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West Atlantic coastal marine biodiversity: the contribution of the platform iNaturalist

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Abstract Data collection by citizen scientists is emerging as an important practice for biodiversity detection, mapping, and compilation of big data in open online platforms such as iNaturalist, acting as a source of biodiversity discovery. However, the validation of species identification is a central issue for the scientific use of these data. Here we compared the list of marine species in the Western Atlantic Ocean obtained in iNaturalist with that generated from scientific collections to understand whether there are taxonomic bias favoring some types of organisms, and to understand the amount of trustful information at the species level in iNaturalist. We also present the first bioblitz results of marine biodiversity in Brazil, an iNaturalist Citizen Science campaign advertised by social media, as a case study. We found that marine taxa with higher richness were well represented in iNaturalist (Arthropoda, Mollusca and Chordata), nonetheless Annelida, Bryozoa, Nematoda,

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Nemertea, Platyhelminthes, Porifera, Chlorophyta, and Rhodophyta were under-represented. Taxa with small, cryptic, parasitic and/or sessile organisms were poorly represented. According to the methods applied in this study, we showed that 72% of the records are probably well identified, except for Bryozoa and Platyhelminthes. Brazilian marine records in iNaturalist add up to only 1/30 of the total West Atlantic records analyzed but there was a steep increase from 2021 to 2022, as a possible contribution of our bioblitz campaign especially for Arthropoda, Echinodermata, and Annelida. We conclude that the record of marine biodiversity by citizen scientists is a valuable tool, but the engagement of taxonomists is strongly recommended to increase the correct identification of species.

Keywords Marine diversity · Citizen science · Identification validation · GBIF · OBIS · Biological data mining

Introduction

Biodiversity encompasses all levels of the complex nature of organisms, which demands great efforts to study and classify organisms (Hortal et al. 2015; Ruggiero et al. 2015), as well as understand how populations and communities are being temporarily or permanently altered (Wallingford and Sorte 2022). Unfortunately, threats to biodiversity have increased in recent decades, such as biological invasions, habitat loss, climate change, ocean acidification, and water pollution (Bellard et al. 2022), and they have proven to be a challenge to conservation, monitoring, and restoration programs, which are usually highly costly, and often financially unsustainable for long periods by government agencies (Monge-Nájera and Seas 2018; Jesus et al. 2021b). Given the current rapid rate of species extinctions (Grieneisen et al 2014) and the necessity to avoid mistakes in species conservation (Ely et al. 2017), the effectiveness of the conservation effort is strictly associated with the biodiversity knowledge, highlighting the continuing need for taxonomic expertise (Fromont et al. 2016)

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and considering a wide scope of taxa (Van Noordwijk et al. 2017).

The small number of taxonomists, the significant amount of time necessary to develop taxonomic skills, and the high costs of collecting and maintaining biodiversity collections, all contribute to the "taxonomic impediment" (Carbayo and Marques 2011; Engel et al. 2021). Describing and identifying biodiversity is especially challenging in the tropics, where countries are usually megadiverse, with limited human and financial resources, and lack infrastructure (Lodi and Tardin 2018; Kawabe et al. 2022; Rosa et al. 2022a). This constitutes a serious obstacle to rapidly responding to demands for listing the species living in each type of biome, their ecological relations, and how they are (or are not) enduring the vast threats of the Anthropocene to biodiversity (Seddon et al. 2016; Johnson et al. 2017; Storch et al. 2022). A further challenge is to map the distribution patterns of species at a rate faster than the current rate of habitat destruction or environmental change (Smith and Nimbs 2022).

A rising way to go around this situation could be the Citizen Science approach. Citizen Science describes different forms of producing scientific knowledge by means of the collaboration of voluntary general public and scientists, as well as increasing social engagement with complex environmental issues, the respective political actions, and management decisions (Bonney et al. 2016; Lodi and Tardin 2018; Mesaglio and Callaghan 2021; Sherbinin et al. 2021; Kawabe et al. 2022; Souto and Batalhão 2022). Citizen Science can also be valuable for the educational process (Echeverria et al. 2021) besides being important for building a collaborative research network between the community and researchers (Bonney et al. 2009; Mesaglio and Callaghan 2021).

Although the collection of scientific data by citizen scientists is an ancient practice (Strasser et al. 2019), it has become incredibly popular in recent years, especially because of new technologies such as smartphones, social media, and specific databases in which those data may be deposited and properly curated (Bonney et al. 2009; Monge-Nájera and Seas 2018; Engel et al. 2021; Oliveira et al. 2021; Cranswick et al. 2022; Souto and Batalhão 2022). Volunteers that collect and/or process/analyze data that make up scientific research have grown and been recognized as a powerful source of scientific information in the last decades (Thornhill et al. 2016; Mesaglio and Callaghan 2021). On the other hand, the availability of information and infrastructure for the application of Citizen Science has socioeconomic, historical, and cultural limitations, thus varying the quality and quantity of information acquired by the locals (Amano et al. 2016). Another limiting factor is the uneven concentration of observations at different times of the year and the specialization of records focusing on a few taxa (Di Cecco et al. 2021). Nevertheless, Citizen Science projects are experiencing an increasing recognition of their importance worldwide (Lodi and Tardin 2018) thanks to mechanisms that ensure good quality data (Sherbinin et al. 2021), despite prejudice by some scientists (Burgess et al. 2017). Additionally, social media (Goddard et al. 2018; Chowdhury et al. 2021; Hartmann et al. 2022) and online databases may help to obtain important data on several aspects of species (*e.g.*, Winterton 2020; Forti et al. 2022; Mesaglio et al. 2021; Silva et al. 2021; Fritz and Ihlow 2022; Rosa et al. 2022a, b). As a result, there are numerous examples of Citizen Science data contributing to environmental and biodiversity studies (*e.g.*, Silvertown 2009; Castro and Bager 2019; Gazdic and Groom 2019; Wilson et al. 2020; Bennett-Smith et al. 2021; Fink et al. 2022; Simon et al. 2022; Tran et al. 2022; Yiu et al. 2022).

Marine and coastal Citizen Science programs are less numerous than terrestrial initiatives (Earp and Liconti 2020) despite the fact that marine environments comprise almost three-quarters of the planet's surface. Fortunately, they are gradually increasing (Giovos et al. 2019), varying from biodiversity (Sandahl and Tøttrup 2020) and marine litter monitoring (Kawabe et al. 2022), species responses to climatic oscillations, such as El Niño and heatwaves events (Goddard et al. 2018; Lonhart et al. 2019; Tanaka et al. 2021), shifts in species' geographical distributional ranges (Smith and Nimbs 2022; Wallingford and Sorte 2022), monitoring invasive species (Mannino et al. 2021; Tran et al. 2021), among others. Marine Citizen Science projects are more abundant in Europe, North America, and Oceania, while in countries from South America, there are few initiatives (Sandahl and Tøttrup 2020). In Brazil, the participation of volunteers in environmental research is still incipient (Cunha et al. 2017), but the popularity of this movement has been growing, resulting in the founding of the Brazilian Citizen Science Network (www.rbcc.ong.br), which the primary aim is to promote citizen science initiatives in the country (Queiroz-Souza et al. 2023). There are examples of Citizen Science data integrated into professional scientific research, for example, the tracking of oil spill pollution (Souto and Batalhão 2022), functional delimitation and management of Marine Protected Areas (Lodi and Tardin 2018), new occurrences and geographical distribution (Jesus et al. 2021b). Other initiatives can be accessed on two platforms (https://civis.ibict.br/; https://www.sibbr.gov.br/cienciacidadada/projetos.html).

