ORIGINAL RESEARCH

Stranding of *Porpita porpita* (Cnidaria, Hydrozoa) in Ligurian coast: sampling bias or evidence of a warming sea?

Alice Guzzi[1,2, 3, *], Stefano Schiaparelli[1, 2, 3], Nicolò Merulla[1], Davide Crupi[1, 2] and Marco Grillo[2, 4]

[1]Department of Earth, Environmental and Life Sciences (DISTAV), University of Genoa, Corso Europa 26, 16132 - Genoa, Italy. [2]Italian National Antarctic Museum (MNA, Section of Genoa), University of Genoa, Viale Benedetto XV No. 5, 16132 Genoa, Italy. [3]National Biodiversity Future Center (NBFC), 90100 - Palermo, Italy. [4]Department of Physical Sciences, Earth and Environment (DSFTA) - University of Siena, Strada Laterina 8, 53100 - Siena, Italy. ORCID *Alice Guzzi* https://orcid.org/0000-0001-8066-9158, *Stefano Schiaparelli* https://orcid.org/0000-0002-0137-3605, *Nicolò Merulla* https://orcid.org/0009-0005-4059-7889, *Davide Crupi* https://orcid.org/0009-0005-8066-0504, *Marco Grillo* https://orcid.org/0000-0002-3188-9012

ABSTRACT. On September 1st, 2023 three specimens of the blue button *Porpita porpita* (Linnaeus, 1758) (Cnidaria, Hydrozoa) were found stranded along the store of the Genoa metropolitan area (northwest Mediterranean Sea, Ligurian Sea) as a result of a citizen science contribution. This record represents the second observation of the species in this area after the first one, occurred in 2019. The general increase in observations of *P. porpita* in the Mediterranean basin, from 2010 on, may suggest a higher abundance of specimens in the sea, likely due to climate change, an intensified effort in reporting sightings of citizens scientist (whose data accounts for more than 85% of total available records), or a combination of both factors. The analysis of environmental data related to this latest stranding event suggests that this occurred under specific meteorological conditions. Since monitoring the spread of non-indigenous species is fundamental to study global warming effects on marine biodiversity, the understanding of the precise environmental settings under which they may occur might reduce observational biases and contribute to the acquisition of sound data less linked to fortuitous observations.

Key words: Medusozoa, blue button jellyfish, pleuston, non-indigenous species, Mediterranean Sea, stranding, citizen science, Global Biodiversity Information Facility.

*Correspondence:
aliceguzzi@libero.it

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Varamientos de *Porpita porpita* (Cnidaria, Hydrozoa) en la costa de Liguria: ¿sesgo de muestreo o evidencia de un calentamiento del mar?

RESUMEN. El 1 de septiembre de 2023, gracias a una contribución de ciencia ciudadana, se observó el varamiento de tres ejemplares de *Porpita porpita* (Linnaeus, 1758) (Cnidaria, Hydrozoa) a lo largo de la costa de la ciudad metropolitana de Génova (noroeste del Mar Mediterráneo, Mar de Liguria). Este registro representa la segunda observación de la especie en esta área después de la primera ocurrida en 2019. El aumento general de las observaciones de *P. porpita* en la cuenca mediterránea a partir de 2010 puede sugerir una mayor abundancia de especímenes en el mar, probablemente debido al cambio climático, un esfuerzo intensificado en la notificación de avistamientos por parte de científicos ciudadanos (cuyos datos representan más del 85% del total de registros disponibles), o una combinación de ambos factores. El análisis de los datos ambientales relacionados con este último varamiento sugiere que éste ocurrió en condiciones meteorológicas específicas. Dado que el seguimiento de la propagación de especies no autóctonas es fundamental para estudiar los efectos del calentamiento global sobre la biodiversidad marina, la comprensión de los entornos ambientales precisos en los que pueden ocurrir podría reducir los sesgos de observación y contribuir a la adquisición de datos sólidos menos vinculados a observaciones fortuitas.

