Hydrobiologia (2025) 852:5313–5332
https://doi.org/10.1007/s10750-025-05852-y

JELLYFISH, ECOSYSTEMS, HUMANS

Opinion Paper

Citizen science-based jellyfish observation initiatives in the Mediterranean Sea

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Received: 1 July 2024 / Revised: 28 February 2025 / Accepted: 4 March 2025 / Published online: 2 April 2025

Abstract We present Citizen Science-based Jellyfish Observation Initiatives (CS JOIs) across the Mediterranean Basin and propose a path toward standardization of the data they produce. We explored data collection and management through a shared database schema. Using an expert opinion questionnaire and adhering to standards that are recognized globally (e.g., by GBIF, OBIS, and EMODnet) such as Darwin Core and IOOS terminology, we propose a three-stage approach toward data management and standardization. JOIs vary in purpose, function, language, data collection, validation methodology, outreach, and levels of citizen engagement and training. This diversity presents unique opportunities and challenges for data collection and management. JOIs typically combine the dual role of providing real-time alert systems and enhancing our long-term knowledge of jellyfish distribution and, eventually, ecology. When global reporting systems are considered, local initiative identity, language, purpose, and community must be preserved to allow meaningful CS processes to evolve, while the integration of JOIs within

Handling editor: Jörg Dutz

Guest editors: Stefano Piraino & Delphine Thibault / Jellyfish, Ecosystems, and Humans.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10750-025-05852-y.

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them (and data collection and management in general) must be performed via standardized and shared methodologies. Finally, we discuss the contribution of novel technologies toward improving the activities and management of JOIs worldwide.

Keywords Jellyfish · Citizen science · Crowdsourcing · Gelatinous zooplankton · Data standardization · Mediterranean Sea

Introduction

The twenty-first century has witnessed a surge in Citizen Science (CS) projects (Silvertown, 2009). Advances in technology (as smartphones became widely available) and communications help these projects realize the potential and effectivity of humans as sensors of the natural world in exciting new ways and scales (Newman et al., 2012; Garcia-Soto et al., 2021). At sea, CS has also been on the rise, enhancing ocean stewardship and benefiting both science and society with projects ranging in size and trophic level from plankton to whales (Kelly et al., 2020; Garcia-Soto et al., 2021). Among marine species, jellyfish, defined here in the broader sense of gelatinous zooplankton,

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including ctenophores, siphonophores, and thaliaceans (salps, doliolids, and pyrosomes), represent a classic “win–win” situation for CS projects. The occurrence of stinging species compromises human health and safety as an ever-growing number of people enter the sea (Edelist et al., 2023), and thus, information about the whereabouts and occurrence of different species is of direct interest to the public. Beachgoers, bathers, swimmers, SCUBA and free divers, surfers, kayakers, sailors, and fishermen are often eager to report on the presence of jellyfish, especially when these observations are used to improve life quality along the coast and contribute to public health and scientific knowledge. This facilitates the added value of partnership in trying to answer questions that interest both the public and scientists and an opportunity for a higher level of CS activity to emerge (Haklay et al., 2021).

Monitoring seasonal changes in jellyfish occurrence across the vast expanses of the oceans is still an expensive and challenging task for conventional science. Jellyfish largely elude satellite imagery and radar, particularly when submerged well below the surface. Acoustics were tested for swarm detection as early as three decades ago (Mutlu, 1996), and tagging has also been tested (e.g., Hays et al., 2008; Fossette et al., 2016; Diamant et al., 2023) but these are not yet available for tracking swarms effectively over large geographical ranges. In addition, submerged cameras, as one of the often-used techniques in jellyfish detection, require large-scale deployment and may be limited by poor visibility (Martin-Abadal et al., 2020). As a result, over the past decade, human sensors, in the form of trained and untrained citizen scientists, aided by technology, are a viable alternative to the abovementioned technologies (Canepa et al., 2020; Marambio et al., 2021; Dobson et al., 2023).

Over the past 15 years, many CS Jellyfish Observation Initiatives (JOIs) have been established, evolving in parallel in different places, particularly in the Mediterranean Sea. JOIs share the common will to contribute to our knowledge about gelatinous marine fauna but vary in purpose, scope, and methodology, highlighting the need for standardization.

The first jellyfish observation program was launched in 2001 by the Mediterranean Science Commission (CIESM) and named *Jellywatch,* with a dedicated web page asking citizens to submit jellyfish sightings (Boero et al., 2008). The public response was limited, and the initiative was relaunched in 2008 when the popular magazine *Focus* adopted the campaign which was renamed *Occhio alla medusa*, under the CIESM umbrella and focusing on the Italian Seas. The first edition of a poster containing the common Mediterranean gelatinous plankters was produced in 2009. In 2010, *Focus* released the smartphone app "*Meteo Meduse*" to receive jellyfish reports and provide maps of their distribution, and between 2013 and 2015, the EU project *Perseus* adopted *Jellywatch*, and citizens from the entire Mediterranean were asked to send observations to local focal points based on poster methodology. Jellyfish scientists from 19 countries with Mediterranean coasts submitted weekly observation summaries, which were presented on an online map and stored in a joint database (https://www.ciesm.org/marine/programs/jellywatch.htm), and in 2018, the Italian database was integrated into the European Marine Observation and Data Network (EMODnet) platform.

The Catalan *Jellyfish Observation Network* was deployed in 2007 (Marambio et al., 2021). Like the Italian initiative, it took several years to develop as a full-fledged Citizen Science endeavor. Other local initiatives began to appear in the second decade of the twenty-first century (Fig. 1). “*Spot the Jellyfish*” in Malta and “*ACRI.ST*” in France started in 2010, “*Meduzot Baam*” in Israel and “*Observadores del Mar*” in Spain were established in 2011. In 2012, *iMedjelly* was launched in Spain, then in 2013, “*Infomedusa*” was initiated also in Spain and “*Meduse.Tunisie*” in Tunisia. “*Yayakarsa*” was established in Türkiye (2014), then in 2016, “*Medusapp*” was created in Spain and “*JellyX*” in Italy. In 2019, “*avvistApp*” in Italy and “*Meduseo*” (a private initiative) were launched, and in 2023, “*Crafting the Sea”* was formed in Croatia and “*I See Sea*” in Romania.

