frontiers in Marine Science

REVIEW
published: 24 March 2021
doi: 10.3389/fmars.2021.621472

Marine Citizen Science: Current State in Europe and New Technological Developments

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OPEN ACCESS

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Specialty section:
This article was submitted to Ocean Observation, a section of the journal Frontiers in Marine Science

Received: *26 October 2020*
Accepted: *24 February 2021*
Published: *24 March 2021*

Citation:
Garcia-Soto C, Seys JJC, Zielinski O, Busch JA, Luna SI, Baez JC, Domegan C, Dubsky K, Kotynska-Zielinska I, Loubat P, Malfatti F, Mannaerts G, McHugh P, Monestiez P, van der Meeren GI and Gorsky G (2021) Marine Citizen Science: Current State in Europe and New Technological Developments. Front. Mar. Sci. 8:621472. doi: 10.3389/fmars.2021.621472

Marine citizen science is emerging with promising opportunities for science, policy and public but there is still no comprehensive overview of the current state in Europe. Based on 127 projects identified for the North Sea area we estimate there might be as much as 500 marine and coastal citizen science projects running in Europe, i.e., one marine citizen science project per ~85 km of coastline, with an exponential growth since 1990. Beach-based projects are more accessible and hence most popular (60% of the projects), and the mean duration of the projects is 18–20 years. Current trends, topics, organizers, aims, and types of programme in terms of participation are presented in this overview. Progress in marine citizen science is specially enabled and promoted through technological developments. Recent technological advances and best practise examples are provided here, untapping the potential of smart mobile apps, do-it-yourself (DIY) technologies, drones, and artificial intelligence (AI) web services.

Keywords: marine citizen science, inventory, European seas, smartphones, DIY, drones, AI, big data

INTRODUCTION

Why Citizen Science?

Citizen Science promotes the collaboration between non-professionals and scientists and in a two-way process. Citizens can engage in various degrees from co-design and co-creation, through problem definition, data collection, analysis, and dissemination of results, to participation as interpreters of information and sensors (Shirk et al., 2012; Haklay, 2013; Chapman and Hodges, 2017). The benefits are shared: scientists enhance their monitoring and analytical capacities and citizens gain scientific knowledge, awareness, and recognition. The results can further influence local policies (Chapman and Hodges, 2017; Hecker et al., 2019) and the public's involvement can stimulate education initiatives (Sullivan et al., 2014; Dunkley, 2017). Citizen science is in this way increasingly viewed as a way to empower communities by involving them in research that can be used to drive forward policy changes (Rowland, 2012; Sullivan et al., 2017).

The term citizen science was simultaneously coined by Alan Irwin in the United Kingdom and Rick Bonney in the United States in the mid-1990s. However, people have for centuries collected observations in fields such as archaeology, astronomy, and have recorded changes in the surrounding nature (Silvertown, 2009). Outbreaks of locusts were recorded for at least 3,500 years in China, cherry blossoms for 1,200 years in Japan, grape harvest days for more than 640 years in France (see Miller-Rushing et al., 2012 and references herein). Throughout the tropics, forest people, as well as fishers, have accumulated knowledge of their activities-concerning local natural environment that is useful for management purposes (Dalzell, 1998; Michon et al., 2007). Long-term records were kept by both amateur and commercial fishermen and amateur flora and fauna collections enriched most of the natural history museums (see Miller-Rushing et al., 2012).

Data from historical observations and collections are used to analyse shifts in the diversity, abundance, distribution, or phenology of species due to changes in land-use or climate. In recent years, citizen science attracted attention because it allows working on projects otherwise unfeasible. In fields like ecology, chemistry, or astronomy non-professionals strongly contribute to scientific knowledge. For example, exoplanets and comets were discovered by amateur astronomers, galaxies were classified (Lintott et al., 2008; Raddick et al., 2010), new solutions in protein design proposed (Koepnick et al., 2019), new RNA structures built (Lee et al., 2014), and bird populations were monitored (Bonney et al., 2009) by citizen scientists. Invasive or toxic species as well as air, land or marine pollution and many more subjects are monitored or analysed in the framework of citizen science projects and increasingly used in habitats' restoring initiatives (Huddart et al., 2016; Tiralongo et al., 2019, 2020)[1] .

Recent improvements in citizen science are also around institutional organisation. Several citizen science associations have further their collaboration through establishing the Citizen Science Global Partnership (CSGP). Launched in 2017, the CSGP brings together the existing networks of citizen science researchers and practitioners with advisory boards representing policy, business, and community-based perspectives. This initiative was founded in partnership with the United Nations Environment Programme (UNEP) and is also supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO). Among their tasks are to explore the possibilities and difficulties of citizen science to make real contributions toward the UN's Sustainable Development Goals and to work with UNESCO on a global Recommendation on Open Science in 2021. Among their members are regional citizen science associations in the United States (CSA), Australia (ACSA), Ibero-America (RICAP), Asia (CitizenScience.Asia), and Europe (ECSA).

The European Citizen Science Association (ECSA) offers since 2013 a platform for organisations and individuals to interact with other European or worldwide projects, to collaborate in the shaping and development of the different aspects of citizen science, its better understanding and use for the benefit of decision making. Through its working groups, ECSA members have developed the 10 principles for citizen science, and contributed to the citizen science ontology demarcation (Eitzel et al., 2017), developed multiple policy briefs addressing the contribution of citizen science to open science, do-it-yourself (DIY) science, defined principles and collected best practices for mobile applications for environmental and biodiversity citizen science (Luna et al., 2018; Sturm et al., 2018) and systematised the characteristics of citizen science to help users, participants, scientist, policy makers and research funders making open and transparent decisions by following a group of defined criteria for identifying the type of activities that belong to citizen science. It is more and more common that research and educational institutions as well as natural areas managers use citizen science to support their studies and monitoring programmes (Freiwald et al., 2018; Irwin, 2018; Wyler and Haklay, 2018; Zipf et al., 2020).