One of the most popular biodiversity databases is iNaturalist (inaturalist.org), in which users upload audiovisual archives and volunteer identifiers provide identifications (Wilson et al. 2020; McMullin and Allen 2022), which enhances the validity of that data and encourages awareness of local biodiversity (Rosa et al. 2022a). iNaturalist can also be used for educational purposes (Martínez-Sagarra et al. 2022) by promoting campaigns designed to stimulate more people to participate and upload data, such as bioblitzes (Rosa et al. 2022a). Currently, there are dozens of millions of biodiversity observations around the globe uploaded by its users (Barbato et al. 2021). These contributions, when reach the "Research Grade" by the community validation, make up the fourth-largest data provider to the Global Biodiversity Information Facility platform—GBIF (Martínez-Sagarra et al. 2022), yet very few studies address the accuracy of data and especially the accuracy in species identification (e.g., Hochmair et al. 2020; Koo et al. 2022; McMullin and Allen 2022).

Here we evaluated the use of iNaturalist as a Citizen Science tool to gather knowledge about marine biodiversity on the Western Coast of the Atlantic Ocean, answering two questions: 1. Are there taxonomic biases in iNaturalist concerning the known richness in each phyla? 2. Are records of marine biodiversity in iNaturalist labeled as "Research grade" accurate? We also present the results of the first bioblitz of marine biodiversity in Brazil, as a case study, and evaluated if it succeeded in increasing the number of records in iNaturalist platform compared to the same period in years without this type of campaign. We also compared iNaturalist records from Brazil and the West Atlantic to understand what is its contribution and whether rank of most represented phyla is comparable.

Material and methods

We compiled the data from the iNaturalist database using the online platform GBIF—Global Biodiversity Information Facility (https://www.gbif.org/), where only "research grade" data is uploaded, that is, registers for which the identifications were confirmed by at least two-thirds of volunteer identifiers in iNaturalist. For the search, we used as data filter criteria: 1 – the countries along the Atlantic coast of Latin, Central, and North America below 41° north latitude; 2 – the invertebrates belonging to Annelida, Arthropoda, Brachiopoda, Bryozoa, Cnidaria, Ctenophora, Echinodermata, Mollusca, Nematoda, Nemertea, Platyhelminthes, Porifera; the chordates belonging to Ascidiacea, the Tetraodontiformes and Perciformes fish, and mammals; and the algae belonging to Chlorophyta and Rhodophyta. To check the taxonomic validity of the species names (not identifications), the data were cross-referenced with the WoRMS—World Register of Marine Species database (https://www.marinespecies.org/) and checked by the authors which are taxonomists of most of the taxonomic groups retrieved. Although iNaturalist opened to the public only in 2011, the platform receives uploads of pictures at any date, and we did not limit a temporal window in our database before 2021 (included), although most of the data comes from the last ten years. This dataset will be referred to as the iNaturalist database hereon.

We also compiled a second dataset based on museum collections and scientific research projects from two online databases: GBIF and OBIS—Ocean Information Biodiversity System (https://obis.org/), complemented by data from the authors' personal databases, using the same filters and temporal window as described previously. All this data was filtered to remove records that did not present geographic coordinates and were placed on land or in the Pacific Ocean. Non-georeferenced data were georeferenced, when possible, by crossing the description of the locality informed with the general data from the GBIF database to obtain the coordinates. This strategy is very effective for georeferencing data in the terrestrial environment. However, for the marine environment, it proved to be ineffective, resulting in a small volume of georeferenced data. This second database will be named "collections" hereon, and was used as a reference of a trustful species list for the region. The iNaturalist and collections databases were crossed to determine common species in both databases, and only those species were used in further analysis.

To check for biases with respect to taxonomic groups in iNaturalist, we summarized the records by high-category taxa (Phylum or Class) considering both the number of species and the number of records per species and compared the rank of the most represented taxa to the rank of the same taxa in WoRMS statistics based on total number of valid species. We also selected the species that had more than 500 registers in iNaturalist and classified them by high-category taxa and type of habitat (rocky shore, beach, mangrove, coral reef, open ocean) to verify which taxa and habitats were more represented.

To test the identification confidence in iNaturalist data, we assumed that records of species in iNaturalist that are geographically located outside and very distant from the locations sampled in collections must be records with identification errors. Thus, we measured the geographic distance between each iNaturalist record of a given species and its closest sample in the collection data. We also calculated the average geographic distance observed among all records in the collection data for each species (Fig. 1a). Then we compared those two values and calculated the percentage difference between them. Negative values indicate that the iNaturalist record distance to the closer collection record of the same species is smaller than the average distance within the collection database, and positive values indicate distances larger than the average distance within collection data. Thus the closer an iNaturalist record is to a collection record of the same species, the higher the probability of correct identification, and the closer its deviation will be to the left blue part of Fig. 1b. We considered that iNaturalist records beyond 10% distant to the average distance among records of the species within the collection data, as potential identification errors. If one iNaturalist record falls within the geographical distribution of a given species in the collection database, then our method always validates it, considering species with both a continuous distribution (Fig. 1, species 1, 2, and 7) or disjointed distribution (Fig. 1, species 3, 4, 5). In contrast, occurrences located out of the limits of the geographical distribution of a species were mostly unvalidated (Fig. 1, species 9–15), but this validation method can fail to recognize as an incorrect occurrence, new records that are out from the limits of a species distribution with a disjointed geographical distribution (Fig. 1, species 8).

The BioGeoMar Scientific Program is a network of Brazilian marine scientists comprising taxonomists, biogeographers, and ecologists. As an outreach activity of this program, we organized a bioblitz in January 2022 (austral summer) toward the biodiversity of coastal Brazil. The bioblitz was advertised from the beginning of December 2021 to the end of January 2022 using social media (Instagram and Facebook), through messages to Brazilian users of the iNaturalist platform, and emails to scientific partners of BioGeoMar scientist collaborators. Data from Biogeomar Facebook and Instagram followers were obtained from the respective mobile applications and they were compared to profiles of bioblitz observers and identifiers, obtained from the iNaturalist platform, considering the gender and their geographic origin.

We also summarized Brazilian data in the same way as iNaturalist West Atlantic total data (by high-category taxa and the most recorded species, without a temporal window) to see how the patterns compare. To understand the possible effect of the 2022 summer bioblitz on the number of species and records from Brazil, we retrieved the last 22-year data of the Brazilian observations made in January of the taxa included in this study.

Results

We gathered 396,326 entries from collections and 128,466 entries from iNaturalist, with 1,777 species overlapping between the two sources. The groups that exhibited higher species richness in iNaturalist were Mollusca (947), Vertebrata (382), Arthropoda (307), and Cnidaria (214). In terms of the number of records per species, ranked in descending order are Vertebrata (101), Cnidaria (76), Arthropoda (75), and Echinodermata (55) (Fig. 2, Table 1S). Nematoda and Nemertea were absent, while Annelida, Bryozoa, Platyhelminthes, Porifera, and Rhodophyta were under-represented, both in terms of species count and records when compared with the total number of valid species in WoRMS (between