One of the criticisms raised regarding citizen science projects, such as the JOIs, is the lack of standardized data. Standardizing CS data is essential for maximizing the potential of JOIs to contribute meaningfully to scientific research, environmental monitoring, and community empowerment. Standardizing and data FAIRness (FAIR: Findable, Accessible, Interoperable, and Reusable) are crucial for many reasons (Wilkinson et al. 2016; Bowser et al., 2020): (a) Quality Assurance (QA)

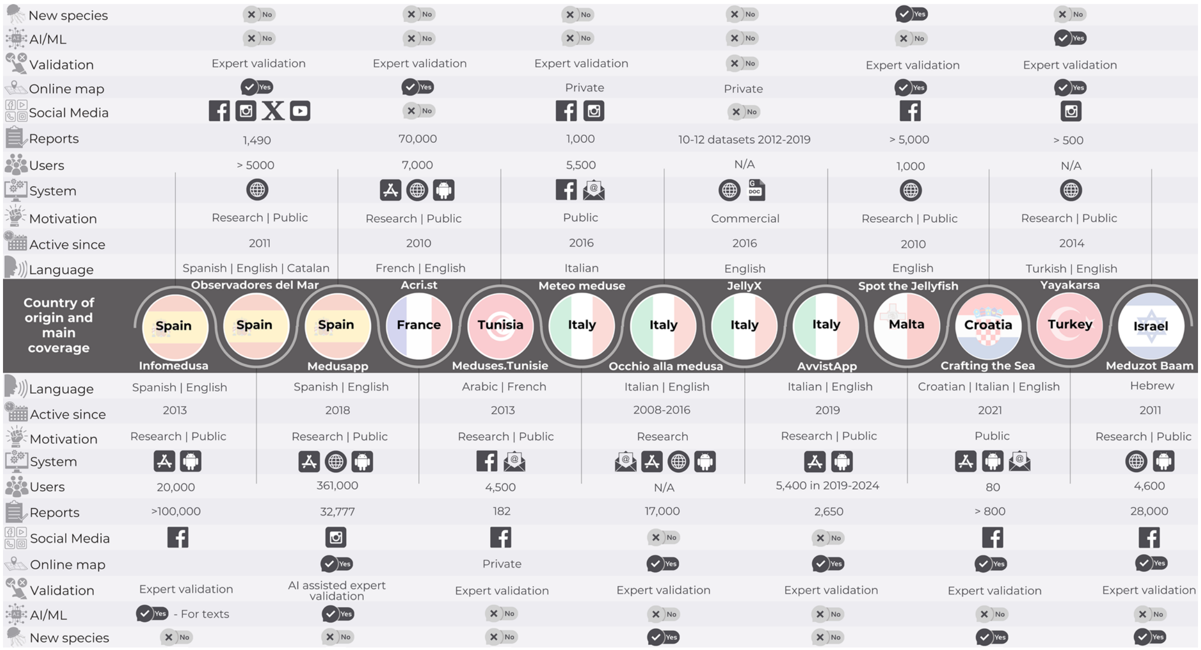

Fig. 1 Descriptive properties for 13 Citizen Science Jellyfish Observation Initiatives in the Mediterranean Sea. Note that in Italy, *Occhio alla Medusa* changed their name to *Meteo Medusae*. Downloads and installations are until April 2024. (AI = Artificial intelligence and ML = Machine learning)

and Quality Control (QC), for consistency and reliability, which are the foundation for trust within the scientific community, (b) interoperability to facilitate data sharing, integration, comparison, and scale-up, (c) consistent and effective archiving and access to data over time while reducing data loss or corruption, (d) incorporation into scientific studies, modeling, and decision-making processes, and (e) engagement and transparency, enhancing trust and credibility among scientists, citizen scientists, policymakers, and the public.

Global projects

Global projects supporting data standardization include EMODnet, Global Biodiversity Information Facility (GBIF), and Ocean Biodiversity Information System (OBIS), all implementing principles of Darwin Core (DwC)—an established framework for compiling biodiversity data from varied sources (Wieczorek et al., 2012). GBIF was established in 2001 to provide free and open data about all types of life on Earth and is the most comprehensive information source on the diversity, distribution, and abundance of life (Heberling et al., 2021). OBIS, the Ocean Biodiversity Information System, collaborates with GBIF and works with the same information standards and tools as the Integrated Publishing Toolkit, which is used by OBIS and GBIF as the recommended platform for sharing marine data (Wieczorek et al., 2012). Both organizations focus on scientifically backed and collected data, and both also feature a growing number of marine CS projects, such as Happywhale.com, NatureWatch NZ on OBIS, or iNaturalist and Observation.org (https://observation.org) on GBIF. iNaturalist released its biodiversity CS app in 2013, and by 2025, among its > 100 million validated observations, are available in GBIF (iNaturalist, 2025), these included > 30,000 observations of scyphozoan medusae (GBIF Occurrence download https://doi.org/10.15468/dl.m5gt6s, January 30, 2025). Similarly, Observation.org, founded in the Netherlands in 2004, is a global hub for biodiversity data with > 230 million observations and > 100 million validated observations and available in GBIF (Observation.org, 2025), these included > 25,000 observations of scyphozoan medusae (GBIF Occurrence download https://doi.org/10.15468/dl.g2jqka, January 30, 2025). Observation.org improves data integrity through expert species validation, complies with European privacy standards, and offers tiered user applications that foster public participation ranging from novices to scientific professionals.

New technologies and future perspectives for CS JOIs

There are different techniques in the literature for detecting jellyfish, including a surge of deep learning of underwater images (Martin-Abadal et al., 2020; Han et al., 2022), environmental DNA (eDNA) (Minamoto et al., 2017), early warning systems using IoT (Internet of Things) devices such as drones or UAVs (unmanned aerial vehicles) (Mcilwaine & Rivas Casado, 2021), or even tracking jellyfish predators such as turtles via satellite (Nordstrom et al., 2019). Nevertheless, high costs, low visibility conditions underwater, or relatively low resolution, atmospheric water vapor (clouds), and water column penetration limitations from the air and space are the main impediments to remote sensing operations (Baliarsingh et al., 2020; Mcilwaine & Rivas Casado, 2021; Dereli et al., 2023). Until the deployment of such technology becomes economically affordable, Citizen Science is still considered the best way to monitor jellyfish. Both Observation.org and iNaturalist include AI-based automatic tools to propose initial suggestions for species identification (Nugent, 2020), and several JOIs such as *Medusapp* (Dobson et al., 2023) and *Infomedusa* (Castro-Gutiérrez et al., 2022) in Spain, and *Spot the Jellyfish* in Malta (Gauci et al., 2020) have trained such image analysis algorithms (Fig. 1). To conclude, while Citizen Science remains a cost-effective method to account for jellyfish blooms, introducing novel technologies into CS projects holds tremendous opportunities, including added value for scientific research, community development, public health, education, and outreach.

In this context, this paper aims to describe the active jellyfish reporting initiatives throughout the Mediterranean Sea, observe the differences in how they operate, propose good practices, as well as provide a path toward standardization and harmonization of the data they collect and manage.

Methods

To identify JOIs, an online Google search in English was employed, using the string "jellyfish" AND "citizen science" And ["Mediterranean Sea" OR "Black Sea" OR "Southern European Seas"], and relevant literature (i.e., jellyfish CS publications from Google Scholar) was searched and reviewed. Google searches yield different results on different occasions and are not replicable. Moreover, since the search was conducted in English, JOIs operating in other languages might have been missed. Therefore, to complement this search, leading authors and experts in the field were approached and queried as to the existence of other known initiatives. This process did not impact the final conclusions, as it assisted in finding and contacting all active around the Mediterranean Sea. The network of jellyfish experts conducting CS-based research programs was formed in 2022 to explore and discuss shared challenges, needs, and aims, and was updated following the 2023 Jellyfish Blooms Symposium (JBS7) in India (Dawson & Kumar, 2023). The network includes 23 experts from 13 JOIs. We conducted a series of meetings with the JOIs to discuss shared challenges and opportunities.

