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Assessing the limits: citizen science data accuracy in underwater monitoring

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Abstract

Citizen science has become a powerful tool for generating extensive ecological data and fostering public engagement in environmental monitoring and conservation initiatives. In marine environments, where monitoring is challenging due to logistical demands and financial constraints, engagement of recreational divers in citizen science projects offers a promising avenue for expanding data collection efforts over large spatial and temporal scales. Here, we evaluate the accuracy of ecological data collected by 118 volunteer divers in three countries in the Mediterranean region by comparing their observations with those of expert scientists during 2012–2016. Using standardized monitoring protocols across multiple sites, we assessed volunteers' abilities to identify marine species, threats and impacts, estimate abundances, and correctly report species' absence. Our results demonstrated a notable success rate (exceeding 70% in many cases) in the detection and assessment of multiple species and threats. Nonetheless, volunteer divers frequently misidentified sessile taxa and fish species and often failed to detect less conspicuous environmental stressors, such as tissue necrosis indicative of mass mortality events. Diving experience and site familiarity were found to significantly influence the quality of information reported by non-experts, with experienced and site-acquainted divers demonstrating higher data accuracy. While citizen science can greatly support ecological research and conservation, our findings indicate that comprehensive training and stringent data-validation procedures are indispensable for reliably capturing complex or less conspicuous ecological variables.

Keywords Ecological data validation · Recreational divers · Marine ecosystems

Introduction

Citizen science, defined as the broad practice of including members of the public in scientific research (Dickinson et al. 2010; Roche et al. 2020), has become a popular and rapidly growing discipline in recent decades (Follett and Strezov 2015; Fraisl et al. 2022), offering numerous benefits to both participants and the scientific community (Bonney et al. 2009; Connors et al. 2012; Fraisl et al. 2020). The rising interest in participatory citizen science approaches originates partly from the growing need of large-scale, long-term monitoring datasets for policy and management (Conrad and Hilchey 2011; Hyder et al. 2015; McKinley et al. 2017). This is particularly the case in vast marine areas, where data collection is challenging and costly (Bauer-Civiello et al. 2018). Citizen scientists help to overcome the challenges posed by limited funding and available research effort (Delaney et al. 2008; Fritz et al. 2019) by generating large volumes of data across broad spatial and temporal scales (Poisson et al. 2020), providing scientists and resource managers with a cost-effective way to expand their data collection capacity. Beyond its function as a tool for data collection, citizen science plays a multifaceted role in enhancing public awareness, facilitating experiential learning for participants, and strengthening societal engagement with scientific research and outreach activities (Bonney et al. 2014; Forrester et al. 2017; Turrini et al. 2018; Hecker et al. 2019).

Data collection and volunteer participation in monitoring of the marine environment present unique challenges. While both terrestrial and marine projects require volunteer training, marine projects usually have the additional requirements of swimming, snorkelling or SCUBA diving skills, along with the use of specialized equipment (e.g., underwater photography) (Goffredo et al. 2010; Gillett et al. 2012; Forrester et al. 2015). Recent decades have witnessed a surge in recreational divers (Cabral et al. 2025), prompting research programmes to recruit these divers as volunteers, leveraging their inherent interest in marine life. Consequently, citizen science initiatives encompass a broad spectrum of data collection efforts, ranging from the measurement of basic abiotic variables (e.g., seawater temperature) to the acquisition of complex biodiversity data involving multiple taxa, habitats and associated threats (Gerovasileiou et al. 2016; Kelly et al. 2020). Although marine citizen science projects constitute specialized applications with diverse scopes, focal subjects, and methodological approaches, they share the fundamental principle common to all citizen science initiatives: a commitment to generating reliable data to support scientific enquiry and inform policy-making processes (Forrester et al. 2015; van der Velde et al. 2017; Earp and Liconti 2020).

Despite the obvious merits of citizen science projects (Dickinson et al. 2010; Fraisl et al. 2022) scientists and decision-makers often question whether volunteers can produce the high-quality data required for rigorous scientific research (Kosmala et al. 2016; Aceves- Bueno et al. 2017; Brown and Williams 2019). Indeed, while several studies suggest that volunteers can perform comparably to professionals (Cox et al. 2012; Forrester et al. 2015; van der Velde et al. 2017), others report that volunteers produce highly variable and inaccurate data (Newman et al. 2010; Moyer-Horner et al. 2012; Bird et al. 2014; Ratnieks et al. 2016). These concerns about data quality underscore the need for volunteer training, expert validation, and systematic evaluation of citizen science data accuracy (Vermeiren et al. 2016; Aceves-Bueno et al. 2017; Figuerola-Ferrando et al. 2024).

