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Specific initial training standards are needed to dive for science in Europe, Occupational *vs*. Citizen Science Diving

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Today, collaboration between scientific research and civil society is growing significantly. The general public's curiosity drives it to engage with the scientific process and culture and in the search for solutions to complex issues (economic, social, health, environmental, cultural, educational, or ethical). Clarification is needed to differentiate between occupational scientific activity and citizen-based science. They do not require the same scientific and technical skills despite using similar equipment and their legal and administrative frameworks being totally different. The confusion created by the indiscriminate use of the same term "scientific diving" to refer to different training courses and activities compromises the quality of existing occupational standards and, ultimately, has a negative impact on the safety of the activity at work. A clear definition of Citizen Scientific Diving and Occupational Scientific Diving makes it possible to differentiate between the objectives and target groups of these two activities and their legal framework. There is a need to establish an accepted and shared standard in the occupational field and to ensure the mobility of scientists. A long process undertaken by a motivated scientific community (late 1980s-2000s) led to the establishment of European initial training standards for Occupational Scientific Diving through the ESDP-European Scientific Diving Panel (firstly under the aegis of the European Marine Board, now of the MARS-European marine stations network). The quality and general acceptance of these standards by a large part of the European scientific community have already adopted them in the occupational health and safety legislation of seven European countries (Belgium, Finland, France, Germany, Norway, Sweden, and the UK in 2023). Adopting them in other countries' health and safety legislation is still desirable. This will increase their recognition, acceptance and use for the benefit of scientific work. Building bridges between academic science and non-academic citizen science is possible and this is done by developing coherent projects that produce results that benefit both science and society. While distinguishing between the two, as an added value, this approach could better guide the recreational diving training sector in developing a new market.

KEYWORDS

academic science, citizen science, recreational diving, European scientific diving panel-ESDP, initial training competence, natural and cultural underwater heritage

1 Introduction

The practice of SCUBA diving is commonly associated with the conflicting notions of both risk and leisure. Today society refuses the notion of risk, resulting in a complex image, often confused. This explains both the apprehension and the lack of interest of states and institutions to recognize and legislate this technique as a research tool distinct from recreational and commercial diving. This has been and still is, depending on the country, a real drawback in the use of the technique in professional science (ESDP, 2022a). Starting in the 1980s, due to the ever-increasing difficulties limiting the use of diving as a research tool, European scientists have been working to find ways to practice it in their own national waters and in collaborative research in other EU countries. The need to control risks inside complex and diverse legal frameworks of EU states led to the elaboration and adoption of minimum standards for initial training. This was aimed at enhancing the mobility of scientists within the EU. Two tested and accepted levels of competence have been endorsed: ESD-European Science Diver and AESD-Advanced European Scientific diver (Sayer et al., 2008; Féral, 2010). A mutual recognition system (equivalence) based on the existing standard has been created to ease the mobility of scientists fully trained in scientific diving inside the EU. The system will state as equivalent inside the EU the national and legally recognized competence certificate of another member state. That system known as the (A)ESD system, already concerns 16 European countries. Nine of them have legislation applying to Occupational Scientific Diving (Belgium, Finland, France, Germany, Norway, Poland, Spain, Sweden, The United Kingdom) (Table 1). Except for Spain and Poland, those countries have standards to guide the application of their legal texts concerning Occupational Scientific Diving.

In the meantime, a new factor has emerged. Leading recreational diving training agencies [among others the Professional Association of Diving Instructors (PADI), the World Underwater Federation (CMAS) and the Global Underwater Explorers (GUE)] offer science labeled training courses. They train, directly or through affiliated associations, recreational divers in some scientific subjects. The World Underwater Federation started that process as early as 2000 with the launch of its "Scientific Specialty Courses" (CMAS, 2000a), changing its name

TABLE 1 European legal references for scientific diving at work: Founding text and definition of minimum standards for initial training [system A(ESD) or equivalent].

Country	Title	Access to legal documents	OSD by law	Standards included
Belgium	Arrêté Royal du 7 Février 2018, code du bien être au travail, titre 4: travaux en milieu hyperbare. Moniteur Belge 26/2/2018/200360	https://emploi.belgique.be/sites/default/files/content/documents/Bien-%C3%AAtre%20au%20travail/R%C3%A9glementation/Code%20livre%20V%20titre%204%20Travaux%20en%20milieu%20hyperbare.pdf	yes	yes
Finland	Valtioneuvoston asetus 1209/2019 rakennustyötä tekevän sukeltajan pätevyydestä ja turvallisuussuunnitelmasta annetun valtioneuvoston asetuksen 2 §:n muuttamisesta	https://www.finlex.fi/fi/laki/alkup/2019/20191209	yes	yes
France	Décret n° 2011-45 du 11 janvier 2011 relatif à la protection des travailleurs intervenant en milieu hyperbare Amended 2022	https://www.legifrance.gouv.fr/loda/id/JORFTEXT000023413027version2023	yes	yes
Germany	Regel "Einsatz von Forschungstauchern" (BGR/GUV-R 2112) Juni 2001 Amended 2011	Arbeitsschutzgesetz _ https://www.gesetze-im-internet.de/englisch _arbschg/englisch_arbschg.html 7. Buch Sozialgesetzbuch _ https://www.ilo.org/dyn/natlex/natlex4.detail?p_lang=en&p_isn=44881&p_country=DEU	yes	yes
Norway	Arbeidstilsynet_Dykking Forskrift om utførelse av arbeid, bruk av arbeidsutstyr og tilhørende tekniske krav (forskrift om utførelse av arbeid) _ Fjerde del: Krav til annet risikoutsatt arbeid _ Kapittel 26. Om sikkerhet og helse ved arbeid under vann eller økt omgivende trykk	https://www.arbeidstilsynet.no/tema/dykking/ https://lovdata.no/dokument/SF/forskrift/2011-12-06-1357/kap26#kap26	commercial diving	yes
Poland	USTAWA z dnia 17 października 2003 r. o wykonywaniu prac podwodnych	https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20140001389/O/D20141389.pdf	yes	no
Spain	Real Decreto 550/2020, de 2 de junio, por el que se determinan las condiciones de seguridad de las actividades de buceo	https://www.boe.es/buscar/act.php?id=BOE-A-2020-6745	depending on community	no
Sweden	AFS 2010:16/Dykeriarbete Arbetsmiljöverkets föreskrifter om dykeriarbete samt allmänna råd om tillämpningen av föreskrifterna. amended 2019	https://www.av.se/arbetsmiljoarbete-och-inspektioner/publikationer/foreskrifter/dykeriarbete-afs-201016-foreskrifter/	yes	yes
United Kingdom	The Diving at Work Regulations 1997: UK Statutory Instruments, 1997, N° 2776	https://www.legislation.gov.uk/uksi/1997/2776/contents/made	yes	yes

Occupational Scientific Diving is recognized by law in 9 European countries. 7 of them have already incorporated minimum initial training standards into their legislation governing such diving.

in 2018 to "Non-professional Scientific Specialty Course" (CMAS, 2018). This new kind of training standard was developed for the recreational diver interested in science. This kind of training is also needed to better support participative science (Citizen Science Divers). Nowadays the generic term "Scientific Diver" for all the individuals diving "at large" for science is in use and creates confusion (ScienceDiver, 2018).