A questionnaire with a Likert scale of 1–5 was distributed among the JOIs to identify best practices for data collection and management. The questionnaire consisted of two main sections: The first consisted of 21 questions in which the importance of the data fields indicated in the scheme was ranked (https://docs.google.com/forms/d/1hXGIuw6hg7Xr2VwPvHUHjpJVSgBg6EK2C6M3QD-3oZI/edit; See supplementary information). The second section consisted of open-ended questions focusing on abundance *vs.* density in observations, taxonomic resolution, and the use of globally recognized data standards such as Darwin Core (DwC)—a well-recognized standard for biodiversity data maintenance facilitating the sharing of biological knowledge, and Public Participation in Scientific Research (PPSR) Core—a set of global, transdisciplinary data, and metadata standards (Wieczorek et al., 2012; Shwe, 2020). JOIs experts who answered the questionnaire included Dor Edelist, Serena Zamparedi, Destan Ozturk, Valentina Tirelli, Tone Falkenberg, Federica Colombo, Noa Nakar, Audrey Zammit, Juan Jesús Bellido Lopez, Eva Fonfria, Antoine Troullier, and Dror Angel.

The ontology (categorization) developed for jellyfish observations follows DwC and PPSR Core, and was applied to the Meduzot dataset as a case study. Data were subsequently submitted to OBIS, and an iterative process of fitting it to the OBIS/GBIF standards ensued, including improvement of geolocation (refitting of observations on land), further duplicate removal, and redefining of null observations and unknown amounts of jellyfish observed. An online iterative expert consultation was conducted to choose widely accepted co-creation, standardization, and harmonization approaches.

Results

Data collected by JOIs in the Mediterranean Sea

A jointly developed shared database schema consisting of the methodology for data collection, management, type, resolution, validation, storage, presentation, and dissemination of each JOI was established (results presented in Fig. 1 and Table 1). Data collection methodologies varied considerably among JOIs. Most require a full name and email in a login procedure during registration. Some also ask for a phone number, while others enable complete anonymity (Table 1). The observation date were mandatory in all initiatives, and for most of them, time was also a prerequisite. Autolocation was available in *Acri.st*, *Observadores del Mar*, *avvistApp*, and *Medusapp*.

Reporting was typically carried out via websites (nine JOIs) or apps (seven JOIs) while Email (two JOIs), social networks, or online spreadsheets (one JOI) were less common (Fig. 1). The relatively open formats for contributing jellyfish observations facilitated wider participation by citizen scientists and the accumulation of large datasets.

Eight JOIs offer a "zero jellyfish" option for the absence of jellyfish, which is important for ground-truthing observations (absence reports help verify that lack of jellyfish in the data is not a result of lack of observations). Photos are mandatory in the following JOIs: *Meduses Tunisie*, *avvistApp*, *Meteo Meduse*, and *Yayakarsa*. Activity type during which the observation was made (e.g., walking on the beach, swimming, surfing, fishing, etc.) was only collected by *Meduzot*, JellyX, *Occhio alla medusa*, and *Yayakarsa*.

The 13 Mediterranean JOIs included in this study operated in nine different languages, with eleven offering an English option (Fig. 1). JOIs are usually academically conceived and public service driven. All JOIs provide a real-time or near real-time jellyfish map with JellyX being the only commercially driven initiative (JellyX works with aquaculture farms). Most JOIs operate as websites, with some adding an app version. Most JOIs also have some presence in Social Media, mainly via Facebook groups and pages (Fig. 1).

Jellyfish quantification proved to be surprisingly diverse (Table 1). Presence was indicated by either abundance (total number of specimens observed) or density (number of specimens per unit of area or volume), typically as ranked abundance (seven JOIs) or density (five JOIs). Assessment of jellyfish amount was either quantitative (ten JOIs) or qualitative (three JOIs). A standardized survey option (following the same transect repeatedly) was only provided by two JOIs—*Meduzot Baam* and *Medusapp*.

The stranded jellyfish field was used by six JOIs, and a stinging field was only available in *Meduzot*. A comment or free text field was provided by 11 of the 13 JOIs, and additional observations included oil spills, marine debris (three JOIs), and non-gelatinous taxa (four JOIs) (Table 1).

All JOIs offered some form of species identification guide and a choice of species for reporting, ranging from 6 to 26 taxa, depending on geographic location. Citizen engagement has also promoted the discovery of jellyfish species new to science, for example, in Italy (Piraino et al., 2014) and Israel (Dragičević et al., 2019), or new to a specific region, such as the nine taxa new to Maltese waters recorded in the *Spot the Jellyfish* program (Deidun & Sciberras, 2017). In Tunisia and Croatia, it enabled the discovery of the geographical distribution of numerous taxa and unveiled divergent seasonal and phenological patterns for certain species (i.e., *Phyllorhiza punctata* von Lendenfeld, 1884, *Rhizostoma pulmo* (Macri, 1778), and *Olindias muelleri* Haeckel, 1879, respectively) depending on the ecoregions (Gueroun et al., 2022).

A total of 35 jellyfish taxa were covered by all of the JOIs in the region (Fig. 2), with taxonomy varying considerably among JOIs, depending mainly on their local abundance, size, and prominence.

Table 1 Main reporting fields of the Citizen Science Jellyfish Observation Initiatives

	Citizen Science Jellyfish Observation Initiatives													
Type of data	Fields	Infomedusa	Observadores del Mar	Medusapp	ACRI-ST	Meduses. Tunisie	Meteo meduse	Jellywatch/ Occhio alla medusa	JellyX	avvistApp	Spot the Jellyfish	Crafting the Sea	Yayakarsa	Meduzot Baam
Personal information	Full name	Yes	Yes	Yes (visible at user's choice)	No	Nickname	No	No	No	Yes	Yes	Yes	Yes	Yes
	Email	Yes	Yes	Yes (private)	Yes	Yes (if data sent by email)	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	Phone	No	Optional	No	No	No	No	No	No	No	Optional	No	Optional	Optional
	Other	No	No	No	No	No	Facebook personal account	CIESM send an email	No	No	No	No	No	No
Spatio-temporal information	Date	Free text	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Time	Free text	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes (AM/PM)	No	No	Yes
	Location	Beach selection	Coordinates (pinpoint) and site (coast/open sea/undetermined)	Autolocation (GPS)	Coordinates (pinpoint)	Free text	Coordinates (manual) and site (coastal/offshore)	Coordinates (manual), zone selection (1–150), and site (coastal/offshore)	Coordinates (pinpoint) and site (coast/opffshore)	Autolocation (GPS)	Longshore (35 bays)	Coordinates (pinpoint)	Longshore (free text) and site (coastal/offshore/other)	Autolocation and zone selection (20 zones)

Table 1 (continued)