To contribute to this discussion, we conducted a field exercise evaluating the performance of citizen scientists in compiling both quantitative and qualitative data, and then we compared their records to those of professional scientists. This assessment was conducted across three sites in three Mediterranean countries, providing a basis for exploring variations in performance under differing levels of data-reporting complexity, both for marine biota components (sessile vs. motile species) and for threat categories (e.g., easily recognized threats such as marine litter versus more complex impacts such as necrosis/mortality events). Additionally, we investigated the influence of diver experience and site familiarity on data accuracy. While we support citizen involvement in marine data collection, our study raises serious concerns about the broader adoption of citizen science for monitoring marine species and the complex threats they face without prior training and validation of participants' skills and data-reporting accuracy.

Methods

Study area, participant selection and diving procedures

Implementation of the monitoring protocols took place in three countries: France (Marseille), Greece (Zakynthos Island) and Türkiye (Ildır Bay/Çeşme) (Fig. 1). The study involved two monitoring exercises to evaluate the effectiveness of citizen scientists in identifying species and threats, and in implementing a standardized protocol, compared with professionals. Threats were associated with abandoned fishing gear, marine litter, anchoring, sedimentation, signs of diver recklessness, necrosis or mortality events, as well as the presence of invasive species and mucilaginous aggregates (evaluated as 0 = absent, 1 = limited, and 2 = extended) (Gerovasileiou et al. 2016). The study also aimed to determine which factors were associated with performance. Monitoring sites and their associated coralligenous assemblages are described in detail by Çinar et al. (2020).

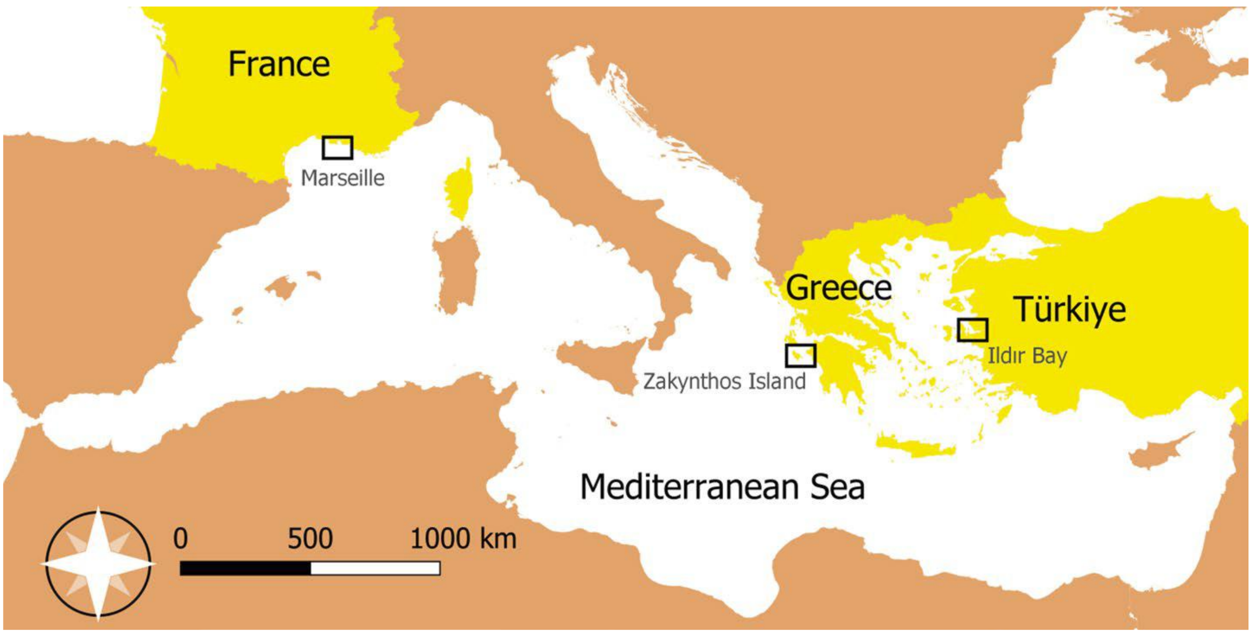

Fig. 1 Map depicting the three Mediterranean sites where the two field exercises took place (i.e., Ildır Bay in Türkiye, Zakynthos Island in Greece and Marseille in France)