Environmental awareness-raising of citizens through involvement in scientific activities and education enables decision-making and plays an essential role in increasing adaptation to climate change and its mitigation (Vohland et al., 2021).

Why Marine Citizen Science?

Global change and the consequent impacts to marine systems, the evolving international marine governance and management and the need for greater advocacy and stewardship are drivers and opportunities to strengthen the role of marine citizen science in policy frameworks (Garcia-Soto et al., 2017; European Commission, 2018).

The marine realm is the largest component of the Earth's system, stabilises climate and supports life on Earth and human well-being. Understanding of the ocean's responses to pressures and defining management actions is fundamental for sustainable development. However, citizen science projects in marine contexts encounter challenges not faced in terrestrial systems. These include safety, culture, logistics, accessibility, equipment, etc. This explains the relatively weak presence of citizen science in marine when compared to terrestrial environment. Yet, because of the vastness of the marine domain, the collaboration between large numbers of non-scientists and scientists is particularly urgent and important. Building on precise protocols (Benedetti-Cecchi et al., 2018) and on instrumental developments, the citizen involvement in coastal zone (Vye et al., 2020) and open sea projects is growing. Given the scale of marine environmental threats and the relatively limited resources to fill the knowledge gaps, citizen science approaches in conjunction with new technologies should increasingly be considered to complement the scientific efforts in the marine regions.

In this article we present a first analysis of the current state of marine citizen science in Europe. We analyse trends, topics, organisers, aims, and types of programme in terms of participation using the limited information available. As a second objective the article reviews the role of technology in citizen science and marine citizen science by providing some recent

[1] https://easin.jrc.ec.europa.eu/easin/CitizenScience/Projects

best practice examples of smart mobile apps, DIY technologies, drones and artificial intelligence (AI) web services. The work represents a continuation of our previous joint publication "Advancing Citizen Science for Coastal and Ocean Research" (Garcia-Soto et al., 2017) that analysed additionally Citizen Science data quality control and modelling, Social engagement, impact and education, Citizen Science and marine policy, and the European coordination of project management networks. We refer the reader to that extensive review (115 pp) for information on those topics.

THE CURRENT STATE OF MARINE CITIZEN SCIENCE IN EUROPE

Estimating Size and Trends of Marine Citizen Science in Europe

There are no dedicated databases on marine citizen science initiatives at present. For this analysis, we could rely on a recent quantitative assessment of North Sea projects, coordinated by one of us and reported in van Hee et al. (2020). A project was earmarked as a marine citizen science initiative according to the principles listed by European Citizen Science Association [ECSA] (2015). To be considered a citizen science project the project should involve citizen scientists at least in one of the stages of the research process (sampling, analysis, etc.), and the project should have a real scientific result. The projects were not considered citizen science projects if the citizens were involved only for education purposes.

The comprehensive study of the North Sea, excluding the English Channel, relied on thoroughly checking literature, searching social media and other online sources, and on direct contact with marine institutes and other organisations in the area. For each project, we defined at least the coordinating organisation, the country and area of activity, the language, the duration, the study topic, the type of programme and the level of participation. We estimate, based on that North Sea study and assuming other marine regions in Europe have equal numbers of marine citizen science initiatives, that there might be as much as 500 marine and coastal citizen science projects running in Europe.

In the North Sea area, we could identify 127 projects, of which 94 were either country specific – i.e., taking place in the exclusive economic zones (EEZs) of one of the riparian countries (85) – or targeting the entire North Sea (9). As the North sea counts about 25,000 km of coastline or 19% of Europe's total length excluding Greenland and Iceland (131,322 km)[2], the overall estimate of 500 European projects – both ongoing or suspended – seems realistic and amounts to one project on average for every 250 km of coastline. Provided we exclude the vast coastline of Norway (with "only" 18 ongoing marine citizen science projects) from this calculation, we can derive one marine citizen science project per 84 km of coastline. In comparison, during the summer of 2019 the French Collectif Vigie Mer's census could identify 81 marine citizen science initiatives in French marine waters, i.e., one initiative per 60 km of coastline (Collectif Vigie Mer, 2019).

[2]World Factbook: https://en.wikipedia.org/wiki/List_of_countries_by_length_of_coastline

Whether other marine regions in Europe have a similar density of marine citizen science initiatives, is unknown as no precise figures or reviews are available. However, it is clear from the Mediterranean basin for instance, that marine citizen science is omnipresent there as well with several projects monitoring coral reefs, gelatinous plankton, fish and non-indigenous species (e.g., "Pure Ocean," CIGESMED, COMBER, Med-Jellyrisk, Aliens in the Sea, AlienFish project, Plastic Buster, SeaCleaner, ACT4LITTER . . .; Zenetos et al., 2013; Panteri and Arvantidis, 2015; Merlino, 2016; Kleitou et al., 2019; Tiralongo et al., 2019).

The mean duration of projects in the North Sea is 18–20 years. Some very attractive topics, including birds (37 years) and marine mammals (28 years), have longer lifespans. In Norway, lobster catch data has been voluntarily collected by citizens for 92 years. On the other hand, extreme citizen science projects score much lower, due to their recent character and the higher demands, both from the organiser and the participants point of view (e.g., mean duration of 10 years).

Citizen science is not new, and today there are thousands of examples of citizen science projects in Europe (European Commission, 2018). In the North Sea the oldest project dates back to 1876, a crowdsourcing initiative by the Conchological Society of Great Britain and Ireland (Light, 2016). The project is still running and has been going on for 143 years. After a slow growth, citizen science projects area started turning into an exponential growth from 1990 onward (**Figure 1**) and became more visible from the late 2000s onward probably due to the increased availability of smart mobile phones, and also as the term citizen science gained popularity and more and more people began to use the term or rebranded themselves as citizen science. Nothing seems to indicate that this process is slowing down. On top of that, there is no reason to believe that it would be different for other European maritime regions.