Type of data	Fields	Citizen Science Jellyfish Observation Initiatives												
		Infomedusa	Observadores del Mar	Medusapp	ACRI-ST	Meduses. Tunisie	Meteo meduse	Jellywatch/ Occhio alla medusa	JellyX	avvistApp	Spot the Jellyfish	Crafting the Sea	Yayakarsa	Meduzot Baam
Jellyfish ID and quantification	Number of species reported	10	26	25	10	12	26	26	14	12	14	11	18	19
	Visual record (photo, video)	Optional	Optional	Optional	Optional	Mandatory	Mandatory	Mandatory	Optional	Mandatory	Optional	Optional	Mandatory	Optional
	Jellyfish size	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes
	Stranded jellyfish	Free text	No	No	No	Yes	Yes	Yes	Yes	Free text	No	No	Yes	Yes
	Transect/ survey	No	No	Optional	No	Optional	No	No	No	No	No	No	No	Optional
	Jellyfish absence	Free text	No	Yes	Yes	Yes	Free text	No	Yes	No	Yes	No	No	Yes
	Abundance/ density	None	1 ind	0	0	< 1 ind m^{-2}	Rare (< 10 ind or < 10 ind m^{-2} or > 10 m between bells)			1 ind m^{-2}	0	No	< 10 ind m^{-2}	0
		Few	2–5 ind	1 ind	1 ind	1 ind m^{-2}	Few (10–100 ind or 10–100 ind m^{-2} or 5–10 m between bells)			1–10 ind m^{-2}	1–5 ind		10–100 ind m^{-2}	Few (1–5 ind)
		Some	6–10 ind	2–5 ind	Few	> 1 ind m^{-2}	Some (100–500 ind or 100–500 ind m^{-2} or 1–5 m between bells)			> 20 ind m^{-2}	6–20 ind		100–500 ind m^{-2}	Some (6–50 ind)
		Many	11–50 ind	6–10 ind	Many	Free text	Many (500–1000 or > 500 ind m^{-2} or 1 m between bells)				21–50		500–1000 ind m^{-2}	Swarm (> 50 ind)
		Swarm	51–100 ind	11–99 ind			Dense swarm (> 1000 ind or 10 cm between bells)				> 50		> 1000 ind m^{-2}	Numerical value option
			> 100 ind	100–999 ind										
				> 1000 ind										

Table 1 (continued)

Type of data	Fields	Citizen Science Jellyfish Observation Initiatives												
		Infomedusa	Observadores del Mar	Medusapp	ACRI-ST	Meduses. Tunisie	Meteo meduse	Jellywatch/ Occhio alla medusa	JellyX	avvistApp	Spot the Jellyfish	Crafting the Sea	Yayakarsa	Meduzot Baam
Complementary information	Stings	Free text	No	Online survey in app	No	No	Free text	Free text	No	No	No	No	No	Yes
	Activity type	No	No	No	No	No	Free text	Yes	Yes	No	No	No	Yes	Yes
	Comments	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
	Gold users number	No	Yes (rescue services)	Yes (> 500)	No	No	No	No	No	No	No	No	No	Yes (> 300)
	Other taxa	No	Yes	No	No	No	No	No	Yes (HABs)	Yes	No	Yes	No	No
	Oil, plastics, debris	No	Yes (Plastics, debris)	Yes (Oil, plastics, debris)	No	No	No	No	No	No	No	No	No	Yes (Oil)

The conspicuous widespread scyphozoan species that appeared in all JOIs were *Aurelia* spp. Lamarck, 1816, *Cotylorhiza tuberculata* (Macri, 1778), *Pelagia noctiluca* (Forsskål, 1775), and *R. pulmo* (Fig. 2). Locally abundant species such as *Rhopilema nomadica* Galil, Spanier & Ferguson, 1990 in the Eastern-Central Mediterranean or *Catostylus tagi* (Haeckel, 1869) and *Rhizostoma luteum* (Quoy & Gaimard, 1827) in the western Mediterranean were included in their respective regions. In addition, several species of less conspicuous yet common ctenophores, siphonophores, salps, and hydromedusae were included by some of the JOIs, according to their prevalence and the level of taxonomic resolution that each JOI elected to use.

Data collection standardization

Twelve experts who manage ten JOIs from eight countries answered the questionnaire that focused on the need for standardization (Fig. 3). High levels of importance were attributed to observation date, taxonomy, and inclusion of as many species as possible. When counting individuals, a quantitative or qualitative abundance ranking was preferred rather than an exact count. Location by precise GPS coordinates was preferred over allocating reporting zones, and for jellyfish surveys, spatial means (e.g., distance covered by observers) were considered more appropriate than temporal ones (e.g., the time spent in the water). Most experts agreed that photographs had great value for taxonomic validation, while a free text description section was only considered important by some. The personal details of each observer, the size of the jellyfish, their depth in the water column, and the recording of stinging events were perceived as less relevant by the experts. In addition to the national language, an English option for reporting was also considered very important (Fig. 3). In agreement with the database schema, most respondents felt that the type of activity the reporter was involved in was not very important, although there was consensus (in interviews and open questions) that activity must be considered in standardization.

No consensus was reached in replies, interviews, and discussions regarding the best way to quantify jellyfish. A four-rank system where a "medium" option is added between "low abundance" and "bloom" to