To assess the accuracy of data collected by volunteers, records of various marine biota components and associated threats from 27 participants were directly compared with those collected by expert scientists during multiple dives conducted at the three sites between July and September 2015 and between May and November 2016. Divers followed a standardized protocol designed to guide data collection and implementation (CIGESMED for divers – Gerovasileiou et al. 2016). The overarching objective of the CIGESMED citizen-science initiative for divers was to establish a Mediterranean-wide network of dedicated observers of coralligenous habitats using a standardized monitoring protocol (Gerovasileiou et al. 2016). The primary target group comprised "dedicated divers," defined as experienced enthusiasts who regularly dive below 20 m and demonstrate strong interest in marine biodiversity and the conservation of their diving sites, including members of local diving clubs, naturalists, and underwater photographers. Prior experience within CIGESMED indicated that many divers fitting this profile were already active in established marine-life networks (e.g., DORIS - https://doris.ffessm.fr/, BioObs - https://bioobs.fr) and were inclined to engage with platforms enabling the systematic sharing of observations. To support the implementation of the CIGESMED for divers monitoring protocol, a multilingual online portal was developed, complemented by the LifeWatchGreece mobile application, which was adapted and extended to include a dedicated citizen-science module. The monitoring protocol captured an array of ecological and environmental information (e.g., coralligenous habitats and associated species, invasive species, human-induced pressures, marine litter) in addition to general site information (e.g., coordinates, observation depth, visibility, habitat continuity, slope, etc.) (Fig. 2). Prior to dives, participants received an electronic educational module (https://cs.cigesmed.eu/) containing guidelines, photographic material and detailed descriptions of the species and threats to be documented, along with general instructions on how to step by step implement the protocol (Gerovasileiou et al. 2016). Local dive centers and expert scientists provided pre-dive briefings (around 15 to 20 min), during which participants could ask questions for clarification. During the dives, expert scientists accompanied one to five volunteer divers, without interfering with their observations. Divers and experts recorded observations at the same marked 2 × 2 m segments on the seabed. For each dive, expert scientists generated an inventory of taxa and threats (with an abundance rating), which was then compared with the inventory created by each volunteer diver to assess data accuracy. The duration of each dive ranged from 25 to 45 min, depending on the site depth and the number of participants.