Science Europe (2018) estimates that 25% of all projects (terrestrial, freshwater, and marine) are marine or coastal. Taking into account the vast area ocean and seas (71%) are covering, one could argue that marine citizen science is under-represented. However, when considering the limited access to offshore waters for most citizens and the narrow contact zone where most ocean-oriented projects take place, that should not surprise us. In the North Sea area, beach-based projects, much more accessible for citizen scientists than projects that require data collected at sea, are more common (60% of the projects).

What Topics Are Those Projects Dealing With?

A survey on EU-wide citizen science conducted in 2016 with participants located in the United Kingdom and Germany, reveal the vast majority of projects is active in the field of life sciences (Science Europe, 2018). The North Sea study (van Hee et al., 2020) confirms this statement, a reality that probably applies for marine citizen science in Europe as a whole. Almost half of all projects in the North Sea (48%) study "species" (see categories in **Figure 2A**). Another 16% has a more general "biodiversity"

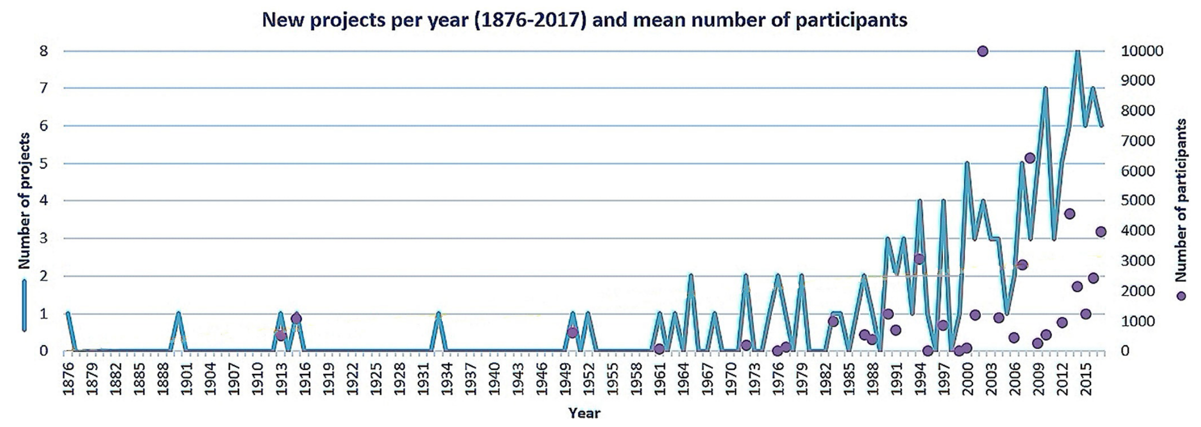

FIGURE 1 | Number of newly started marine citizen science projects in the North Sea and mean number of participants per project (from van Hee et al., 2020).

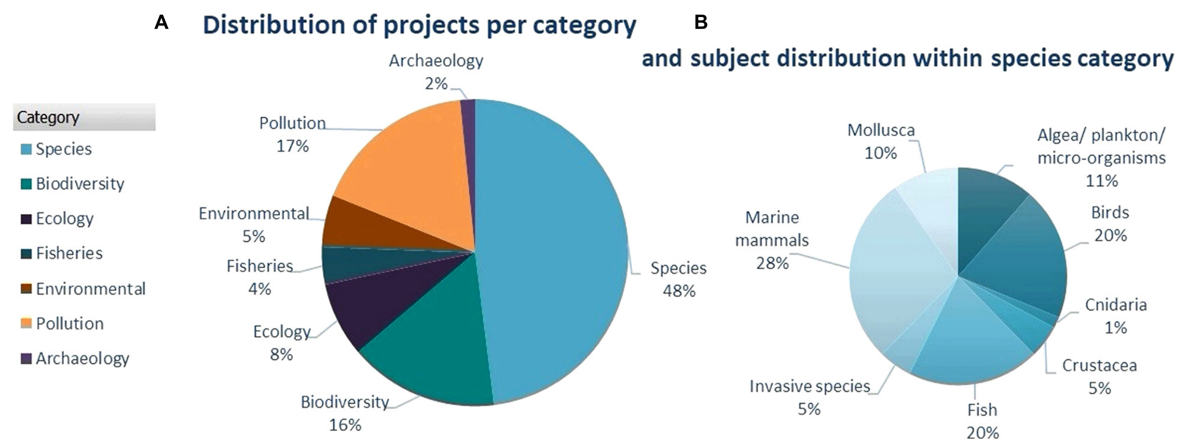

FIGURE 2 | (A) Distribution of marine citizen science projects by topic categories in the North Sea and **(B)** Subject distribution within the "species" category (from van Hee et al., 2020).

focus, collecting information on many different species, for instance to map the biodiversity of a specific region. And the category "ecology" (8%) includes projects on for instance coastal ecology, the state of certain habitats, species interaction with the habitat, or the impact of climate change on the ecosystem. Only 17% of the projects deal with pollution, such as marine litter or the effect of oil spills on birds. The remaining 11% performs research on "fisheries" (fishery catches or fish stocks), "environmental variables" (such as water quality, temperature or sea level rise), and "archaeology" or maritime history. In other parts of Europe the situation is not all that different. In Norway for instance, 78% of the marine citizen science initiatives deal with life science, and in France, life sciences account for 94% of the projects.

Within the category "species research" (**Figure 2B**), marine mammals (28%), fish (20%), and birds (20%) are most wanted, followed by seaweeds and plankton (each 11%) and molluscs (10%) (van Hee et al., 2020). Only seven projects deal with crustaceans, invasive species or cnidarians such as jellyfish. In Norwegian waters, there is relatively more CS activity on crustaceans (19%) and jellyfish (14%), and less focus on seabirds (11%) and marine mammals (17%). In France, many marine citizen science projects are not species-specific but deal with marine biodiversity as a whole (57%), although here as well larger animals (21%) still are well-presented: marine mammals (7%), seabirds (10%), and turtles (4%).