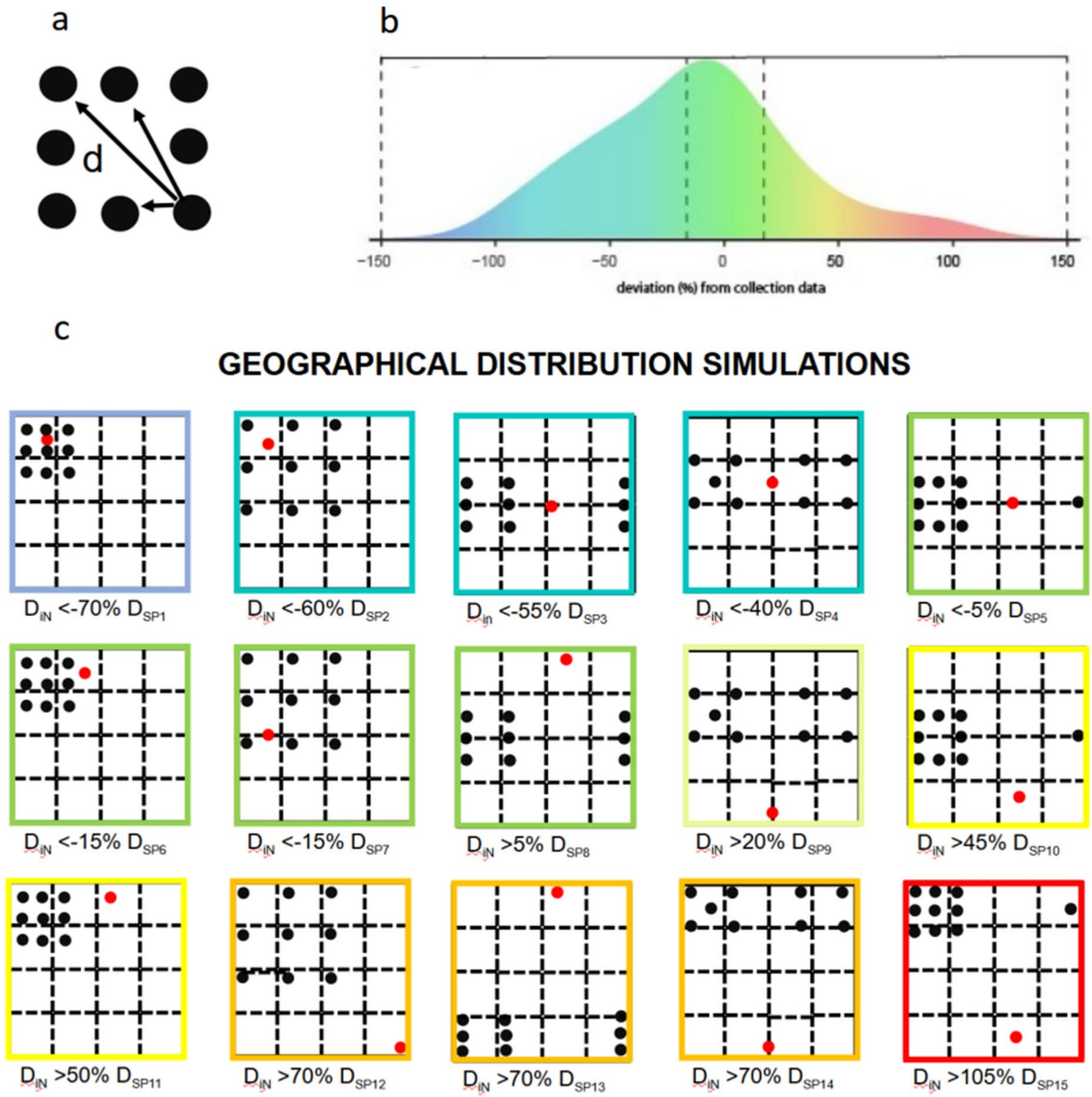

Fig. 1 Geographical distribution simulation that informed the decision criteria for the validation of iNaturalist records. **a** Hypothetical distribution of eight records of a species in collection data; **b** Frequency distribution of deviations of iNaturalist occurrence records from the closest collection data record compared to the average distance within records in collection data (**a**); **c** Geographical distribution examples for 15 species and the calculation of iNaturalist record distance (the color of the quadrat matches the color of the curve in **b**). d = distances between two occurrences of the same species in data collection, D_{iN} = distance from one record in iNaturalist from the closest record in collection data, D_{sp} = average geographical distance among all records of the species in collection data

6,000 and 13,000). In terms of the number of records per species, most taxa maintained their respective ranks, except for Mollusca, which rose to the fifth position (Fig. 2). Rhodophyta and Bryozoa, on the other hand, dropped to the last and second-to-last positions, respectively.

Among the 1,777 species considered in this study, we found 60 species with more than 500 observations

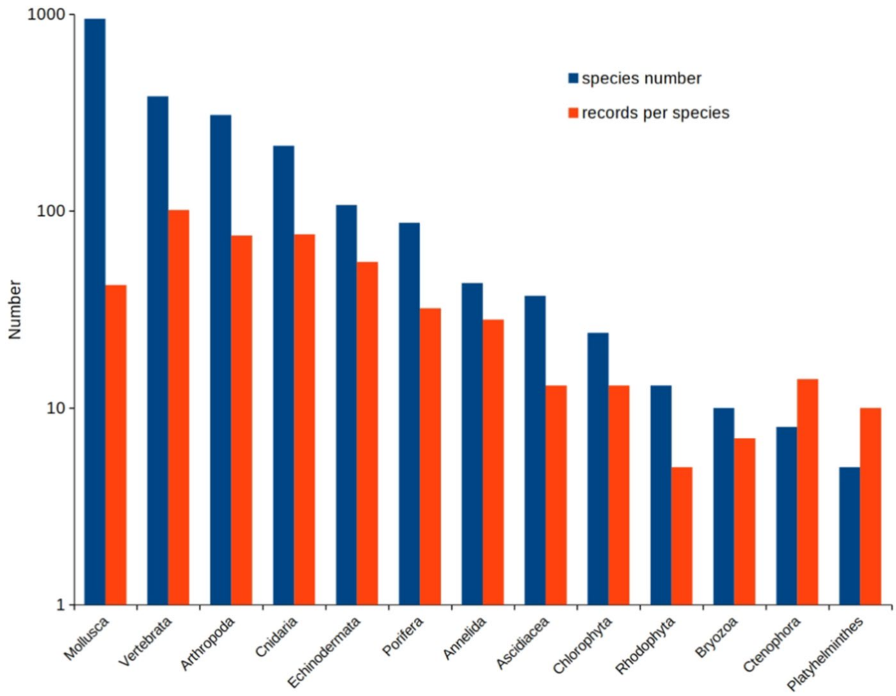

Fig. 2 Number of species and records per species (total number of records/ total number of species) by taxonomic group (considering the complete iNaturalist dataset for the West Atlantic (40°N – 55°S) before 2021 (included). Note that Y-axis is logarithmic

each in iNaturalist, belonging to five phyla only: Chordata (20), Mollusca (17), Arthropoda (11), Cnidaria (8), and Echinodermata (4) (Table 2S). The five species with the most observations were the ghost crab *Ocypode quadrata* (Fabricius, 1787) (3,829 records), the blue crab *Callinectes sapidus* Rathbun, 1896 (2,261), the Portuguese man o' war *Physalia physalis* (Linnaeus, 1758) (2,209), the common bottlenose dolphin *Tursiops truncatus* (Montagu, 1821) (2,086), and the pinfish *Lagodon rhomboides* (Linnaeus, 1766) (2,016). Those species were mostly photographed in reef systems and beaches, followed by rocky shores and mangroves or estuaries.

The pattern of deviation of the distance between iNaturalist records to its closer collection record of the same species compared to the average distance within collection records of that species was similar among taxons (Fig. 3a), except for Bryozoa and Platyhelminthes. These two groups exhibited a notable concentration of records with a deviation exceeding 10%. Approximately 21% of the iNaturalist records displayed a deviation similar to that observed within the collection data (with a maximum deviation of 10%, as depicted in Figs. 3b and c). Moreover, 51% of the iNaturalist records were closer to the same species record in the collection database than the average distance of that species determined for the collection database. These findings indicate that 72% of the samples from iNaturalist have a high potential for correct identification. Conversely, around 28% of the iNaturalist samples exhibit a deviation surpassing the average distance observed in the collection samples, indicating potential errors in identification.