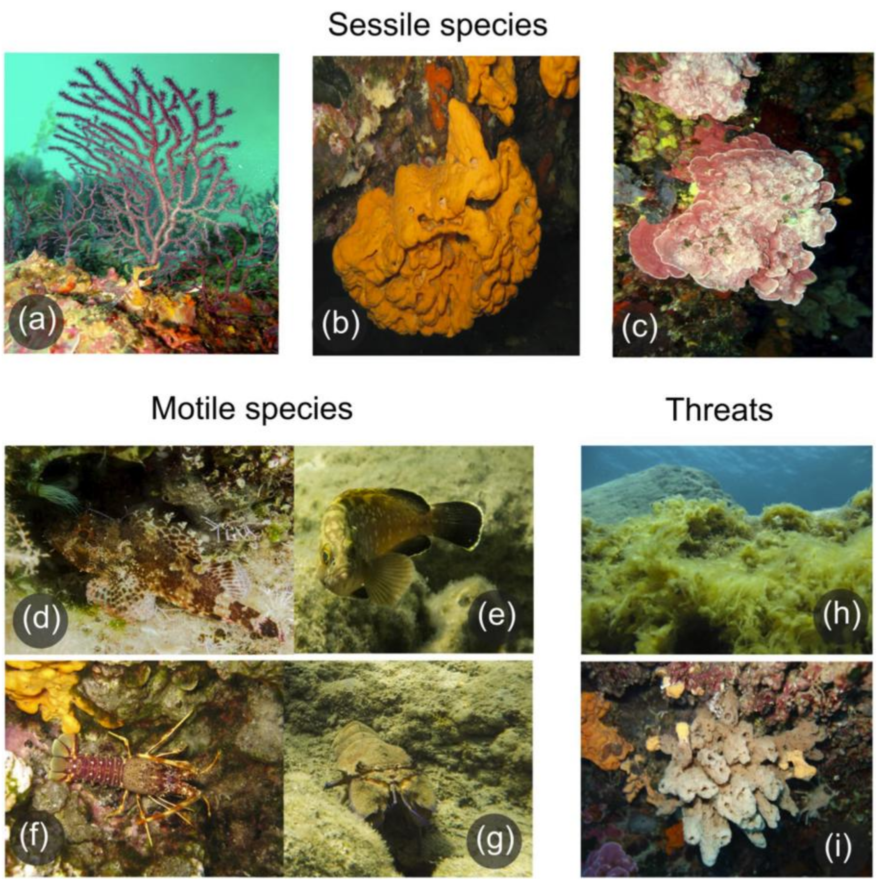

Fig. 2 Examples of typical species and threats included in the monitoring protocol used in this study. Sessile species: (a) *Paramuricea clavata*, (b) *Agelas oroides*, (c) calcareous red algae. Motile species: (d) *Scorpaena* sp., (e) *Epinephelus marginatus*, (f) *Palinurus elephas*, (g) *Scyllarides latus*. Threats: (h) mucilaginous aggregates, (i) necrosis/mortality events. Photo credits: Vasilis Gerovasileiou (a), (b), (c), (f), (h), (i) and Charalampos Dimitriadis (d), (e), (g)

An additional performance assessment study involving 91 divers was conducted at the National Marine Park of Zakynthos, Greece. Participants applied a standard underwater visual census protocol for fish species (Harmelin-Vivien et al. 1985) along fixed transects (15–20 m depth; dive duration approximately 40 min) at popular diving sites during 2012 (Koester 2013). The purpose of this exercise was two-fold: (a) to assess the extent of false-positive species reporting by asking divers to confirm the presence of two fish species known to be absent from the area at the time (*Sparus aurata* and *Lagocephalus* spp.), and (b) to evaluate false-negative reporting by examining whether divers failed to report the presence of a very common and abundant invasive species (*Siganus luridus*), whose occurrence in the area was verified by experts through continuous monitoring. In the case of *Sparus aurata*, it was assumed that it could be easily misidentified as other morphologically similar species within the Sparidae family, such as *Diplodus sargus* or *D. vulgaris*. Conversely, it was assumed that the conspicuous morphological characteristics of *Lagocephalus* spp. would reduce the likelihood of misidentification. The protocol included a section for collecting background information of participants, such as diving experience and number of dives at the specific location, to determine which factors most strongly influenced performance (supplementary information 1).

During fieldwork, ethical considerations for involving divers in data collection focused on ensuring informed consent, protecting participant safety, safeguarding personal data, providing transparent communication on data use and preventing environmental disturbance. Prior to diving, all participants provided informed consent and agreed to comply with the ethical considerations, safety standards, and operational procedures established by relevant international diving associations, in cooperation with and under the protocols of the local dive centres.

Data analysis

Data collected on the abundance of both species and threats were transformed into ordinal categories: 0 – absent, 1 – limited, 2 - moderate, 3 – extended. These data were then converted to binary data (0 – absent, 1 – present). The presence/absence data allowed us to determine whether divers could reliably identify species or threat occurrence, while species abundance estimation and threat intensity estimation demonstrated their ability to provide quantitative assessments. Species were further categorized by mobility status, creating two groups for both presence/absence and abundance data: motile and sessile species.

Expert divers' observations served as the baseline for comparison with volunteer divers' data. For presence/absence data analysis, we evaluated whether volunteer observations at each location were correct (true) or incorrect (false) compared to expert data. We calculated the frequencies of true and false answers for each species or threat, and then converted them into percentage success scores across all dives. Based on data categorizing volunteer observations as true or false, we performed one-sided binomial tests to evaluate volunteers' ability to accurately identify species and threats in the marine environment. The hypothesis tested was that true and false identifications occur with equal probability ($p = 0.5$). A p-value less than 0.05 indicates that volunteer divers performed significantly better than 50% accuracy, while a p-value greater than 0.05 suggests equal probability of correct and false identifications, indicating poor performance by volunteers. For abundance estimation analysis, we only included species/threats that were correctly identified. The filtered scores were grouped by category (motile species, sessile species, and threats) and a non-parametric paired Wilcoxon signed-rank test was conducted to compare volunteer and expert data.

