



Citizen science: a key tool for addressing knowledge gaps in the conservation status of protected species in Tuscan Mediterranean Sea

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ABSTRACT

The Mediterranean Sea is a biodiversity hotspot. The heterogeneity of habitats and the great richness of species are a resource to be protected. According to the Habitats Directive (92/43/EEC), Natura 2000 network is the main instrument of the European Union for biodiversity conservation. The aim of this contribution is to apply a citizen science approach as an innovative and effective method to address knowledge gaps regarding the conservation status of six marine species in Tuscan waters (NW Mediterranean) and listed in the Habitat Directive: *Centrostephanus longispinus*, *Corallium rubrum*, *Lithophaga lithophaga*, *Pinna nobilis*, *Patella ferruginea*, *Scyllarides latus*. This method identifies these rarest or cryptic invertebrate through well-trained citizens (divers, kayakers) whose observations (photos, videos or detailed description made by experienced observers) were validated by experts for updating Standard Forms, the identity cards of Natura (2000) sites. Results confirmed the “Endangered” *C. rubrum* distribution in historical sites and the presence in Tuscan archipelago of four alive specimens of “Critically Endangered” *P. nobilis*. For the first time the presence of *P. ferruginea* was recorded in a new site in Elba Island and information concerning species whose ecology is still little known as *C. longispinus*, *L. lithophaga* and *S. latus*, are collected. The involvement of direct observers of the marine environment makes monitoring effective and continuously updated. Information obtained may allow to propose the extension and/or the establishment of Natura (2000) sites for the safeguard of ecosystems. This innovative method can lay the basis for a temporal distribution status assessment of this species.

1. Introduction

The Mediterranean Sea is recognized as one of the world's biodiversity hotspots (Coll et al., 2010). Despite it accounts for just 0.82 % of the global ocean surface area and 0.32 % of its volume (Defant, 1961), this semi-enclosed basin is home to an astonishing diversity of marine life. Over 17,000 marine species have been documented in the Mediterranean. Notably, an average value of 20.2 % of these species are endemic to the Mediterranean basin (Coll et al., 2010). The heterogeneity of the habitats and the remarkable species richness in this hotspot

highlight it as a valuable resource that must be protected. For this purpose, Natura 2000 network was established by the European Union as a key tool for biodiversity conservation. This ecological network has been established under Directive 92/43/EEC, commonly known as the Habitats Directive (EEC: Habitats Directive 92/43/EEC, 1992), to ensure long-term maintenance of natural habitats and the protection of endangered or rare species of flora and fauna at the Community level. The Natura 2000 network comprises Sites of Community Importance (SCI), identified by the Member States in accordance with the Habitats Directive. Standard Forms (*sensu* Dir 92/43/EEC) are the identity cards