Who Is Organising the Projects? What Are the Aims?

North Sea Citizen Science projects are enabled by a wide-ranging group of stakeholders (charities and foundations, governmental organisations, research institutes, partnerships, individual people). NGOs are the main contributors to North Sea CS-initiatives (56%; see **Figure 3**), followed by research institutes (29%). The same two groups are taking the lead in France and Norway though in very different proportions (France: NGOs 85%; Norway: R.I. 88%). Often, there is collaboration between these two stakeholders in one or more stages of the projects. Only a small number (15%) of the North Sea projects is being coordinated by a collaborative effort, through government organisations or by individuals. NGOs as well as

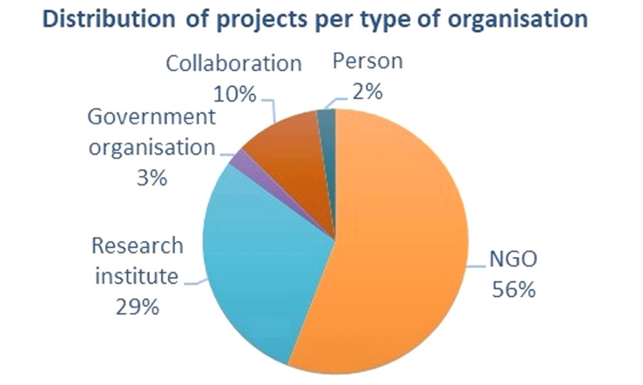

FIGURE 3 | Distribution of marine citizen science projects per type of organization in the North Sea (from van Hee et al., 2020).

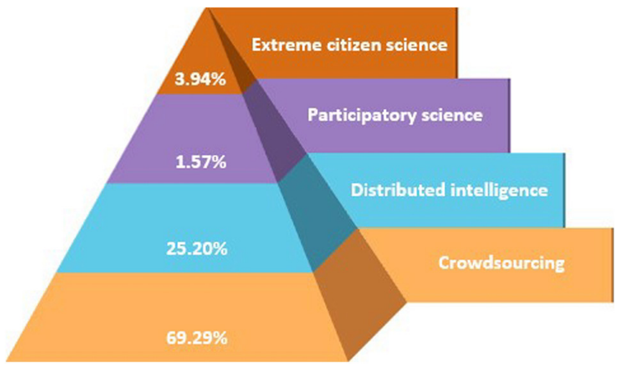

FIGURE 4 | Distribution of marine citizen science projects by types of participation in the North Sea (from van Hee et al., 2020).

research institutes have a focus on species-specific research (55%). Governmental organisations focus on pollution related topics and species research.

In terms of general aim, one can distinguish three major types of initiatives: "descriptive" (=purely collecting data), "performance oriented" (= monitoring and evaluation), and "composite" projects (= tackling important policy issues) (Lehtonen et al., 2016). All types of institutions in the North Sea area cover a mixture of those general aims. Governmental organisations have a slight preference for composite projects. Research institutes are more into the descriptive citizen science initiatives and NGOs have a slight preference for performance initiatives.

Types of Programme in Terms of Participation

Shum et al. (2012) and Haklay (2013) define four types of programmes in terms of the participation that is needed. "Crowdsourcing" requires the lowest level of participation. No knowledge on the subject is required, and citizens act merely as sensors often in the form of reporting observations "Distributed intelligence" requires more effort and a certain level of knowledge from the citizen scientist. "Participatory science" involves citizens in defining the problem, composing a method, and in data collection, while "extreme citizen science" pushes participants to interact in all the research steps, including data analysis. The level of participation obviously determines the number of existing projects. In the North Sea study (**Figure 4**), crowdsourcing is most frequent (69%), followed by distributed intelligence (25%). Two projects explored participatory science, and only five projects reached the most interactive level of extreme citizen science. This is in accordance with the expectations, as demonstrated with the citizen science pyramid: the higher the level of participation, the more effort needed from the citizen scientists (and from the organisers) and the less projects are found. The lowest level of involvement – crowdsourcing – requires least effort or knowledge in order to participate and therefore is most successful in terms of number of projects and participants.

The required time investment also influences the level of involvement. Currently, 72% of the North Sea projects and 78% of the Norwegian ones collect data in a continuous way (with no obligations). Projects that are collecting data in a continuous way, are often at a crowdsourcing level (73% in North Sea).

THE ROLE OF TECHNOLOGY IN MARINE CITIZEN SCIENCE. RECENT DEVELOPMENTS

The future of citizen science, including marine citizen science, is and will likely be inextricably linked to emerging technologies (**Figure 5**). Development of new technologies will increase the number of projects and participants, will ease the collection and analysis of data, and will facilitate the interaction between stakeholders (Thiel et al., 2014; Sandahl and Tøttrup, 2020). New technologies, such as mobile applications (Leeuw and Boss, 2018; Yang et al., 2018), wireless sensor networks (Benabbas et al., 2019), and online computer/video gaming (Lee et al., 2014; Koepnick et al., 2019), show great promise for advancing citizen science. Software developed for use on portable devices such as smartphones (Compas and Wade, 2018) and other mobile, web-enabled equipment (Seafarers et al., 2017) are already central in citizen science activities. Wireless sensor networks consist of spatially distributed, autonomous or semi-autonomous sensors that monitor georeferenced environmental conditions, such as physical, chemical and biological parameters, sound (Mukundarajan et al., 2018)[3], pollutants[4], vibration or motion. Emerging technologies have the potential to engage broad audiences, motivate volunteers, improve data collection, control data quality, corroborate model results, and increase the speed with which decisions can be made. The volume of data generated fits the big-data. Advances in AI and machine learning are also allowing for efficiency gains. Development of virtual forums and virtual meetings will ease the promotion, formation,