For the performance assessment evaluating the false presence and absence of fish species, divers were tasked with labelling the three species (*Sparus aurata*, *Lagocephalus* spp., and *Siganus luridus*) as either present or absent. Based on expert-verified data regarding the true presence or absence of these species, each participant's response was classified as false (0) or true (1). Success scores were calculated for each species based on the proportion of correct responses. Additionally, we recorded diver characteristics, including diving experience level [low (less than 30 dives) = 1, high (more than 31 dives) = 2] and number of dives performed at the specific location [low (0–10 dives) = 1, moderate (11–20 dives) = 2, high (> 20 dives) = 3] (Arvanitidis et al. 2011). Using chi-squared tests, we examined relationships between diver success and their diving experience or site familiarity.

Results

The accuracy of volunteer divers in threat identification ranged from 48% to 100%, with most threats catalogued in the protocol receiving scores above 80% (Fig. 3a) (mean = 80%, standard error = 3.85). Lower scores were observed for sedimentation (63%) and necrosis/ mortality events (48%), with p-values greater than 0.05 in their binomial tests, indicating that volunteers were unable to reliably identify these threats (Fig. 3a). For sessile species identification, volunteer divers achieved an average success score of 79% (standard error = 3.05), with individual scores ranging from 38% to 100%. The lowest success scores for sessile species (Scleractinians: 48%, *Axinella* spp.: 56%, *Cliona* spp.: 38%, other erect bryozoans: 67%) corresponded with higher p-values on the binomial test, indicating poor volunteer performance (Fig. 3a). For the remaining 11 out of 15 sessile taxa, volunteers' success scores exceeded 73%, whereas in only five of them detection success exceeded 90% (Fig. 3a). Motile species identification maintained high success rates overall (> 70%, average 80%, standard error = 2.51), although the "other sea urchins" group (sea urchins other than the conspicuous hatpin urchin *Centrostephanus longispinus*, such as *Arbacia lixula*, *Paracentrotus lividus*, and *Sphaerechinus granularis*) recorded a lower success score of 59%, volunteer records for the latter group indicated insufficient identification accuracy (p-value > 0.05) (Fig. 3a).

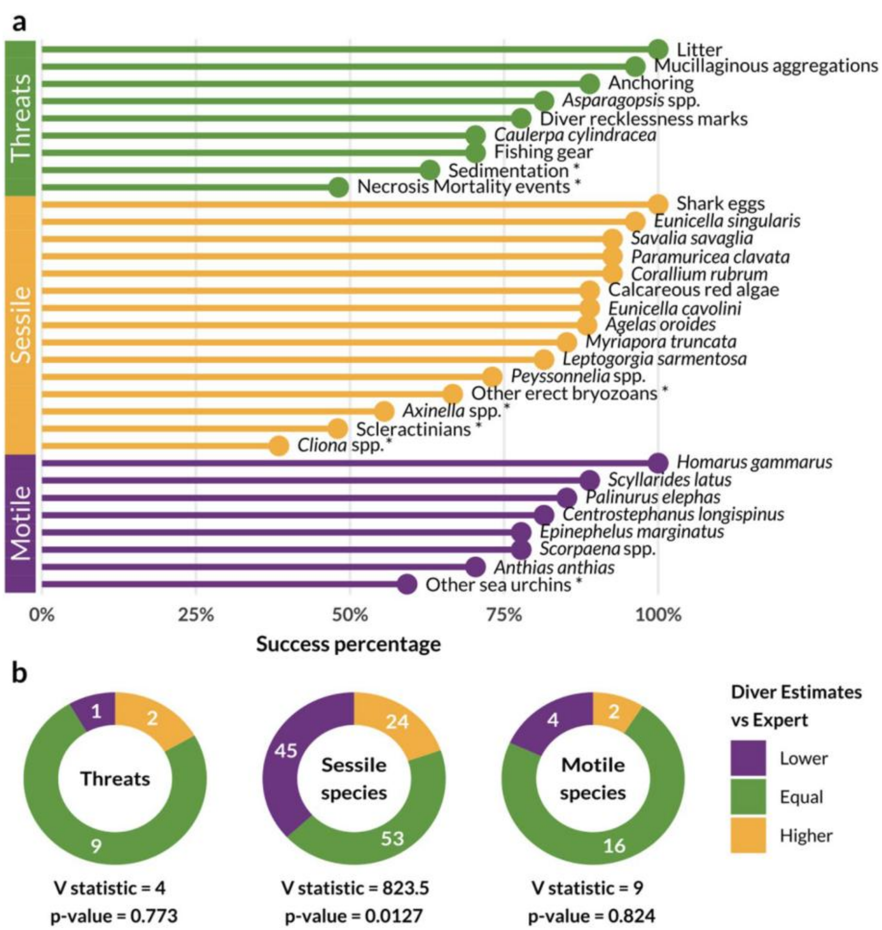

Fig. 3 Results of the first monitoring exercise testing participants' effectiveness to identify species and threats: (a) Accuracy scores for identifying species and threats from volunteer divers, asterisks (*) indicate a binomial test p-