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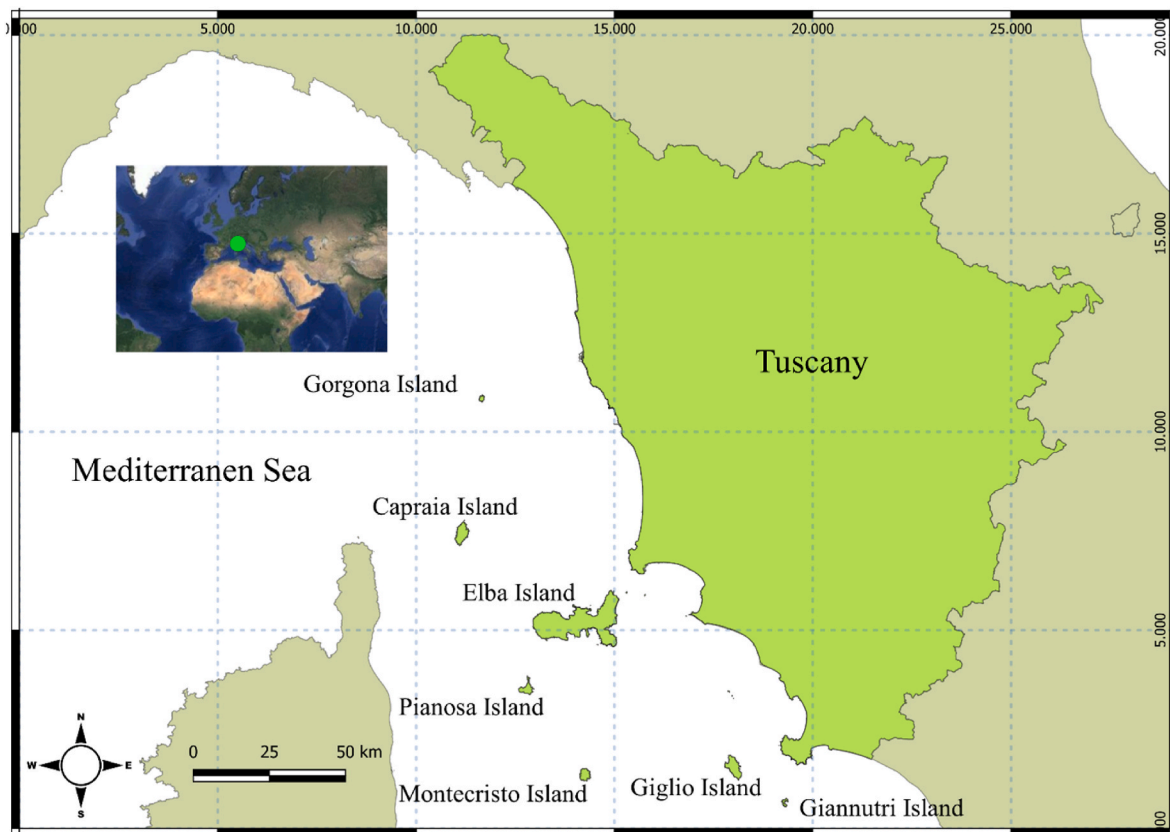


Fig. 1. Map showing the location and outline of the study area.

of Natura (2000) sites and show the state of health of protected species and habitats. Their constant updating is crucial for environmental conservation and the implementation of efficient protection measures. Given the scale of this task, a multidisciplinary approach is appropriate. Citizen science projects can engage many people for environmental and biodiversity monitoring not only to address global challenges like climate change and environmental pollution, but also help mitigate their consequences, such as biodiversity loss (Berger et al., 2019; Dick et al., 2017; Fink et al., 2014).

The term “citizen science” refers to a collaborative partnership between citizens and scientists. This method builds on the evolving concept of science from the 19th century to the present: citizens involved in scientific projects become more informed and passionate about scientific issues (Silvertown, 2009; Vohland et al., 2021) and their participation significantly boosts the effectiveness of conservation efforts (Dickinson et al., 2012). The use of this method in the marine field is already known not only for efficient data collection and promotion of proper sea protection measures but also to raise volunteers’ awareness about environmental issues (Ambrose et al., 2019; Peterson et al., 2020).

Based on previous reports, six species of marine invertebrates have been selected due to their ecological and conservation importance, or because of the limited knowledge on their distribution and abundance: longspined sea urchin (*Centrostephanus longispinus*), red coral (*Corallium rubrum*), European date mussel (*Lithophaga lithophaga*), Mediterranean pen shell (*Pinna nobilis*), ferruginous limpet (*Patella ferruginea*), and European slipper lobster (*Scyllarides latus*).

According to the IUCN Red List, four of these species (*C. longispinus*, *L. lithophaga*, *P. ferruginea*, and *S. latus*) are not listed at the global and the Mediterranean level, while *S. latus* is globally assessed as “Data Deficient” (Butler et al., 2011). The Mediterranean assessments, however, list *C. rubrum* as “Endangered” (Garrabou et al., 2015) and *P. nobilis* as “Critically Endangered” (Kersting et al., 2019). These species are either cryptic or endangered, reflecting a wide range of conservation

concerns.

Historically, the red coral has been heavily exploited for handcrafted jewelry (Tsounis et al., 2010), while the noble pen shell is threatened by mass mortality events due to widespread multifactorial epidemic/disease in the Mediterranean basin (Carella et al., 2023a; Scarpa et al., 2020; Theodorou et al., 2024; Vázquez-Luis et al., 2017). The European date mussel has suffered from destructive harvesting practices (Colletti et al., 2020), and the European slipper lobster, elusive and cryptic, displays nocturnal behavior and prefers sheltered habitats like caves (Spanier and Lavalli, 1998). The deep-sea urchin remains poorly studied, particularly regarding its environmental drivers and population distribution (González-Irusta et al., 2015). Lastly, the ferruginous limpet, a rare and endemic species in the western Mediterranean, despite his presence has been reported in Montecristo, Gorgona and Capraia Islands (Appelius, 1869; Porcheddu and Milella, 1991; Terreni, 1981), the species still has significant distribution gaps, especially in the Tuscan Archipelago (Ferranti et al., 2023). For detailed information on the distribution of the six species in the Tuscan marine region, as provided by the most up-to-date standard forms, refer to Table S1.