[3] https://portal.frogid.net.au/

[4] https://www.producthunt.com/posts/the-ocean-cleanup-plastic-survey

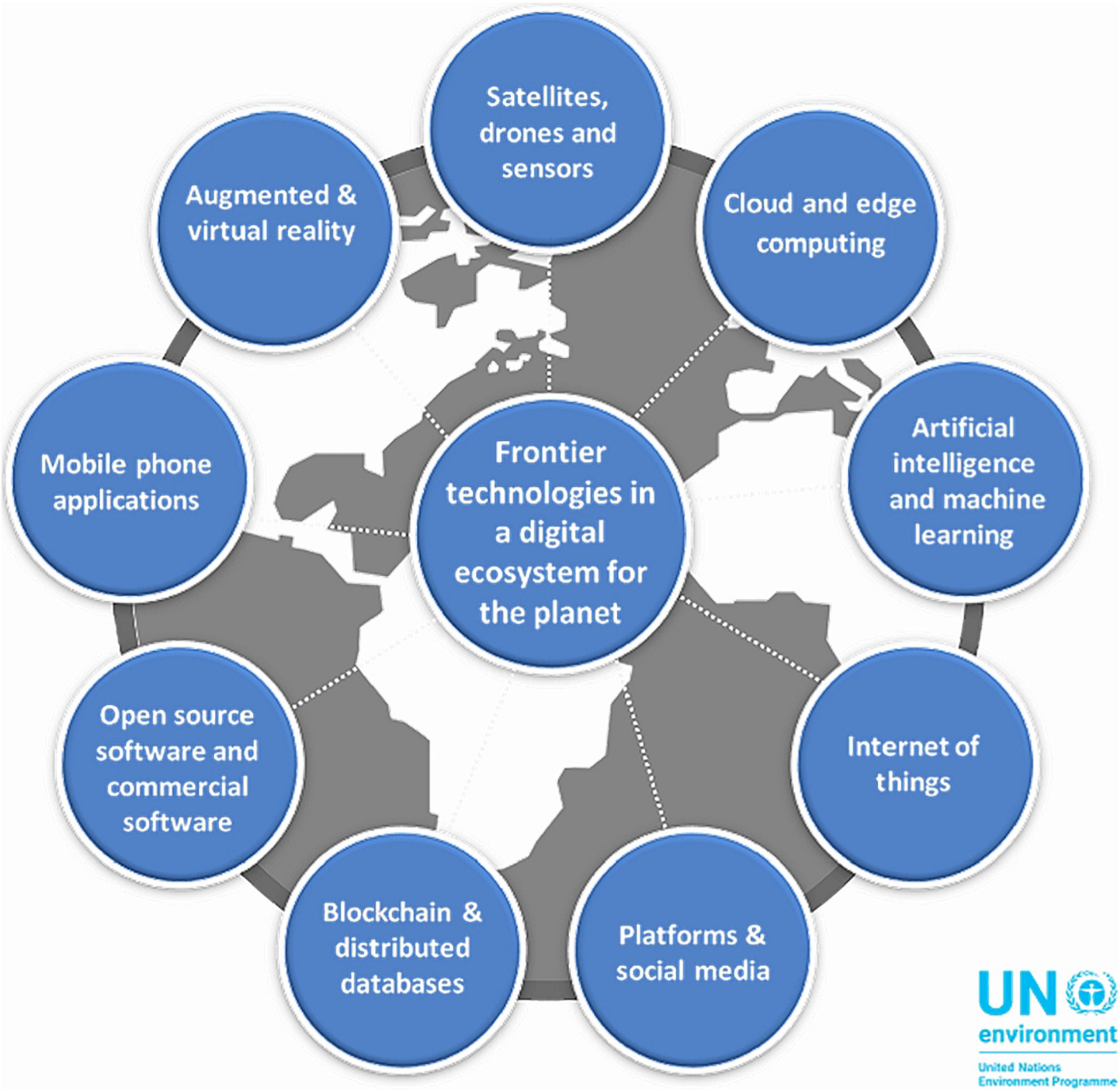

FIGURE 5 | Citizen science activities are embedded in the emerging digital technologies for the monitoring of natural resources and anthropogenic impact on the environment (from Jensen et al., 2019; Courtesy of UN Environment Programme).

quality checking, and analysis of data through the active contact between professional and citizen scientists.

Smartphones and Citizen Science

Technological innovations such as smartphone networked devices equipped with high resolution cameras have a strong potential for data collection, including large scale monitoring activities (i.e., Price et al., 2018), environmental alerts, etc. State of knowledge in the peer-reviewed literature related to the use of smartphone technologies is given in Andrachuk et al. (2019). Web-based and mobile applications contribute to data collection in the form of photographs, sound recordings or visual sightings but also to online tasks, such as transcription of datasheets or classification of media such as images, audio, and video. Metadata, such as position and time of measurement, can be automatically captured using embedded time and global positioning sensors, which are now standard in modern devices. The App BeachExplorer for example allows determination of coastline sightings (natural or anthropogenic) along the Wadden Sea (North Sea) coastline, by means of a visual guide. Beach sightings can be recorded including metadata and photographs. Another examples are the smartphone Apps "Meteomedusa" and "Infomedusa," which allow users to record user comments about the presence of jellyfish on the beaches of Italy (Zampardi et al., 2016) and southern Spain (Bellido et al., 2020).

A new use of smartphones is the possibility to transform them into light, compact and portable high resolution microscopes[5]

[5]https://www.kickstarter.com/projects/blips/diple-the-revolutionary-microscope-for-any-smartphone?lang=fr%20or%20www.smartmicrooptics.com/product/new-blips-labkit-2-explore-the-micro-world/

or their use for taxonomic[6] or acoustic mapping (Mukundarajan et al., 2018). A few oceanographic applications started to emerge recently. One of them is a mobile application called HydroColor that utilises a smartphone's camera and auxiliary sensors to measure the remote sensing reflectance of natural water bodies (Leeuw and Boss, 2018). HydroColor uses the smartphone's digital camera as a three-band radiometer. In the same direction, an add-on for portable spectroscopy and polarimetry (Burggraaff et al., 2020) is a low-cost instrument to mount on a mobile phone for citizen science measurements of aerosols and ocean colour.