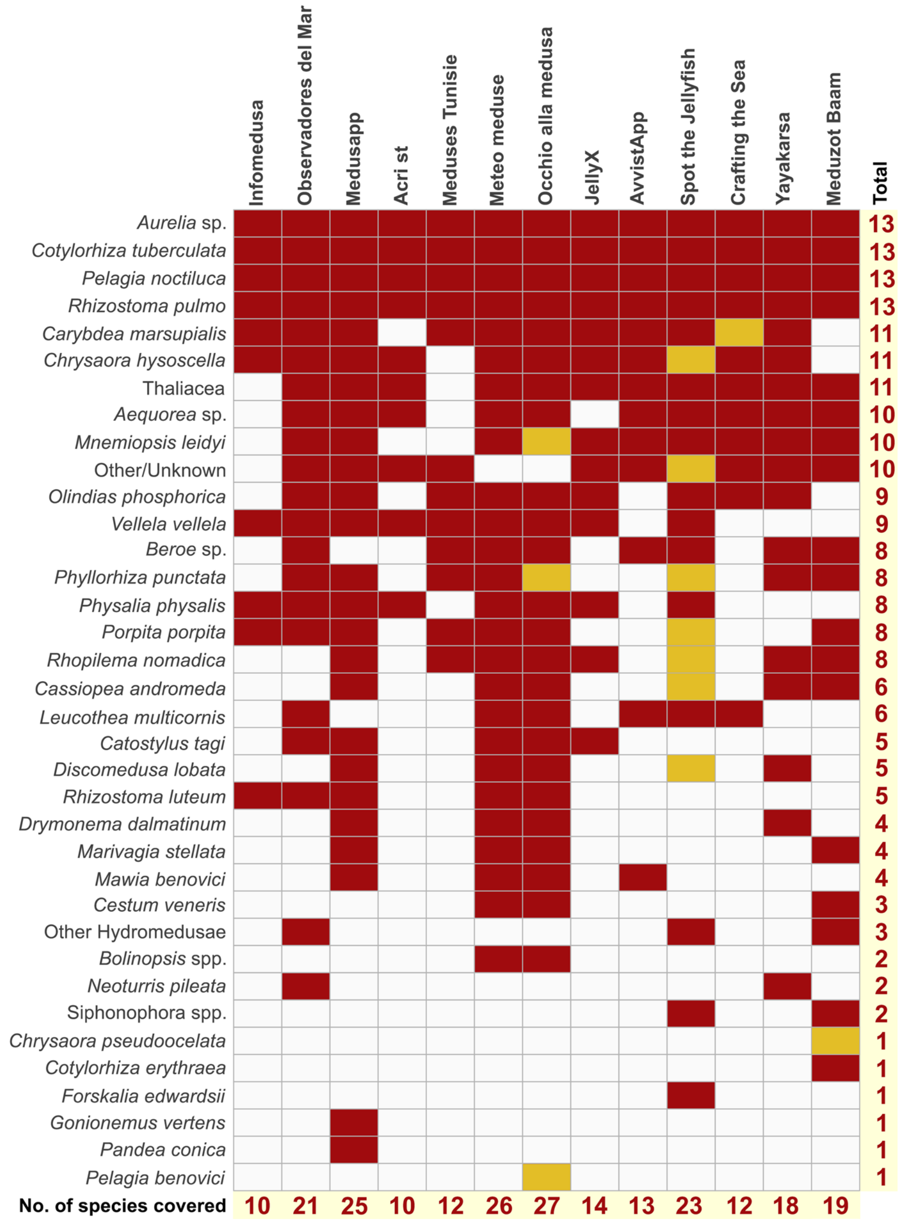

Fig. 2 Jellyfish taxa reported by Citizen Science Jellyfish Observation Initiatives (CS JOIs) in the Mediterranean Sea, by number of JOIs covering each species presence, from all (top) to only one JOI (bottom). The dendrogram at the bottom depicts species selection similarity among the JOIs. Yellow cells indicate new species (to the region or to science) discovered by JOIs

increase resolution was preferred by most experts. We also asked whether it is advisable to use different ranked abundance indices with different thresholds for large, conspicuous scyphozoan species compared to the smaller, less conspicuous but often numerous hydromedusae, salps, and ctenophores. Only three experts supported this idea, and nine experts opposed it, with the main reasons for supporting a single-ranked abundance classification system being the simplicity of presentation, higher taxonomic expertise needed for the smaller species, and ease of use. A consensus was reached among the experts on the topic of including rare species: all respondents agreed that all species occurring in the region should be included (Fig. 3), with some advocating an "expert mode" for the rarer species, and most respondents stressing the importance of photographs to improve identification accuracy and for validation purposes.

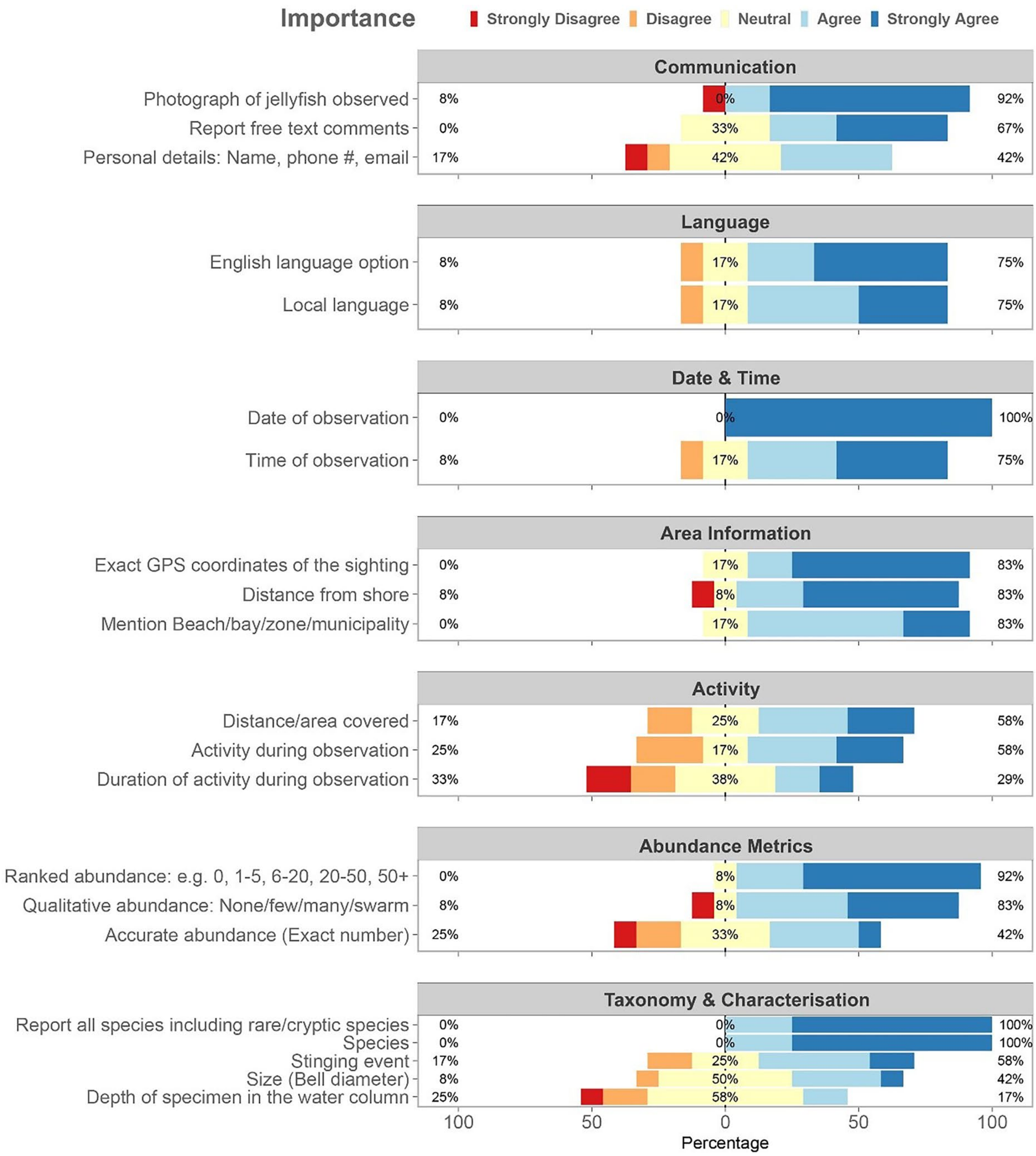

Fig. 3 Results of the expert questionnaire. Five-level Likert scale for the importance of each field for prioritizing jellyfish reporting is represented with a color scale (from red, strongly disagree, to blue, strongly agree). Percentages correlate to general disagreement (left, red and orange), neutrality (middle, yellow), and general agreement (right, light blue, and blue)