The aims of this study were: i) to apply a citizen science approach as an innovative and effective method to address knowledge gaps regarding the conservation status of certain marine species listed in the Habitats Directive, within the Tuscany Region (Italy, NW Mediterranean); ii) to involve well-trained citizens (e.g., divers, kayakers) in the detection of these rare or cryptic species and the collection of data in the Tuscan marine region. The results could support proposals for extending or establishing new SCI and SAC, with immediate action particularly needed for Elba and Giglio, the only two islands in the Tuscan Archipelago without a marine extension to their terrestrial SCIs.

Table 1
Involved kayak/diving centers and their respective diving area.

Diving/kayak center location	N° Diving/kayak centers	Diving/kayak spots
Elba Island	14	Elba Island Pianosa Island Cerboli Island Palmaiola Island Scoglietto of Portoferraio Capraia Island
Argentario Promontory	1	Argentario Promontory Giglio Island Giannutri Island

2. Materials and method

2.1. Study area

The study area is represented by Tuscan marine region in Italy, Northwestern Mediterranean Sea (Fig. 1). This area is characterized by the presence of 11 marine Sites of Community Importance (SCI) or Special Areas of Conservation (SAC) Capraia Island - land and sea area (IT5160006), Gorgona Island - land and sea area (IT5160002), Pianosa Island - land and sea area (IT5160013), Montecristo Island and Formica di Montecristo - land and sea area (IT5160014), Continental slope of the Tuscan Archipelago (IT5160020), Calafuria - land and sea area (IT5160023), Giannutri Island - land and sea area (IT51A0024), Scoglietto of Portoferraio (IT5160019), Scoglio dell'Argentarola (IT51A0038), Protection of the *Tursiops truncatus* (IT5160021), Backdrops between the mouths of the Chiarone River and Fiora River (IT6000001), and a Marine Protected Area (MPA), Secche della Meloria MPA (IT5160018), in 9 of which at least one of the target species has been certified according to the latest assessment reported in the Standard Forms.

2.2. Data collection of target species and validation method

Data collection of six target species was conducted over a five-month period, spanning from May to September 2023, involving a total of 15 diving and kayak centers. As shown in Table 1, 14 centers were located on Elba Island, and one is situated on the Argentario Promontory, covering the whole area of the Tuscan Archipelago apart from Montecristo Island and Gorgona Island because of their specific environmental protection regulations. A map showing the location of these centers is given in Fig. S2. The report was structured in three sections. The first section gathered detector information, including the observer's name and contact details. The second section focused on the observation details such as the species and/or habitats observed, sighting coordinates, depth, monitoring duration, and included the upload of photos and videos. The final section was designed to estimate abundances where possible. Sightings of longspined sea-urchins, European slipper lobsters and ferruginous limpets were quantified by recording the number of observed individuals. As regards the red coral and European date mussel, the exact number of individuals cannot be indicated due to their colonial nature or cryptic behaviour, and the only presence/absence data were recorded. For the endemic noble pen shell, both live and dead specimens were reported to quantify the impacts of mass mortality events. To ensure precise characterization of target species, a specific question is included to gather detailed information about the habitat associated with the observed specimens. After a presentation of the objectives and aims of the citizen science project and how to report the target species through the observation card to diving or kayak instructors who have agreed to participate to the project, a short briefing was held by diving instructors to citizens before monitoring (diving, kayak tour) to make participants aware about project's purposes and how data is collected through the underwater visual census or kayak to be monitored. The major issues that have made this species and the associated habitats so significant were also explained. Reports were administered only to citizens who had attended the briefing session immediately before taking part in the activities of diving and kayak centers and were therefore considered informed and well-trained for the purposes of the project. Afterwards, the validation process made by experts consisted in the review of the observation reports alongside the