The Brazilian data in iNaturalist encompass roughly one-fifth of the total Western Atlantic marine species count; however, those species have approximately 30 times fewer records, despite following the same pattern of phylum representation in terms of both species and records per species. Only 14 species were observed more than 50 times, with half of them belonging to the phylum Arthropoda (Table 3S). The five most recorded species were the ghost crab *O. quadrata* (311 records), the Portuguese man o' war *P. physalis* (172), the mangrove root crab *Goniopsis cruentata* (Latreille, 1803) (144), the mottled shore crab *Pachygrapsus transversus* (Gibbes, 1850) (117), and the wedge clam *Donax hanleyanus* R. A. Philippi, 1847 (88). By examining the time series of Brazilian observations in January, we can observe a notable increase in both the number of records and species across most groups over the past five years (Fig. 4). Notably, for Arthropoda, Echinodermata, and

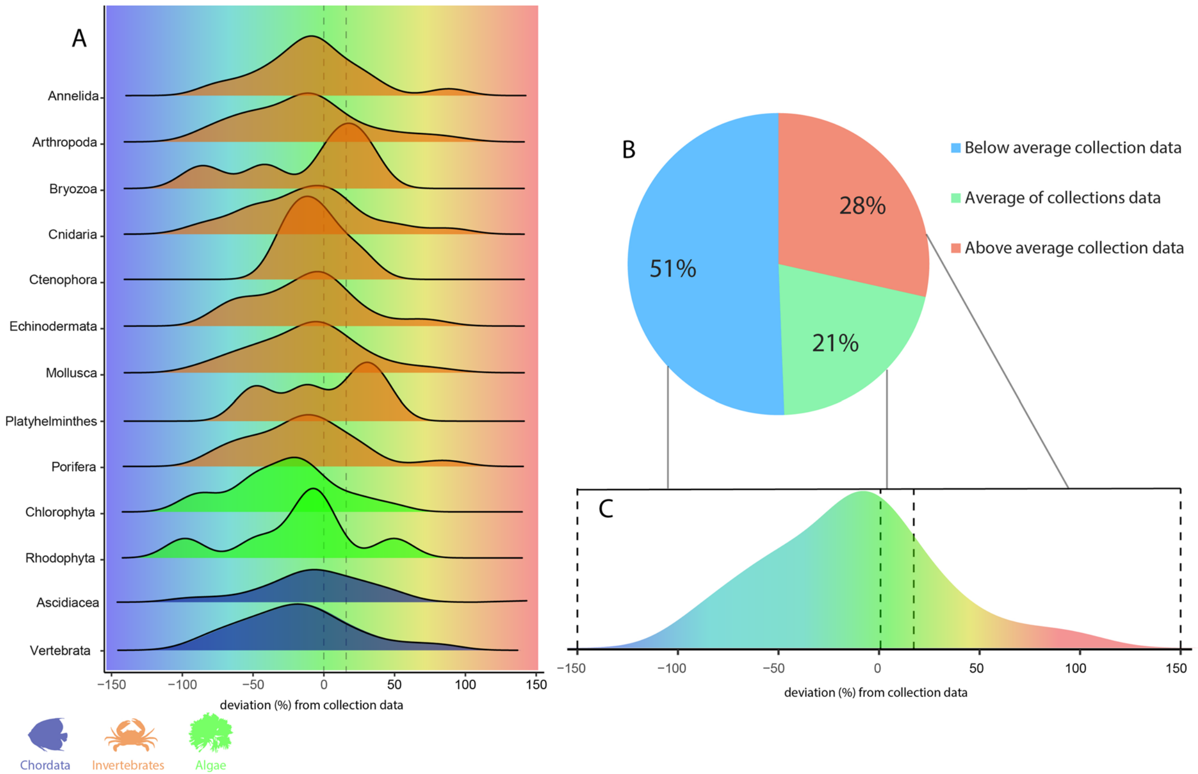

Fig. 3 Percentage of deviation of iNaturalist samples from the average geographic distance of records within collection database. **a** distribution of deviations in each analyzed group; **b** pooled percentage considering all data; **c** distribution of deviations of all groups of organisms in relation to distances within collection database. Negative values indicate distances smaller than the average, while positive values indicate distances larger than the average. “Average” were values within average (between − 10% and + 10%)

Annelida, there is an additional significant increase from 2021 to 2022, which could be attributed to the influence of our summer BioGeoMar bioblitz.

Out of the 74 naturalists who participated in the bioblitz, a mere five contributors accounted for half of the total 1,971 records. Interestingly, 35 of the participants have professional or educational affiliations related to the ocean, including 12 undergraduate students and five graduate students. Although most followers of the social media that advertised the bioblitz were women, 65% of the pictures shared during the bioblitz were uploaded by men (Fig. 1S). Conversely, the participants’ origins aligned with the social media followers, as the three states with the highest number of followers also happened to contribute the most pictures (Rio de Janeiro, São Paulo, and Santa Catarina) (Fig. 2S). The collaborators that helped to identify the records were mainly from Brazil (108) and the United States (83), but also from other 41 countries.

Discussion

In this study, we recovered data from 11 animal and 2 algae phyla representing, respectively, 30% and 60% of the phyla with marine species recognized by WoRMS Editorial Board (2023). The three phyla with higher species richness and number of records in iNaturalist (Mollusca, Chordata, and Arthropoda) were also the ones with more valid species in the world, but Cnidaria was more represented in iNaturalist than expected, given that Annelida and Platyhelminthes have more valid species compared to Cnidaria (WoRMS Editorial Board 2023). The very few Platyhelminthes and Bryozoa species, and the absence of Nematoda in iNaturalist was a surprise, given that those phyla have 13,298, 6,461, and 6,606 valid species, respectively (WoRMS Editorial Board 2023). The algae Chlorophyta and

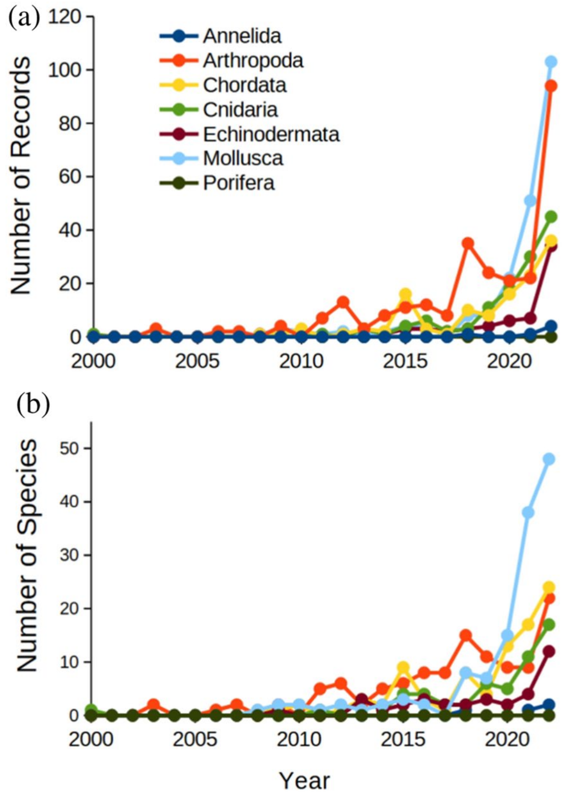

Fig. 4 Number of records **a** made in January along the years in Brazil and uploaded to iNaturalist, **b** number of "research grade" species in the same temporal scale. Only species also present in collections database were included (see methods)

Rhodophyta were also under-represented compared to the total number of valid species.

It is clear that there is a taxonomic bias in iNaturalist with a tendency to better record some taxa than others. The null or under-representation of some phyla could be explained by their small size and/or cryptic habit (Gastrotricha, Gnathostomulida, Kinorhyncha, Nematoda, Nemertea, Phoronida, Priapulida, Rotifera, Tardigrada, Xenacoelomorpha), and a lifestyle as parasites (Acanthocephala, Loricifera, Nematomorpha) or as sessile organisms (Porifera and Bryozoa). The absence of marine Nematoda in iNaturalist is striking given its richness (more than 6,5 thousand species) and the fact that it is one of the most abundant metazoan groups in nearly all environments (McIntyre 1971) and that in benthic environments often occurs in millions/m^2. When one searches for Phylum Nematoda in iNaturalist it is possible to retrieve more than 5,000 records, but of 142 species only, and most of the records are in continental habitats. On the other extreme, large organisms in habitats easily accessible to the public have more records in iNaturalist. The Cnidaria exemplifies well, with large and colorful corals, anemones, and jellyfish living in shallow water well recorded (Table 2S). *Physalia physalis*, for instance, was the most recorded cnidarian (Tables 2S, 3S), possibly because of its conspicuous floating bag (pneumatophore) and coloration, and presence in sandy beaches, besides being responsible for painful envenomations (Haddad-Jr et al. 2013).