Discussion

Scoping review of data collected by JOIs

JOIs work was extensively published in peer-reviewed literature, mostly on seasonality and spatio-temporal patterns, new taxa in the region or new to science, and jellyfish stings. In Italy, the *Meteo meduse* project reported jellyfish outbreak increase and epidemiological phenomena (De Donno et al., 2014). Project data were summarized (Zampardi et al., 2016) and submitted to EMODnet and GBIF platforms (Boero et al., 2019). *AvvistApp* provided spatio-temporal patterns of *Mnemiopsis leidyi* A. Agassiz, 1865, and other jellyfish (Dragičević et al., 2019; Tirelli et al., 2021) and documented an exceptional bloom of *R. pulmo* in the Gulf of Trieste (Reyes Suárez et al., 2022). In Türkiye, *Yayakarsa* also documented an unusually large bloom of *R. pulmo* in the Marmara Sea (Öztürk & Sümen, 2020), as well as a first record of *Drymonema dalmatinum* Haeckel, 1880, for the Sea of Marmara (Öztürk, 2020). In Malta, *Spot the Jellyfish* reported the seasonality of swarms of multiple gelatinous species (Gatt et al., 2018), and in Israel, *Meduzot Baam* documented a phenological change in swarming patterns of *R. nomadica* (Edelist et al., 2020) and tracked its bloom origins (Edelist et al., 2022). *Meduses Tunisie* described diversity, trends, and patterns, and recorded 66 taxa in the only CS JOI from North Africa (Gueroun et al., 2022). In Spain, citizen reports were used to show seasonality, abundance, and correlation with environmental factors by *Infomedusa* (Bellido et al., 2020; Gutiérrez-Estrada et al., 2021) and *Medusapp* (Dobson et al., 2023).

Counting jellyfish

Marambio et al. (2021) combined two different monitoring approaches reporting either only presence and estimated abundance (Italy and Malta) or both presence and absence of jellyfish (Spain and Tunisia), grouped into three categories following Canepa et al. (2014) as low (< 10 individuals per beach), medium (< 1 individual m^{-2}), or high (> 1 individual m^{-2}) to show how standardizing data streams from several CS JOIs can unfold regional patterns. Such endeavors facilitated inter-country comparisons while exposing the challenges in doing so and the need for unified standards. Despite presence-only data being shown as effective in characterizing jellyfish swarms (Marambio et al., 2021), a "zero jellyfish" or "none" option was shown to be important for developing jellyfish swarming indices (Edelist et al., 2022; Dobson et al., 2023). Density (as individuals per m^2 or m^3) is indeed a more informative metric than total counts, but one must also be realistic in what is asked from citizens, and both are still challenged by the inbuilt complexities of visibility, swarm patchiness, size spectra, and a very wide range (up to 4 orders of magnitude) of actual densities. When asked which method of density measurement was most appropriate, seven experts chose the number of individuals per m^2, four preferred the distance between bells (individuals), and one chose the number of individuals per m^3 (Fig. 3). There was, however, a general agreement that density or exact abundance is less applicable than a ranked abundance system, and experts also felt that ranking should also be used for size spectra. Moreover, there was no agreement on a fixed value that could represent a swarm, neither for abundance nor for density, neither for ctenophores nor for scyphozoans. While such definitions are indeed arbitrary, the lack of consensus underscores the diversity of species, situations, and occurrence of jellyfish swarms and their evasive perception not only among the public but also among experts.

Additional free text suggestions by the experts included incorporating climatological/oceanographic data such as wind, waves, temperatures, productivity, and currents in the websites, as well as improved gamification to increase attractiveness and public involvement. Another suggestion concerned the combination of data certainty levels (a field for the level of familiarity of the observer with jellyfish), such as experts, gold users (trained citizens), and the general public. Having many jellyfish species for selection and relevant information about them were deemed of utmost importance in the questionnaire, predominately for taxonomic accuracy, and public alert, since some species are venomous while others are not.

Application of data generated by JOIs

CS JOIs observations were usually not mirrored by scientific campaigns or other "official" data, and hence, the presence of these jellyfish would have gone unrecorded without CS campaigns (Boero, 2013). Using the cumulative CS knowledge proved useful for detecting both long-term and short-term trends. To this end, environmental data such as currents, winds, salinity, chlorophyll, nutrients, productivity, oxygen, temperature, and others were used by the JOIs in conjunction with jellyfish observations (Canepa et al., 2014; Gatt et al., 2018; Bellido et al., 2020; Marambio et al., 2021; Castro-Gutiérrez et al., 2022; Edelist et al., 2022; Dobson et al., 2023). Currents characterizing the canyons inhabited by *P. noctiluca* were considered important in explaining the bloom dynamics of this species, and bathymetry was also considered important for other species (Canepa et al., 2014; Benedetti-Cecchi et al. 2015; Marambio et al., 2021). Producing and visualizing these trends help the public and other stakeholders plan for and respond to incoming blooms. The review of this literature reveals that while most JOIs did not present a clear trend of an overall long-term increase in jellyfish blooms, in some cases, especially where a new species invaded and became part of the gelatinous fauna (Boero et al., 2019), an increase was noted. For example, *R. nomadica* (Edelist et al., 2020), *M. leidyi* (Malej et al., 2017; Tirelli et al., 2021), or *P. punctata* (Kaminas et al., 2022) are new arrivals that proliferated in the newly invaded ecosystems. Whether seas are becoming more gelatinous (e.g., Richardson et al., 2009) or whether larger oscillations and other factors (Condon et al., 2012, 2013; Duarte et al., 2015; Fernández-Alías et al., 2024) are at play remains an open question of scale, time, and location. For CS JOIs to assist in resolving this issue in the Mediterranean Sea, their longevity, expansion, and improved data standardization, as suggested here, are imperative.

Jellyfish data management and a roadmap to its standardization

For a scientist or a stakeholder looking to create a new CS JOI, there are two main options: (i) to develop an app/website from scratch or (ii) to create it within an existing framework. We recommend the latter based on the economic costs associated with both the creation and long-term maintenance of these platforms and their respective apps, which must also comply with the data protection laws that apply in different countries. Moreover, this will facilitate building upon experience gained for observations and for keeping FAIR data (Wilkinson et al. 2016).

In this regard, Observation.org is an EU platform for citizen science and biodiversity monitoring with worldwide coverage that provides the necessary long-term technological support and also makes available the use of Artificial Intelligence (AI) for species recognition through its website and two applications. One application (Obsmapp) has a more scientific character that includes two kinds of sampling effort assessment (i.e., transects), records of absence (zero presence), individual characteristics (e.g., “adult” and “non-native”), and state (e.g., “feeding” or “stranded”), a possibility for hiding/embargoing the record, the possibility to record the interaction between species, and Artificial Intelligence guidance for species identification (NIA). A second app (Obsidentify) is easy to use, also incorporates the help of the NIA, is ideal for people just starting in citizen science. Projects/groups who wish to maintain their identity within the platform can create subsites, areas, projects, etc. (similar to ECSA or iNaturalist). The quality of the data is assured in Observation.org as data are expert-validated. Sensitive data (e.g., species with conservation criteria or data in scientific use) can be embargoed for a certain time and/or area. A privacy policy outlines how personal information is collected, used, and protected, and the security measures taken. Finally, the validated data with permission to be shared are uploaded to GBIF, complying with the DwC standard format, so interoperability is fully assured. Such DwC and PPSR standards are united, supported, and underlined by a common structured framework as a globally recognized best practice (Shwe, 2020). When asked here about the use of DwC, ten JOIs experts replied that they apply or consider applying it as a standard for biological data management and documentation, and two replied that they are still unfamiliar and would like to learn more.