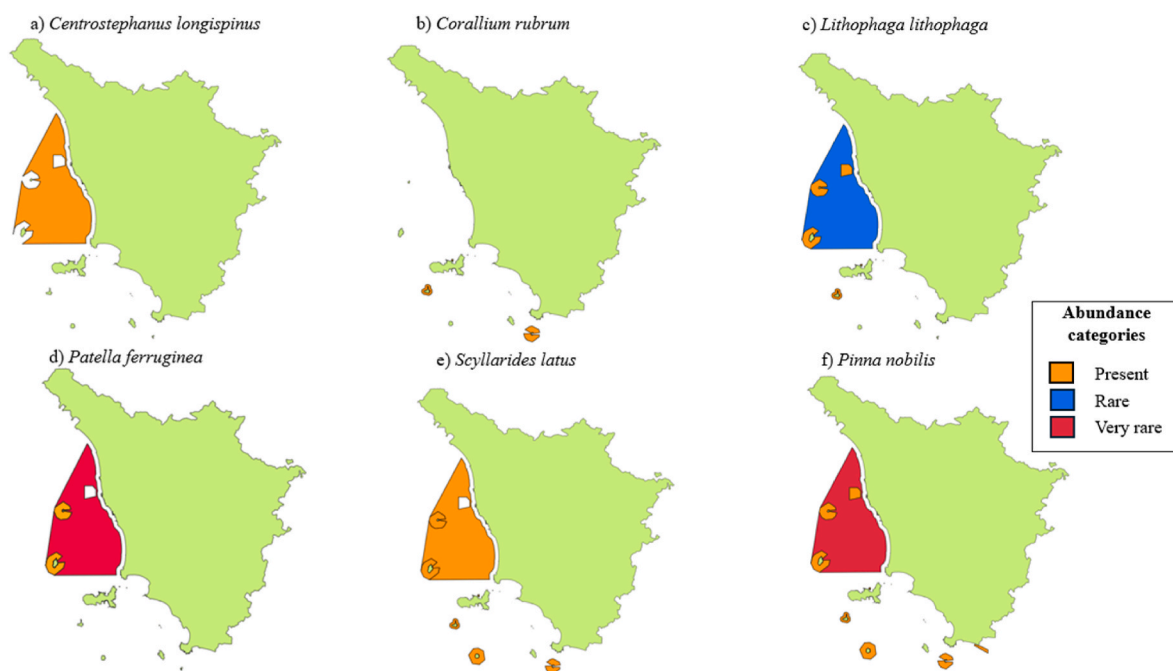


Fig. 2. Map illustrating the abundance of the six target species in the study area (a) *C. longispinus*, (b) *C. rubrum*, (c) *L. lithophaga*, (d) *P. ferruginea*, (e) *S. latus*, (f) *P. nobilis* and categorized as present, rare, and very rare, based on the latest assessment reported in the Standard Forms.

