Draft: Citizen Science as a contributor to the Marine Strategy Framework Directive implementation (Draft version)

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1. Introduction

In this second White Paper, published in the framework of the Horizon-CSA project OTTERS, having the full title "Social Transformation for Water Stewardship through Scaling Up Citizen Science", we explore the role of citizen science in aiding the implementation of EU marine policies, emphasizing on the Marine Strategy Framework Directive (Directive 2008/56/EC, establishing a framework for community action in the field of marine environmental policy). As the implementation of marine legislation requires intensive datasets collected over whole ecosystems for long periods of time, Citizen Science could support such policies by obtaining and processing environmental data in a cost-effective manner. Moreover, Citizen Science can help improve acceptability by empowering communities and involving them in research that can be used to drive policy changes (Garcia-Soto et al., 2021).

OTTERS aims to promote successful water-related citizen science initiatives in the marine and freshwater domains, demonstrating their capacity in the participatory research of environmental monitoring, improving data quality and standardizing data and metadata management to ensure interoperability. This is particularly important since the quality of citizen science data has been a major drawback in integrating them in the systematic scientific monitoring framework required by the EU water-related policies, like the Water Framework Directive (WFD), the Birds and Habitats Directives and the Marine Strategy Framework Directive (MSFD). Therefore, an extensive citizen science data accuracy assessment is required in regards to the adopted methodology, the instrumentation used, the analysis followed and the harmonization of data and metadata (Lovell et al., 2009; Butt et al., 2013; Fuccillo et al., 2015). This approach is needed to allow the connection between the existing and future Citizen Science projects and initiatives and the main EU data repositories, like EMODnet, CMEMS, EDITTO and others.

2. The MSFD data requirements for GES assessment

The MSFD has been the environmental pillar of the European Integrated Maritime Policy. It is an ambitious and challenging EU policy instrument aiming to achieve the Good Environmental Status (GES) across all European Seas, namely the Baltic Sea, the North Sea, the Black Sea, the

Mediterranean Sea and the Nort-east Atlantic. The GES is achieved when the natural resources are exploited in a sustainable manner so that biodiversity is maintained and that the European regional seas are clean, healthy and productive, thus minimizing the threats to the marine environment resulting from human use (EC, 2008). To assess GES at each marine area, the ecosystem state of each EU marine area is monitored and assessed using ecological indicators, associated reference levels and targets. The MSFD introduced 11 qualitative descriptors, sub-divided into 29 associated criteria and 56 indicators, that represent the structural and functional processes of typical EU marine ecosystems (i.e., biological and physico-chemical), as well as human pressures (i.e., hazardous pollutants, hydrological changes, litter, underwater noise, and biological disturbance like the introduction of non-indigenous species) (Cardoso et al., 2010).

Table 1. The MSFD Descriptors and their respective GES targets.

Descriptors	Descriptor Title	GES Target
D1	Biodiversity	Biodiversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions.
D2	Non-indigenous species	Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems.
D3	Commercial Fisheries	Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.
D4	Food Webs	All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.
D5	Eutrophication	Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters.
D6	Seafloor Integrity	Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.
D7	Hydrographic Conditions	Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.
D8	Contaminants	Concentrations of contaminants are at levels not giving rise to pollution effects.
D9	Contaminants in Fish and Seafood	Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

D10	Litter	Properties and quantities of marine litter do not cause harm to the coastal and marine environment
D11	Energy and Noise	Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

The Directive is structured around a cycle of adaptive management and obliges Member States to coordinate efforts across regional seas. Member States may consider different criteria and indicators according to the relevant conditions of each ecosystem, and define a series of indices to describe the baseline to be used in their assessments, following the systematic monitoring programs and implement their programs of measures to achieve GES (Berg et al., 2015).

In parallel, the MSFD indicators implemented within the monitoring and assessment programs are closely linked to the United Nations' Sustainable Development Goal 14: 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development' targets and indicators (IOC, 2017), leading to a holistic view of oceans and seas based on the ecosystem approach and addressing the anthropogenic impacts and cumulative impacts to marine environment (Fraschetti et al., 2022). SDG 14 focusses on life below water, with a view to conserving and sustainably using the oceans, seas and marine resources for sustainable development (Langlet and Rayfuse, 2019), emphasizing on coastal eutrophication, ocean acidification, ocean warming, plastic pollution and overfishing (UN, 2015).

Moreover, the parameters monitored in the framework of MSFD Descriptors are also relevant to most of the Essential Ocean Variables (EOVs), established by GOOS experts, including physical (e.g., temperature, salinity, currents, ice), biogeochemical (e.g., dissolved gases and nutrients, acidification, particulate matter and tracers) and biological (e.g., phytoplankton) parameters (Constable et al., 2016; Muller-Karger et al., 2018).

3. Citizen Science and Marine-related Environmental Monitoring

Citizen science refers to the participation of non-scientists and volunteers in a scientific research project (Buytaert et al., 2014), in collaboration with professional scientists. Although its application is centuries-old, the term 'citizen science' was first defined by Alan Irwin, and has only been in dictionaries since 2014 (Irwin, 1995; The Zooniverse, 2014). Through Citizen Science (CS) projects and initiatives, members of the general public collect and analyze environmental samples and data following structured methodologies, using easy-to-use portable sensors, smart-phone apps, cameras and other IoT technologies and producing shared with scientists' databases (Newman et al., 2012; Yang et al., 2018). Jordan et al. (2015) considered CS as a relatively new field, which merits acknowledgement as a distinct discipline. In marine applications CS could involve data from coastal areas and open seas, including information on the water and sediment (e.g., physicochemical parameters), as well as on the wealth of marine life inhabiting them (Garcia-Soto et al., 2017).

Most marine CS projects in Europe focus on the field of life sciences. For example, in the North Sea, 48% of all projects study “species”, 16% have a “general biodiversity” focus, and 8% study “ecology” (van Hee et al., 2020). Among marine species, mammals, fish, birds, crustaceans and jellyfish are typically the most active fields of research drawing on Citizen Science, with jellyfish projects particularly common in Southern European Seas (Garcia-Soto et al., 2021).

Table 2. Key Citizen Science projects collecting data (like samples, observations, photos, etc.) from marine water bodies.

Project	Subject	Country	Link
Marine mammals	Collecting data on strandings and sightings of marine mammals	Belgium	https://eu-citizen.science/project/284
OSPARITO	Develop a scientific protocol for marine litter collection and classification	France	https://eu-citizen.science/project/242
Surfing for Science	Assess level of microplastics	Spain-Mediterranean Sea	https://www.asensiocom.com/surfingforscience/en/
Plastic Pirates – Go Europe!	collecting plastic waste in water bodies	Europe	https://www.plastic-pirates.eu/en
Explore Your Shore!	mapping marine species along the Irish coast	Ireland	https://exploreyourshore.ie/
SIMILE	Monitoring of Insubric Lakes and their Ecosystems	Italy-Switzerland	https://eu-citizen.science/project/171
FLOODUP	collect observations on the impacts of floods	Spain	https://eu-citizen.science/project/173
FILMAR	marine mammal research	Canary archipelago	https://eu-citizen.science/project/269
SIREN	Hydrological data collection	Italy	https://www.zooniverse.org/projects/siren-project/siren-project
CoCoast	marine biodiversity (phenology,	UK coasts	https://www.sams.ac.uk/science/projects/cocoast/

	distribution, abundance)		

In recent years, several mobile sensing apps have been developed to be used by citizens in water-related monitoring topics, like the MarineLitterWatch for monitoring beach and ocean litter (Jambeck and Johnsen, 2015), EyeonWater to assess the water clarity (Novoa et al., 2014), and the Algal Watch to report algae occurrences (Kotovirta et al., 2015).

