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6.13. The contribution of citizen science and participatory monitoring systems to ocean knowledge and conservation

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The ocean and its biodiversity shape the characteristics of the Earth. The ocean dictates our climate, represents a large part of our food supply, plays an essential role in the global economy and supports a great diversity of life and ecosystems. The ocean and humans are deeply interconnected. However, our knowledge of this important ecosystem is relatively limited: it is estimated that less than 5% of it has been explored, and, as a result, there could be about one million species unknown to science (Ocean Literacy Network 2020). There is an urgent need to increase our knowledge of the oceans at a faster rate. Citizen science and participatory monitoring systems are part of the critical strategies for reducing these knowledge gaps.

Citizen science is a growing practice in which scientists and citizens actively collaborate to produce new knowledge for science and society (Vohland *et al.* 2021), but it is not a new practice. Historically, fishers and sailors have contributed their observations and knowledge to the study of marine life and the understanding of the ocean. The collaborative production of knowledge between scientists and volunteers in the ocean, including coastal beaches and estuaries, is known today as marine citizen science (MCS).

Marine citizen science: context and contribution

Thousands of volunteers have been involved in a wide range of marine research, such as collecting observational data on marine species and monitoring marine debris and environmental variables such as water turbidity, sediments and other essential variables for monitoring climate change. MCS is also a powerful tool for monitoring the arrival and encroachment of invasive non-native species. It is estimated that 500 MCS projects are currently underway in Europe, with exponential growth since 1990, and this trend is reflected globally (Garcia-Soto *et al.* 2021). In most MCS projects, volunteers are exclusively involved in data collection (Garcia-Soto *et al.* 2021). More collaborative approaches in which citizens participate in the whole research process are less common but extremely necessary for generate a transformative change both in the way of building knowledge and in its ability to impact socio-ecosystems.

MCS projects vary from days to decades and focus mainly on coastal ocean environments, closely followed by easily accessible coastal regions. The most popular methods for collecting data are field surveys and reporting of opportunistic sightings. Novel methods are also developed, such as ocean temperatures recorded from divers' computers and surfboard fins with sensors that collect real-time ocean parameters (Earp *et al.* 2020). Technological innovation has also made it possible to expand the spectrum of participation, for example, with do-it-yourself sensors such as KdUINO, which measures water transparency, or through the *Patí Científic* platform, which uses the instrumentation of recreational boats to capture oceanographic variables. Virtual participation has also made