High number of projects and applications for smartphones exist; most of them organised through platforms, community hubs for high-quality citizen science exchange, sharing knowledge, tools, training, and resources. An example is the site https://eu-citizen.science/offering to join in about 120 EU citizen science projects. The projects accessible on different platforms worldwide allow collecting a wide range of data using mobile phones. Citizens by mapping habitats and ecosystems; by determination of abundance and distribution of coastal and invasive species, by reports on water levels changes or by monitoring marine debris, in marine conservation projects demonstrate the scientific value of citizen monitoring (Harley et al., 2019). Using smartphone technologies citizen scientists increase the temporal and spatial data acquisition scales and play an important role in monitoring marine protected areas, coastlines and intertidal zones (Vye et al., 2020).

Complementarity of smartphone based marine citizen science data with scientific datasets has been shown. As an example, citizens can assess water colour by means of a Smartphone App (EyeOnWater). In the App, water colour (camera photo) is assigned to the so-called Forel Ule colour scale. The Forel Ule colour can be derived from ocean colour satellite instruments (van der Woerd et al., 2018) and is hence directly comparable to data derived by citizen scientists (Busch et al., 2016a,b). The corresponding Marine Data Repository of the EU project Citclops (finalised in 2015 and taken up by the EyeOnWater initiative) (Ceccaroni et al., 2020) has received about 10,500 entries by January 2021, which shows the use of smartphone technology in marine citizen science projects. This complementary use of citizen science datasets allows a successful integration of citizen science data to advance marine science.

Do It Yourself Sensors for Citizen Science

Even though the DIY approach is only at the dawn of its widespread use by citizens, it can constitute a powerful way to actively engage citizens in both the application and improvement of the sensors. Building a temperature sensor and connecting it to the smartphone can be realised with low costs and low technical knowledge. Quantifying a water parameter such as chlorophyll fluorescence, a proxy closely linked to phytoplankton abundance in the sea, can be achieved using self-assembled electronics in a mechanical housing printed on 3D-printers (Friedrichs et al., 2017). The scientific community proposed two inexpensive turbidimeters under DIY for citizen scientists. The turbidity tube (Myre and Shaw, 2006) is extremely simple to construct but is less precise than the Open Source Turbidimeter (Kelley et al., 2014). A simple hand-held DIY Secchi disc designed to measure the water clarity (or turbidity) of lake, estuarine and near shore regions is described in Brewin et al. (2019). The device is 3D printed. It is inexpensive, lightweight, easy to use from small watercraft and platforms, and accessible to a wide range of users. A low cost multi-sensor prototype for measuring chlorophyll *a* and Coloured Dissolved Organic Matter (CDOM) under water by using contact fluorescent imaging is proposed by Blockstein and Yadid-Pecht (2014). A simpler method proposed by Friedrichs et al. (2017) is the SmartFluo system based on a combination of a smartphone offering an intuitive operation interface and an adapter implying a cuvette holder, as well as a suitable illumination source. It is designed as DIY instrument well adapted for CS use.

A portable light-emitting-diode (LED) photometer has been developed to provide low-cost seawater pH measurements. The benefits of the new system include a simple "do-it-yourself" construction design, a hundredfold reduction in cost relative to benchtop spectrophotometric systems, routine calibration-free operation in the field, and precision and accuracy well suited to applications such as education, coastal zone monitoring (including citizen science programmes) and aquaculture (Yang et al., 2014).

High-resolution microplankton (20–200 microns) images (**Figure 6**) can be acquired by the PlanktoScope, an inexpensive imaging platform (Pollina et al., 2020). Its modular configuration is based on DIY hardware and open software. The control of the instrument is possible from any device able to access a browser through a WiFi connection and the image processing is based on a python-based library designed to handle large volumes of imaging data. The *In situ* Plankton Assemblage eXplorer (IPAX) enables the transition toward higher size spectra. It is an open-source low cost-imaging platform for zooplankton (>100 microns). It is a programmable instrument with LED illumination and a high resolution camera for *in situ* recording. Its field of view and focal depth are $50 \times 30 \times 5$ mm. It allows autonomous plankton survey (Lertvilai, 2020).

The DIY activity has the potential to aggregate multidisciplinary citizen know-how around signal acquisition and processing with rigorous data quality control. It may stimulate the move from simple data collection to hypotheses based projects.

Autonomous Unmanned Systems or Drones

In recent decades, autonomous unmanned systems (AUS) or drones, both aerial and submarine, have received increasingly significant attention due to their potential to enhance unmanned system intelligence, unmanned system performance, and efficiency. One of the key objectives of AUS systems is to realise a high degree of autonomy under dynamic, complex environments.

Recent advances in unmanned aerial vehicles (UAV) or aerial drones imagery, sensor quality/size, and geospatial image processing can enable UAVs to rapidly and continually monitor

[6]https://www.inaturalist.org

FIGURE 6 | Examples of Mediterranean microplankton imaged by PlanctonScope. PlanktonScope is an inexpensive imaging platform for citizen oceanography (Pollina et al., 2020) with a modular configuration based on do it yourself hardware and open software. The control of the instrument is possible from any device able to access a browser through a WiFi connection (Courtesy of EcoTaxa plankton imagedatabank; https://ecotaxa.obs-vlfr.fr/).

coral reefs and other coastal environments (Parsons et al., 2018; Merlino et al., 2020). Aerial drones can provide cost-effective monitoring of the environment at spatial and temporal resolutions that are appropriate to the scales of many ecologically relevant variables. Citizen scientists have used them to study El Niño, observe erosion, and monitor the behaviour of sea turtles and marine mammals (Hodgson et al., 2013). The advancements in aerial drone technology have revolutionised the production of aerial imagery. Aerial drones were used by citizen scientists to measure eelgrass meadow extent, patchiness, and dynamics through time on transects along the coast using Public Participation Geographic Information System (PPGIS)[7].