4. Can citizen science complement official scientific data sources to improve MSFD monitoring?

Citizen science has the potential to complement and supplement official scientific data sources in marine monitoring, thus aiding the implementation of MSFD. However, this has to be done in a well-organized manner, following the scientific methodologies of MSFD descriptors and criteria and producing data and metadata according to the standards of MSFD databases. Under these prerequisites, CS could produce cost-effective and scalable data of specific use by scientific teams in the assessment of GES of marine ecosystems.

García-Soto et al. (2017, 2021) highlight the importance of citizen science in marine policy while emphasizing the role of improving ocean literacy and empowering citizens, hence enhancing the acceptability of monitoring results while providing a 'social license' for marine conservation. The recent boom in publications reflected in the current survey offers many avenues for cost-effective and scalable research to marine monitoring in European seas across diverse challenges, descriptors and GES targets. It is true that CS allows for large-scale, spatio-temporal, biodiversity monitoring (Chandler et al. 2016) and the detection of long-term ecosystem changes (Gouraguine et al. 2019). However, CS focus is currently given to those initiatives pertaining to biodiversity and pollution.

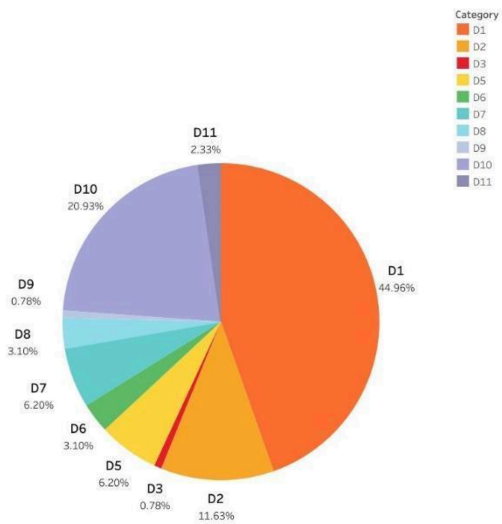

Figure 1. CS publications collecting data with potential contribution to MSFD Descriptors.

In this review, we examined 130 CS scientific publications in terms of their capacity to aid the implementation of the various MSFD Descriptors. We have found that most works refer on CS in relation to D1 (Biodiversity) and D10 (Marine Litter). The spatial distribution of alien species (D2), the hydrographic conditions (D7) and the marine water pollution (D8) are topics covered by rather limited publications. It is apparent that with the proper motivation, management and tools, the CS approach could be extended to contribute in the MSFD implementation in other descriptors.

An example of CS application can be seen in the MedSens index, developed to bridge the gap between citizen science and coastal management (Turicchia, 2021). This index integrates citizen science data into an institutional monitoring program tailored for specific sensitivities to the pressures indicated by the MSFD. Trained snorkelers, freedivers, and volunteering scuba divers collect data on species distribution in the Tuscan Archipelago National Park. The open data on distributions and abundances collected by trained volunteers using the Reef Check Mediterranean Underwater Coastal Environment Monitoring (RCMed U-CEM) protocol subsequently helps decision-makers identify the main pressures acting in these habitats, as required by the MSFD, supporting them in the implementation of appropriate marine biodiversity conservation measures and improves communication of results of their actions. The data collected from this activity, focusing on the taxa, like algae, invertebrates, and fishes, contribute towards the MSFD implementation in D1 (biodiversity), D2 (non-indigenous species), and D6 (Sea floor integrity).

Another example is the implementation of fish assemblage monitoring (Descriptor 1 – Biodiversity) using underwater visual census (UVC) surveys and the analysis of eDNA samples, i.e., the DNA extracted from environmental samples, such as seawater, with the help of trained divers (Rey et al., 2023). In addition, the mobile app “Dive Reporter” was developed and used to compile information on the frequency and abundance of marine taxa by recreational scuba divers in Madeira (Radeta et al., 2022).

Local fishermen contributed in the study of pufferfish species in the Strait of Sicily (Lampedusa Island, Italy), playing an essential role in the monitoring of potentially toxic marine species (Descriptor 2 – Non-indigenous Species) (Malloggi et al., 2023). In a similar context, the role of citizen science was conceived as of paramount importance by the Mediterranean Commission (CIESM) (Boero and Briand, 2001), since the Jellywatch Program has proved to be a useful tool to monitor both the spreading of gelatinous NIS and the occurrence of local blooms of native species (Langeneck et al., 2019). Kousteni et al. (2022) illustrated the significance of CS in recording marine alien taxa at both large and small geographical scale, providing the information needed towards the monitoring of marine invasions.

Yang et al. (2018) used the mobile app “HydroColor” to acquire sea water reflectance data with the help of both trained and untrained citizens onboard the BC ferry Queen of Oak Bay. This data collection could contribute towards the scope of D5 (Eutrophication) and D7 (Hydrographic Conditions). In the same framework Li et al. the vSEA algorithm allowing citizens to measure the pH of coastal waters. Given the fact that the quantitative accuracy of vSEA pH measurements reached 0.018 units, with an uncertainty of <0.01, such application could be used for the D7 monitoring.

5. Key CS contributions to MSFD monitoring

Table 3 presents the most important scientific publications collecting CS data that could be potentially be used in the framework of environmental monitoring for MSFD.

Table 3. Number of CS publications and one key publication per MSFD Descriptor.

MSFD Descriptor	Number of Publications	Publication
D1	58	Matear et al. (2019)
D2	15	Tirelli et al. (2019)
D3	1	Buzinkai et al. (2023)
D5	8	Wernand et al. (2012)
D6	4	Anbleyth-Evans (2018)
D7	8	Yang et al. (2018)
D8	4	Martinelli and Moroni (2018)
D10	28	Kawabe et al. (2022)
D11	3	Turicchia et al. (2021)

The work of Matear et al. (2009) on the monitoring of marine mammals utilized long-term data (since mid-1990s) collected from trained citizens to investigate the cetaceans’ spatial patterns in the Bay of Biscay. These surveys are similar to those performed in MSFD for Descriptor D1 (Biodiversity) and criteria D1C2 (on species population abundance) and D1C4 (on species distributional range). Data were used for statistical analysis and to extract the Simpson Diversity Index, Species Evenness and Species Richness.