Palabras clave: Medusozoa, medusa botón azul, pleuston, especies no autóctonas, Mar Mediterráneo, varamientos, ciencia ciudadana, Infraestructura Mundial de Información sobre Biodiversidad.

INTRODUCTION

The Mediterranean Sea, an intercontinental sea nestled between Europe, Africa, and Asia, has long been an environmental focal point due to its unique climatic characteristics. Over the past Century, this region has witnessed significant changes in sea surface temperatures, largely attributed to climate warming. This ongoing increase in temperature has led to several ecological changes, such as shifts in the distribution of marine species (Hughes 2000; Puce et al. 2009; Rivetti et al. 2014; Gravili et al. 2017) and the spread of non-native species (Coll et al. 2010; Montesanto et al. 2023) with drastic consequences on the biodiversity of marine ecosystems (Bonanno and Orlando-Bonaca 2019; Bonello et al. 2022). Considering the number of non-indigenous species and their introduction rate, the Mediterranean can be regarded as one of the most affected seas by biological invasions (Zenetos et al. 2010). More precisely, the gradual rise in global temperatures is facilitating the expansion of warm-water taxa in the Mediterranean, a phenomenon commonly referred to as 'tropicalization' (Bianchi and Morri 2003; Bianchi 2007; Por 2009; Bianchi et al. 2012, 2018; Peleg et al. 2020). Gathering spatio-temporal data on these non-native species and monitoring their expanding geographic ranges represents an unavoidable and necessary step for managing and conserving marine ecosystems and their biodiversity (Katsanevakis et al. 2020). Records of alien species are frequently documented and published when they represent the 'first records' within a particular geographical area but only rarely, after this first step (sometimes also 'sensationalistic' from a media point of view) further monitoring efforts are performed. Usually, these additional steps are taken only in the case of invasive species (e.g. the alga *Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817; the lionfish *Pterois miles* Bennet, 1828; the blue crab *Callinectes sapidus* Rathbun, 1896 (https://iucn-medmis.org/en). In addition, instances of species observed within their already established invasion ranges are seldom reported. As a result, valuable spatio-temporal data, of significant interest to both researchers and stakeholders, often remain unreported and also fragmented across various repositories or personal files (Ragkousis et al. 2023). This information gains even greater significance in the case of the Mediterranean Sea, which is experiencing exceptionally rapid warming compared to the global ocean and unmatched biological invasions (Schroeder et al. 2016; Cramer et al. 2018; Pörtner et al. 2019; Pisano et al. 2020).

Citizen science projects represent a well-known tool to significantly expand the geographic and temporal extent of data collection, allowing for better monitoring and understanding of marine ecosystems. Additionally, citizen scientists provide a cost-effective workforce for data collection, allowing research efforts to stretch further and cover larger geographical areas (Kelly et al. 2020; Terenzini et al. 2023). This makes it possible to monitor remote or less-studied regions, which can be of critical importance for conservation efforts or track sporadic events that can pass unnoticed as the stranding of small size marine organisms.

The Ligurian Sea, located in the northernmost part of the western Mediterranean Sea, with its overall extension of 100 km of the beaches (Ferretti et al. 2003) is not new to stranding events, especially in the case of the macroscopic resident/autochthonous species such as the blue wind sailor *Velella velella* (Linnaeus, 1758) (Betti et al. 2019) and the gastropod *Jantina pallida* W. Thompson, 1840 (Betti et al. 2017). A different situation is for those remarkable records of Atlantic species that may strand under the same environmental circum-

stances but are smaller or less recognizable. These species such as the pteropod *Cymbulia parvidentata* Pelseneer, 1888 (Schiaparelli et al. 2023) and the pedunculate barnacle *Dosima fascicularis* (Ellis and Solander, 1786) (Betti et al. 2017) are evidently linked to ongoing process of atlantification in the Mediterranean basin, making them worth of careful consideration.