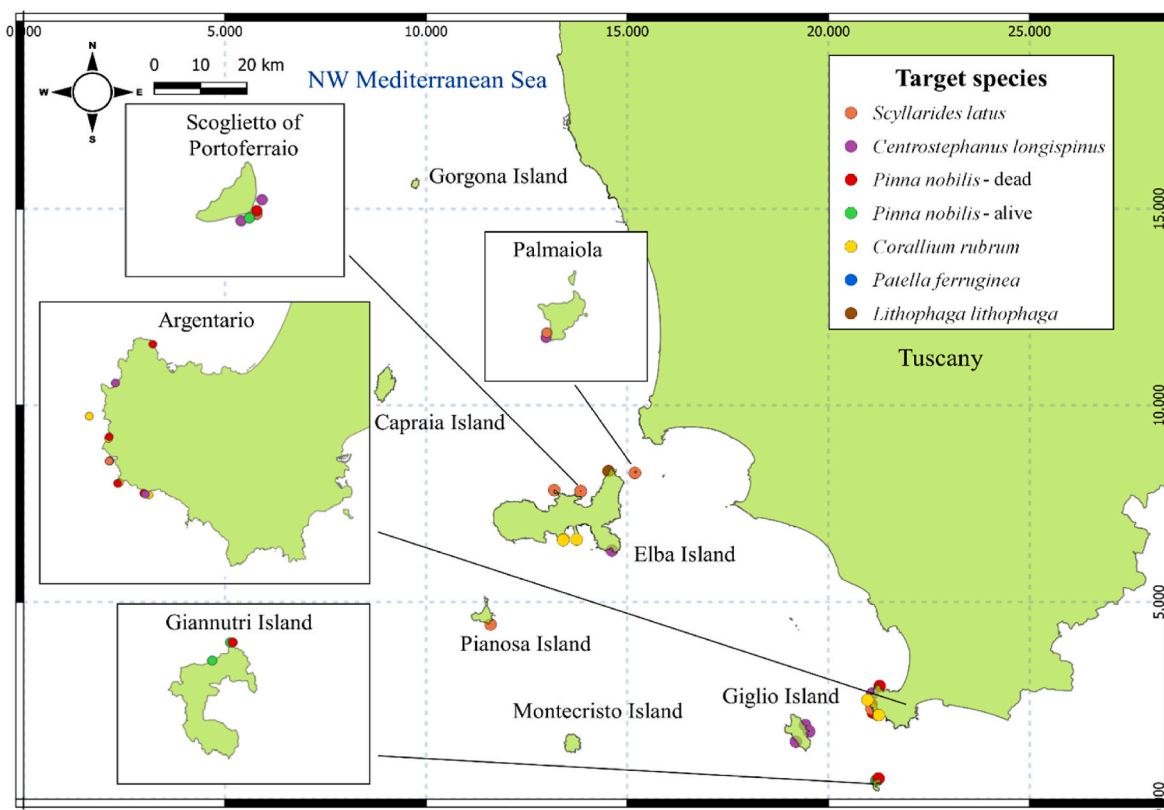


Fig. 3. Geographical distribution of sightings of the target species.

accompanying photographic or video evidence. Citizens were characterized in three categories according to their level of experience: scientific observers (a) including students, researchers and scientific project participants, diver/kayak instructors (b) with a good knowledge of the diving/kayak techniques as well as of the monitoring sites and recreational observers (c) without specific training in marine biology. When reports are not supported by photos or videos, they are validated only if the observer is experienced and provides detailed, precise descriptions of the observations.

2.3. Cartography and database creation

The software GIS version 3.22.14, Bialowieza (QGIS Development Team, 2021) was used for the creation of cartography based on observation reports.

3. Results and discussions

The data collected from May to September 2023 from the 15 diving and kayaking centers showed that most sightings (97.7 %) came from diving centers, while the remaining 2.3 % were reported by kayaking centers underscoring the significant contribution of diving activities to the detection and reporting of marine species in this study. Data derived from 16 different observers, of which most of all observations came from scientific observers (a) (63.9 %), followed by diver/kayak instructors (b) (22.2 %) and recreational observers (c) (13.9 %). The accuracy ratio (correct observation/total observation) related to the three observers' categories taken into account was 1 for (a), 0.75 for (b) and 0.60 for (c). These results may be due to the level of knowledge of the marine environment and the ability to recognise target species as well as the environmental awareness of marine issues which increases in line with the diver's own experience gradient (Godoy et al., 2010; Ward-Paige et al., 2011). According to the information provided by Standard Forms,

Fig. 2 shows the abundance of the six target species in marine SCI or SAC of the study area, categorized as present, rare and very rare. Considering the knowledge gaps in the conservation status and the fragmented and cryptic distribution of the six species investigated of marine invertebrates (longspined sea-urchin, red coral, European date mussel, noble pen shell, ferruginous limpet, European slipper lobster), cartographical and sightings data are a fundamental resource for conservation purposes (Stranga et al., 2024). According to IUCN Red List of Threatened Species four of the six species have no status assessment (*C. longispinus*, *L. lithophaga*, *P. ferruginea*, *S. latus*) for the Mediterranean Sea. Within this study, two forms were completed for the species *P. ferruginea*, one of which was valid, while the other was excluded due to incorrect data. One individual of the endemic Mediterranean gastropod *P. ferruginea* has been recorded in north Elba Island (Fig. 3). The presence of this endemic species in the sighted area has never been recorded before (Ferranti et al., 2023; Luque et al., 2018). Bibliographical sources reported only isolated specimens of ferruginous limpet in Capraia Island and Gorgona Island (Appelius, 1869; Porcheddu and Milella, 1991; Terreni, 1981) while the richest and closer populations are located along the coasts of Corsica and Sardinia (Casu et al., 2011; Espinosa et al., 2014; Luque et al., 2018). The duration of the swimming larval phase of *P. ferruginea* and the great dispersion capacities make exchanges between the populations of NE Sardinia and Corsica and Tuscan Archipelago possible (Ferranti et al., 2022; Guallart et al., 2022). The presence of *S. latus* was reported in seven forms, five valid and two incomplete. This study reported the presence of the European slipper lobster in Elba Island and Palmaiola Island, for a total of 3 recorded individuals, 1 sighting concern Pianosa Island and 1 the Argentario. The nocturnal crustacean *S. latus* is frequently captured through bycatch so much that in recent decades, there has been a decline of large crustaceans such as *S. latus*, due to overfishing and coastal anthropization combined with several factors due to the change in ocean climate (temperature, salinity, carbonatic chemistry) (Addison and Bannister,