Tirelli et al. (2021) developed avvistAPP, a citizen science mobile app, allowing the reception, cataloguing and visualization of citizens' reports on marine species, like jellyfish, sea turtles, dolphins and salps. The app identifies the species and based on mobile's phone geolocation; it creates maps of species distribution. The app was tested in the Adriatic Sea when 1,224 sightings were recorded, tracking the spreading of the invasive ctenophore *Mnemiopsis leidyi*. It is interesting to mention that the data obtained through avvistAPP are stored at the OGS-NODC (Italian National Oceanographic Data Center) and are made available in the European Network for Marine Observation (EMODNET).

Based on images of sea surface, the EU-funded research project CITCLOPS developed the WACODI app, capable to allow citizens to perform precise monitoring of key environmental parameters related to the MSFD Descriptor 5 (Eutrophication) and Descriptor 7 (Hydrographic Conditions), like the water colour, transparency, attenuation of light and fluorescence (Ceccaroni et al., 2020). These parameters are related to the presence of particulate matter originating from biological activity (phytoplankton and zooplankton debris), and on suspended inorganic solids.

The local ecological knowledge of fishermen in relation to the direct and indirect impacts of aggregate dredging from the seabed were integrated in the scientific study of Anbleyth-Evans (2018). The work is indirectly related to Descriptor 6 (Seabed Integrity) and illustrates the educative benefits of integrating fishers' local ecological knowledge into science.

Figure 2. Word cloud made of keywords from CS publications.

Martinelli and Moroni (2018) developed an integrated water quality monitoring system using a specially-designed app to report for oil spill sightings by volunteers. CS data were blended with remote sensing data (SAR images), AUVs (hyperspectral-thermal images and e-nose sensors), and oil spill dispersion numerical models to produce alerts. This Marine Information System could serve as an excellent example of CS contribution in the MSFD Descriptor 8 (Contaminants) environmental monitoring of a marine area.

Kawabe et al. (2022) reviewed the marine litter citizen science literature, related to the MSFD Descriptor 10. Authors concluded that although CS marine litter data are detailed, expanding our understanding of the occurrence and trends of marine litter, they seem biased to shoreline sampling. CS initiatives focus mainly on sandy beaches (68.5%) (MSFD Criteria D10C1), while limited emphasis is placed on studies targeting of floating or seafloor micro-litter (D10C2) or the interactions between litter and the biota (D10C3, D10C4).

The subdivision of the publications reviewed herein into the collection of data that could contribute in the monitoring program to MSFD criteria is shown in Figure .

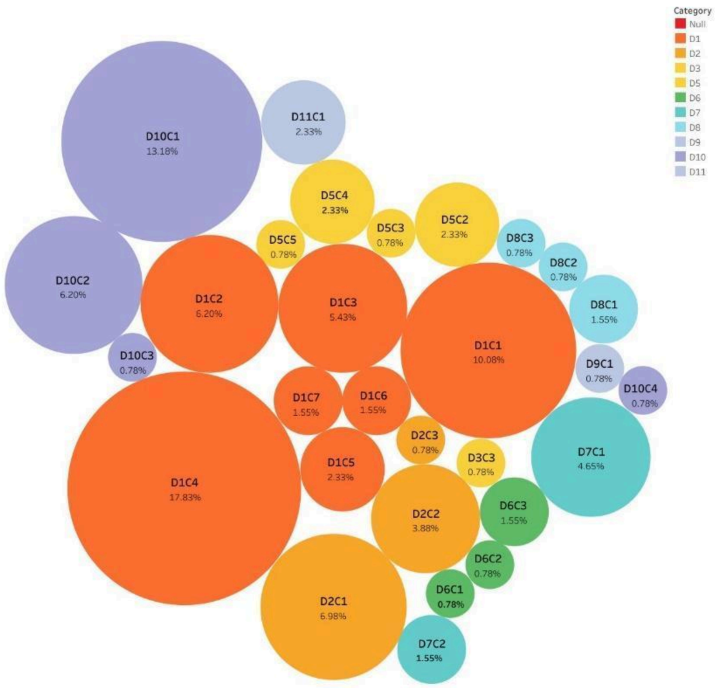

Figure 3. Scientific publications collecting environmental marine data that could potentially aid the implementation of MSFD criteria. Most publications (17.8%) collect data in accordance to the GES Criterion D1C4, referring to the spatial species distribution and its patterns, and ensuring that these are representative of the physiographic, geographic and climatic conditions of the area. The GES Criterion D10C1 on the composition, quantity and spatial distribution of litter on the coastline, at the surface of the water column and at the seabed vary at levels that do not cause damage to the coastal and marine environment concentrate 13.1% of the publications. Finally, it occurs that 10.1% of the works are relevant to the implementation of monitoring in relation to the GES Criterion D1C1 referring to the mortality rates per species from by-catch, which should be kept below levels that endanger the species, therefore to ensure its long-term viability.

6. Citizen Science Best Practices

6.1. CS Jelly Fish Observation Initiatives

Citizen Science based Jellyfish Observation Initiatives (CS JOIs) have been on the rise over the past decade globally, and especially in the Mediterranean Sea, especially at primary tourist destinations in which jellyfish are of particular importance. Projects vary in purpose, function, data collected, validation methodology, outreach mode and levels of citizen science engagement and training. The main SDGs that CS JOIs address are:

a) SDG 3 – Good health and wellbeing, as human health, particularly public health and medicine are all affected by jellyfish stings and how Citizen Science operations help find solutions for them (De Donno et al., 2014; Edelist et al., 2023),
b) SDG 14, life below water, affecting coastal management, marine economy and marine policy (Cigliano et al., 2015; Dobson et al., 2023; Ruiz-Frau, 2022), and
c) SDG 4 – Quality education, as CS projects help educate coastal community and enhance ocean stewardship.

Jellyfish CS monitoring is related to many MSFD descriptors, like D1 (Biodiversity), D2 (Non-indigenous Species), D4 (Food Webs). These indicators are interconnected as both indigenous and nonindigenous jellyfish often drive changes across the entire pelagic ecosystem. In parallel, jellyfish obstruct commercial fisheries (D3), and their populations may increase as a result of fishery overexploitation (D3), Eutrophication (D5), certain Hydrographic Conditions (D7) and even the occurrence of Marine Litter (D10), as plastics may serve as settlement substrate for their polyps (Richardson et al. 2009).

Within the ILIAD and OTTERS projects, a network of 22 experts from CS JOIs was formed, to collate and inform stakeholders and policy makers of the potential benefits and specific project needs, and to help standardize data collection protocols. Most CS JOIs are crowdsourcing projects that provide a direct alerting or mapping service to the public and other stakeholders. They provide a unique and important local account of jellyfish swarms. Projects are typically run by scientists and combine the dual purposes of enhancing long-term knowledge of jellyfish ecology with real-time alert systems of incoming swarms. Here we review their short history, recent evolution and civil and scientific achievements based on a series of publications. Geospatial, temporal and legal caveats on the way to pan-basin or global reporting systems are discussed, highlighting the need to also preserve local initiative identity and connections with the community to allow meaningful interactive CS processes to evolve in light of the rise of global biodiversity data collection projects.