value > 0.05. (b) Diver-estimated abundance of threats, sessile and motile marine species compared to expert assessments, donut charts show the number of times citizen science divers estimated abundance to be lower, equal, or higher compared to the expert. Below each chart the results of a Wilcoxon signed-rank test are reported (V statistic and p-value)

For correctly identified species, volunteer divers' abundance estimates aligned closely with expert scientists' assessments for both threats and motile species. Wilcoxon signed-rank tests (V = 4 for threats, V = 9 for motile species) revealed no significant differences between the estimates of volunteer divers and expert scientists (Fig. 3b). However, for sessile species, volunteers showed a lower success rate in abundance estimation, with a significant difference compared to expert assessments, typically underestimating abundance (Fig. 3b).

Divers frequently misreported the presence of *Sparus aurata* when it was absent at the diving sites (42% success score), similarly to the false absence reporting of *Siganus luridus* (49%) (Fig. 4). Volunteer divers performed better with the morphologically conspicuous *Lagochephalus* spp., though the success rate remained limited to 70%. Both diving experience and site familiarity (i.e., the number of dives conducted at the same site) significantly influenced accuracy (p-value < 0.05) (Fig. 3). Performance improved with diving experience, with scores increasing by 54% from beginners (*n* = 38) to experienced divers (*n* = 53) for *S. aurata* and by 58% for *S. luridus*. Site familiarity also improved accuracy (low: *n* = 42, moderate: *n* = 36, high: *n* = 13): success score for *S. aurata* rose from 5% with low dive frequency to 92% with high dive frequency (Fig. 3). Similarly, success score for *S. luridus* increased from 9% with low dive frequency to 82% with medium frequency, reaching 100% with high frequency. Accuracy for *Lagocephalus* spp. also showed significant dependence (p-value < 0.05) on diving experience and site familiarity (Fig. 4).