Citizen-science aerial drone surveys are a cost-effective method, which both engages local communities in management

[7]http://www.citizensciencegis.org

and delivers highly precise and accurate data for researchers and managers. This type of drones enable rapid surveying of beach volumes and therefore provide critical information for determining the dynamism of beaches. Pucino et al. (2021) documented this work undertaken by citizen scientists using a protocol made by Australian scientists. The results show that citizen scientists' data were of comparable accuracy to professionally acquired UAV datasets. Another example is the combination of citizen science observations, aerial drone photography and satellite imagery to document and analyse hurricane impacts in eastern Caribbean. Quantifying the impact of the hurricane event on landscape is an important critical step guiding restoration of ecosystem communities (Boger et al., 2020). Coastal habitats are the critical first line of defence from storm damage. It takes just a few hours to produce a high-resolution orthorectified mosaic from multiple individual aerial images taken by aerial drones equipped with associated flight control and image processing applications. In spring 2020 NASA released a new citizen science opportunity – a video game where players build a map of the world's coral reefs. Special "fluid lensing" cameras were mounted on drones to survey the seafloor. Just by playing their video game, NeMO-Net, volunteers help map the world's coral reefs[8]. Beside continuous amelioration of UAS, the next developments will include swarming methods usually inspired by nature, such as bird flocks or fish schools, to achieve complex common objectives through collaborative behaviours.

[8]www.nasa.gov/solve/Nemo-Net/

Unlike aerial drones the underwater or surface drones are not cost-effective and are only rarely used by non-professional scientists. Nevertheless, they have a strong educational potential. For example the project "Adopt a float"[9] is based on the idea that middle school classes adopt profiling Argo floats, to accompany their long-term data acquisition to better understand the marine environment and the scientific method while sharing with the scientists the discoveries in near real time Underwater drones will help discover things that are impossible to achieve using scuba diving. Typically, these drones are divided into two camps: remotely operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs). ROVs are the devices that are now coming down into the consumer price range. Consumer ROVs today require a tether, or a cable that connects them to the remote control device. They generally come with lights and high-resolution cameras that can send photos and videos back to any device able to run a standard Web browser, such as a laptop or tablet computer[10].

Artificial Intelligence and Big Data Treatments

Artificial intelligence has become an integral part of our lives. Search engines, language translators, customer portals, diagnostic systems, manufacturing robots. The list of AI applications is long, but it is only at the beginning. No technological innovation has developed as rapidly as this branch of information technology in the last 10 years. However, the question if AI can contribute

[9]http://www.monoceanetmoi.com/web/index.php/en/adopt-a-float-project
[10]https://www.mpacollaborative.org/resources/rovprogram/

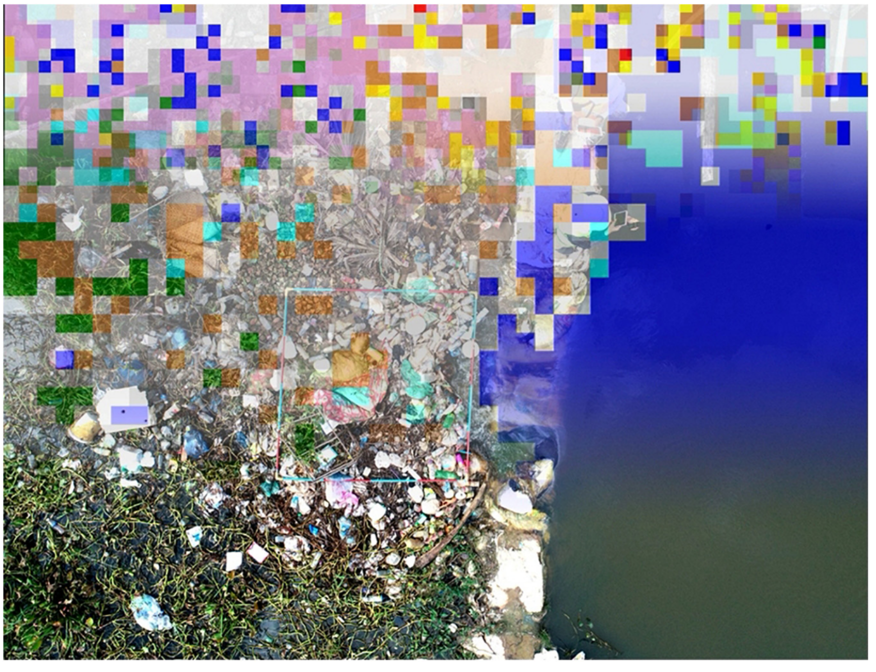

FIGURE 7 | Application of the APlastic algorithm, originally designed for UAV operations over plastic liter, from a citizen smartphone (Courtesy of DFKI-German Research Center for Artificial Intelligence).

to saving the (blue) planet is still to be answered. In a study published in 2018 by the World Economic Forum ("Harnessing Artificial Intelligence for the Earth"), the six most urgent challenges for the use of AI are identified: Climate change, biodiversity conservation, healthy oceans, water security, clean air, and resilience to extreme weather events and natural disasters. The utilisation of AI as an empowerment for citizens to monitor the marine realm and contribute to its protection is in its infancy but of highest potential, given the rapid development of this technology and its pervasiveness of our daily lives.