The result is a blurred landscape between, on the one hand, professional scientists diving in the framework of national laws and health and safety regulations at work (the Occupational Scientific Diver) and, on the other hand, volunteer recreational divers active in Citizen Science projects (the Citizen Science Diver). The main differences between the two activities lie in the purpose, the targeted social group, the training content and time scale, and the time validity of certification. For the occupational scientific diver, the purpose is scientific research. It is operated by professional scientists using diving as a tool for research. For the citizen science diver, the purpose is the participate in scientific research on a volunteer basis. It is operated by recreational divers. Occupational qualification is time-limited, usually 5 years, allowing for activity verification following given criteria, while the certification for a Citizen Science diver is for life. Those constraints contribute significantly to the lower accident rate for Occupational Scientific Diving than for any scuba diving activities (Sayer, 2004; Sayer and Forbes, 2007; Dardeau et al., 2012; Lucrezi et al., 2018a).

To enhance the mobility of scientists using diving inside the EU and to guarantee a safe practice, there is a need for uniform Occupational Scientific Diving training standards. This is the first step towards equivalence, based on competence certificates, recognized by the EU Member States. Accepted and recognized initial training accompanied by the issue of a certificate validated by a legal authority (e.g. Ministry of Research or Ministry of Labor) achieves the goal.

This demonstrates a need to define both types of underwater activities linked to science and their productive interactions for science. Further it is of general interest for legislators, managers, heads of laboratories, health and safety departments, research vessel cruise organizers and the diver to avoid any misunderstanding about what scientific diving is.

The aim of this article is to present the state of the art of Occupational Scientific Diving in Europe. This is in light of the circumstances and events that have led to the establishment of minimum standards of competence required to use diving at work as a research tool for different scientific fields. As the situation has not yet stabilized, this article also suggests ways to draw up an [equivalence list] of nationally delivered certificates. This would guarantee the mobility of trained occupational scientific divers as well as the safety of the activity. This further guarantees the possibility of using diving techniques to observe, monitor and gather *in-situ* data in all European countries adhering to such a system. This article also demonstrates the added value the recreational diving sector provides to science. There is, therefore, a need to define in relative terms what these modes of diving are, as well as the types of divers and their roles in a successful coordinated research project. This paper also illustrates the importance of the overall policy changes needed in the EU to facilitate and guarantee the use of diving as an indispensable tool that is effective for research, observation, data collection, monitoring and management of underwater environments from the surface to the mesophotic zone. Nowadays, a depth of 100 m is easily and safely reached by using mixed gases closed circuit rebreathers (Norro, 2016; Pollock et al., 2016).

1.1 Definitions and rationale

1.1.1 Occupational Scientific Diving

Occupational Scientific Diving is diving that supports professional research and education. Moreover, Occupational Scientific Diving is key in protecting, conserving, and monitoring the natural and cultural heritage. Occupational Scientific Diving exists in a health and safety framework that involves certified scientific divers, diving officers, hyperbaric physicians, scientific project leaders, heads of scientific laboratories, administrators, and legislators.

Diving in an occupational framework is a highly productive, cost-effective research tool that supports a wide range of aquatic science disciplines, including underwater archaeology and water body management (Sayer et al., 2008; Féral, 2010; Benjamin and MacKintosh, 2016; Flemming, 2021a; ESDP, 2022a and ESDP, 2022b). In addition to surface-operated sampling from research vessels, medium and deep-water landers and the application of Remotely Operated underwater Vehicle (ROV), Autonomous Underwater Vehicle (AUV), and gliders, Occupational Scientific Diving supports cutting-edge aquatic sciences in both marine and freshwater environments. Furthermore, diver-supported aquatic research allows for high-quality, highly selective, accurately repeated, and ecologically compatible research. Today, Occupational Scientific Diving is considered an essential tool for many research projects, predominantly in depth ranges of 0 - 50 m water depth (Lang et al., 2013a). But with the technical capability of a rebreather and mixed gases, it is possible to extend the depth and/or bottom time of the dive to reach and explore the mesophotic zone (Lang and Smith, 2006; Sayer, 2006; Sayer et al., 2008; Norro, 2016; Pollock et al., 2016; ESDP, 2021).

Occupational Scientific Diving is an investigative tool employed widely throughout Europe, and elsewhere, supporting many high-quality marine research programs over many scientific disciplines (Sayer and Barrington, 2005; Lang et al., 2013a). This tool also permits the publication of numerous high-quality papers (impact factor of 5 or more https://www.esdpanel.eu/sd-supported-articles-in-if5-journals/). It is a versatile vehicular platform that can deliver sustainable specimen collection, quantitative observations, and *in-situ* measurement of biotic and abiotic targets. Often, diving supports complex experimental work, sometimes in restrictive environments and gives the scientist the opportunity for direct access to their underwater work. Furthermore, Occupational Scientific Diving strongly supports research in coastal waters (Cattaneo-Vietti and Mojetta, 2021), which, according to IPCC-reports (Cooley et al., 2022; Costello et al., 2022), are the most vulnerable marine environments to the effects of global warming. Occupational Scientific Diving is also beneficial in various disciplines, such as geology (Caramana, 2013) or geochemistry (Caramanna et al., 2021). There is a clear need for developing "intelligent monitoring systems", which, in coastal waters, can be achieved much more efficiently and cost-effectively by combining scientific skills and capabilities underwater with technologies (ROV, gliders, AUV, or landers). This is particularly effective for undertaking science in coastal or restricted/remote environments, *e.g.*, polar regions and under the ice, where Occupational Scientific Diving can offer an accurate and reliable method for deploying, maintaining, and retrieving equipment in remote locations. Occupational Scientific Diving can be used to research global scientific questions, including climate change, ocean acidification, seafloor ecosystem functioning, or paleoclimate reconstruction.

In the same way, Occupational Scientific Diving was introduced and developed for archaeological research as soon as equipment accessible to the public appeared (Link, 1959; Goggin, 1960). Underwater archaeology involves more than study of wrecks (shipwrecks, aircraft). Sites are diverse in nature, including areas where people lived or visited (*e.g.* mapping of ancient topographies), more or less recently submerged due to sea level rise due to local seismic events or broader continental-scale climate change (Flemming, 2021b), wells, remnants of infrastructure (bridges, harbors), and waste or debris (garbage, ships, aircraft, munitions, and machinery) disposed of by dumping at sea, lakes, or rivers (Benjamin and MacKintosh, 2016).

Occupational Scientific Diving is becoming increasingly important as a relevant monitoring tool supporting policy needs, particularly in addressing legal and statutory monitoring requirements. Occupational Scientific Diving is also consistent with the international demand for a responsible, resource-conserving, and sustainable research methodology in Europe. A major constraint is that occupational scientific divers must work according to the current employment rules and the employer's/state's responsibilities. In addition to the intrinsic specificities of Occupational Scientific Diving (objectives, training, working population), this aspect represents an additional significant difference from the other diving aspects that may cohabit in science. For example, Citizen Scientific Diving involves different insurance coverage systems and is aimed at recreational divers who exist in large numbers and with extremely varied profiles. There is a significant added value for science should one take advantage of the large number of data such a group could produce. Building bridges between Occupational Scientific Diving and Citizen Science Diving is becoming more and more of an operational necessity. Developing cooperative ventures will make science more effective and open up an increasingly important field of action for recreational diving, one of the positive consequences of which will be a growing awareness of the underwater environment.