The first CS JOIs were Jellywatch – in 2009, two identically named and quite different initiatives were formed. The first was jellywatch.org, initiated in MBARI (Monterey Bay Aquarium Research Institute) as a global scale Citizen Science JOI (Elliott et al., 2010). Jellywatch.org was mainly promoted online and featured a predominately US following, although observations were encouraged from everywhere. This was soon followed by the Jellywatch program, launched by the Mediterranean Science Commission (CIESM) involving partners from 98 locations across 19 countries in Southern European Seas. CIESM's Jellywatch printed posters in eight languages and circulated them both online and in beaches. Via the Perseus jellyfish spotting campaign between 2013 and 2015 (http://www.perseus-net.eu/en/jellyfish_map/index.html), citizens were asked to send observations to local focal points and based on these observations, Jellyfish scientists then 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). While Jellywatch has laid the first 'rules of play' for reporting, in the early stages it was not a ‘classic’ CS endeavor, as most observations were by the scientists themselves. Similar initiatives started even earlier, such as the Catalan Jellyfish Observation Network in 2007, but it took several years for these to be developed as full-fledged Citizen Science endeavors.

In the second decade on the 21st century, local initiatives began to appear. The spatial and temporal resolution of the large-scale jellywatch initiatives were insufficient as a real time alert tool that can serve the needs of public stakeholders, such as beachgoers and tourists, or commercial actors, such as aquaculture farms, power and desalination plants, and local/national JOIS sought to bridge this gap. The first local initiatives to appear were “Spot the Jellyfish” in Malta (established 2010), “ACRI.ST” in France (2010), “Meduzot Baam” in Israel (2011) and “Observadores del Mar” in Spain (2011). They were later joined by “Infomedusa” (2015) and in 2016 several more groups were formed: Gelavista in Portugal, MedusApp in Spain, Occhio alla Medusa in Italy (originally as a part of CIESM Jellywatch), Yayakarsa in Turkey and JellyX in Italy. In 2019, AvvistApp in Italy and Meduseo (eliciting reports from any nation) were formed. Some CS JOIs were created and neglected since they had little traction or due to operability problems, for example Grumering, Archipelagos, Ionian divers, Swymm, or Medusas Ibiza. Citizen engagement has promoted the discovery of jellyfish species new to science, for example in Italy (Piraino et al., 2014) or Israel (Dragičević et al., 2019), or new to regions, such as the 9 species new to Maltese waters recorded in the Spot the Jellyfish program (Deidun & Sciberras, 2017) and many of the 66 species described for Tunisia (Gueroun et al., 2022).

CS JOIs varied considerably from one another in motivation. Some JOIs were driven by scientific research for knowledge enhancement, or by altruistic purposes (alerting the public to the presence of stinging species), while some had commercial purposes (developing a product to be sold to stakeholders). Some JOIs drew from the reporting methodology of Jellywatch while others developed their own reporting methodology. Collaborating organizations included mainly academy and universities, and also government (e.g., the “Spot the Jellyfish”) public organizations and municipalities (e.g., “Infomedusa”) and even aquaculture farms (“JellyX”). The main challenges shared by all JOIs include funding, user retention, data validation and the decline of reporting outside of the bathing season. Beyond the public itself, the connection with policy stakeholders as partners, possible funding sources and end-users was thus identified as having prime importance to the success of projects and for ensuring their long-term sustainability.

Citizen science projects typically do well in terms of data quality assessment and governance (Figure X), 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).

Results of JOIs activities are typically published in peer reviewed literature and these were reviewed in the present assessment for this white paper. In Italy, the Meteomeduse project has reported jellyfish outbreak increase and epidemiological phenomena (De Donno et al., 2014). Data was updated and summarized (Zampardi et al., 2016) and AvvistApp added spatio-temporal patterns of ctenophore (Tirelli et al., 2021). In Portugal, Gelavista used their app to similarly unearth patterns of Vellella (Pires et al., 2018). In Malta, Spot the Jellyfish determined and reported the seasonality of swarms of multiple gelatinous species across the Maltese bays (Gatt et al., 2018). In Turkey, Yayakarsa documented unusually large blooms of R. pulmo in the Marmara Sea (Öztürk & Sümen, 2020), and in Israel, the Meduzot Baam project used CS reports to uncover a phenological change in swarming patterns (Edelist et al., 2020) and track the origins of Levantine R. nomadica blooms (Edelist et al., 2022). Meduses. Tunisie also published on diversity, trends and patterns and described 66 species in the only CS JOI from North Africa (Gueroun et al., 2022), and in Spain, citizen reports were used to show seasonality and how local swarming patterns correlate with environmental factors (Gutiérrez-Estrada et al., 2021; Dobson et al., 2023) by the MedusApp and Infomedusa projects. In the Western and Central Mediterranean, a breakthrough paper (Marambio et al., 2021) combined two different monitoring approaches reporting either only presence (Italy and Malta) or both presence and absence of jellyfish (Spain and Tunisia), grouped in three categories following (Canepa et al., 2014b) 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 facilitate inter-country comparisons, while exposing the challenges in doing so and the need for unified standards.

Using this cumulative knowledge for detecting both long-term and short-term trends is vital for forecasting systems to evolve. Using atmospheric data, such as currents, winds, salinity, chlorophyll, nutrients, productivity, oxygen, temperature and others (Bellido et al., 2020; Canepa et al., 2014a; Castro-Gutiérrez et al., 2022; Dobson et al., 2023; Edelist et al., 2022; Gatt et al., 2018; Marambio et al., 2021). Canyons were correlated to Pelagia blooms and bathymetry was also considered important for certain species (Canepa et al., 2014a; Marambio et al., 2021). Another significant outcome of reviewing this literature, is that unlike the early 2000s trend of menacing jargon threatening with gelatinous seas and a global rise of Gelationus zooplankton (e.g. Richardson et al., 2009), and in agreement with later publication (Condon et al., 2012, 2013), JOIs did not point to any evidence of a long-term trend of increase in jellyfish swarming. Significant interannual changes were noted, but the absence of a clear increasing trend held true except for cases where new species (NIS) appeared and became established in the ecosystem, such as R. nomadica, M.Leidyi, or P. punctata, (Dobson et al., 2023; Gatt et al., 2018; Tirelli et al., 2021).

6.2. CS Marine Litter Observation Initiatives

The quantity and composition of marine litter monitored by CS could be used to evaluate the effectiveness of the EU Plastics Strategy and the Circular Economy Action Plan, both serving as the building blocks of the EU Green Deal. The classification and characterization of marine litter features by CS surveys may also inform sources and pathways. Moreover, methodologies and data should be standardized (or harmonized), leading to interoperable datasets that could potentially be integrated in the findings of scientific studies.

Vlachogianni et al. (2020) reported on assessing the occurrence, composition and sources of marine macro-litter on the beaches of the Mediterranean and generated fit-for-purpose data on marine litter, in particular plastics and single-use plastics through the use of a harmonized protocol and via a participatory-science initiative. The publication provides baseline information and supporting evidence for the EU Single-Use Plastics Directive and the EU Plastics Strategy, as well as the EU MSFD and the UNEP/MAP Regional Plan for Marine Litter Management in the Mediterranean (UNEP/MAP IG.21/9).