Examining the possibility for ontology alignment between different jellyfish observatories to ensure common semantic data model elements for interoperability among related datasets, we named relevant instances from the *Parameter* class of the Integrated Ocean Observing System (IOOS) Biological Data terminology—the NOAA set of standards for recording biological data. Instances of Internationalized Resource Identifier (IRI) terms that extend the Darwin & Dublin core and that are potentially useful for

Citizen Science jellyfish observatories are, among others: quantificationMethod, sightingCue, sampleLengthInMeters, samplingConditions, etc. Note that these terms not only help to contextualize some of the CS observations but possibly even allow us to address data quality concerns using the Data Quality Vocabulary (DQV). Moreover, data quality concerns are inherent to CS observations and may be addressed by better metadata provisioning, such as Dublin and Darwin Core (Wieczorek et al., 2012).

Modeling of CS observation traits and bias, as described above, should be best done in a co-creation fashion by aligning existing observations to such terms. To accommodate the co-creation process of semantic alignment and interoperability, we envision a three-staged approach:

1. Define (co-create) the requisite degree of citizen participation (e.g., sightings, transects, and other) and create the appropriate approach (e.g., area, subsite, and project) on a global hub, such as Observation.org.
2. Adopt classes from OBIS/GBIF and DwC, first standard classes, then those that enable extended metadata for quantification, size, activity, and any other relevant class.
3. Adopt classes from IOOS that enable extended metadata on data quality and potential bias in observations.

With the first, we propose to adopt the co-creation process described above. In the second stage, we suggest following required the OBIS-GBIF DwC terms: occurrenceID, eventDate, decimalLongitude, decimalLatitude, scientificName, occurrenceStatus, basisOfRecord, and the strongly recommended scientificNameID.

The following additional elements are also considered as vital for JOIs:

- recordedByID, accounting for pseudo-anonymized observer,
- quantificationMethod to account for activity type,
- organismQuantity to indicate a ranked abundance of jellyfish (proposed here as swarm, some, few, or none),
- organismQuantityType (individuals),
- sampleSizeValue and sampleSizeUnit for bell diameter in cm,
- machineObservation indicating photos or videos,
- coordinateUncertaintyInMeters, enabling translation of zone/bay/beach-based schemes.
- if standardized surveys are being carried out: use eventType to describe transects while walking, sailing diving etc.

Third, we adopt an extended version of DwC called ExtendedMeasurementOrFact Extension (eMoF), based on Expanding OBIS with environmental data. Within this, specific jellyfish reporting terms can be used, such as:

- strandedJellyfish, indicating beached specimens,
- distancefromShore for decoupling onshore reports from inshore and offshore reports,
- stingingEvent, to indicate when such unfortunate interactions occur.

For the co-design and co-creation, the *Meduzot* data were transformed into this recommended semantic interoperable format, and integrated into the Iliad project Ocean Information Model (OIM), which is the semantic backbone of the Digital Twins of the Ocean (DTO) ecosystem in the Iliad project (Zaborowski et al., 2023). Access was based on a standard OGC Application Programming Interface (API). The standardized dataset was deposited in OBIS in January 2025 and is available at: http://ipt.medobis.eu/archive.do?r=dori&v=2.1.

The benefits of networking: toward standardization of data collection and analysis

The main challenges shared by all JOIs in the interviews include funding, user retention, data validation, and the decline in reporting outside the bathing season. Some JOIs are funded by academic grants, some by local or national government, while others operate voluntarily. Assuring funding is pivotal, as the costs of software development, data storage, manpower for validation, and other costs are rising. Funding increases the longevity of projects and facilitates multiannual user retention and engagement with diverse and dedicated communities. Beyond the benefits of streamlining scientific efforts, standardizing data collection and management can highlight the utility of CS JOIs, assist in sharing these benefits with stakeholders, and increase their acceptability and legitimacy, winning the hearts and minds of the public and stakeholders. Moreover, analysis of long time series of standardized data as recommended here and carried out in the previous works (e.g., Marambio et al., 2021), has the potential to help overcome seasonal and other reporting biases. Finally, this type of standardization sets a standard for the minimum requirements, but also desired ones, for novel avenues of addressing classification and validation methods (e.g., trained volunteers, AI/ML).

Observations of living ecosystem components may be very challenging to collect, integrate, and analyze compared to other ocean variables. Surely the challenges of standardizing abundance and distribution increase when pelagic (and often metagenic) organisms such as jellyfish are concerned. Most JOIs employ expert validation of reports, that may be based on photos, deletion of duplicates and unsubstantiated reports of rare taxa swarms, out-of-season or in illogical sizes by observers with lower expertise. Since many observations are made by tourists and laymen during summer, extra care should be given to these masses of reports in order to reduce errors. As citizens also vary widely in training and expertise, the use of "gold users" with higher taxonomic and reporting expertise (e.g., *Meduzot* and *Medusapp*, Table 1) becomes extra-important for validation purposes. Troll reports may be avoided by mandatory two-step verification login. Resolving abundance biases can be achieved by adopting common categories with the lowest common denominator, for example, by covering four scenarios: none, low, medium, or swarm abundance categories (Marambio et al., 2021). The relatively low importance allocated to jellyfish size (bell diameter in cm, Fig. 3) among the JOIs is surprising, given the high emphasis on animal size classes in biological studies and sessile invertebrate standardization processes (Ruhl et al., 2023) as well as its importance for stock assessment (Brotz & Pauly, 2012). This lower importance compared to other critical descriptors, was due to the smaller size range of jellyfish in some regions and the challenges of carrying measurement instruments into the field for citizens. Moreover, as most observations are not made during scientific surveys, exact measurements are usually not possible. The integration of digital and smartphone measurement tools into apps could surely improve this aspect in the future.

User engagement and real-time mapping

Project longevity of the initiatives is pivotal for user acquisition and retention, reproducibility, sufficient coverage, and enabling long-term ecological fluctuations to be expressed. Successful CS monitoring projects typically take time to mature (Bonney et al., 2021), and obtaining the necessary participation of the users for the spatial and temporal resolution that jellyfish swarm mapping, modeling, and alerting mandate are challenging. At least nine CS JOIs were able to provide public online jellyfish observation maps, helping to raise awareness and recruit new citizen scientists to the projects. Real-time mapping and ongoing user engagement are shown here to ensure long-term jellyfish reporting. Many JOIs also have social media accounts, and the digital footprint that they leave has recently been shown to be useful for monitoring as well (Levy et al., 2024). Project longevity can be secured through various approaches, and several CS JOIs have even secured national funding. For example, *Spot the Jellyfish* was commissioned by the Maltese tourism authority to install seaside panels along most of the Maltese coastline, and like many other initiatives (Fig. 1), they regularly publish informative social media posts and hold an array of social events, outreach, and publications, including the MED-JELLYRISK sting treatment booklet which was a joint Central and western Mediterranean initiative. In Israel, *Meduzot* has similarly engaged with citizens in various ways, including developing a sting treatment protocol for *R. nomadica* in the eastern Mediterranean based on an epidemiological survey (Edelist et al., 2023).