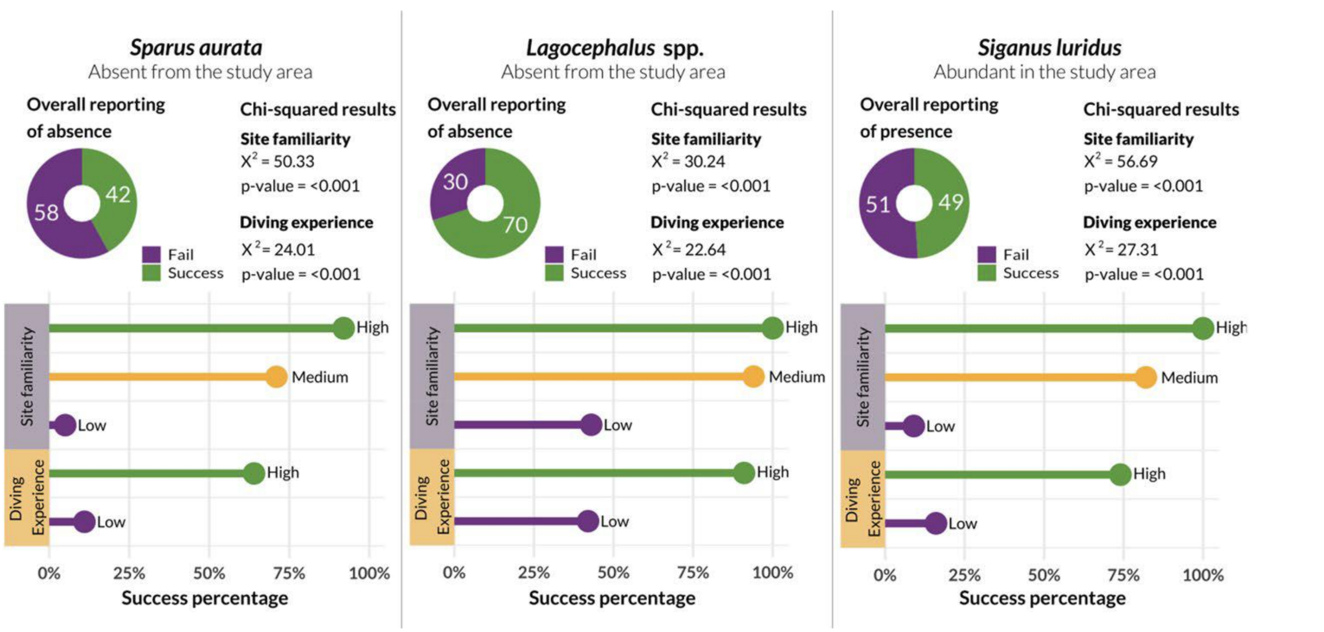

Fig. 4 Success scores and chi-squared test results from the second monitoring exercise examining the relationships between diver success and their diving experience or site familiarity [absent from the study area refers to false-positive species reports, where the species was known to be absent from the area at the time of the field exercise (i.e., *Sparus aurata* and *Lagocephalus* spp.); abundant in the study area refers to false-negative reports for a very common and abundant invasive species (*Siganus luridus*), as verified by experts through continuous monitoring]

Discussion

Exploring citizen science limits in data collection

Our findings revealed that citizen scientists' accuracy, relative to expert data, in identifying and recording presence–absence for various marine taxa and threats was case-dependent. Volunteer divers exhibited notably high identification success for several species and threats, and they provided abundance estimates for threats and motile species that were largely consistent with expert evaluations. In contrast, substantial discrepancies emerged in volunteers' assessments of sessile species abundance, and participants were frequently susceptible to both false-positive and false-negative reporting, often misidentifying fish species that were either absent from or present at the dive sites. Despite the clear benefits of citizen-science data collection, our results underscore the need for rigorous data-quality assessments in such initiatives. They also highlight the importance of establishing clear thresholds defining the conditions under which divers can reliably complement professional scientific monitoring, particularly when high taxonomic expertise is required or when the ecological variables under scrutiny are neither straightforward nor conspicuous.

Divers demonstrated limited effectiveness in recognizing environmental stressors commonly included in several citizen science programs, such as instances of tissue necrosis linked to marine heatwaves and broader impacts of climate change—parameters that are critical for assessing ecosystem health and resilience (Starko et al. 2024; Trégarot et al. 2024). Conversely, volunteer divers demonstrated an improved performance in recording marine litter, anchoring, or discarded fishing gear, as these are relatively straightforward to detect and do not require specialized expertise. This likely highlights a limitation in citizen scientists' ability to detect more complex environmental stressors or impacts that are not immediately apparent. These findings raise critical concerns regarding the potential boundaries and limitations of citizen science programmes in capturing complex ecological phenomena.

Disparities in accuracy emerged between sessile and motile species. For sessile taxa, volunteers' reports differed significantly from those of experts for 4 of the 15 taxa assessed. Discrepancies in motile taxa were primarily confined to "other sea urchins". Abundance estimates for motile species were generally in agreement with expert scientists, whereas estimates for sessile taxa showed greater variability. These findings align with previous studies, which demonstrated that volunteer performance often varies by species type and may be influenced by individual interests (Branchini et al. 2015; Vieira et al. 2020). For instance, macro photography enthusiasts might focus on benthic organisms, while those interested in larger species may overlook smaller or less conspicuous taxa (Meschini et al. 2021). Species detectability further complicates this dynamic, as less common or elusive species are inherently more challenging to identify, leading to more accurate data for common and easily recognizable taxa (Cox et al. 2012; Kosmala et al. 2016; Farr et al. 2023).

Strengths, weaknesses and factors involved

Our analyses revealed a significant dependence of volunteer data accuracy on participants' diving experience and familiarity with dive sites. According to various studies (Hermoso et al. 2021a, b; Lucrezi et al. 2018; Cerrano et al. 2017; Martin et al. 2016) experienced divers demonstrated greater precision, potentially due to enhanced confidence in their equipment and underwater skills, enabling them to concentrate more effectively on their surroundings. Additionally, familiarity with specific sites likely facilitated the recognition of local marine species and environmental features, thereby reducing errors and enhancing data reliability. We, therefore, encourage that specific diving skills and experience with the study sites should be used as the initial criteria for filtering citizen science collected data in demanding marine contexts.