In this context, we documented a novel occurrence of the 'blue button jelly', *Porpita porpita* (Linnaeus, 1758), a pleustonic hydrozoan which is typically found in tropical and temperate waters (Calder 2010; Pandya et al. 2013; Gul and Gravili 2014; Ramanibai et al. 2014; Chowdhury et al. 2016) also providing information about the environmental settings under which these events may occur.

MATERIALS AND METHODS

On September 1st, 2023 at 16:45, three stranded specimens of *P. porpita* were reported by one of the authors (N. M.) on the shore of Capo Santa Chiara (Genoa, Ligurian Sea, latitude 44.389933, longitude: 8.977783 (Figure 1) in the framework of the citizen science project St[r]anding (https://strandingcitizenscience.wordpress.com/; App: https://play.google.com/store/apps/details?id=com.stranding.stranding). Specimens were damaged, except only for one that was found in perfect conditions. Upon specimen collection, the samples were handed over to the DISTAV (University of Genoa, Italy) laboratory. Subsequently, identification procedures were conducted on the freshly acquired organisms following (Pattnayak et al. 2023). Materials were then fixed in ethanol (Et-OH 96%). The three specimens were deposited in the zoological collection of DISTAV with the vouchers UGZC-16113, UGZC-16114, UGZC-16115. Measurements of the central body were taken with a Leica S9i Stereozoom microscope. For the intact specimen, diameter measurements were taken for the complete aboral portion and the float limit (ring canal serving as the outermost limit), both along the vertical and horizontal axes. However, for the other two specimens,

Figure 1. Sampling location of *Porpita porpita* reported in the present study (left). Aboral (top) and oral (bottom) views of the intact specimen found stranded (right) (IZUG-16113).

only measurements of the float were feasible due to specimen damage. The wet weight of all organisms was determined using an analytical balance (± 0.0001 g). Information regarding weather conditions was retrieved from the Liguria Region (2023) web page, being WIND-D the direction of origin of the maximum wind, and WIND-I the maximum wind intensity layers. Wind data were recovered from the permanent monitoring station 'GENOVA - PORTO ANTICO (GEPOA)' (latitude 44.40816, longitude 8.92317, height above sea level 25 m), as it was the closest to the stranding area (5 km distance) and should therefore report the most accurate environmental conditions. Temperature was used as an additional proxy to analyze the stranding event. Temperature information was retrieved from the Copernicus Marine Service (https://marine.copernicus.eu/) (Clementi et al. 2021). Information regarding the occurrence of *P. porpita* in the Mediterranean Sea was downloaded from the Global Biodiversity Information Facility (GBIF 2023).

RESULTS

Specimens can be ascribed to *P. porpita* thanks to their peculiar morphological characters, above all the flattened, disc-shaped body filled with gas. They all have a round colonial structure with a prominent central pore, numerous minute pores or stigmata in rows radiating from the center, that give the upper surface its specific pattern. This portion comprises polymorphic individual polyps with specific roles within the colony (Mariscal 2017). The lower side of the disc present the small, central gastrozooid with a terminal mouth and is surrounded by many gonozooids, and dactylozooids towards periphery. Tentacles, found only on dactylozooids, are short, capitate and arranged in three longitudinal rows, distally on each dactylozooid, as the species is known (Schuchert 2010).

The only sample retrieved in perfect conditions had a measurement of the complete aboral portion of 12.36 ± 0.28 mm, and the float part (averaged over all organisms) a size of 10.29 ± 0.71 mm. This aligns consistently with scientific literature, which typically reports measurements of a few centimeters in diameter for the organism's body (Shimabukuro et al. 2006; Karunarathne and De Croos 2022). The three individuals that stranded had an average wet weight of 0.1775 ± 0.0183 g. Detailed morphometric measures are given in Supplementary material.