The work of Ambrose et al. (2019) used marine litter data collected by citizen scientists, to assess debris composition, concentration and variation, as well as the relationships between debris abundance and coastal exposure, the role of wind and the relative exposure index (REI) as a factor in debris accumulation on the beaches of The Bahamas. Results showed that 93% of the debris collected was made of plastic, like plastic fragments, fishing gear (rope, buoys, floats, lures/lines, packaging straps), smoking (cigar tips, cigarettes, lighters), foodware (straws, food wrappers, utensils, cups, six-pack rings, balloons), plastic bottles and jugs, plastic bags and film, foam, plastic caps. Authors identified a clear relationship between the fetch and the wind exposure of the examined beaches to the long-range transport of marine debris.

Long-term CS beach litter data from the MPAs along the British coasts were analyzed in the works of Nelms et al. (2017, 2020). Although most CS surveys and data analysis are sparse in time and space, this long-term dataset was analyzed in a harmonized, i.e., data were standardized in terms of items found, length and duration of each survey and number of volunteers. Litter density, litter composition by material and source, litter abundance and its temporal trends were derived from this database.

Bergmann et al. (2017) collected and reported CS litter data on the pollution of the “pristine” Arctic beaches by engaging cruise tourists in a citizen science campaign. The campaign revealed the considerable contamination of the arctic environment with marine man-made litter, comprised mostly from plastics (82-100%). Participants also collected photographs of marine organisms interacting with the litter.

Kordella et al. (2013) reported quantified beach-stranded litter data collected from volunteers during nation-wide clean-up campaigns. 80 Greek beaches were surveyed by 10,938 and 15,748 volunteers in 2006 and 2007 within the “Clean-up the Med” initiative. Plastic (43–51%) was the most abundant litter material found on the surveyed beaches, followed by paper (13–18%) and aluminum (7–12%). Onshore and nearshore recreational activities, such as bathing and recreational boating, appeared to be the most dominant litter sources. Navigation seemed to be the dominant source of marine-based litter, affecting more than half of the surveyed beaches.

Lavers et al. (2016) attempted to validate the accuracy in marine litter beach surveys, questioning the capacity of existing beach clean-up operations to precisely estimate the amount of plastic. Their work focused mostly on microplastics, i.e., items ranging in size from 2.5 to 60 mm. They concluded that the detection of plastic particles on a beach depends on factors like the experience of the observer, visibility, or other objects that can be confused with or obscure plastic particles. The probability of detection per item type was assessed, a data correction factor useful to remove bias in existing datasets or monitoring programs, thus estimate the true amount of beach plastics.

Jambeck et al. (2015) developed a cell phone app (the Marine Debris Tracker) for the collection of global CS standardized data at a scale, speed, and efficiency. Additionally, Clark et al. (2021) developed a web-based visualization tool to build the Australian CS marine debris database. Merlino et al. (2015) introduced SeaCleaner, user-friendly mobile app for monitoring beach litter and applied it at five Italian MPAs.

7. Conclusions and Recommendations

The basic conclusions of the Second White Paper are:

- Citizen science (CS) is a dynamic scientific field involving non-technical volunteers in research. These volunteers could become a large workforce and could contribute to applied marine science through their participation in monitoring programs in which experience scientists lead them. Such monitoring programs could be part of the systematic surveys conducted by scientists at all EU Member States in the framework of the Marine Strategy Framework Directive.
- Public participation in science and policy implementation can enhance the ability of decision-makers, stakeholders and non-government organizations to monitor, manage and conserve natural resources and advance ocean literacy.
- Modern CS works involve the use of low-cost sensors, mobile apps, cameras and other IoT technologies and producing shared with scientists' databases.
- The review of recent and mostly cited CS publications illustrates the tendency to implement CS initiatives to collect and process data on biodiversity and marine litter. Biodiversity collected data could potentially be linked to Descriptor 1, and mostly to criterion D1C4 (17.8%) referring to species geographical distribution and patterns. In parallel, CS data potentially related to criterion D1C1 (10.1%) referring to the mortality rates per species from fishing by-catch. In terms of marine litter data collection, 13.1% of the works are relevant to D10C1 on the composition, quantity and spatial distribution of litter on the coastline.

However, CS initiatives and produced data should be integrated in scientific research with care, considering the special restrictions related to these works. The first challenge is related to the quality of collected data and the methodology followed for quality assurance and data robustness analyses. Extensive cross-checking for consistency with existing literature and parallel scientific observations is required. The use of apps and advanced machine learning models for image recognition may reduce errors related to limited volunteers training.

The second challenge is related to the bias introduced by the CS sampling, especially in marine data collection, when most of CS campaigns take place in sandy beaches or at coastal waters and during spring and summer. These significant biases may lead to spurious conclusions on long-term trends or spatial patterns of species distribution (D1) or marine litter abundance (D10). Aggregating CS with scientific datasets could reduce the impacts of these biases, extend and increase the density of sampling coverage, fill the data gaps and reduce monitoring costs.

Finally, compliance with the existing international data standards increases the acceptability of CS data for international data repositories, such as SeaDataNet (www.seadatanet.org), CMEMS (Copernicus Marine Environmental Monitoring Service, https://marine.copernicus.eu/), and EMODnet (www.emodnet.eu). Standardizing the collected data and metadata may lead to compliance of CS initiatives with rigorous scientific monitoring requirements in the framework of MSFD.

References

Ambrose, K. K., Box, C., Boxall, J., Brooks, A., Eriksen, M., Fabres, J., Fylakis, G., Walker, T. R., 2019. Spatial trends and drivers of marine debris accumulation on shorelines in South Eleuthera, The Bahamas using citizen science. Marine Pollution Bulletin, 142, 145–154. https://doi.org/10.1016/j.marpolbul.2019.03.036.

Bellido, J.J., BÁEez, J.C., Souviron-Priego, L., Ferri-Yanez, F., Salas, C., Lopez, J.A., Real, R., Siokou, I., 2020. Atmospheric indices allow anticipating the incidence of jellyfish coastal swarms. Mediterranean Marine Science, 21(2), 289–297. https://doi.org/10.12681/mms.20983.

Berg, T., Fürhaupter, K., Teixeira, H., Uusitalo, L., Zampoukas, N., 2015. The Marine Strategy Framework Directive and the ecosystem-based approach – pitfalls and solutions. Marine Pollution Bulletin, 96 (1–2), 18-28, https://doi.org/10.1016/j.marpolbul.2015.04.050.

Bergmann, M., Lutz, B., Tekman, M.B., Gutow, L., 2017. Citizen scientists reveal: Marine litter pollutes Arctic beaches and affects wild life. Marine Pollution Bulletin, 125 (1–2) 535-540. https://doi.org/10.1016/j.marpolbul.2017.09.055.

Boero, F., Briand, F., 2001. Executive summary. In: Briand F (ed), Gelatinous Zooplankton outbreaks: theory and practice. CIESM Workshop Series 14: 7–22.