Occupational Scientific Diving should not be confused with diving for Citizen Sciences (Citizen Scientific Diving). Figure 1 distinguishes the processes in the Academic Sciences and illustrates feedback loops between Occupational Scientific Diving and Citizen Scientific Diving. The modern public awareness of the protection of the environment and/or the global warming (Lucrezi et al., 2018a; Kelly et al., 2020; Flemming, 2021a; Marlowe et al., 2021 and Marlowe et al., 2022) is increasing the involvement of the citizens in participating in science where possible. This can include using the SCUBA diving techniques. Understanding the importance of participating in scientific research to improve safety standards in SCUBA diving should be part of the "end of course" package for beginners. This could motivate young divers to participate in Citizen Science to support safety policy (Lucrezi et al., 2018b).

A project such as ScienceDiver (ScienceDiver, 2018; Tourtas et al., 2020) aimed at creating a new market for specific scientific-oriented diving is an initiative resulting from increased public awareness. The necessity for the most extensive possible clientele following the creation of a new market means that existing training standards, adapted to the realities of scientific needs, safety, and professional insurance coverage (sometimes by the state itself), may risk being lowered so that the initial requirements are not too restrictive, and therefore not limiting the number of potential customers and the revenues expected from the new market. The evidence of this strategy is understandable when the confusion between the vocational practice of researchers, university lecturers and professors, and PhDs on the one hand and that associated with activities linked to the Citizen Sciences, on the other hand, is appreciated. Again, a clear distinction is needed to avoid proposing to an insufficiently informed public, training not directly followed by the delivery to successful applicants of a legally accepted certification for the anticipated career.

1.1.2 Citizen Scientific Diving

This term has yet to be widely used, due to the confusion caused by the weak definitions of Scientific Diving. From an overall point of view, the development of underwater diving techniques and their ever-increasing popularity explains why the use of SCUBA diving to implement and develop voluntary Citizen Science actions has grown enormously. It should, however, be borne in mind that the legal framework, objectives, actors, and audience are different from Occupational Scientific Diving. Another essential aspect, Citizen Science (common synonyms are amateur science, community science, crowd science, crowd-sourced science, civic science, and volunteer monitoring), is participation in scientific research conducted, in whole or in part, voluntarily by amateur and/or nonprofessional scientists. Citizen Science is sometimes described as public participation in scientific research or participatory monitoring. Those participatory actions of research conduct often advance scientific research by improving the scientific communities' capacity. It also contributes to the public's awareness and understanding of science and, thus, respect for the environment. This agrees with the definition of BioDiversa reported by Goudeseune et al. (2020): "*the involvement of the non-academic public in the process of scientific research - whether community-driven research or global investigations*".

The fields of action are so broad and different, as are the data collection and processing, that it is challenging to define Citizen Science (Haklay et al., 2021a). Haklay et al. (2021b) comprehensively explore the diverse perceptions of Citizen Science. It is to be noticed that the main fields of development of Citizen Scientific Diving are ecology and the environment (Dickinson et al., 2012; Fraisl et al., 2022), including pollution

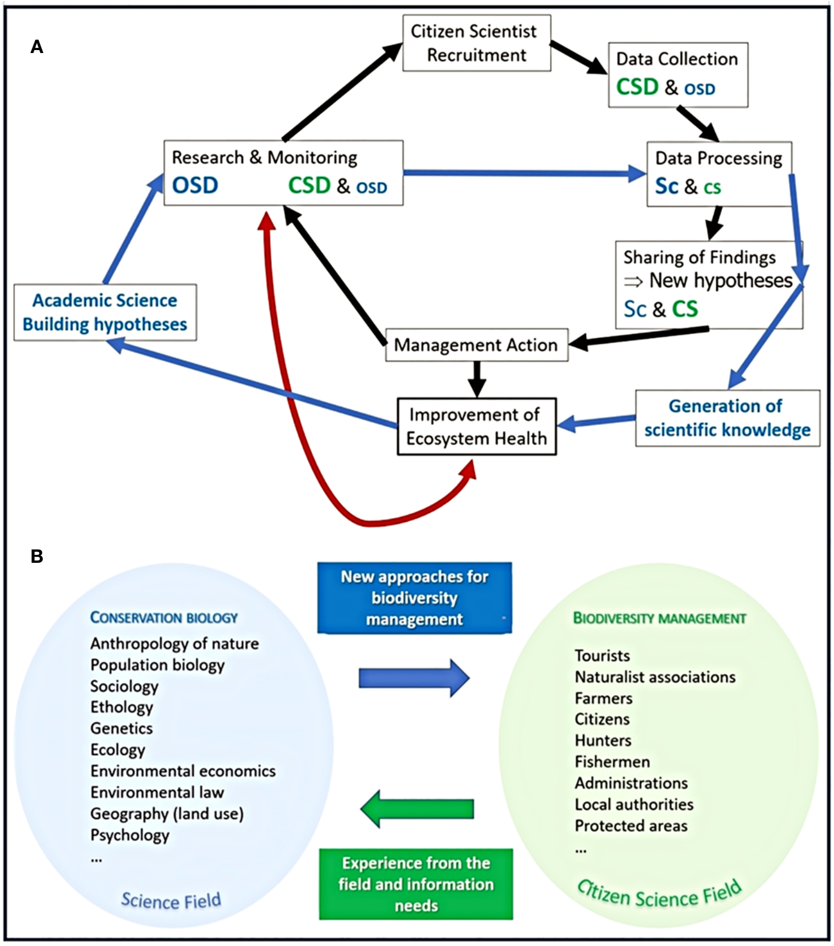

FIGURE 1
Role of Citizen Scientific Diving in the mainstream subaquatic research and monitoring. **(A)** Citizen science creates a feedback loop (*black arrows*) propelling research and monitoring forward improving ecosystem health (after Metcalfe et al., 2022). *Blue arrows: academic scientific process.* **(B)** Example of feedback loop between researcher works and Citizen Science actions for adaptive biodiversity management. *OSD, Occupational Science Diving; CSD, Citizen Science Diving; Sc, Science [academic research]; CS, Citizen Science.*

(Hyder et al., 2017) or biological invasions (Delaney et al., 2008; Encarnação et al., 2021), monitoring, and archaeology (Smith, 2014; Viduka, 2020a and Viduka, 2020b; Flemming, 2021a). However, underwater projects are increasingly being developed (*e.g.* Tessier et al., 2013 – video transects and fish visual censuses, Carballo-Cárdenas and Tobi, 2016 – invasive species, Wright et al., 2016 – divers as oceanographic samplers, Prato et al., 2017; Marlowe et al., 2021 and Marlowe et al., 2022 – assessment of fish assemblages, Richardson et al., 2019 – ghost gear mapping, Marlowe et al., 2021 – water temperature measurements, Turicchia et al., 2021 – environmental monitoring protocols, Spyksma et al., 2022 – diver-generated photomosaics).

From a general point of view, and despite the difficulty in defining the various objectives and practices of Citizen Science, the advantages are the collection of often large amounts of data and the opening of science to society. This is essential to enrich research and to reinforce society's trust in science and innovation. There are four aspects involved in Citizen Science practice: (1) anyone can participate, (2) participants use the same protocol so data can be combined and be of usable quality, (3) data can help professional scientists reach conclusions, and (4) a broad community of scientists and volunteers work together and share data to which the public, as well as professional scientists, have access (Cavalier and Kennedy, 2016; Flagg, 2016).