There are some taxa, especially within invertebrates, that cannot be identified by photos to the species level because diagnostic characters are either internal or very small. This is the case with microscopic invertebrates such as Gastrotricha, Gnathostomulida, Kinorhyncha, and Priapulida which are less known and poorly studied even among scientists. Other examples are the sponges for which skeleton spicules are an essential character for species-level identification (Łukowiak et al. 2022), and ascidians that demand dissection to assess internal features (Rocha et al. 2012).

Societal preferences and access to the organisms can also orientate which biodiversity data are gathered. The most popular groups among citizens, such as birds and mammals, are also those with the most records in databases, such as GBIF (Troudet et al. 2017). Among marine taxa, our results showed that Vertebrata, Mollusca, and Arthropoda were the most popular among iNaturalist contributors, both in the total number of records per species and within the group of most recorded species. Vertebrata was represented here by Cetacea and two orders of fish. Fish were by far the most documented group, accounting for one-third of the group of species with more than 500 records. Yet, more than 400 species of fish present in iNaturalist were not considered in our analysis and summary of data because they did not belong to the two orders chosen for this study (Tetraodontiformes and Perciformes). Despite the popularity of fish, it is surprising to see their dominance on the platform, considering that most of the pictures were taken by divers who require expensive photography equipment. In contrast, among the 60 species with over 500 records, only one cetacean—the common bottlenose dolphin—was included. Although cetaceans are highly appealing to the public, it seems that their oceanic habitat makes them challenging to access and photograph.

The comparison between Mollusca and Arthropoda is also interesting because Mollusca ranked higher in species richness but Arthropoda ranked higher in the number of records in the iNaturalist database (Fig. 2). This was surprising given that shells are very popular, there are many amateur conchologists (Duncan and Ghys 2019), and the animals are usually slow and easy to photograph. Among the most photographed species, there were 10 Gastropoda, 6 Bivalvia, and 1 Polyplacophora, with the Atlantic giant cockle (*Dinocardium robustum* ([Lightfoot], 1786)) appearing in the 12th position only (Table 2S). In contrast, three crabs were among the 10 most recorded species (Table 2S), and the ghost crab (*Ocypode quadrata*) and the blue crab (*Callinectes sapidus*) were the two species at the top of the list, probably because both are very abundant, with a large geographic distribution and living in habitats accessible to the population (Sakai and Türkay 2013; Mancinelli et al. 2021).

Our second question was whether we can trust the identification of marine organisms in iNaturalist. Considering the geographical distribution of records, our results showed that almost ¾ were within or very close to the known geographical distribution of the species, which suggests a correct identification. INaturalist also uses the geographical location of the record to suggest possible identifications, using the same reasoning as our test. An important limitation of this logic is the presence of two or more cogeneric sympatric species, especially when the external morphology depicted in photos is not sufficient to distinguish species (Koo et al. 2022). Again, small and not very colorful organisms will not be well identified in iNaturalist, or they will be recorded within higher taxonomic categories (genus or family). In this case, data will not be useful to answer questions that need species-level resolution in fields such as biogeography, distribution modeling, niche conservation, and bioinvasion, among others.

Around one-fifth of the records were outside the geographical distribution of the species established by current records in scientific collections, and more than 10% distant from the average distance among records in those collections. Those could be interpreted as possible misidentifications, but part of those records could also be correct new locations not previously recorded in GBIF or in the literature, both for native and non-native species. For instance, Rosa et al. (2022a, b) showed that Citizen Science records expanded the distribution of native species of terrestrial mollusks outside their previously known area in Brazil. In the case of non-native species, Citizen Science can significantly reduce the time to the first detection (Encarnação et al. 2021), for example, seven non-native fish and one mollusk were recorded first by citizens in Europe (Kousteni et al. 2022). In addition, Citizen Science also helps in understanding the expanding distribution of non-native species (Lehtiniemi et al. 2020; Langeneck et al. 2022; Mancinelli et al. 2021). Citizen scientists are not constrained by research methods in terms of how, where, and when to look for organisms, they are thus more likely to find a broader set of species, including rare species (Roberts et al. 2022). Thus, compared to traditional scientific studies, Citizen Science can scale up species distribution records at a lower financial cost (Van der Wal et al. 2015).

Additionally, local species extinctions in marine environments are twice as high as in the terrestrial environment (Pinsky et al. 2019), and because of climate change, marine species are expanding their areas of occurrence toward the poles an average of six times faster than those on land (Lenoir et al. 2020). Even with the need to curate data, the great volume and geographical spread of citizen data can be a valuable tool to detect the expansion or decrease in the geographical distribution of species due to climate change or habitat degradation (Smith and Nimbs 2022). Our method can flag those species and records that should be checked in more detail to verify if they represent misidentifications, new detection of invasive species, or distribution range expansions of native species.

With the increasing use of iNaturalist, there is also an increasing concern about the scientific use of all this data, which depends on its identification accuracy. While our approach focused on a large number of species from very different phyla, with a general result of 72% of potential good identifications, studies testing identification accuracy in iNaturalist that focused on a few species or genera by checking all records or a sub sample of them retrieved figures between zero and 100% identification accuracy (Hochmair et al. 2020; Koo et al. 2022; McMullin and Allen 2022). All of those studies concluded that data in iNaturalist should be curated before being used in scientific research, even when classified as research grade, and that species identifications dependent on microscopic structures, chemical information, behavior, and sound information are not trustworthy. Best practices include improving the quality of pictures and training citizen scientists to get pictures of the organisms from different angles, to register the substrate and general habitat when taking pictures, and training volunteer identifiers to not rely on the identifications suggested by the platform unless critical diagnostic structures are available in the pictures (McMullin and Allen 2022). In the marine realm getting good pictures is still more challenging, but we are confident that technology is getting better and less expensive even for underwater photography practice.

Our case study in Brazil showed that structured Citizen Science campaigns increased the number of records in iNaturalist by many folds, improving the register of biodiversity toward scientific high-quality data. Despite the very long littoral and its megadiversity, the Brazilian contribution of records to iNaturalist is still very modest compared to some small countries in the West Atlantic (e.g., Bonaire, Cuba, Puerto Rico). Thus increasing public engagement has a huge potential to amplify our knowledge of species biodiversity, and to increase awareness and engagement of society toward the necessity to preserve this biodiversity and the ecosystem services it provides. We used Instagram and Facebook to advertise the campaign, where most of Biogeomar's followers are female (Fig. 1S), which agrees with the Brazilian estimated population for 2022 (51% female, https://www.ibge.gov.br/estatisticas/sociais/ populacao/9109-projecao-da-populacao.html). However, most participants (both observers and identifiers) in the 2022 summer bioblitz were identified as men (Fig. 1S). It is not uncommon that the demographics of participation in citizen science do not reflect the demographics of the population, with white wealthy men with some degree of education usually over-represented (Pandya 2012; Blake et al. 2020; Pateman et al. 2021). Although race and wealth could not be inferred from iNaturalist profiles, 47% of our 2022 summer bioblitz observers and 50% of the identifiers indeed had professions related to life sciences (including marine biology) or the environment (such as photographers, journalists, documentarists, and divers).

While public engagement in other volunteer programs such as protecting turtle nests (Marcovaldi and Dei Marcovaldi 1999) and cleaning beaches of litter and marine debris (Ribeiro et al. 2021) is currently high in Brazil, we still have a long road to engaging the general public to look for marine organisms and get interested in identifying them. We also need to engage more specialists to improve identifications and agree with Callaghan's et al. (2022) suggestion that institutional support would be welcome in order that experts dedicate part of their time to identify observations on the platform. The correct identification of species is paramount to enhance the confidence of scientists in the use of biodiversity data generated by Citizen Science projects and the pictures shared provide a type of voucher that can be curated. The validation method described here permits researchers to classify data by their probability of correct identification and to easily determine records that need further curation to assert their identity.