1994; Caputi et al., 2013; Giraldez et al., 2015). For this reason, *S. latus* should be considered a species of great importance for conservation aims. A total of 13 completed forms, while one was excluded due to incorrect data constituting the second highest percentage (23.6 %) of the total forms reported the presence of *C. longispinus*, accounting for a total of 95 sighted individuals. Overall, in this study the individuals of the cryptic echinoderm species *C. longispinus*, were reported in Scoglietto of Portoferraio, Palmaiola Island, Elba Island, Giglio Island and Argentario. These data are crucial because of the severe lack of information on the distribution and abundance of longspined sea-urchin but also for the pressures (e.g., trawling) that threaten this species (González-Irusta et al., 2012). Dead *P. nobilis* also had the second highest number of records (23.6 %) of completed forms with 13 forms of which 12 valid, an additional incomplete observation forms for dead individuals were excluded from the analysis accounting for a total of 24 reported individuals. The role that the shell has as a refuge and secondary substrate for epibionts persists even after the death of specimens, continuing to play a fundamental role in maintaining high functional diversity in the ecosystem. In fact, the diversity associated with empty shells is equal to or greater than that associated with live specimens (Iannucci et al., 2023), which is why it is prohibited to collect even the shells of dead specimens, which are also colonised internally and used as a refuge by vagile animals. Overall, 3 validated reports testified the sighting of 4 living individuals of the same species (5.5 %). Another important result of this study is the sighting of 4 alive specimens of the critically endangered bivalve species *P. nobilis* recorded in Giannutri Island (3 specimens in 2 different diving spots) and Scoglietto of Portoferraio (1 specimen) reported in Fig. 3. The presence of this endemic species was already witnessed in Standard Forms of the two areas updated in 2019. The mass mortality events that affected the species across the Mediterranean Sea started in early autumn of 2016 within Spanish Mediterranean Sea. These events have reduced the Tyrrhenian population of noble pen shell between 80 % and 95 % varying according to season and location, reaching peaks of 100 % considering the Mediterranean basin (Carella et al., 2019; Vázquez-Luis et al., 2017; Mihaljević et al., 2021) and still afflicts the species even today. One of the major causes of these events was attributed to the presence of the parasitic pathogen *Haplosporidium pinnae*, the effect of which may be amplified by the presence of viruses and *Mycobacterium* spp (Carella et al., 2019, 2023b; Lattos et al., 2020; Scarpa et al., 2020). However, 22 dead specimens were sighted, highlighting the severe current of the event. For this reason, the sighting of alive specimens is crucial for the assessment of the effects of the event and the survival capacity of the species. Citizen science based on the visual recognition of *Pinna nobilis* is an accepted and widely used method for monitoring the species (Denti et al., 2023; Tiscar et al., 2022; Vázquez-Luis et al., 2017). *P. nobilis* and *Pinna rudis*, the only other bivalve of the genus *Pinna* present in the Mediterranean, are generally distinguishable based on morphological characteristics, as well as their distinct habitat preferences: *P. nobilis* typically inhabits seagrass meadows and sandy bottoms (Rouanet et al., 2015), while *P. rudis* is more frequently found on rocky substrates (Kersting and Ballesteros, 2021). However, following the mass mortality event, an apparent increase in the presence of *P. rudis* has been reported, along with the emergence of hybrid individuals exhibiting intermediate morphological traits between the two species (Coupé et al., 2023; Oprandi et al., 2024). The observations considered in this study were submitted by experienced observers or accompanied by photographs in which the morphological features were clearly identifiable; therefore, no further investigations were deemed necessary. In doubtful cases, molecular analysis would be useful to ensure correct species identification (Vázquez-Luis et al., 2021). However, such analysis requires the collection of mantle tissue samples. Given the critically endangered status of *P. nobilis* and the very limited number of surviving individuals, emerging non-invasive technique like environmental DNA should be taken into account but they are still being refined to distinguish hybrids (Martínez-Martínez et al., 2025). The species *C. rubrum* was reported in