An example of AI-supported analysis of sensor data is the World Bank-funded initiative to collect plastic waste information over Asian rivers (Wolf et al., 2020). Research shows that more than 2/3 of the plastic waste in the ocean is discharged by just 20 rivers, most of it in Asia (Lebreton et al., 2017; Schmidt et al., 2017). Wolf et al. (2020) use multispectral image data of drone flights from Cambodia, the Philippines and Myanmar to determine both the amount and the composition of the debris using a two-step approach of artificial neural networks. The former is relevant for efficient waste disposal, while the detailed information on individual waste components (cups, food packaging, and transport containers) helps local authorities to identify the sources of plastic waste and to take countermeasures. "Closing the Loop" is the name of the appropriate initiative of the United Nations, which aims to enable the Southeast Asian ASEAN countries to tackle the problem of littered rivers, coasts and seas through technological innovations. With respect to the wider integration of citizens (beyond the broad availability of UAV platforms or drones), their algorithm is adaptable to smartphones, enabling direct applications (see **Figure 7**).

Artificial intelligence is above all a tool: designed to recognise patterns in complex data, to learn from this data, and to use what has been learned to achieve specific goals through flexible adaptation (Kaplan and Haenlein, 2019). It brings risks but also important opportunities for environmental protection and the transformation of our society toward ecological, social and economic sustainability. Integration of citizen science activities and AI may allow scientists to create and process larger volumes of data than possible with conventional methods (McClure et al., 2020). With the increasing capacity to collect big datasets, data processing may become a major bottleneck. Complementarity of citizen science and AI has the potential to maximise outcomes in ecological monitoring for scientists and conservation managers by analysis of big data sources (Ditria et al., 2020). Crowdsource projects, for example on the Zooniverse platform, can combine AI with image identification, classification, and validation by citizen scientists. AI based automated identification of sound or images is already used in conservation biology (Kwok, 2019). Future technological advances in the application of interconnected devices combined with citizen science may provide ecologists with management systems where continuous environmental information flows at high temporal resolution.

Social Media in Citizen Science Projects

By the end of 2020 there were 2.7 billion Facebook and 262 million Twitter users around the world. Europe has 387 million Facebook users[11]. Internet is a source of unprecedented amounts of diverse and accessible data, via webpages, social media, and various other platforms. Social media may significantly contribute to the development of Citizen Science by providing forums to discuss projects, share results and to feel part of a community, which they are contributing to. Digital data that are constantly created and stored in the digital realm may provide new understandings of ecological dynamics and mechanisms, in complement to traditional methods. A number of information is gathered through Facebook groups (Encarnação et al., 2021) such as observations of non-indigenous species at sea and on land (Bariche et al., 2018; Rahayu and Rodda, 2019; Azzurro and Tiralongo, 2020). Emergence of new data sources will require the use of search machines, new ways of data handling and dedicated methods to analyse them (Jarič et al., 2020).

CONCLUSION AND FUTURE PERSPECTIVES

This first analysis of the current state of marine and coastal citizen science in Europe is largely based on a review of the North Sea area with extensions added from surveys in Norway and France. A quantitative assessment of this kind is not available yet for all marine regions in Europe, but we consider, from the many existing initiatives in the Mediterranean basin for instance, that marine citizen science is omnipresent all over the continent, and holds a high and partly untapped potential.

An overall directory of existing marine citizen science projects in Europe is still missing and we strongly recommend developing such a directory in order to increase transparency and overview Citizen science can be a powerful tool in shaping an open science landscape in Europe.

Whereas today a majority of the citizen science projects is having a focus on life sciences and the study of species, new opportunities are present in the field of coastal morphology and protection, history, weather and climate, human health at the coast, etc. Also in terms of policy, marine and coastal citizen science is a promising and still undervalued format. It will help bridging the gap between researchers and the wider public and create higher ocean awareness.

Development of new technologies both instrumental and dematerialised shows great potential for advancing citizen science. Progress made in affordability and networking capacities allow for example citizen science activities in low-income countries. Data collection can now be carried out through a wide range of new instruments, devices and tools including mobile apps, interactive web services and DIY technologies. More than 5 billion privately owned smartphones with the possibility to deliver geocoded data are used on a daily basis all over the world.

Effective efforts are urgently required to improve the capacity of marine conservation as highlighted by the United Nations Decade of Ocean Science for Sustainable Development 2021–2030. Citizen science can

[11]https://www.omnicoreagency.com/facebook-statistics

act at large geographic scales as well. However, the methodological approaches necessary to ensure the quality of data provided by citizen science must evolve with technological development and the nature of projects.

The current demographics demonstrate that special attention should be paid to those that are, mostly unintentionally, excluded from citizen science activities (Haklay et al., 2018). Understanding of scientific reasoning helps evidence-based policy-making particularly nowadays when society has difficulties to discern between scientific facts and misinformation (Scheufele and Krause, 2019). Therefore efforts should be deployed to support citizen science activities in national and international research calls.

AUTHOR CONTRIBUTIONS

CG-S conceived the manuscript. JS led section "The Current State of Marine Citizen Science in Europe." OZ, GG, and JB led section "The Role of Technology in Marine Citizen Science. Recent Developments." All authors contributed to the article and approved the submitted version.

FUNDING

This study was funded by the project of the European Union BLUEMED (GA 727453).

ACKNOWLEDGMENTS

Most of the authors belong to the Working Group on Citizen Science of the European Marine Board (EMB) that published the EMB Position Paper 23 "Advancing Citizen Science for Coastal and Ocean Research" (Garcia-Soto et al., 2017). See https://www.marineboard.eu/citizen-science. The present article is a continuation of that previous joint work. GIvM acknowledges the help of the following Norwegian researchers that accommodated her with project statistics and other input from Norway: Bjørn Einar Grøsvik (IMR), Hans Victor Koch (IMR and Dugnad for Haved), Tycho Anker Nilssen (NIVA and SEAPOP), Torild Loenneche Moen (Artsdatabanken), Karoline Viberg (MASNN), and Franz Uibein (IMR and Fiskefunn). The authors thank the Assistant Editor TN and the reviewers that helped to improve the article.

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Conflict of Interest: IK-Z was employed by Today We Have, and PL and GM were employed by Collectif Vigie Mer-LPO.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.