Citizen scientists typically are not professional scientists. The training of volunteer recreational divers in scientific specialties (marine biology or oceanology certifications or even geology or archaeology) as organized by recreational diving agencies such as the World Underwater Federation (CMAS, 2000a) or PADI, GUE, etc., may increase the quality of the data gathered by Citizen Scientific Diving. As such, project-oriented training provides a true added value to science by increasing the quality of the data gathering. Such training also aims to increase a broad public's consciousness and encourages further participation in Citizen Science projects. Kelly et al. (2020) presented a broad overview of the current extent and potential of marine Citizen Science and its contribution to marine conservation. However, the importance of the published results concerning Citizen Science would be qualitatively and quantitatively underestimated. Noting this under-representation of Citizen Science results, Bergerot (2022) suggests a more careful and detailed consideration of the data that must be published to be completely accessible to scientists in available databases.

Citizen Science is currently being transformed by technology. By integrating the Internet into everyday life, the number of projects has greatly expanded, as well as their visibility and accessibility (Bonney et al., 2014). Garcia-Soto et al. (2021) pointed out that advances in marine Citizen Science are particularly enabled and encouraged by recent technological developments. They allow for the potential of innovative mobile apps (Sturm et al., 2017), do-it-yourself (DIY) technologies, drones, and artificial intelligence (AI) web services. The creation of recommendation algorithms adapted to each project in AI that would lead to higher contribution levels represents another advance concerning Citizen Science. It is beginning to be considered as a new challenge (Ben Zaken et al., 2021). It is also possible to automatically filter a considerable amount of data using machine learning models, for example, to identify images. Combining machine learning tools and citizen participation can increase the analysis capabilities. One can use hundreds of hours of video, which was impossible before these techniques became available (Anton et al., 2021; Westphal et al., 2022). While increasing the potential for attracting and retaining volunteers on programs, it is noted that the involvement of professional scientists is compulsory to ensure success in this process.

Academic Science is increasingly aware of this very positive aspect of the potential contribution of Citizen Science and the interest in feedback loops between volunteers, society, and professional scientists. Citizen Science projects concerning coastal and oceanic research have been recorded by the European Marine Board (Garcia-Soto et al., 2017). Few of them involve scuba diving. Taking examples in the EU, some are "pure" Citizen Science actions (*e.g.* ANEMOON, The Netherlands, recreational divers are engaged in sea mollusks inventory; COMBER, Greece, divers and snorkelers identify fish species and enter observations into the database). Others are associated with scientific teams or programs (*e.g.* GHOST FISHING, Norway; Collaboration between the Norwegian Diving Association and the Institute of Marine Research to provide standardized reports for every set of ghost fishing gear found; RED POSIDONIA, Spain, volunteer divers assist scientists in monitoring seagrass meadows or REEF LIFE SURVEY PROGRAM, worldwide, trained volunteer divers work with scientists to survey reef life). Finally, some citizen actions are fully integrated into a scientific project and are the subject of a specific work package (WP) of a research program (*e.g.* CIGESMED for DIVERS [Gerovasileiou et al., 2016; Gatti et al., 2022], WP5 of the CIGESMED program - Coralligenous based Indicators to evaluate and monitor the "Good Environmental Status" (GES) of the Mediterranean coastal waters [Féral et al., 2016]). Similar actions, mainly involving volunteer divers, are developed in archaeological disciplines. The MARITIME ARCHAEOLOGY TRUST, in the United Kingdom, regularly undertakes outreach activities at schools, clubs, and public events, organizing diving campaigns for volunteers and students, when conditions permit, particularly on submerged sites or shipwrecks that lie on the seabed, accessible only by divers https://maritimearchaeologytrust.org/projects-research/.

2 Assessment of policy/guidelines options and implications

2.1 Occupational Scientific Diving operational safety needs mutually recognized European initial training standards

2.1.1 Awareness of the need to establish initial training standards on a European scale

As mentioned above, the vital need for action was already foreseen in the late 1970s when scientists using scuba diving in their research sought to initiate the harmonization of the rules and procedures for Occupational Scientific Diving in Europe as a solution to overcome cultural and administrative barriers to the safe use and development of Occupational Scientific Diving and international programs. The premises were manifested in national actions in some European countries. They were directly led by scientists in voluntary approaches like in 1972 in Germany with KFT: *Kommission Forschungstauchen Deutschland* (commission for Occupational Scientific Diving in Germany), or in 1979 in France with the creation of Colimpha - *Association française des plongeurs scientifiques* (French association of [occupational] scientific divers). In the United Kingdom the *Underwater Association* (UA) was formed in 1966. The aim was first to organize the Occupational Scientific Diving community at a national level by harmonizing the rules and practices for the safe and efficient use of Occupational Scientific Diving for research and monitoring purposes (Boucher et al., 1999). Second, it was to officially recognize Occupational Scientific Diving as a research tool and ultimately give it legal existence. One should note that there is a risk that the commercial diving legislation and sector may impose their frame to Occupational Scientific Diving. Nevertheless, as an example, when a firm "sector" for Occupational Scientific Diving is present, this can be avoided like in France in 1991, United Kingdom in 1997, Belgium in 2003 or Sweden in 2010 and a more recent update for Norway in 2021. In parallel with these national initiatives, underwater scientists' situation and difficulties were being examined at a European level in terms of mobility since professional scientists diving for their research started to experience problems during the 1980's. The absence of "norms" [standards] recognized by all Member States (EU and associated countries) for Occupational Scientific Diving makes it difficult, if not impossible, to ensure the safe MOBILITY of qualified scientific divers. These standards are also needed to allow Member States to assess the level of training of a VISITING SCIENTIST and to promote the development of specialized European core and optional training. The aim was only to enable better and safer use of SCUBA diving techniques for science. It was never aimed at developing a new market nor business opportunity, which was and remains, out of its scope.

2.1.2 Recognition of minimum initial training standards: towards a European platform

In the late 1980s, scientists sought to harmonize the rules and procedures for Occupational Scientific Diving in Europe (European Scientific Diving *ad hoc* Committee), an approach closely related to the construction of minimum standards recognized by Member States for initial training in scuba diving by scientists at work.

2.1.2.1 First step

In the early 1990s, starting statements were formalized in the framework of MAST III, a European Union R&D program in marine science and technology (DG XII, Marco Weydert). This was based on observing that some EU-funded projects involving Occupational Scientific Diving tasks and work packages were stopped by national rules on certification of occupational scientific divers and/or medical control. Several workshops were held in Brussels. As a product of the workshop on advanced training and standards in Occupational Scientific Diving held on 26-27 April 1993, chaired by Marco Weydert and Nicholas Flemming, a group of experts in Occupational Scientific Diving was created and tasked to develop a set of procedures (standards) to ensure the mobility of certified scientific divers inside the EU countries. Countries represented were Belgium, France, Germany, Greece, Ireland, Italy, Portugal, Spain, and The United Kingdom, with observers from the USA and Australia. The World Underwater Federation-CMAS was invited to the first meeting as an observer. This first step was achieved by the EU 'Isola d'Elba' Course/Seminar for the Instructors of European Scientific Divers (1-11 May 1997) funded by EU-DG XII, MAST 1994-1998, Sub-area D. Supporting initiatives, 2. Standards for training and work - grant MAS3-CT96-6351 from the European Commission gathering 35 European participants from Belgium, France, Greece, Ireland, Italy, Spain, The United Kingdom, and outside Europe from the USA and Australia (Abbiati, 1997). Two competence levels were defined and tested: European Scientific Diver (ESD) and Advanced European Scientific Diver (AESD).