Good practices

Global standards and best practices for CS such as ECSA's (European Citizen Science Association) 10 principles of CS or toolkits such as MICS (Measuring the Impact of Citizen Science) tools (Wehn et al., 2021) are already in fairly wide usage in terrestrial ecosystems, and their extension to the marine environment is increasing (Kelly et al., 2020). Although truly uniform sampling is unlikely, the standardization of methods helps to ensure that observations are conducted and analyzed similarly and comparably. The proper management of metadata helps account for issues such as data quality, observation effort, and pseudo-replication that tend to arise due to clustered sampling (Bird et al., 2014). To ensure FAIR data, and facilitate best practices in the standardization of CS data, projects must record data on the environment, the surveyor (e.g., observer ID and contact details), the observation methods, and all parameters that may influence the results (Bird et al., 2014). Proper attention must also be given to data privacy and protection of citizens and to ensure informed consent using a responsible data management plan. This is imperative to the sustainability of citizen science for legal, ethical, and practical reasons (Pierce & Evram, 2022). CS projects typically do well in terms of data quality assessment and governance but are sometimes lacking in providing open access to data outputs, properly documenting data, ensuring interoperability through data standards, or building robust and sustainable infrastructure (Bowser et al., 2020). For JOIs data to be findable and accessible, a multitude of repositories exists, including ones dedicated to CS (e.g., ECSA or Zooniverse), and global marine repositories such as EMODdnet, OBIS, or GBIF. Data, however, must be meticulously prepared for this purpose, as well as for interoperability and reuse purposes, and we recommend doing so by using PPSR Core and DwC, making sure both metadata and data are organized according to globally recognized standards (Wieczorek et al., 2012; Shwe, 2020). Some JOIs (e.g., *avvistApp* and *Occhio alla Medusa*) already comply with DwC terminology, and for the present paper, we matched the Israeli *Meduzot* and Maltese *Spot the Jellyfish* data using the OBIS standards (https://manual.obis.org/darwin_core.html) and the process described above. Concurrently, drawing from the local and regional experience, using standards adopted and adapted herein can also benefit international organizations seeking to improve resolution and add case-specific terms, standards, and best practices.

From local to global fora

Some local projects may be jellyfish-specific, like most Mediterranean JOIs or the *Hong Kong Jellyfish Project*, which replicates CIESM methodology to document jellyfish in Hong Kong (Terenzini et al., 2023). Jellyfish observations are also collated within national-level wildlife reporting initiatives such as Norway's *Artskart* or *Dugnadforhavet*, Sweden's *Artfakta*, the Portuguese, *Gelavista*, or the UK-based *iSPOT*. Other initiatives, like "*Is it Alien to you? Share it!!!*" in Greece cover alien species broadly (Giovos et al., 2019). The wide coverage of global-scale nature-watching initiatives like Biodiversity.org or iNaturalist may facilitate global-scale analyses (e.g., Anthony et al., 2023), but cannot replace JOIs, unless they assume the locally fostered roles of alert, engagement, and community. For instance, quantification in such initiatives must transcend mere presence and single-animal records that are usually applied when photos are mandatory. Indeed, these global initiatives are now allowing itineraries and recording of absences in projects. Moreover, as they now allow full project integration within them and since, like OBIS and GBIF, they apply PPSR Core and DwC principles, the validated observations (both machine and human) have considerable interoperable value, and the dual role of JOIs may be conserved.

Conclusions

Jellyfish are a shoo-in for Citizen Science projects. CS JOIs have stepped into an academic-public arena that helps scientists understand jellyfish ecology and patterns in time and space, helps the public witness these and avoid stings, and serves to connect participants with marine nature and research. By reviewing both the methodology and findings of JOIs, we observe their utility, diversity, differences and similarities, and the challenges they face. These challenges include data standardization, addressed here by a roadmap adopting good practices, as well as user retention and funding, that may be supported by increasing the legitimacy of Jellyfish Citizen Science across stakeholder groups. The willingness of CS JOIs to work together toward improved standardization, curation, and management of crowdsourced information, is part of a larger undertaking of Citizen Science, to catch up with the recent surge in scientific norms for open data, documentation, publication, and data FAIRness (Bowser et al. 2020). We advocate this course of action and adoption of the standards developed herein by both existing and future CS JOIs, as part of this global endeavor.

Acknowledgements The authors wish to thank all citizen scientists partaking in reporting jellyfish throughout the years.

Funding Open access funding provided by University of Haifa. *Meduzot* received funding from the European Union's Horizon 2020 and Horizon Europe Framework Programmes for Research and Innovation under Grant Agreement No. 101037643 (Iliad) and 101094041 (Otters).Spot the JellyfishCS campaign in Malta is funded by the International Ocean Institute (IOI) as well as by the Malta Tourism Authority (MTA).avvistAppwas developed in the Noce di Mare project, funded by the Regione Autonoma Friuli Venezia Giulia (Italy) (legge regionale n. 14/2018, articolo 2 commi 51–55), and VT and SP acknowledge the support of the National Biodiversity Future Center—NBFC funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4—Call for tender No. 3138 of December 16, 2021, rectified by Decree No. 3175 of December 18, 2021, of Italian Ministry of University and Research funded by the European Union—NextGeneration EU; Project code CN_00000033, Concession Decree No. 1034 of June 17, 2022, adopted by the Italian Ministry of University and Research, CUP F83B22000050001.Meduses.Tunisiewas developed in the framework of the European project MED-JELLYRISK (ENPI-CBCMED/ref: I-A/1.3/098).Medusappis currently being improved in the framework of the GVA-THINKINAZUL/2021/043 project, supported by the MCIN with funding from European Union NextGenerationEU (PRTR-C17.I1) and by Generalitat Valenciana.CraftingTheSeawas developed in the context of the UN Decade of Ocean Science for Sustainable Development (2021–2030) and financed by the UNESCO, PRADA Group, BATANA, and Ruđer Bošković Institute, and has been currently operating within the Interreg VI A Italy—Croatia project ALIENA (ITHR0200330).

Data availability The expert questionnaire may be found in Supplementary information. The *Meduzot* dataset was published in OBIS in January 2025 and is available at: http://ipt.medobis.eu/archive.do?r=dori&v=2.1.

Declarations

Competing interests The authors have no competing or financial interests to declare that are relevant to the content of this article. One of the authors, Dr. Stefano Piraino, is on the editorial board for the Hydrobiologia "Jellyfish, Ecosystems, and Humans" special issue.

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