During the three-month span from early June to late August, the temperature of the Ligurian Sea experienced the classic summer rise, ascending from 20.4 to 25.3 °C. This warming trend peaked on August 23rd, reaching the highest temperature record for the season, i.e. 28.6 °C. In the days preceding the stranding event, atmospheric and marine conditions remained relatively stable and characterized by a consistent high pressure, sunny weather and a predominant wind blowing from the northeast direction toward southwest at an average speed of more than 10 m s^{-1} (Figure 2). This was followed by a notable change in marine conditions on August 30th, 2023, due to a marked shift in both intensity and direction of the wind. From this day, the predominant wind direction shifted from south to north. The intensity dropped from the high value of the precedent day to 5.3 m s^{-1} on the 30th and to 4.6 m s^{-2} on the 31st. During September 1st, 2023, winds blew with a predominant direction between south-southeast towards north-northwest. The most frequent wind was from the south with an average speed of 5.56 ± 2.66 m s^{-1} (max. = 10.00 m s^{-1}, min. = 2.30 m s^{-1}). This alteration in environmental factors triggered the stranding event, ultimately leading to the discovery of three organisms on the coastline of Capo Santa Chiara. Analysis of satellite-derived data pertaining to currents and wind patterns in the study region revealed a noteworthy trend during the specific event under consideration (both the direction of the current and the wind exhibited a notable orientation toward the shoreline).