2.1.2.2 Second step

After the Elba meeting, a provisional European Scientific Diving Supervisory Committee (ESDSC) was created in 1998 and placed under the management of EMaPS (European Marine and Polar Secretariat, which became the Marine Board) at the European Science Foundation. SCUBA diving was *de facto* recognized as a scientific tool at work by the European Commission, as illustrated by the answer to a written question from European Research Commissioner Philippe Busquin (Anonymous, 2000). He emphasized that ESDSC was expected to establish national committees in several Member States and coordinate them while maintaining a list of certificates that meet the requirements of the agreed draft standards. ESDSC also liaised with national authorities to promote the recognition of scientific diver training under Council Directive 92/51/EEC (Anonymous, 1992) on a second general system of professional education and training recognition. It was agreed that if the conditions of this directive can be met, Member States will be required to recognize the qualifications given to the trained occupational scientific divers. The role of NGOs (EUF - The European Underwater Federation, CMAS, etc.) was further discussed because their SCUBA diving certificates (*e.g.* CMAS 2 or 3 stars diver) are used as entry-level for occupational scientific diving training.

Further, the World Underwater Federation Scientific Diver standards (CMAS, 2000b) were made very similar on purpose to the last draft (A)ESD in June 2000. This was done to maximize the chance of success of the new standard for the scientific community. Still, most often, in several Member States already having dedicated legislation, administrations of scientific institutions cannot recognize for an employed working diver the diploma delivered by recreational diving agencies. On the one hand, they involve the delivery of certification for life and, on the other hand, the lack of effective quality control in their delivery. Finally, the two degrees of standards proposed by the ESDSC were validated during the Workshop supported by the CNRS (Centre National de la Recherche Scientifique) and the French National Committee on Scientific Diving (CNPS) organized in Banyuls-sur-Mer, France (14 October 2000). 15 European countries approved the decision (Belgium, Finland, France, Germany, Greece, Ireland, Iceland, Italy, The Netherlands, Norway, Poland, Portugal, Spain, Sweden, and The United Kingdom).

ESD and AESD standards do not include regulations such as insurance, medical examinations, employment rules, safety rules, diving limits, rules for recognition of national Occupational Scientific Diving training schools, etc. National laws and European Directives cover these aspects. Nor do the ESD and AESD consider any special requirements by employers. Instead, they define the minimum basic training of an occupational scientific diver as needed for work and ensuring cross-border mobility inside the EU. They are accepted basic training levels on which the employer can build further training modules if required or requested by law. This result was in line with European Research Area (ERA) creation, through which the Commission intended to form a unified area across Europe that would enable researchers to move and interact seamlessly based on a series of aligned working directives. The EU research network consists of 33 countries comprising the EU member states (27 countries) plus six non-EU member countries with an associated status. The challenge for European Occupational Scientific Diving has been integrating existing national programs through a single organizational structure that supports the promotion of recognized Occupational Scientific Diving standards within European science while advancing the broader acceptance of Occupational Scientific Diving as a research tool. However, the lack of official announcements giving visibility in many countries to this vital decision meant that they remained unknown for several years, although already adopted (directly or by equivalence) by several member states (Belgium, Germany, France, Finland, Sweden, and The United Kingdom) that were organized with a national Occupational Scientific Diving committee.

2.1.2.3 Third step

In 2007, leading scientists who employ Occupational Scientific Diving techniques within eight European countries (Belgium, France, Finland, Germany, Italy, Poland, Sweden, and The United Kingdom) started an EU-wide initiative to establish a pan-European platform to support Occupational Scientific Diving. They also promoted and enhanced scientific excellence within diving-supported aquatic research and sought to establish harmonized rules and guidelines for the sector. Based on a KFT initiative in Berlin (25-26 June 2007) and a Symposium on Scientific Diving - National and European Perspectives in Bremerhaven (15-16 October 2007), the European Scientific Diving Committee (ESDC) was formally constituted promoting the ESD and AESD competencies as the primary European scientific diving standards at work. On October 21, 2008, ESDC was accepted at an approved Panel of the Marine Board of the European Science Foundation (MB-ESF Plenary meeting, Toulon, France). Occupational Scientific Diving in Europe was, therefore, from that date on, overseen by the European Marine Board – European Scientific Diving Panel (EMB-ESDP).

Regarding its representation of the "marine" scientific community, the MB-ESF brings together the major European marine research organizations or institutes and most concerned universities of 18 countries, including 35 institutional members (Table 2). The Terms of Reference (ToR) of the ESDP were written under its control, giving it legitimacy even if such a panel is not a legal entity. National legality is provided by considering the ESDP standards (or equivalent) in the laws of the Member States that apply them (Table 3). ESF panels are not permanent structures. They are assumed not to last more than four years. However, given the crucial need to harmonize Occupational Scientific Diving in Europe and the results already achieved, the MB-ESF supported the ESDP until April 2017. ESDP is a panel of the European network of marine stations – MARS, a foundation created by, and open to, Europe's marine research institutes and stations, https://www.marinestations.org/ (Féral, 2018).

2.1.3 Present situation of Occupational Scientific Diving in Europe (2023)

Occupational scientific diving worldwide has an excellent safety record (e.g. Carter et al., 2005; Sayer and Barrington, 2005; Dardeau et al., 2012; Lang et al., 2013b; Sellers, 2016). However, through its very nature, many national legislators view Occupational Scientific Diving as carrying a higher-than-normal risk (Sayer, 2004; Sayer and Forbes, 2007), even though data analysis proves otherwise (Sayer, 2004; Sayer and Forbes, 2007; Benjamin and MacKintosh, 2016; Dunford et al., 2020; Flemming, 2021a). These authors insist that the very low number of accidents in the sector of Occupational Scientific Diving is directly related to the use of sufficiently high standards of initial training and to the scientific practice itself based on protocols adapted to the type of research and to the environmental conditions. Because of this, many countries insist on scientific divers having validated levels of training and qualifications to dive as part of their work. Although these qualifications have many commonalities between nations, it has been evident for some time that national consideration may impede the ability to use Occupational Scientific Diving easily between all nations that may partner with pan-European research programs.

TABLE 2 European Marine Board members (currently 35 members from 18 European countries, representing over 10,000 scientists and technicians).