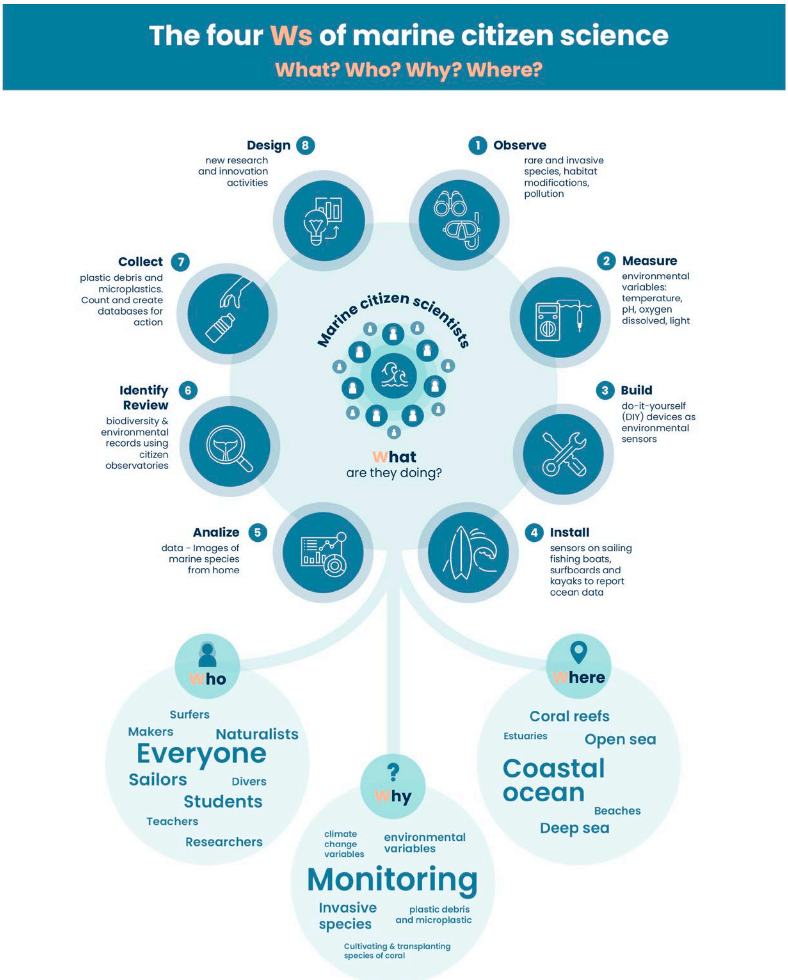

Figure 1. The four Ws of marine citizen science: What? Who? Why? Where? The spectrum of participation in marine citizen science (MCS) is wide. More and more enthusiasts and researchers collaborate by collecting data, analyzing information, building monitoring devices, and even designing investigations. The 4ws of MCS is a panoramic look at the diversity of participant profiles, activities that are being carried out, types of projects and ecosystems in which MCS has been contributing to the knowledge of the ocean.

its way into MCS. Volunteers from around the world participate "virtually" from the comfort of their homes, analysing over two million images of the seafloor to investigate the distribution of commercially important marine species. Other approaches such as iEcology and Culturomics also use data accumulated in digital sources generated passively or unintentionally by citizens to quantify patterns and processes in the natural world (Sbragaglia *et al.* 2022).

MCS has also been contributing to scientific publications. Earp *et al.* (2020) identified that 44 MCS projects had contributed data to at least 1483 peer-reviewed journal articles. Other significant contributions to the documentation of marine life are biodiversity guides authored by citizen scientists; some examples are the Seasearch guide of sea squirts and sponges of Britain and Ireland and the recent Barcelona Participatory Marine Guide. Another significant contribution by MCS includes enhanced marine policy and environmental stewardship. Marine regulation often requires evidence supported by large databases that citizen science can provide cost-efficiently. For example, in the UK, the Seasearch data set that extends back to 1984 has contributed to the designation of 38 marine conservation zones and several other marine protected areas (Earp *et al.* 2020). Climate change has been another area in which MCS has contributed. The Marine Biodiversity and Climate Change (MarClim) project continuously provides data to highlight changes in the geographical distribution of marine species caused by climate change and offers advice for policy-making.

Marine citizen science: challenges and opportunities

Data quality and long-term engagement of participants are among the most common challenges facing MCS projects. Despite evidence that the quality of citizen science data is comparable to that collected by scientists, it is not yet fully recognized by the scientific community (Martin *et al.* 2016). Many factors also affect participant engagement, especially because marine systems pose their own unique challenges: greater inaccessibility makes them less easy to monitor than land-based habitats, and the logistics can require boats, diving gear, specific equipment and previous skills in the case of diving for example.

Overcoming these challenges involves designing activities for the wider public that eliminate as many barriers as possible, such as observation in accessible coastal areas focusing on mammalian, avian or seashore species, which can be identified above water. Also, the strategies implemented should consider social factors, such as the networks of participants (i.e. family and friends) to increase long-term involvement (Martin *et al.* 2016). Regarding data quality, it is important to increase the use of standards in the citizen science community and to promote interoperability between platforms. It is also necessary to strengthen the infrastructure to facilitate the publication of open data following the principles of FAIR data (findability, accessibility, interoperability and reusability). Strengthening the technological facilities that support citizen science, known as citizen observatories, is also necessary. These facilities allow biodiversity and environmental data to be gathered, stored and made available in an open and interoperable space. Another way to decrease knowledge gaps and increase engagement is to strengthen the citizen observatory mechanisms for collaborative validation of observations.

MCS has been shown to have great potential for reducing ocean knowledge gaps and contributing to the conservation and management of marine ecosystems. Its ability to generate information on multiple spatio-temporal scales, to actively involve a wide range of stakeholders and to increase ocean literacy makes it a pillar for achieving a sustainable ocean.

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