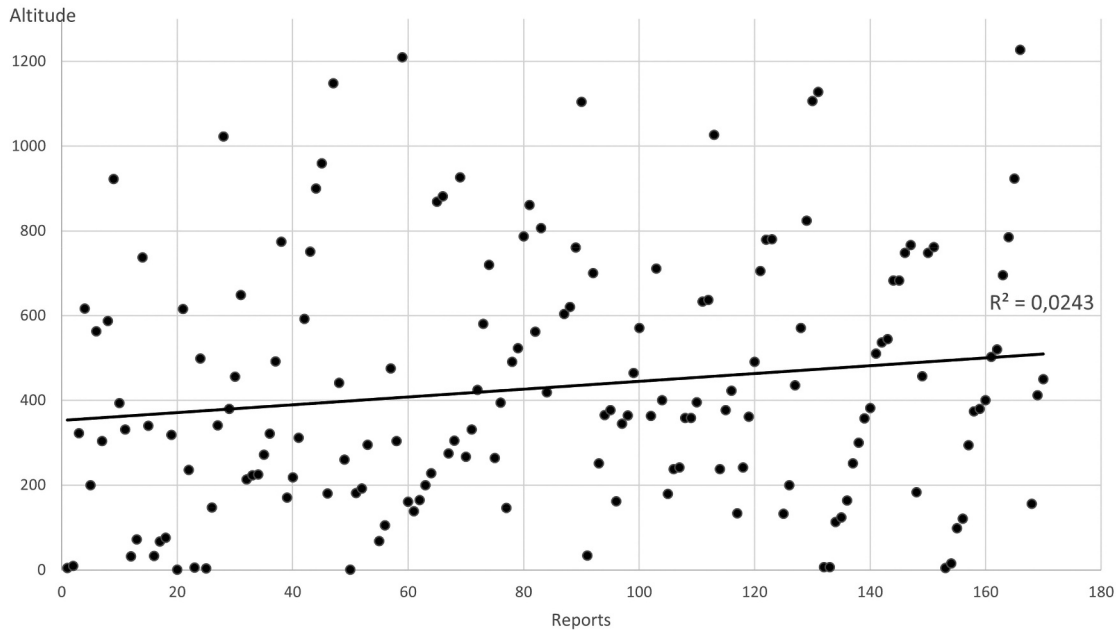


Figure 6. Elevation of *Saga pedo* locations as m a.s.l., ordered from the oldest (1855) to the newest (2023) recorded from 167 occurrence data, generic mountain localities omitted.

according to Repetto et al. (2024), the expansion of forest cover and intensification of agriculture are the main threats to *Saga pedo*. Also, its elusive and cryptic behavior reduces its detection, leading to underestimations of its population (cf. also Galli & Rocca 2006; Lapini et al. 2013).

Conclusions

Our results confirm what Ancillotto and Labadessa (2023) highlighted, that, although Nationally or Regionally protected areas and Natura 2000 provide comparable protection to *S. pedo*, only one third of the species' suitable range is currently protected. Although species monitoring under the Habitat Directive is planned, Italian regions have never organized such an activity. Knowledge of species distribution relies solely on the voluntary work and passion of many naturalists who report the presence of species listed in the Directive.

Despite the rarity of this orthopteran, a monitoring campaign of its populations in at least some densely populated sites could be of great interest for its conservation management. The addition of 80 new reports from various social platforms has significantly updated the species' distribution data. Although other methods for species conservation and population abundance assessments have been suggested (e.g., the use of

surrogate taxa or habitats: Mumby et al. 2008), our study demonstrates how citizen science can effectively enhance knowledge of the distribution and ecological preferences of target organisms. This approach is feasible, of course, only if the species is conspicuous and easily identifiable in photographs. All Italian regions, except Val d'Aosta, are now known to be inhabited by *Saga pedo*, with the first reports from the Marche region. Many of the recent reports are from areas near localities where the species was previously recorded, but some new reports (e.g., Umbria and Marche) are located far from these "historic" sites. There is also an altitudinal increase in distribution, indicating the growing influence of climate change on the populations of this species. Orthopteran communities are known to be sensitive to both climate change and to land use (Thomas et al. 2004; Hickling et al. 2006), and our results align with this trend. As widely documented, global warming is a key factor contributing to the range expansions of these thermophilus insects (Thomas et al. 2004).

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No potential conflict of interest was reported by the authors.

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