Country	Members
Belgium	- Belgian Science Policy Office (BELSPO) - Fonds National de la Recherche Scientifique (FNRS) - Fonds voor Wetenschappelijk Onderzoek - Vlaanderen (FWO) / *Research Foundation - Flanders*
Croatia	- Institut za oceanografiju i ribarstvo (IOF)/*Institute of Oceanography and Fisheries* - Institut Ruđer Bošković (IRB) / *Ruđer Bošković Institute*
Denmark	- Institut for Akvatiske Ressourcer (DTU Aqua) / *National Institute for Aquatic Resources*
Estonia	- Eesti Teaduste Akadeemia (ETA) / *Estonian Academy of Sciences*
France	- Centre National de la Recherche Scientifique (CNRS) / *National Centre for Scientific Research* - Institut Francais de Recherche pour l'Exploitation de la Mer (IFREMER)/*French Research Institute for Exploitation of the Sea* - Universités Marines (UM)/*Marine Universities of France*
Germany	- Konsortium Deutsche Meeresforschung (KDM) / *German Marine Research Consortium* - Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR) / *Helmholtz Centre for Ocean Research Kiel*
Greece	- Ελληνικό Κέντρο Θαλάσσιων Ερευνών / Hellenic Centre for Marine Research (HCMR)
Ireland	- Marine institute - Irish Marine Universities Consortium
Italy	- Consiglio Nazionale delle Ricerche (CNR) / *National Research Council* - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) / *National Institute of Oceanography and Applied Geophysics* - Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa) / *National Inter-University Consortium for Marine Sciences* - Stazione Zoologica Anton Dohrn (SZN)/*Anton Dohrn Marine Station*
The Netherlands	- Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NIOZ) / *Royal Netherlands Institute for Sea Research* - Deltares
Norway	- Havforskningsinstituttet (HI) / *Institute of Marine Research (IMR)* - Norges forskningsrad/*The Research Council of Norway (RCN)* - Norsk Marint Universitetskonsortium (NMU)/*Norwegian Marine University Consortium*
Poland	- Instytut Oceanologii Polskiej Akademii Nauk (IO-PAN) / *Institute of Oceanology of the Polish Academy of Sciences*
Portugal	- Centro de Investigação Marinha e Ambiental (CIMAR) / *Centre of Marine and Environmental Research* - Fundação para a Ciência e a Tecnologia (FCT)/*Science and Technology Foundation*
Romania	- Romanian Black Sea Research Consortium (RBRC)
Spain	- Instituto Espanol de Oceanografia (IEO) / *Spanish Institute of Oceanography* - Centro Tecnológico del Mar (CETMAR) / *Technological Centre of the Sea*
Sweden	- Göteborgs Universitet (UGOT) / *University of Gothenburg*

(Continued)

TABLE 2 Continued

Country	Members
Turkey	- Türkiye Bilimsel ve Teknik Arastirma Kurumu (TÜBITAK) / *Scientific and Technological Research Council of Turkey*
United Kingdom	- Marine Alliance for Science and Technology Scotland (MASTS) - Natural Environment Research Council (NERC) - National Oceanography Centre (NOC)

That results in different national approaches that may infringe on European Union working directives (e.g. Directive EC/2005/36 on the recognition of professional qualifications, allowing EU citizens to work in another member state in regulated professions with the qualifications they received in their original member state Anonymous, 2005.

On this basis, ESDP aims to maintain and further develop a framework on which competencies for Occupational Scientific Diving recognized in different Member States can be translated easily and effectively to facilitate mobility and participation by scientists in diving-based pan-European research programs. The certification may be obtained under various training options and inside different national legislation but should sustain the collective advancement of underwater science, techniques, and technologies.

The essential items included in the ESDP-Terms of Reference are (1) to encourage international mobility in the European

TABLE 3 Main competency requirements for the European and Advanced European Scientific Diver standards (updated from Sayer et al., 2008).

European Scientific Diver (ESD)	Advanced European Scientific Diver (AESD)
A ESD is a diver capable of ***acting as a member of*** a scientific diving team. He/she may attain this level by either a course or by in-field training and experience under suitable supervision or by a combination of both these methods.	A AESD is a diver capable of ***organising*** a scientific diving team. They may attain this level by either a course or by in-field training and experience under suitable supervision or by a combination of both these methods.
- show proof of ***basic*** theoretical knowledge and a ***basic*** understanding of: 1. diving physics and physiology, the causes and effects of diving-related illnesses and disorders and their management 2. the specific problems associated with diving to and beyond ***20*** m, calculations of air requirements, correct use of decompression tables, 3. equipment, including personal dive computers and guidelines as to their safe use, 4. emergency procedures and diving casualty management, 5. principles of dive planning, 6. legal aspects and responsibilities	- show proof of theoretical knowledge and a ***comprehensive*** understanding of: 1. diving physics and physiology, the causes and effects of diving-related illnesses and disorders and their management 2. the specific problems associated with diving to and beyond ***30m***, calculations of air requirements, correct use of decompression tables, 3. equipment, including personal dive computers and guidelines as to their safe use, 4. emergency procedures and diving casualty management, 5. principles ***and practices*** of dive planning ***and the selection and assessment of divers***, 6. legal aspects and responsibilities

(Continued)

TABLE 3 Continued

European Scientific Diver (ESD)	Advanced European Scientific Diver (AESD)
relevant to scientific diving in Europe and elsewhere.	relevant to scientific diving in Europe and elsewhere, 7. ***dive project planning.***
- be fully competent with/in: 1. diving first aid, including cardio-pulmonary resuscitation (CPR) and oxygen administration to diving casualties, 2. SCUBA rescue techniques and management of casualties, 3. the use and user maintenance of appropriate SCUBA diving equipment.	- be fully competent with/in: 1. diving first aid, including cardio-pulmonary resuscitation (CPR) and oxygen administration to diving casualties, 2. SCUBA rescue techniques and management of casualties, 3. the use and user maintenance of appropriate SCUBA diving equipment ***including dry suits and full-face masks,*** 4. ***basic small boat handling and electronic navigation,*** 5. ***supervision of diving operations***.
- be fully competent with: 1. search methods, 2. survey methods, both surface and subsurface, capable of accurately locating and marking objects and sites, 3. the basic use of airbags and airlifts for controlled lifts, excavations, and sampling, 4. basic rigging and rope work, including the construction and deployment of transects and search grids, 5. underwater navigation methods using suitable techniques, 6. recording techniques, 7. ***acting as surface tender for a roped diver,*** 8. sampling techniques appropriate to the scientific discipline being pursued.	- be fully competent with: 1. search methods, ***such as those utilizing free-swimming and towed divers together with remote methods suitable for a various range of surface and sub-surface situations,*** 2. survey methods, both surface and sub-surface, capable of accurately locating and marking objects and sites, 3. the basic use of airbags and airlifts for controlled lifts, excavations, and sampling, 4. basic rigging and rope work, including the construction and deployment of transects and search grids, 5. underwater navigation methods using suitable techniques, 6. recording techniques, 7. ***roped/tethered diver techniques and various types of underwater communication systems such as those utilizing visual, aural, physical, and electronic methods,*** 8. sampling techniques appropriate to the scientific discipline being pursued.
- show proof of having undertaken ***70*** open-water dives to include a minimum of: 1. ***20*** dives with a scientific task of work such as listed above, 2. ***15*** dives between ***15 and 24 m,*** 3. ***5*** dives ***deeper than 25 m,*** 4. ***12*** dives in the last ***12*** months, including at least ***6*** with a scientific task of work	- show proof of having undertaken ***100*** open-water dives to include a minimum of: 1. ***50*** dives with a scientific task of work such as listed above, 2. ***20*** dives between ***20 and 29 m,*** 3. ***10*** dives ***between 29 m and the national limit,*** 4. ***12*** dives in the last ***12*** months, including at least ***6*** with a scientific task of work 5. ***20 dives in adverse conditions such as currents, cold or moving water***, 6. ***20 dives as an in-water dive leader***

All evidence must be recorded in nationally acceptable logs, countersigned by suitably qualified persons/authorities.
Bolded values highlight the differences between the ESD and AESD standards.