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Data availability The datasets generated and analyzed during the current study are available to all those interested.

Declarations

Conflict of interests There are no competing interests.

References

Amano T, Lamming JD, Sutherland WJ (2016) Spatial gaps in global biodiversity information and the role of citizen science. Bioscience 66(5):393–400. https://doi.org/10.1093/biosci/biw022

Araujo ML, Quaresma AC, Ramos FN (2022) GBIF information is not enough: national database improves the inventory completeness of Amazonian epiphytes. Biodivers Conserv 31:2797–2815. https://doi.org/10.1007/s10531-022-02458-x

Barbato D, Benocci A, Guasconi M, Manganelli G (2021) Light and shade of citizen science for less charismatic invertebrate groups: quality assessment of iNaturalist non-marine mollusc observations in central Italy. J Molluscan Stud 87(4):eyab033. https://doi.org/10.1093/mollus/eyab033

Bellard C, Marino C, Courchamp F (2022) Ranking threats to biodiversity and why it doesn't matter. Nat Commun 13:2616. https://doi.org/10.1038/s41467-022-30339-y

Bennett-Smith MF, Majoris JE, Titus BM, Berumen ML (2021) Clownfish hosting anemones (Anthozoa, Actiniaria) of the Red Sea: new associations and distributions, historical misidentifications, and morphological variability. Mar Biodivers Rec 14:22. https://doi.org/10.1186/s41200-021-00216-6

Blake C, Rhanor A, Pajic C (2020) The demographics of citizen science participation and its implications for data quality and environmental justice. Citizen Sci Theor Pract 5(1):21. https://doi.org/10.5334/cstp.320

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J (2009) Citizen science: a developing tool for expanding science knowledge and scientific literacy. Bioscience 59(11):977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney R, Phillips TB, Ballard HL, Enck JW (2016) Can citizen science enhance public understanding of science? Public Underst Sci 25(1):2–16. https://doi.org/10.1177/0963662515607406

Burgess HK, DeBey LB, Froehlich HE, Schmidt N, Theobald EJ, Ettinger AK, HilleRisLambers J, Tewksbury J, Parrish JK (2017) The science of Citizen Science: Exploring barriers to use as a primary research tool. Biol Conserv 208:113–120. https://doi.org/10.1016/j.biocon.2016.05.014

Callaghan CT, Mesaglio T, Ascher JS, Brooks TM, Cabras AA, Chandler M, Cornwell WK, Ríos-Málaver IC, Dankowicz E, Dhiya'ulhaq NU, Fuller RA, Galindo-Leal C, Grattarola F, Hewitt S, Higgins L, Hitchcock C, Hung KJ, Iwane T, Kahumbu P, Kendrick R, Kieschnick SR, Kunz G, Lee CC, Lin C, Loarie S, Medina MN, McGrouther MA, Miles L, Modi S, Nowak K, Oktaviani R, Olewe BMW, Pagé J, Petrovan S, Saari C, Seltzer C, E, Seregin AP, Sullivan JJ, Sumanapala AP, Takoukam A, Widness J, Willmott K, Wüster W, Young AN (2022) The benefits of contributing to the citizen science platform iNaturalist as an identifier. PLoS Biol 20(11):e3001843. https://doi.org/10.1371/journal.pbio.3001843

Carbayo F, Marques AC (2011) The costs of describing the entire animal kingdom. Trends Ecol Evol 26(4):154–155. https://doi.org/10.1016/j.tree.2011.01.004

Castro ÉP, Bager A (2019) Sistema Urubu: a ciência cidadã em prol da conservação da biodiversidade. Revista Brasileira de Tecnologias Sociais, Itajaí 6 (2):111–130. https://doi.org/10.14210/rbts.v6n2.p111-130

CBD (1992) Convention on the Biological Diversity. Accessed on 15/04/2023 at https://www.cbd.int/convention/text.

Chowdhury S, Braby MF, Fuller RA, Zalucki MP (2021) Coasting along to a wider range: niche conservatism in the recent range expansion of the Tawny Coster, *Acraea terpsicore* (Lepidoptera: Nymphalidae). Divers Distrib 27:402–415. https://doi.org/10.1111/ddi.13200

Cranswick AS, Constantine R, Hendriks H, Carroll EL (2022) Social media and citizen science records are important for the management of rarely sighted whales. Ocean Coast Manag 226:106271. https://doi.org/10.1016/j.ocecoaman.2022.106271

Cunha DG, Marques JF, Resende JC, Falco PB, Souza CM, Loiselle SA (2017) Citizen science participation in research in the environmental sciences: key factors related to projects' success and longevity. An Braz Acad Sci 89(3):2229–2245. https://doi.org/10.1590/0001-3765201720160548

Di Cecco GJ, Barve V, Belitz MW, Stucky BJ, Guralnick RP, Hurlbert AH (2021) Observing the observers: How participants contribute data to iNaturalist and implications for biodiversity science. Bioscience 71(11):1179–1188. https://doi.org/10.1093/biosci/biab093

Duncan PF, Ghys A (2019) Shells as collector's items, chapter 20. In: Smaal AC, Ferreira JG, Grant J, Petersen K, Strand Ø (eds) Goods and services of marine bivalves, Springer Open, Cham, pp 381–411. https://doi.org/10.1007/978-3-319-96776-9_20

Earp HS, Liconti A (2020) Science for the future: the use of citizen science in marine research and conservation. In: Jungblut S, Liebich V, Bode-Dalby M (eds) YOUMARES 9—the oceans: our research, our future. Springer, Cham. https://doi.org/10.1007/978-3-030-20389-4_1

Echeverria A, Ariz I, Moreno J, Peralta J, Gonzalez EM (2021) Learning plant biodiversity in nature: the use of the citizen–science platform iNaturalist as a collaborative tool in secondary education. Sustainability 13:735. https://doi.org/10.3390/su13020735

Ely CV, Bordignon SAL, Trevisan R, Boldrini II (2017) Implications of poor taxonomy in conservation,

Encarnação J, Teodósio MA, Morais P (2021) Citizen science and biological invasions: a review. Front Environ Sci 8:602980. https://doi.org/10.3389/fenvs.2020.602980

Engel MS, Ceríaco LM, Daniel GM, Dellapé PM, Löbl I, Marinov M et al (2021) The taxonomic impediment: a shortage of taxonomists, not the lack of technical approaches. Zool J Linn Soc 193(2):381–387. https://doi.org/10.1093/zoolinnean/zlab072

Fink D, Auer T, Johnston A, Strimas-Mackey M, Ligocki S, Robinson O, Hochachka W, Jaromczyk L, Rodewald A, Wood C, Davies I, Spencer A (2022) eBird Status and Trends, Data Version: 2021; Released: 2022. Cornell Lab of Ornithology, Ithaca, New York. https://doi.org/10.2173/ebirdst.2021

Forti LR, Hepp F, Souza JM, Protazio A, Szabo JK (2022) Climate drives anuran breeding phenology in a continental perspective as revealed by citizen-collected data. Divers Distrib 28:2094–2109. https://doi.org/10.1111/ddi.13610

Fritz U, Ihlow F (2022) Citizen Science, taxonomy and grass snakes: iNaturalist helps to clarify variation of coloration and pattern in *Natrix natrix* subspecies. Vertebr Zool 72:533–549. https://doi.org/10.3897/vz.72.e87426

Fromont J, Abdul Wahab MA, Gomez O, Ekins M, Grol M, Hooper JNA (2016) Patterns of sponge biodiversity in the Pilbara. Northwestern Aust Divers 8:21. https://doi.org/10.3390/d8040021

Gazdic M, Groom Q (2019) iNaturalist is an unexploited source of plant-insect interaction data. Biodiv Inform Sci Stand 3:e37303. https://doi.org/10.3897/biss.3.37303