Bowser, A., Cooper, C., De Sherbinin, A., Wiggins, A., Brenton, P., Chuang, T. R., Faustman, E., Haklay, M., Meloche, M., 2020. Still in need of norms: The state of the data in citizen science. Citizen Science: Theory and Practice, 5(1). https://doi.org/10.5334/CSTP.303.

Butt, N., Slade, E., Thompson, J., Malhi, Y., Riutta, T., 2013. Quantifying the sampling error in tree census measurements by volunteers and its effect on carbon stock estimates. Ecological Applications, 23, 936–943.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., Dewulf, A., et al., 2014. Citizen science in hydrology and water resources: Opportunities for knowledge generation, ecosystem service management, and sustainable development. Frontiers in Earth Science, 2, 26.

Buzinkai, M., Radeta, M., Rodrigues, C., Silva, F., Freitas, R., Chebaane, S., Parretti, P., Schäfer, S., Silva, R., Gizzi, F., Almeida, S., Gueroun, S. K. M., Canning-Clode, J., Monteiro, J.G., 2023. Crowdsourcing biodiversity data from recreational SCUBA divers using Dive Reporter. Ecological Informatics, 77, 102191. https://doi.org/https://doi.org/10.1016/j.ecoinf.2023.102191.

Canepa, A., Fuentes, V. L., Sabatés, A., Piraino, S., Boero, F., Gili, J.-M., 2014a. Chapter 11: Pelagia noctilica in the Mediterranean Sea. Jellyfish Blooms, 9–44.

Canepa, A., Fuentes, V., Sabatés, A., Piraino, S., Boero, F., Gili, J.M., 2014b. Pelagia noctiluca in the Mediterranean Sea. Jellyfish Blooms, 9789400770157, 237–266. https://doi.org/10.1007/978-94-007-7015-7_11/COVER.

Cardoso, A.C., Cochrane, S., Doerner, H., Ferreira, J.G., Galgani, F., Hagebro, C., Hanke, G., Hoepffner, N., Keizer, P.D., Law, R., Olenin, S., Piet, G.J., Rice, J., Rogers, S.I., Swartenbroux, F., Tasker, M.L., van de Bund, W., 2010. Scientific Support to the European Commission on the Marine Strategy Framework Directive. Management Group Report Office for Official Publications of the European Communities, EUR 24336 EN – Joint Research Centre, Luxembourg, p. 57.

Castro-Gutiérrez, J., Gutiérrez-Estrada, J.C., Aroba, J., Pulido-Calvo, I., Peregrín, A., Báez, J.C., Bellido, J.J., Souviron-Priego, L., 2022. Estimation of jellyfish abundance in the south-eastern Spanish coastline by using an explainable artificial intelligence model based on fuzzy logic. Estuarine, Coastal and Shelf Science, 277. https://doi.org/10.1016/j.ecss.2022.108062

Ceccaroni, L., Piera, J., Wernand, M.R., Zielinski, O., Busch, J.A., Van Der Woerd, H.J., et al., 2020. Citclops: A next-generation sensor system for the monitoring of natural waters and a citizens' observatory for the assessment of ecosystems' status. PLoS ONE, 15, 3, e0230084. https://doi.org/10.1371/journal.pone.0230084.

Cigliano, J.A., Meyer, R., Ballard, H.L., Freitag, A., Phillips, T.B., Wasser, A., 2015. Making marine and coastal citizen science matter. Ocean and Coastal Management, 115, 77–87. https://doi.org/10.1016/j.ocecoaman.2015.06.012.

Clark, G. F., Gacutan, J., Lawther, R., Johnston, E. L., Tait, H., Bednarz, T., 2021. A visualization tool for citizen-science marine debris big data. Water International, 46(2), 211–223. https://doi.org/10.1080/02508060.2021.1888495.

Condon, R.H., Duarte, C.M., Pitt, K.A., Robinson, K.L., Lucas, C.H., Sutherland, K.R., Mianzan, H.W., Bogeberg, M., Purcell, J.E., Decker, M.B., Uye, S.I., Madin, L.P., Brodeur, R.D., Haddock, S.H.D., Malej, A., Parry, G.D., Eriksen, E., Quinõnes, J., Acha, M., … Graham, W.M., 2013. Recurrent jellyfish blooms are a consequence of global oscillations. Proceedings of the National Academy of Sciences of the United States of America, 110(3), 1000–1005. https://doi.org/10.1073/PNAS.1210920110.

Condon, R.H., Graham, W.M., Duarte, C.M., Pitt, K.A., Lucas, C.H., Haddock, S.H.D., Sutherland, K.R., Robinson, K.L., Dawson, M.N., Decker, M.B., Mills, C.E., Purcell, J.E., Malej, A., Mianzan, H., Uye, S.I., Gelcich, S., Madin, L.P., 2012. Questioning the rise of gelatinous Zooplankton in the world's oceans. BioScience, 62(2), 160–169. https://doi.org/10.1525/BIO.2012.62.2.9.

Constable, A.J., Costa, D.P., Schofield, O., Newman, L., Urban, E.R.Jr., Fulton, E.A., et al., 2016. Developing priority variables ("ecosystem Essential Ocean Variables" - eEOVs) for observing dynamics and change in Southern Ocean ecosystems. Journal of Marine Systems, 161, 26–41. doi: 10.1016/j.jmarsys.2016.05.003.

De Donno, A., Idolo, A., Bagordo, F., Grassi, T., Leomanni, A., Serio, F., Guido, M., Canitano, M., Zampardi, S., Boero, F., Piraino, S., 2014. Impact of stinging jellyfish proliferations along south Italian coasts: Human health hazards, treatment and social costs. International Journal of Environmental Research and Public Health, 11(3), 2488–2503. https://doi.org/10.3390/ijerph110302488.

Deidun, A., Sciberras, A., 2017. Unearthing marine biodiversity through citizen science-the Spot the Jellyfish and the Spot the Alien Fish campaign case studies from the Maltese Islands (Central Mediterranean). Bulletin of the Entomological Society of Malta, 9, 86-88.

Dobson, J. Y., Fonfría, E. S., Palacios, R., Blasco, E., Bordehore, C., 2023. Citizen science effectively monitors biogeographical and phenological patterns of jellyfish. Ocean & Coastal Management, 242, 106668. https://doi.org/10.1016/j.ocecoaman.2023.106668.

Dragičević, B., Anadoli, O., Angel, D., Benabdi, M., Bitar, G., Castriota, L., Crocetta, F., Deidun, A., Dulčić, J., Edelist, D., Gerovasileiou, V., Giacobbe, S., Goruppi, A., Guy-Haim, T., Konstantinidis, E., Kuplik, Z., Langeneck, J., Macali, A., Manitaras, I., … Zenetos, A., 2019. New Mediterranean biodiversity records (December 2019). Mediterranean Marine Science, 20(3), 636–656. https://doi.org/10.12681/mms.20913.