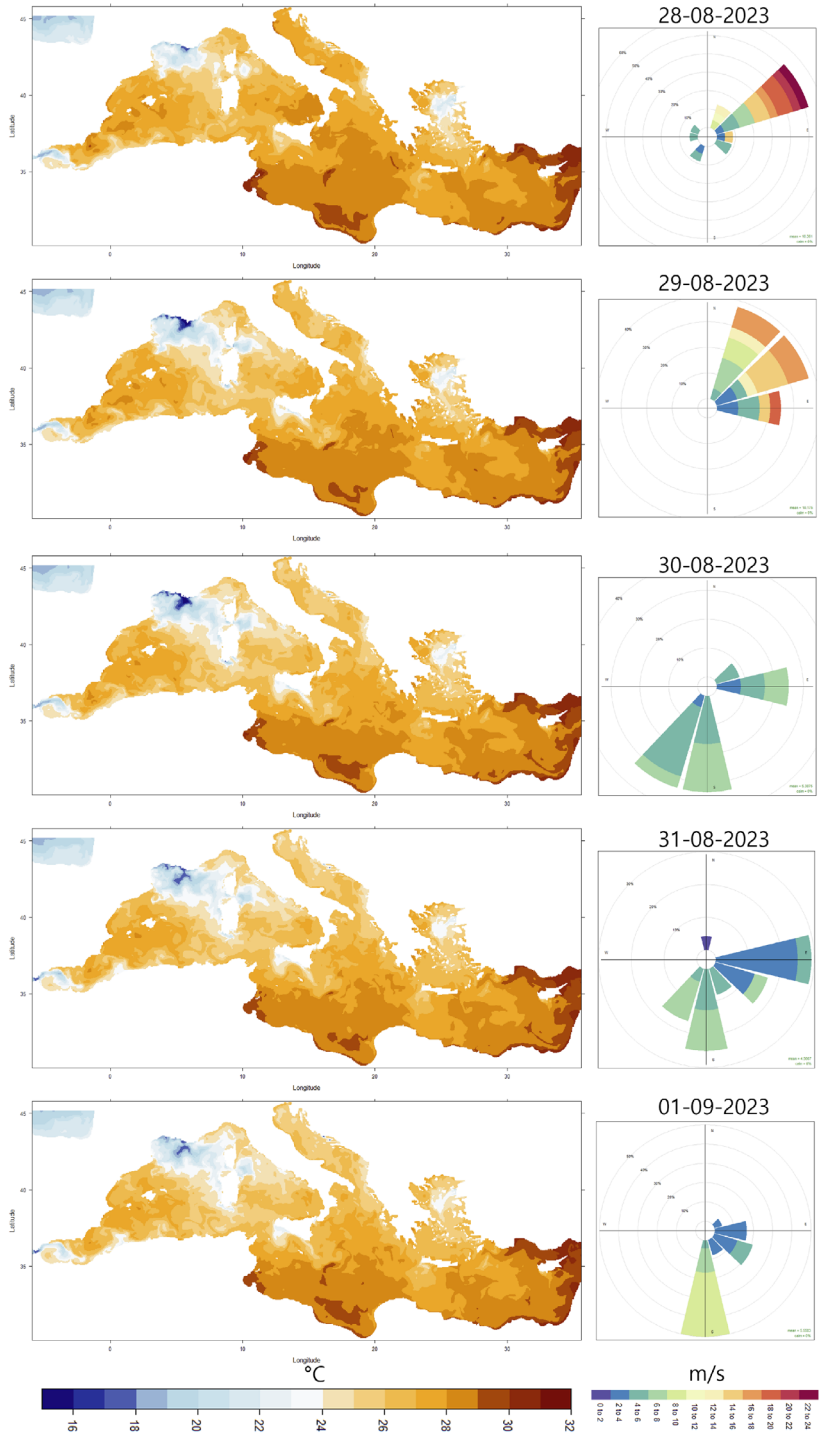

Figure 2. Variability of temperature (on the left) and radar plot of wind direction and intensity (on the right) during the days from August 28th, 2023, to September 1st, 2023 (the day of stranding event of *Porpita porpita*).

The downloaded distributional record of *P. porpita* in the Mediterranean Sea from GBIF yielded 55 records spanning from 1882 to 2023 (Figure 3). The dataset incorporated the initial documented occurrence in the Ligurian Sea of the species, which took place on July 31st, 2019, in Savona (latitude 44.282229, longitude 8.446389). These information have been seamlessly integrated into the GBIF system through the exchange of data with iNaturalist (https://www.inaturalist.org/), the platform where the observation was initially recorded by voluntarily contribution. The trend in records revealed a notable upswing from 2010, reaching a peak of 14 reports in 2014; however, there was a massive informative gap spawning from 1922 to 2010. Although not all records provided accurate information regarding the day of sighting, information on the month was available for all records, except for the initial one in 1882. Data suggested a seasonality, with more than 85% of the reports concentrated between May and September distributed on the ranging years, accounting for a total of 47 reports out of the 55. Out of the 55 records accessible on GBIF, a substantial majority, specifically 47, emanated from citizen science initiatives. Notably, 22 of these records were attributed to the Italian project 'Occhio alla Medusa' (Boero et al. 2019), underscoring the significant contribution of this citizen science initiative to the available data. Additionally, two records originated from the French project 'BioObs' (https://bioobs.fr/blog/, Inventaire National du Patrimoine Naturel, last search 21st November 2023), emphasized the collaborative cross-border nature of biodiversity monitoring efforts. Furthermore, 23 records were sourced from the iNaturalist platform (iNaturalist contributors, last search 21st November 2023), highlighting the valuable role played by this platform in engaging a global community of observers and enthusiasts in the documentation of biodiversity. In the context of the Mediterranean Sea sector relevant to this publication, specifically the Ligurian Sea, it is noteworthy that the initial report of *P. porpita* in this region was derived again from a citizen science record dating back to 2019.