Occupational Scientific Diving community, (2) to promote safety in Occupational Scientific Diving across Europe (achievable, among other things, through the application of ESDP standards and the application of effective quality control during training and certificates issuing), and (3) to advance underwater scientific excellence in Europe.

Since the endorsement of the 2000's European's draft standards (so-called ESDP standards), there have been an increasing number of aquatic-aligned EU projects on worldwide relevant topics like global climate change and biodiversity and a growing number of internationally relevant archaeological projects falling into the frame of the UNESCO world heritage program. This increase in diving-supported scientific research has highlighted the need to develop a harmonized capability for Occupational Scientific Diving within the EU. Doing so will become increasingly important to facilitate scientific excellence in diving-supported programs within the EU-research Area framework.

Due to legal or administrative difficulties or even the lack of coordination or organization at a national level, the two proposed standards are difficult to implement in some countries. In these countries, NGOs such as the World Underwater Federation (CMAS) or the Global Underwater Explorers (GUE)., train recreational divers and sometimes professional scientists in what they call "scientific diving". For that, they use lower-level standards (training content, age, prerequisites, qualification delivered for life and lack of efficient quality control. This may result for the professional scientist on a lack of international recognition of its certification within an occupational framework. However, applying ESDP standards, or equivalents, can be made voluntarily, which does not require any new law. Even without official recognition, the quality and widespread acceptance of these standards by much of the European scientific community (ESDP, 2022b) has resulted in them already becoming adopted within the health and safety legislation of some EU countries (to date: Belgium, Germany, Finland, France, Norway, Sweden, and The United Kingdom – Table 4) and in some European or world-wide standards (e.g. see EN ISO 19493 [Anonymous, 2007a]). From a legal point of view, scientific exchanges and mobility in the EU must meet the requirements of several directives (Féral, 2018; ESDP, 2022b) (Table 5).

A remaining question concerns how to handle the special case of university students. Again, that depends on the National legislation framing the activity. Working using SCUBA diving requires training and experience that *per se* are of a longer time scale than that of a master's thesis. Moreover, the training time scale increases when the scientific study concerns the mesophotic zone and the use of rebreathers and mixed gases (Norro, 2016). However, training students as soon as a scientific institution acknowledges them is possible in some countries.

TABLE 4 European member states which legally recognize occupational scientific diving (situation in 2023).

Country	Competent National Authority	National Status
Belgium	Belgian Working Group on Scientific Diving https://www.belspo.be/belspo/research/coop_diving_en.stm	The WG has been created at the Belgian Federal level under the Federal Public Service Belgian science policy (BELSPO)
Finland	Suomen tutkimussukelluksen ohjausyhdistys *Finnish Scientific Diving Steering Association (FSDSA)* http://tutkimussukellus.net	The FSDSC is recognized by the Finnish Examination Board for Professional Diving (Ministry of Education)
France	Comité National de la Plongée Scientifique (CNPS) *National Committee for Scientific Diving* http://www.imbe.fr/comite-national-de-la-plongee.html	The CNPS is the national authority to represent occupational scientific diving in France. Training and activities are outlined by the law (Ministry of Labor).
Germany	Kommission Forschungstauchen Deutschland (KFT) *German Commission for Scientific Diving* http://www.forschungstauchen-deutschland.de	The KFT is the single authority recognized by the German Statutory Accident Insurance (German Government body responsible for occupational health and safety)
Norway	Norske Vitenskapelige Dykkere *Norwegian Scientific Divers* http://scientificdivers.no/	Norwegian Labor Inspection Authority
Sweden	Swedish Scientific Diving Committee (SSDC)	The SSDC is recognized by the Swedish Armed Forces (vocational certificate issuer) as the single organization representing scientific diving in Sweden
United Kingdom	UK Scientific Diving Supervisory Committee (SDSC) http://www.uk-sdsc.com	The SDSC is the single authority recognized by the UK Health and Safety Executive to represent the Scientific and Archaeological diving industry sector

The initial training meets the requirements of the ESD and ESDA standards. The training centers are approved by law. and the issuance of certificates of competence is done by a competent authority recognized by the ministry in charge of this aspect of labor law.

3 Actionable recommendations

3.1 An ever-increasing need for underwater data, due to the ever-larger spatial scale of investigations and monitoring

Considering ecological and environmental issues, in an era of rapid global change, conservation managers urgently need improved tools to monitor and even counteract ecosystem decline (Sheppard, 2019). This need is particularly acute in the marine realm, where threats are out of sight, under-mapped, cumulative, and often poorly understood, generating inefficiently managed impact. Recent

TABLE 5 Scientific exchanges and mobility in Europe, meeting the requirements of several directives.

European official texts	Object	Reference
Council Directive 89/391/ EEC of June 12, 1989	Introduction of measures to encourage improvements in the safety and health of workers at work	Anonymous, 1989
Official Journal of the European Communities, 2000/C 203 E/068, written question	Entry into force of European scientific diving standard.	Anonymous, 2000
Directive 2005/36/EC of the European Parliament and of the Council of 7 September 2005	Recognition of professional qualifications	Anonymous, 2005
Treaty on the Functioning of the European Union - TFEU 2007: article 45	Freedom of movement for workers within the Union	Anonymous, 2007b

advances in macroecology, statistical analysis and the compilation of very large datasets will play a central role in improving conservation outcomes, provided that regional and local data streams can be integrated to produce locally relevant and interpretable results. As Edgar et al. (2016) summarize, progress will be facilitated by (1) expanded deployment of systematic surveys that quantify species patterns, including some surveys conducted with the help of citizen scientists, (2) coordinated experimental research networks that use large-scale manipulations to identify the mechanisms underlying these patterns, (3) a better understanding of the consequences of threats through the application of recently developed statistical techniques to analyze global species distribution data and associated environmental and socio-economic factors, (4) the development of reliable ecological indicators for accurate and understandable monitoring of threats, and (5) the improvement of data processing and dissemination tools.

The difficulty of penetrating underwater environments means that the logistical challenges associated with collecting data on organisms and their environments have led to an initial focus on small plots in the more accessible intertidal and shallow subtidal areas. Local-scale studies indicate that particular abiotic and biotic factors determine species and community responses. However, the importance of identified local factors may collapse when re-evaluated at a regional scale (Webb et al., 2009). Data at regional and global scales are now recognized as fundamental to progress in ecology (Kerr et al., 2007). Managers have also adopted the multi-scale paradigm of ecosystem processes, as threats to marine biodiversity are generally globally distributed and interactive and non-linear. The availability of ecological data at regional and global scales is a necessary aid to management in many areas as Edgar et al. (2016) reported. A large part of the solution concerns Citizen Science, particularly Citizen Scientific Diving, which must organize itself (in connection with academic scientists) from data collection to processing and dissemination to the environmental management decision-making bodies.

Access to wrecks, among other things, has been a powerful driver for the development of recreational divers' interest in this branch of archaeology, creating an important pool of volunteers for underwater archaeology research, which is traditionally much needed. Such programs enable greater monitoring and recording as more and more people are introduced to the methodology (Viduka, 2020b). However, in the occupational sector, as for other scientific disciplines, becoming an underwater archaeologist takes several years of education and training beyond several years of college. One must be specially trained in Occupational Scientific Diving, mastering specific on-site skills.

From a general perspective, while underwater archaeology workcamps need to draw in many volunteers, long-term data that are key to understanding how species, communities, and habitats change over time are increasingly staff-intensive. Citizen Science programs can support data collection at larger spatial and temporal scales than other scientifically collected data, which tend to be project-specific and are often tied to short funding periods (Campbell et al., 2022).