Edelist, D., Angel, D. L., Barkan, N., Danino-Gozlan, C., Palanker, A., Barak, L., Robertson, E., Bentur, Y., 2023. Jellyfish sting web survey: clinical characteristics and management of Rhopilema nomadica envenomation in the Mediterranean Sea. Regional Environmental Change, 23(3). https://doi.org/10.1007/s10113-023-02104-4.

Edelist, D., Guy-Haim, T., Kuplik, Z., Zuckerman, N., Nemoy, P., Angel, D.L., 2020. Phenological shift in swarming patterns of Rhopilema nomadica in the Eastern Mediterranean Sea. Journal of Plankton Research, 42(2), 211–219. https://doi.org/10.1093/plankt/fbaa008.

Edelist, D., Knutsen, Ø., Ellingsen, I., Majaneva, S., Aberle, N., Dror, H., Angel, D.L., 2022. Tracking Jellyfish Swarm Origins Using a Combined Oceanographic-Genetic-Citizen Science Approach. Frontiers in Marine Science, 9. https://doi.org/10.3389/fmars.2022.869619.

Elliott, K., Case, A., Haddock, S., 2010. Jellywatch.org: a website for collecting citizen-reported jellyfish sightings. AGU Ocean Sciences Meeting. American Geophysical Union.

European Commission. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Communities L 2008, 164: 19.

Fraschetti, S., Fabbrizzi, E., Tamburello, L., Uyarra, M.C., Micheli, F., Sala, E., Pipitone, C., Badalamenti, F., Bevilacqua, S., Boada, J., Cebrian, E., Ceccherelli, G., Chiantore, M., D'Anna, G., Di Franco, A., Farina, S., Giakoumi, S., Gissi, E., Guala, I., Guidetti, P., Katsanevakis, S., Manea, E., Montefalcone, M., Sini, M., Asnaghi, V., Calò, A., Di Lorenzo, M., Garrabou, J., Musco, L., Oprandi, A., Rilov, G., Borja, A., 2022. An integrated assessment of the Good Environmental Status of Mediterranean Marine Protected Areas. Journal of Environmental Management, 305, 114370, https://doi.org/10.1016/j.jenvman.2021.114370.

Fuccillo, K.K., Crimmins, T.M., de Rivera, C.E. et al., 2015. Assessing accuracy in citizen science-based plant phenology monitoring. International Journal of Biometeorology, 59, 917–926. https://doi.org/10.1007/s00484-014-0892-7.

Garcia-Soto, C., Seys, J. J. C., Zielinski, O., Busch, J. A., Luna, S. I., Baez, J. C., Domegan, C., Dubsky, K., Kotynska-Zielinska, I., Loubat, P., Malfatti, F., Mannaerts, G., McHugh, P., Monestiez, P., van der Meeren, G. I., & Gorsky, G. (2021). Marine Citizen Science: Current State in Europe and New Technological Developments. Frontiers in Marine Science, 8, https://doi.org/10.3389/fmars.2021.621472.

Garcia-Soto, C., van der Meeren, G. I., Busch, J. A., Delany, J., Domegan, C., Dubsky, K., Fauville, G., Gorsky, G., von Juterzenka, K., Malfatti, F., Mannaerts, G., McHugh, P., Monestiez, P., Seys, J., Węsławski, J.M., Zielinski, O., 2017. Advancing Citizen Science for Coastal and Ocean Research. French, V., Kellett, P., Delany, J., McDonough, N. [Eds.], Position Paper 23 of the European Marine Board, Ostend, Belgium. 112pp. ISBN: 978-94-92043-30-6.

Gatt, M., Deidun, A., Galea, A., Gauci, A., 2018. Is Citizen Science a Valid Tool to Monitor the Occurrence of Jellyfish? The Spot the Jellyfish Case Study from the Maltese Islands. Journal of Coastal Research, 85, 316–320. https://doi.org/10.2112/SI85-063.1.

Gueroun, S.K.M., Piraino, S., KÉfi-Daly Yahia, O., Daly Yahia, M.N., 2022. Jellyfish diversity, trends and patterns in Southwestern Mediterranean Sea: a citizen science and field monitoring alliance. Journal of Plankton Research, 44, 6, 819–837. https://doi.org/10.1093/plankt/fbac057.

Gutiérrez-Estrada, J.C., Pulido-Calvo, I., Peregrín, A., García-Gálvez, A., Báez, J.C., Bellido, J.J., Souviron-Priego, L., Sánchez-Laulhé, J.M., López, J.A., 2021. Integrating local environmental data and information from non-driven citizen science to estimate jellyfish abundance in Costa del Sol (southern Spain). Estuarine, Coastal and Shelf Science, 249. https://doi.org/10.1016/j.ecss.2020.107112

Intergovernmental Oceanographic Commission (of UNESCO), 2017. Outcomes of the UN SDG14 conference (5–9 June 2017): Information Document, (Intergovernmental Oceanographic Commission, Paris, 2017).

Irwin, A., 1995. Citizen Science. London: Routledge. https://doi.org/10.4324/9780203202395.

Jambeck, J.R., Johnsen, K., 2015. Citizen-Based Litter and Marine Debris Data Collection and Mapping. Computing in Science & Engineering, 17(4), 20-26. https://doi.org/10.1109/MCSE.2015.67

Jambeck, J.R., Johnsen, K., 2015. Citizen-based litter and marine debris data collection and mapping. Computing in Science and Engineering, 17, 4, 20-26. https://doi: 10.1109/MCSE.2015.67.20–26.

Jordan, R.C. et al., 2015. Citizen Science as a Distinct Field of Inquiry. BioScience, 65(2), pp.208–211. http://bioscience.oxfordjournals.org/content/early/2015/01/15/biosci.biu217.abstract.

Kawabe, L.A., Ghilardi-Lopes, N.P., Turra, A., Wyles, K.J., 2022. Citizen science in marine litter research: A review. Marine Pollution Bulletin, 182, 114011, https://doi.org/10.1016/j.marpolbul.2022.114011.

Kordella, S., Geraga, M., Papatheodorou, G., Fakiris, E., Mitropoulou, I.M., 2013. Litter composition and source contribution for 80 beaches in Greece, Eastern Mediterranean: A nationwide voluntary clean-up campaign. Aquatic Ecosystem Health & Management, 16, 1, 111-118. https://doi.org/10.1080/14634988.2012.759503.

Kotovirta, V., Toivanen, T., Järvinen, M., Lindholm, M., Kallio, K., 2014. Participatory surface algal bloom monitoring in Finland in 2011–2013. Environmental Systems Research, 3, 24. https://doi.org/10.1186/s40068-014-0024-8.

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

Langeneck, J., Crocetta, F., Doumpas, N., Giovos, I., Piraino, S., Boero, F., 2019. First record of the non-native jellyfish Chrysaora cf. achlyos (Cnidaria: Pelagiidae) in the Mediterranean Sea. BioInvasion Records 8, 3, 608–613, https://doi.org/10.3391/bir.2019.8.3.17.

Langlet, D., Rayfuse, R., 2019. The Ecosystem Approach in Ocean Planning and Governance. Perspectives from Europe and Beyond. Brill Open, 491 p. Publications on Ocean Development: A series of studies on the international, legal, institutional, and policy aspects of ocean development, Volume 87.