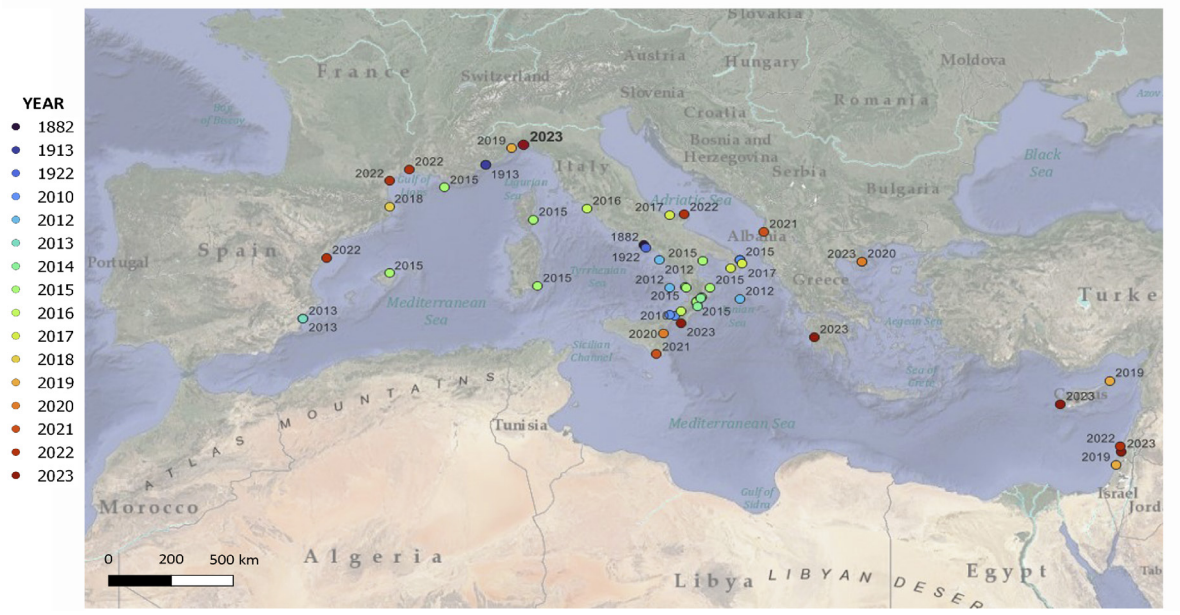

Figure 3. Mediterranean records of *Porpita porpita*. Past records are collected from GBIF dataset and color coded based on year of observation. In bold the new record of the present work.

DISCUSSION

The Mediterranean basin is currently experiencing profound transformations attributed to a rapid increase in sea surface temperature, surpassing the global average rate by more than threefold (Pörtner et al. 2019). This draws particular concern and focus to the Mediterranean Sea, given the increasing occurrences of extreme weather events that significantly impact its biodiversity and species distribution. The altered environmental conditions also pave the way for the arrival of alien species, potentially affecting fisheries and various other socio-economical spheres. The semi-enclosed nature of this basin suggests that substantial changes are on the horizon, and the extent and consequences of these changes cannot be accurately assessed with the current available data.

In our study we documented the second-time occurrence of *P. porpita* on the Ligurian coast (western Mediterranean Sea). The spatial distribution of *P. porpita* could be of importance as an indicator of climate change in the marine environment of the west Mediterranean (Mamish et al. 2019), particularly underscoring the process of Atlantification of the Mediterranean Sea. The new arrival of alien jellyfish may have a significant impact on fisheries resources and coastal ecosystems (Tiralongo et al. 2022). The documented increase in the temperature of the Mediterranean Sea can potentially enhance the proliferation and survival of non-native organisms exhibiting tropical affinities such as *P. porpita*. The temperature increase prior to the observed stranding event might suggest it to be a proxy, together with other factors such as tides, wind and currents, to cause them to swarm near the shore. Another factor contributing to swarming is the availability of abundant food. The diet of *P. porpita* primarily consists of carnivorous calanoid copepods, accounting for approximately 90%, while crab megalopa and fishes constitute the other 10% (Bieri 1970). The precise trajectory of these organisms within the Mediterranean Sea basin prior to the stranding event remains elusive based on the current information. Furthermore, it is challenging to ascertain a definitive timeframe indicating how long these organisms may have been present in these waters. A hypothesis has been posited suggesting that the altered conditions in the Mediterranean basin may support the transport and colonization of this hydrozoan (young 0.3 mm, and adult up to 2.5 mm) through ballast water (Mamish et al. 2019). This mechanism allows for the migration of these species from regions with water temperatures resembling those of the Indo-Pacific, highlighting the potential role of ballast water in facilitating their spread.