Giovos I, Kleitou P, Poursanidis D, Batjakas I, Bernardi G, Crocetta F, Doumpas N et al (2019) Citizen-science for monitoring marine invasions and stimulating public engagement: a case project from the eastern Mediterranean. Biol Invasions 21:3707–3721. https://doi.org/10.1007/s10530-019-02083-w

Goddard JHR, Treneman N, Prestholdt T, Hoover C, Green B, Pence WE et al (2018) Heterobranch sea slug range shifts in the Northeast Pacific Ocean associated with the 2015–16 El Niño. Proc Cal Acad Sci 65(3):107–131

Grieneisen ML, Zhan Y, Potter D, Zhang M (2014) Biodiversity, taxonomic infrastructure, international collaboration, and new species discovery. Bioscience 64(4):322–332. https://doi.org/10.1093/biosci/biu035

Haddad VJr-, Virga R, Bechara A, Silveira FL, Morandini AC, (2013) An outbreak of Portuguese man-of-war (*Physalia physali*s - Linnaeus, 1758) envenoming in Southeastern Brazil. Rev Soc Bras Med Trop 46(5):641–644. https://doi.org/10.1590/0037-8682-1518-2013

Hartmann MC, Schott M, Dsouza A, Metz Y, Volpi M, Purves RS (2022) A text and image analysis workflow using citizen science data to extract relevant social media records: Combining red kite observations from Flickr, eBird and iNaturalist. Ecol Inform 71:101782. https://doi.org/10.1016/j.ecoinf.2022.101782

Hochmair HH, Scheffrahn RH, Basille M, Boone M (2020) Evaluating the data quality of iNaturalist termite records. PLoS ONE 15(5): e0226534. https://doi.org/10.1371/journal. pone.0226534

Hortal J, de Bello F, Diniz-Filho JAF, Lewinsohn TM, Lobo JM, Ladle RJ (2015) Seven shortfalls that beset large-scale knowledge of biodiversity. Annu Rev Ecol Evol Syst 46(1):523–549

Jesus MD, Sales JBL, Martins RS, Ready JS, Costa TAS, Ablett JD, Schiavetti A (2021a) Traditional knowledge aids description when resolving the taxonomic status of unsettled species using classical and molecular taxonomy: the case of the shallow-water octopus *Callistoctopus furvus* (Gould, 1852) from the Western Atlantic Ocean. Front Mar Sci 7:595244. https://doi.org/10.3389/fmars.2020.595244

Jesus MD, Zapelini C, Schiavetti A (2021b) Can citizen science help delimit the geographical distribution of a species? The case of the *Callistoctopus* sp. ("eastern octopus") on the Brazilian coast. Ethnobiol Conserv 10:03. https://doi.org/10.15451/ec2020-09-10.03-1-15

Johnson CN, Balmford A, Brook BW, Buettel JC, Galetti M, Guangchun L, Wilmshurst JM (2017) Biodiversity losses and conservation responses in the Anthropocene. Science 356(6335):270–275. https://doi.org/10.1126/science.aam9317

Journal for Nature Conservation, 36: 10–13. https://doi.org/10.1016/j.jnc.2017.01.003.

Kawabe LA, Ghilardi-Lopes NP, Turra A, Wyles KJ (2022) Citizen science in marine litter research: A review. Mar Pollut Bull 182:114011. https://doi.org/10.1016/j.marpolbul.2022.114011.

Koo K-S, Oh J-M, Park S-J, Im J-Y (2022) Accessing the accuracy of citizen science data based on iNaturalist Data. Diversity 14:316. https://doi.org/10.3390/d14050316

Kousteni V, Tsiamis K, Gervasini E, Zenetos A, Karachle PK, Cardoso AC (2022) Citizen scientists contributing to alien species detection: the case of fishes and mollusks in European marine waters. Ecosphere 13 (1):e03875. https://doi.org/10.1002/ecs2.3875

Langeneck J, Minasidis V, Doumpas N, Giovos I, Kaminas A, Kleitou P, Tiralongo F, Crocetta F (2022) Citizen science helps in tracking the range expansions of non-indigenous and neo-native species in Greece and Cyprus (Eastern Mediterranean Sea). J Mar Sci Eng 10(2):256. https://doi.org/10.3390/jmse10020256

Lehtiniemi M, Outinen O, Puntila-Dodd R (2020) Citizen science provides added value in the monitoring for coastal non-indigenous species. J Environ Manag 267:110608. https://doi.org/10.1016/j.jenvman.2020.110608

Lenoir J, Bertrand R, Comte L, Bourgeaud L, Hattab T, Murienne J, Grenouillet G (2020) Species better track climate warming in the oceans than on land. Nat Ecol Evol 4:1044–1059. https://doi.org/10.1038/s41559-020-1198-2

Lodi L, Tardin R (2018) Citizen science contributes to the understanding of the occurrence and distribution of cetaceans in southeastern Brazil: a case study. Ocean Coast Manag 158:45–55. https://doi.org/10.1016/j.ocecoaman.2018.03.029

Lonhart SI, Jeppesen R, Beas-Luna R, Crooks JA, Lorda J (2019) Shifts in the distribution and abundance of coastal marine species along the eastern Pacific Ocean during marine heatwaves from 2013 to 2018. Mar Biodivers Rec 12:13. https://doi.org/10.1186/s41200-019-0171-8

Łukowiak M, Van Soest R, Klautau M, Pérez T, Pisera A, Tabachnick K (2022) The terminology of sponge spicules. J Morphol 283(12):1517–1545. https://doi.org/10.1002/jmor.21520

Mancinelli G, Bardelli R, Zenetos A (2021) A global occurrence database of the Atlantic blue crab *Callinectes sapidus*. Sci Data 8(1):111. https://doi.org/10.1038/s41597-021-00888-w

Mannino AM, Borfecchia F, Micheli C (2021) Tracking marine alien macroalgae in the Mediterranean Sea: the contribution of citizen science and remote sensing. J Mar Sci Eng 9:288. https://doi.org/10.3390/jmse9030288

Marcovaldi MÂ, Dei Marcovaldi GG (1999) Marine turtles of Brazil: the history and structure of Projeto TAMAR-IBAMA. Biol Conserv 91(1):35–41

Martínez-Sagarra G, Castilla F, Pando F (2022) Seven hundred projects in iNaturalist Spain: performance and lessons learned. Sustainability 14:11093. https://doi.org/10.3390/su141711093

McIntyre AD (1971) Observations on the status of subtidal meiofauna research. In: Proceedings of first international conference of Meiofauna. Smiths Contrib Zool vol 76, pp 149–154

McMullin RT, Allen JL (2022) An assessment of data accuracy and best practice recommendations for observations of lichens and other taxonomically difficult taxa on iNaturalist. Botany 100(6):491–497. https://doi.org/10.1139/cjb-2021-0160

Mesaglio T, Callaghan CT (2021) An overview of the history, current contributions, and future outlook of iNaturalist in Australia. Wildlife Res 48(4):289–303. https://doi.org/10.1071/WR20154

Mesaglio T, Soh A, Kurniawidjaja S, Sexton C (2021) 'First known photographs of living specimens': the power of iNaturalist for recording rare tropical butterflies. J Insect Conserv 25:905–911. https://doi.org/10.1007/s10841-021-00350-7

Monge-Nájera J, Seas C (2018) Citizen science and roadkills: trends along project lifespan and comparison of tropical and temperate projects. UNED Res J 10(1):61–66. https://doi.org/10.22458/urj.v10i1.2042

Oliveira SS, Barros B, Pereira JL, Santos PT and Pereira R (2021) Social media use by citizen science projects: characterization and recommendations. Front Environ Sci 9:715319. https://doi.org/10.3389/fenvs.2021.715319

Pandya RE (2012) A framework for engaging diverse communities in citizen science in the US. Front Ecol Envir 10(6):314–317. https://doi.org/10.1890/120007

Pateman R, Dyke A, West S (2021) The diversity of participants in environmental citizen science. Citizen Sci Theor Pract 6(1):1–16. https://doi.org/10.5334/cstp.369