Table 2

Completed forms (CF) (number and percentage on the total of completed forms) of investigated species collected by citizen science campaign in the period May–September 2023. Valid completed forms and species associated habitats are also reported.

Species	CF N	CF (%)	Valid CF N	Species associated Habitat
<i>Scyllarides latus</i>	7	12.7	5	Coralligenous reef
<i>Centrostephanus longispinus</i>	13	23.6	12	Coralligenous reef
<i>Lithophaga lithophaga</i>	1	1.8	1	Limestone cliff
<i>Corallium rubrum</i>	16	29.1	14	Coralligenous reef
<i>Pinna nobilis alive</i>	3	5.5	3	Posidonia seagrass
<i>Pinna nobilis dead</i>	13	23.6	12	Posidonia seagrass
<i>Patella ferruginea</i>	2	3.7	1	Granite cliff

16 forms, two of which were invalid, making up the highest percentage of completed forms (29.1 %). The presence of the precious and endangered *C. rubrum* along the Tuscan coast has been witnessed for centuries. Colonies are historically distributed from the northern sector of Tuscan (Meloria Shoal, Calafuria and Vada sholas) to the coasts of Argentario Promontory in the southern part of the region. This area, rich in small and scattered populations present in shallow waters (Scatizzi, 1935), has hosted pioneeristic scuba diving underwater collecting activities since the 1950s (Liverino, 1998). In addition, the Tuscan archipelago, like Elba Island where the species is present, has been the subject of historical and recent harvesting (Angiolillo et al., 2015). This study confirms the presence of red coral in the southern part of Elba Island and near the Argentario Promontory (Fig. 3). Citizen's observations provided data on the presence/absence of the species, but a specific questionnaire for divers focused on density (high, medium or low) of red coral colonies, quantification of colony damage or necrosis in terms of percentages and nets impacts may be appropriate (Bramanti et al., 2011). Continuous reporting of the presence and quantity of red coral colonies is a fundamental tool for assessing the conservation status of the species and the improvement of management measures.

A calcareous rock with *L. lithophaga* was reported in one form, which is the smallest number of compiled forms (1.8 %). *L. lithophaga* is a bivalve species inhabiting subtidal rocky habitats that has been significantly impacted by intensive fishery harvesting activities (Colletti et al., 2020). Despite only one compiled observation form for a sighting in the northern part of Elba Island, the presence of this bivalve species living on the limestone wall can give an important indication regarding preservation and the contrast of habitat loss. Fig. 3 shows the target species reporting sites.

The average duration of monitoring session (e.g., diving, kayaking) was 49.6 min corresponding to a total duration of 30.4 h of diving.

Analyzing the habitats associated with the target species, *S. latus*, *C. longispinus* and *C. rubrum* were mainly linked to coralligenous reefs, while *P. nobilis* was associated with *Posidonia oceanica* seagrass ecosystem. *L. lithophaga* was linked to limestone cliff and *P. ferruginea* to granite cliffs (Table 2). *Posidonia oceanica* seagrass and coralligenous reefs are the two main biodiversity hotspots of the Mediterranean Sea (Boudouresque, 2004; Boudouresque et al., 2016). The ecological complexity of these two habitats is due to their three-dimensional structure, offering different ecosystem service such as breeding areas and nursery areas for a great number of associated species, providing also a nutrient transfer between the pelagic and benthic environments (Campagne et al., 2015; Gili and Coma, 1998; Thierry de Ville d'Avray et al., 2019). At the same time these habitats of primary importance are particularly affected by anthropogenic pressures like coastal overfishing, environmental contamination and climate change (Coll et al., 2012; Katsanevakis et al., 2014; Zunino et al., 2017). In this study three of the species investigated (*S. latus*, *C. rubrum*, *C. longispinus*) were observed in coral reefs correlation while *P. nobilis* was linked at Posidonia seagrass. The results obtained clearly demonstrate that citizen science is an