The influence of wind emerges as a pivotal factor in the context of stranding events involving planktonic organisms, especially pleustonics, a facet that has garnered attention and scrutiny in various scientific investigations (e.g. Keesing et al. 2016; Betti et al. 2017, 2019; Mamish et al. 2019; Sahu et al. 2020; Pattnayak et al. 2023; Schiaparelli et al. 2023). This phenomenon has been extensively highlighted and explored in a multitude of academic publications, underscoring the intricate relationship between wind patterns and the coastal dynamics affecting these marine organisms. The Gulf of Genoa is situated in one of the most cyclogenetic regions of the Mediterranean basin (Trigo et al. 2002; Soukissian and Sotiriou 2022). The intricate interplay between the synoptic flow and the complex alpine topography gives rise to the formation of deep orographic lows. These lows, known for their dynamic nature, typically move rapidly eastward under the influence of the upper-level flow. Consequently, the lower-level winds undergo a swift transition from ‘Scirocco’ (south-east) to ‘Libeccio’ (south-west), with coastal effects notably amplifying their intensity (Onorato et al. 2006). In such scenarios, sea conditions exhibit a complex crossed state, marked by the superposition of wave components generated by diverse strong wind fetches. The convergence of wind and current towards the shore during the studied event ampli-

fies the significance of atmospheric conditions in driving the movement and potential stranding of nektonic organisms. The interplay between meteorological factors, such as wind direction and intensity, and oceanic currents, can significantly impact the navigation and distribution of marine life. Recognizing this interdependence is fundamental not only for comprehending the specific stranding event but also for advancing our broader understanding of marine ecology and the intricate mechanisms governing the movements of marine organisms in coastal regions. This intricate atmospheric and oceanographic interplay can contribute to the stranding of marine organisms especially passive drifter such as *P. porpita*.

Now that the environmental settings under which stranding events of pelagic marine life can occur in the Ligurian region have been better defined, it would be desirable to establish an 'alert mechanism' to engage citizen scientist in the right timeframes for this kind of observations. In this way, they could focus their efforts when condition for a stranding event exist instead of accumulating totally random observation that, despite being extremely useful as in this case, prevent the achievement of a robust dataset to be used in more advanced analytic activities such as species distribution modeling.

Citizen scientists play a vital role in understanding biodiversity, especially in the current era of rapid planetary warming and increasing human impact. Their observations, collected through open access platforms like such as GBIF, provide crucial data, comprising 85% (47 observations) of the total available in our case.

However, the voluntary nature of these contributions introduces variability in standards and methodologies, leading to potential data gaps and inconsistencies. For instance, a significant temporal gap in our dataset from 1922 to 2010 complicates analyses of species distribution during that period. The surge in records since 2010 may reflect either an actual increase in specimen abundance, potentially linked to climate change, or heightened public reporting efforts, or a combination of both. This ambiguity highlights the inherent bias in citizen science data, which must be carefully addressed when interpreting trends.

Despite these challenges, citizen science offers a cost-effective means of addressing knowledge gaps and fostering interdisciplinary collaboration. Such initiatives are invaluable for marine conservation, enabling early detection of non-native species and monitoring habitat shifts. Sustained and structured citizen involvement should be prioritized as a key resource for conservation efforts.

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Supplementary material

The following supporting information can be downloaded at Supplementary material, Table S1 - Detailed morphometric measures.

Conflict of interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Author contributions

Alice Guzzi: investigation; data curation; conceptualization; formal analysis; methodology; visualization; writing-original draft; writing-review and editing. Stefano Schiaparelli: supervision; funding acquisition; writing-review and editing. Nicolò Merulla: investigation; writing-review and editing. Davide Crupi: investigation; data curation; writing-review and editing. Marco Grillo: methodology; data curation; conceptualization; writing-review and editing.

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