Another important concern arises from the observation that divers were more prone to false-positive species identifications than to false negative ones. This tendency suggests a potential bias toward overreporting, which may reflect an eagerness to contribute or a lack of taxonomic certainty. Such patterns could compromise data reliability by inflating perceived biodiversity, thereby underscoring the need for improved training protocols and validation mechanisms within citizen science frameworks. Without rigorous validation methods, inconsistencies and observer bias can undermine the scientific credibility and usefulness of citizen science data, limiting its potential contribution to further applications such as ecological modelling, conservation planning, and policy development. Systematic evaluation not only helps identify potential sources of error but also guides the development of training protocols, data verification tools, and quality control mechanisms. This ultimately strengthens the role of citizen science in advancing scientific data production (Lukyanenko et al. 2016; Stevenson 2018; Anhalt-Depies et al. 2019).

For citizen science to make a meaningful contribution to ecological research, both the scientific community and the public must have confidence in the accuracy of the data. In fact, the proportion of published studies relying on citizen science data does not reflect the abundance and diversity of active citizen science programmes (Kullenberg and Kasperowski 2016; Davis et al. 2023), potentially due to concerns about data quality among peer reviewers (Theobald et al. 2015; Davis et al. 2023). Verification processes, whether applied to entire datasets or selected subsets, can enhance confidence in the reliability of citizen-collected data. However, implementing verification is not straightforward, often requiring means of comparison (e.g., images, videos or even the presence of experts along with citizens). Therefore, while verifying subsets of data may enable researchers to estimate error rates and identify additional sampling needs for hypothesis testing, the associated costs (time, effort, professional availability) raise questions about whether verification or comprehensive training for citizens prior to their involvement is the more effective approach. Ultimately, citizen science offers considerable prospects for advancing ecological and conservation research. Understanding, quantifying and eliminating biases in these data is an essential step towards their widespread application in addressing ecological questions and monitoring biodiversity (Burgess et al. 2017).

Limitations of the study

Limitations of this study should be acknowledged when interpreting the results. The number of volunteer divers participating at each site was relatively small, which may have constrained the statistical power of our comparisons. The study was also geographically restricted to three Mediterranean sites dominated by coralligenous habitats, which are characterized by high structural complexity and often require specialized taxonomic knowledge (Çinar et al. 2020). Consequently, volunteer performance may differ in other habitat types, regions, or environmental conditions (Vieira et al. 2020; Hermoso et al. 2021a, b). Additionally, despite expert scientists refraining from intervening during dives, their presence may have introduced subtle observer effects that could influence volunteer behaviour, consistent with a Hawthorne-type response effect (McCambridge et al. 2014).

Conclusions and recommendations

Enhancing data quality in citizen science initiatives involves several strategies, including targeted training programmes, skill-based prequalification and ongoing feedback for long-term participants (Kosmala et al. 2016; van der Wal et al. 2016). However, intensive training may inadvertently reduce participation, potentially limiting the educational and engagement benefits of such programs. Although citizen scientists often produce data comparable to marine professionals (Forrester et al. 2015; van der Velde et al. 2017), they face greater challenges with specialized tasks, such as difficulty in species identification (Farr et al. 2023; Díaz-Calafat et al. 2024) or abundance estimation (Gillett et al. 2012; Done et al. 2017). Certain attributes are inherently more subjective or complex, further complicating data collection. Therefore, in light of the findings of our study, we caution that citizen science projects, and the users of the data collected under such projects, should carefully consider the trade-off between higher data reliability and broader public engagement. Citizen-science projects should also address key questions related to underwater data collection logistics, the time required for data acquisition, and the level of training needed for volunteers to produce records of acceptable quality. Moreover, the data-collection process must be designed to be engaging, enjoyable, and sufficiently straightforward to encourage volunteer participation and foster a sense of responsibility.

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Author contributions C. D.: Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft, Supervision. K. K.: Visualization, Validation, Methodology, Writing – original draft, Writing – review & editing. M. E. Ç.: Investigation, Data curation, Writing – review & editing, Project administration. A. D.: Investigation, Data curation, Writing – review & editing. V. G.: Investigation, Data curation, Writing – review & editing. G. G.: Investigation, Data curation, Writing – review & editing. L. T. de V. d'A.: Investigation, Data curation, Writing – review & editing. M. S.: Investigation, Data curation, Writing – review & editing. K. S.: Investigation, Data curation, Writing – review & editing. A. D. M.: Validation, Methodology, Writing – original draft, Writing – review & editing. D. K.: Writing – review & editing, Project administration, Resources.

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