Fig. 4. Photos from the observation forms. From left: (a) *S. latus*, (b) cliff showing *L. lithophaga* presence, and (c) *C. rubrum*.

innovative and effective method for producing high-quality data, particularly in monitoring cryptic species at new sites or confirming their presence or absence at previously reported locations. Moreover, this study confirms the findings of Edgar and Stuart-Smith (2009), who asserted that when project participants are well trained and informed, the data they collect can be comparable to that produced by professional scientific monitoring. Furthermore, the study corroborates Kosmala et al. (2016), highlighting that citizen science projects offer a valuable opportunity to gather large-scale data that would otherwise be unattainable, thereby significantly enhancing the efficiency of scientific research and environmental management. These data could provide a fundamental tool for science-based management projects both for scientific and marine management aims (Hermoso et al., 2021; Shirk et al., 2012). When a species is particularly difficult to identify, however, observer biases must be considered (Lehtiniemi et al., 2020). Biases are minimal or avoided if data are meaningful and accurate and if the reports are accompanied by photographs or compiled by experienced observers (Yamamoto, 2012). Nonetheless, an additional source of bias in citizen science arises from the potential non-participation or under-reporting by certain experienced observers, such as spearfishers, who, despite their detailed ecological knowledge, may withhold information on specific taxa, particularly those subject to illegal exploitation, such as *L. lithophaga* (Hermoso et al., 2021). Fig. 4 shows the attached images present in observation forms allow for immediate validation or rejection of data. In the absence of immediate validation, observation forms provide the basis for more detailed scientific monitoring. In this study it was not possible to assess the seasonal distribution of species and make a homogeneous assessment of data that could be allowed by an integration with data that will be collected in future. Visual census can be made more efficient by extending the project to new diving centers and replicating the study in future years.

4. Conclusions

This study shows the importance of the application of an integrated approach between citizen science and scientific monitoring. Citizens confirm the presence of the target species in sites in which they had never sighted before and which does not yet have marine protection like in case of *P. ferruginea* and testify the survival capacity of endangered or critically endangered species like *C. rubrum* and *P. nobilis*. This innovative method also provides the basis for surveying species whose distribution status is incomplete in the case of *L. lithophaga* and *C. longispinus* or indirectly deduced, as for *S. latus*. Information gathered on species and associated habitats may form the basis for the scientific community to interact with stakeholders and policy makers. Their presence is essential for the proposal of new SCIs or the extension of the existing ones, where the best conservation and management measures may be adopted. The involvement of direct observers of the marine environment such as divers and kayakers who combine their passion for the sea with science-based observations, makes monitoring effective and continuously updated. These implications in conservation actions will enable

the achievement of the Sustainable Development Goals set out in the 2030 Agenda and in particular Global Goal 14 that aims to protect marine and coastal environments. The same monitoring model could be used as a key instrument for the observation of alien marine species and for the safeguard of key species, whose ecological role and vulnerability to climate changes make so important and threatened at the same time. The six marine species can be used to compare different study areas around the world and to create a temporal trend assessment of their distribution and conservation status in the same area.

CRediT authorship contribution statement

Chiara Marescalchi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Cecilia Mancusi:** Writing – review & editing, Supervision, Methodology. **Francesca Capanni:** Writing – review & editing, Methodology, Conceptualization. **Valentina Menonna:** Writing – review & editing, Validation. **Andrea Casadio:** Writing – review & editing, Validation. **Gilda Ruberti:** Writing – review & editing, Validation. **Niccolò Della Giovampaola:** Writing – review & editing, Investigation. **Francesco Bonucci:** Writing – review & editing, Investigation. **Valeria Paoletti:** Writing – review & editing, Methodology, Investigation. **Massimiliano Maschio:** Writing – review & editing, Methodology, Investigation. **Letizia Marsili:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Letizia Marsili reports financial support was provided by Tuscany Region. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecss.2025.109476>.

Data availability

Data will be made available on request.

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