Lavers, J.L., Oppel, S., Bond, A.L., 2016. Factors influencing the detection of beach plastic debris. Marine environmental research 119, 245-251. https://doi.org/10.1016/j.marenvres.2016.06.009.

Lovell, S., Hamer, M., Slotow, R. et al., 2009. An assessment of the use of volunteers for terrestrial invertebrate biodiversity surveys. Biodiversity Conservation, 18, 3295–3307. https://doi.org/10.1007/s10531-009-9642-2.

Malloggi, C., Rizzo, B., Giusti, A., Guardone, L., Gasperetti, L., Dall'Ara, S., Armani, A., 2023. First Toxicological Analysis of the Pufferfish Sphoeroides pachygaster Collected in Italian Waters (Strait of Sicily): Role of Citizens Science in Monitoring Toxic Marine Species. Animals, 13, 1873. https://doi.org/10.3390/ani13111873.

Marambio, M., Canepa, A., Lòpez, L., Gauci, A.A., Gueroun, S.K.M., Zampardi, S., Boero, F., Yahia, O.K.-D., Yahia, M.N.D., Fuentes, V., et al., 2021. Unfolding Jellyfish Bloom Dynamics along the Mediterranean Basin by Transnational Citizen Science Initiatives. Diversity, 13, 274. https://doi.org/10.3390/d13060274.

Martinelli, M., Moroni, D., 2018. Volunteered Geographic Information for Enhanced Marine Environment Monitoring. Applied Sciences, 8, 1743. https://doi:10.3390/app8101743.

Muller-Karger, F.E., Miloslavich, P., Bax, N.J., Simmons, S., Costello, M.J., Sousa Pinto, I., et al., 2018. Advancing marine biological observations and data requirements of the complementary essential ocean variables (EOVs) and essential biodiversity variables (EBVs) frameworks. Frontiers in Marine Science, 5(211). doi: 10.3389/fmars.2018.00211.

Mutlu, E., Çağatay, I.T., Olguner, M.T., Yilmaz, H.E., 2020. A new sea-nettle from the Eastern Mediterranean Sea: Chrysaora pseudoocellata sp. Nov. (Scyphozoa: Pelagiidae). Zootaxa, 4790 (2), 229–244. https://doi.org/10.11646/zootaxa.4790.2.2.

Nelms, S.E., Coombes, C., Foster, L.C., Galloway, T.S., Godley, B.J., Lindeque, P.K., Witt, M.J., 2017. Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data. Science of The Total Environment 579: 1399-1409. https://doi.org/10.1016/j.scitotenv.2016.11.137

Nelms, S.E., Eyles, L., Godley, B.J., Richardson, P.B., Selley, H., Solandt, J.-L., Witt, M.J., 2020. Investigating the distribution and regional occurrence of anthropogenic litter in English marine protected areas using 25 years of citizen-science beach clean data. Environmental Pollution, 263, 114365. https://doi.org/10.1016/j.envpol.2020.114365.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., Crowston, K., 2012. The future of citizen science: emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment, 10:298–304. http://dx.doi.org/10.1890/110294.

Novoa, S., Wernand, M., Van derWoerd, H., 2014. The modern Forel-Ule scale: A 'do-it-yourself' colour comparator for water monitoring. Journal of the European Optical Society-Rapid Publication, 9. DOI: 10.2971/jeos.2014.14025.

Öztürk, D.İ., Sümen, G.S., 2020. Unusual mass mortality of jellyfish Rhizostoma pulmo on the coast of the Sea of Marmara in December 2020. Journal of the Black Sea/Mediterranean Environment, 26 (3).

Piraino, S., Aglieri, G., Martell, L., Mazzoldi, C., Melli, V., Milisenda, G., Scorrano, S., Boero, F., 2014. Pelagia benovici sp. nov. (Cnidaria, Scyphozoa): A new jellyfish in the Mediterranean Sea. Zootaxa, 3794(3), 455–468. https://doi.org/10.11646/zootaxa.3794.3.7.

Pires, R.F.T., Cordeiro, N., Dubert, J., Marraccini, A., Relvas, P., Santos, A., 2018. Untangling Velella velella (Cnidaria: Anthoathecatae) transport. Marine Ecology Progress Series, 591, 241–251. https://doi.org/10.2307/26502949.

Radeta, M., Monteiro, J.G., Gizzi, F., Schäfer, S., Parretti, P., Rodrigues, C., Freitas, R., 2022. Dive Reporter-Mobile App for Counting Underwater Marine Biodiversity. Authorea Preprints. https://doi.org/10.22541/au.166516587.77115447/v1.

Rey, A., Viard, F., Lizé, A., Corre, E., Valentini, A., Thiriet, P., 2023. Coastal rocky reef fish monitoring in the context of the Marine Strategy Framework Directive: Environmental DNA metabarcoding complements underwater visual census. Ocean and Coastal Management, 241, 106625, https://doi.org/10.1016/j.ocecoaman.2023.106625.

Richardson, A.J., Bakun, A., Hays, G.C., Gibbons, M.J., 2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends in Ecology and Evolution, 24 (6), 312–322. https://doi.org/10.1016/j.tree.2009.01.010.

Ruiz-Frau, A., 2022. Impacts of jellyfish presence on tourists' holiday destination choices and their willingness to pay for mitigation measures. Journal of Environmental Planning and Management. https://doi.org/10.1080/09640568.2022.2061926

The Zooniverse, 2014. 'Citizen Science' added to Oxford English Dictionary. Retrieved June 17, 2019, from daily.zooniverse.org: https://daily.zooniverse.org/2014/09/16/citizen-science-indictionary/

Tirelli, V., Goruppi, A., Riccamboni, R., & Tempesta, M., 2021. Citizens' eyes on mnemiopsis: How to multiply sightings with a click! Diversity, 13(6). https://doi.org/10.3390/d13060224.

Tirelli, V., Goruppi, A., Riccamboni, R., Tempesta, M., 2021. Citizens' Eyes on Mnemiopsis: How to Multiply Sightings with a Click! Diversity 2021, 13, 224. https://doi.org/10.3390/d13060224.

UN, 2015. Transforming our world: the 2030 agenda for sustainable development. Resolution Adopted by the General Assembly on 25 September 2015, United Nations, New York, NY.

van Hee, F., Seldenrath, A., Seys J., 2020. Policy Informing Brief: Marine Citizen Science in the North Sea area - and what policy makers can learn from it.

van Hee, F., Seldenrath, A., Seys J., 2020. Policy Informing Brief: Marine Citizen Science in the North Sea area - and what policy makers can learn from it. VLIZ, van Hall Larenstein, University of Applied Sciences, 41 p.

Yang, Y., Cowen, L.L.E., Costa, M., 2018. Is Ocean Reflectance Acquired by Citizen Scientists Robust for Science Applications? Remote Sensing, 10, 835.

Zampardi, S., Licandro, P., Piraino, S., Boero, F., 2016. Indigenous and Non-Indigenous Species along the Italian coasts: jellyfish records from a "Citizen Science" approach.