Pinsky ML, Eikeset AM, McCauley DJ, Payne JL, Sunday JM (2019) Greater vulnerability to warming of marine versus terrestrial ectotherms. Nature 569:108–111. https://doi.org/10.1038/s41586-019-1132-4

Queiroz-Souza C, Viana B, Ghilardi-Lopes N, Kawabe L, Alexandrino E, França J, Koffler S, Saraiva AM, Loula A (2023) Opportunities and barriers for Citizen Science growth in Brazil: reflections from the first workshop of the Brazilian Citizen Science Network. Citizen Sci Theor Pract 8(1):1–9. https://doi.org/10.5334/cstp.521

Ribeiro VV, Pinto MAS, Mesquita RKB, Moreira LB, Costa MF, Castro IB (2021) Marine litter on a highly urbanized beach at Southeast Brazil: a contribution to the development of litter monitoring programs. Mar Pollut Bull 163:111978. https://doi.org/10.1016/j.marpolbul.2021.1119

Roberts CJ, Vergés A, Callaghan CT, Poore AGB (2022) Many cameras make light work: opportunistic photographs of rare species in iNaturalist complement structured surveys of reef fish to better understand species richness. Biodivers Conserv 31:1407–1425. https://doi.org/10.1007/s10531-022-02398-6

Rocha RM, Zanata TB, Moreno TR (2012) Keys for the identification of families and genera of Atlantic shallow water ascidians. Biota Neotrop 12:269–303

Rosa RM, Cavallari DC, Salvador RB (2022a) iNaturalist as a tool in the study of tropical molluscs. PLoS ONE 17(5):e0268048. https://doi.org/10.1371/journal.pone.0268048

Rosa RM, Salvador RB, Teixeira L, Bornschein MR, Cavallari DC (2022b) The rapid expansion of the Jumping Snail *Ovachlamys fulgens* in Brazil. Diversity 14:815. https://doi.org/10.3390/d14100815

Ruggiero MA, Gordon DP, Orrell TM, Bailly N, Bourgoin T, Brusca RC et al (2015) A higher level classification of all living organisms. PLoS ONE 10(4):e0119248. https://doi.org/10.1371/journal.pone.0119248

Sakai K, Türkay M (2013) Revision of the genus *Ocypode* with the description of a new genus, *Hoplocypode* (Crustacea: Decapoda: Brachyura). Mem Queens Mus 56(2):665–793

Sandahl A, Tøttrup AP (2020) Marine citizen science: recent developments and future recommendations. Citizen Sci: Theory Pract 5(1):24. https://doi.org/10.5334/cstp.270

Seddon N, Mace GM, Naeem S, Tobias JA, Pigot AL, Cavanagh R, Mouillot D, Vause J, Walpole M (2016) Biodiversity in the Anthropocene: prospects and policy. Proc R Soc B 283:20162094. https://doi.org/10.1098/rspb.2016.2094

Sherbinin A, Bowser A, Chuang T-R, Cooper C, Danielsen F, Edmunds R et al (2021) The critical importance of citizen science data. Front Clim 3:650760. https://doi.org/10.3389/fclim.2021.650760

Silva DSM, Tavares GC, Fianco M, González JM (2021) First report of the rare arboreal grasshopper *Bactrophora dominans* Westwood, 1842 (Insecta, Orthoptera, Caelifera, Romaleidae) from Brazil. Check List 17(3):895–903. https://doi.org/10.15560/17.3.895

Silvertown J (2009) A new dawn for citizen science. Trends Ecol Evol 24(9):467–471

Simon ADF, Adamczyk EM, Basman A, Chu JWF, Gartner HN, Fletcher K et al (2022) Toward an atlas of Salish Sea biodiversity: the flora and fauna of Galiano Island, British Columbia, Canada. Part I. Marine zoology. Biodiv Data J 10:e76050. https://doi.org/10.3897/BDJ.10.e76050

Smith SDA, Nimbs MJ (2022) Citizen scientists record significant range extensions for tropical sea slug species in subtropical eastern Australia. Diversity 14:244. https://doi.org/10.3390/d14040244

Souto RD, Batalhão ACS (2022) Citizen science as a tool for collaborative site specific oil spill mapping: the case of Brazil. An Acad Bras Cienc 94(Suppl. 2):e20211262. https://doi.org/10.1590/0001-3765202220211262

Storch D, Šímová I, Smyčka J, Bohdalková E, Toszogyova A, Okie JG (2022) Biodiversity dynamics in the Anthropocene: how human activities change equilibria of species richness. Ecography 4:e05778. https://doi.org/10.1111/ecog.05778

Strasser BJ, Baudry J, Mahr D, Sanchez G, Tancoigne E (2019) Citizen Science? Rethinking science and public participation. Sci Techn Stud 32(2):52–76. https://doi.org/10.23987/sts.60425

Tanaka KR, Van Houtan KS, Mailander E, Dias B, Galginaitis C, O'Sullivan J, Lowe CG, Jorgensen SJ (2021) North Pacific warming shifts the juvenile range of a marine apex predator. Sci Rep 11:3373. https://doi.org/10.1038/s41598-021-82424-9

Thornhill I, Loiselle S, Lind K, Ophof D (2016) The Citizen science opportunity for researchers and agencies. Bioscience 66(9):720–721

Tran LT, Bafort Q, Steen F, Gómez Garreta A, D'Hondt S, Miller KA, Vranken S, Žuljević A, Smith JE, De Clerck O (2021) *Dictyota cyanoloma* (Dictyotales, Phaeophyceae), a newly introduced brown algal species in California. J Phycol 57(1):370–378. https://doi.org/10.1111/jpy.13100

Tran TT, Carter BE, Castillo Vardaro JA (2022) Predicted threats to a native squirrel from two invading species based on citizen science data. Biol Invasions 24:3539–3553. https://doi.org/10.1007/s10530-022-02859-7

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Sci Rep 7:9132

Trubovitz S, Lazarus D, Renaudie J, Noble PJ (2020) Marine plankton show threshold extinction response to Neogene climate change. Nature Com 11(1):5069

Van der Wal R, Anderson H, Robinson A, Sharma N, Mellish C, Roberts S, Siddharthan A (2015) Mapping species distributions: a comparison of skilled naturalist and lay citizen science recording. Ambio 44:584–600. https://doi.org/10.1007/s13280-015-0709-x

Van Noordwijk CGE, Baeten L, Turin H, Heijerman T, Alders K, Boer P, Mabelis AA, Aukema B, Noordam A, Remke E, Siepel H, Berg MP, Bonte D (2017) 17 years of grassland management leads to parallel local and regional biodiversity shifts among a wide range of taxonomic groups. Biodivers Conserv 26:717–734. https://doi.org/10.1007/s10531-016-1269-5

Wallingford PD, Sorte CJB (2022) Dynamic species interactions associated with the range-shifting marine gastropod *Mexacanthina lugubris*. Oecologia 198:749–761. https://doi.org/10.1007/s00442-022-05128-5

Wilson JS, Pan AD, General DEM, Koch JB (2020) More eyes on the prize: an observation of a very rare, threatened species of Philippine Bumble bee, *Bombus irisanensis*, on iNaturalist and the importance of citizen science in conservation biology. J Insect Conserv 24:727–729. https://doi.org/10.1007/s10841-020-00233-3

Winterton SL (2020) A new bee-mimicking stiletto fly (Therevidae) from China discovered on iNaturalist. Zootaxa 4816(3):361–369

WoRMS Editorial Board (2023) World Register of Marine Species. https://www.marinespecies.org at VLIZ. Accessed 2023 Apr 08. https://doi.org/10.14284/170

Yiu SKF, Chow CFY, Tsang SHT, Zhang X, Chung JTH, Sin SYT, Chow WK, Chan LL (2022) New record of Japanese SEAHORSE, *Hippocampus mohnikei* Bleeker, 1853 (Syngnathiformes: Syngnathidae). Hong Kong Waters 18(3):455–461. https://doi.org/10.15560/18.3.455