Citizen Science organizations face trade-offs when balancing volunteer commitment with methodological complexity. The results provide essential information for managers and researchers considering using volunteer data or protocols to assess biodiversity in aquatic systems, helping to quantify the value of thousands of existing surveys (Holt et al., 2013). On the one hand, organizations focus primarily on public participation and educational outcomes, which need to employ methods that are simple and manageable by all participants. On the other hand, data collection focuses on the necessary quality of scientific results (Kosmala et al., 2016). For this purpose, tasks will be assigned to Occupational Scientific Diving leading a Citizen Scientific Diving team having received specific training at the necessary scientific level (Prato et al., 2017), but at the cost of a more limited commitment (Edgar et al., 2016).

3.2 "Scientific diver" is still a vague concept that needs to be used with care

Whatever the scientific level and complexity required by an academic or participatory project, the search for the least biased data collection efficiency must consider not only the technical skills to dive but also the scientific level of the volunteers, their specialty, their desire or not for further training and their commitment, as well as the time they can devote to a given project. Differences in diver profiles could affect their willingness and ability to contribute to Citizen Science. Conducting a transect requires intensive activities during the dive, and relevant diving experience. Project-oriented training are required (Roelfsema et al., 2016; Gatti et al., 2022), which reduces the pool of potential volunteers. Another point is that transect protocols are often incompatible with most dives conducted by a dive center. Therefore, such a task should either be assigned to an occupational scientific diver or a highly trained amateur. If this is impossible, simplified protocols should be developed (Gerovasileiou et al., 2016) and accounted for in data processing (Freitag et al., 2016). The same analyses of the situation are made on the sites of underwater archaeology (Viduka and Edney, 2022). The gradation and sequencing of skills should allow the assignment of the "right" type of task to each group (Figure 2).

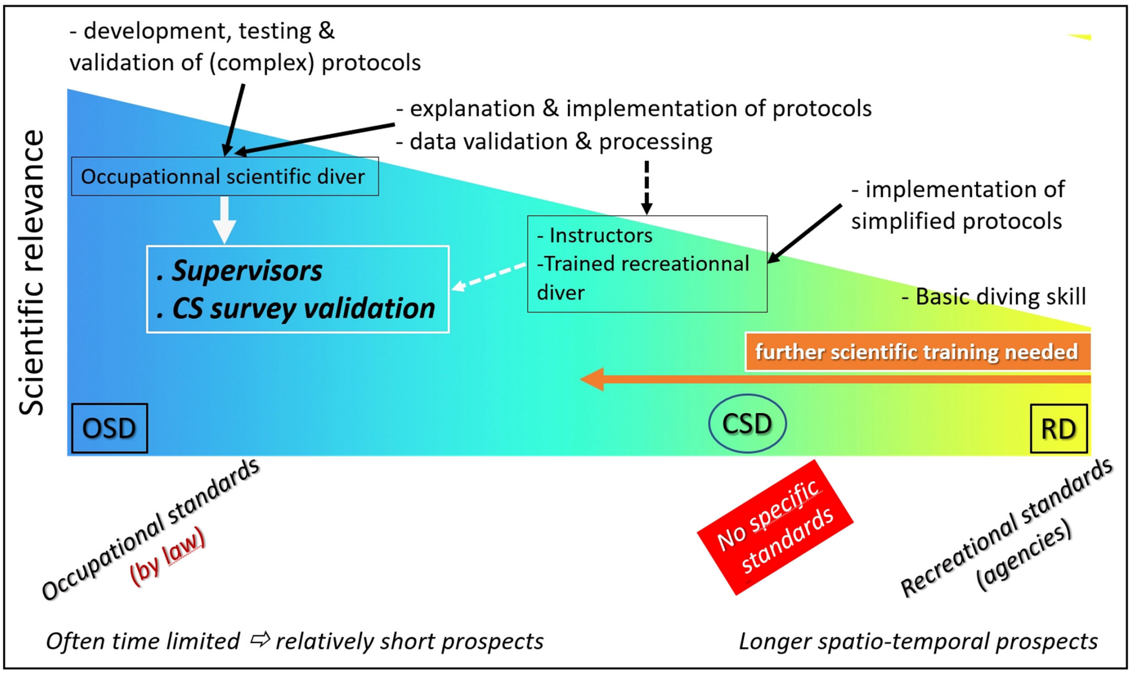

FIGURE 2
Roles of the different types of divers (occupational *vs*. recreational) depending on their scientific background, technical skill, training, and (free) time to dive for science. Professional scientists define the problems to be addressed and develop the necessary, sometimes complex, protocols for observations, measurements, and data collection. After being tested by occupational scientific divers, the protocols, simplified if necessary, are validated for implementation by citizen scientific divers trained specifically for the project. Instructors and experienced recreational divers may also supervise certain operations. Each project may require the development of new investigative techniques. This may imply new training requirements for citizen scientific divers. Investigations by professional scientists are sometimes limited by the duration of grants or contracts they obtain. The collaboration of citizen scientific divers is increasingly essential, given the growing need for data over larger areas and more extended periods. CS, Citizen Science; OSD, Occupational Scientific Diving; CSD, Citizen Scientific Diving; RD, Recreational Diving.

Hermoso et al. (2019) proposed five diver types (artisanal fishermen, recreational divers, instructors, scientific divers, and others). Fishermen (1) have more dive experience and are familiar with local species, making them essential collaborators for studying changes over time, by contributing their deep local ecological knowledge (LEK) (Stephenson et al., 2016). However, they may have more limited access to some communication channels and technologies. These characteristics make them ideal contributors to local ecology and ecosystem change detection. Recreational divers (RD) (2) have the least experience but the most accessible time during their dives and reasonable access to cameras and communications channels. This makes them suitable partners for large-scale Citizen Science projects that do not require a high level of specific science knowledge (Shirk et al., 2012). However, due to their relatively little experience with diving and marine ecosystems, it is necessary to set up sound validation systems for these Citizen Science projects. RD may improve their skills over time If long-term engagement is achieved. RD projects should consider starting out with more simple tasks (e.g. reporting photographic records) and advancing toward more complex tasks (including specific samplings or transect protocols). Instructors (3) are well-placed to coordinate and supervise Citizen Science activities thanks to their extensive diving experience, general interest in Citizen Science and direct interaction with recreational divers (Lucrezi et al., 2018b). Considering the so-called scientific divers group (4), Hermoso et al. (2019) underlined the complexity of the scientific diver concept as some divers have a specific certification for scientific diving but have no professional scientific background or training, while some, at the other end of the spectrum, are aquatic scientists who do not yet dive for research purposes.

Spear fishermen group was among the “others” (5), cited as an example of diversified volunteer profiles that may help contribute to the documentation of long-term shifts in resource traits (Young et al., 2015). Such a group can also contribute to the targeted sampling of an invasive species in sufficient quantities to analyze and track its diet over time (Dahl et al., 2017). The approach allowing the success of any multi-scale project in the underwater field requires respect for a continuum of skills (technical and scientific) that must be analyzed and adapted project by project. Tasks must be distributed according to needs and skills. Strategic choice of profiles is needed for a successful strategy, academic as well as Citizen Science.

4 Discussion

4.1 Diving as a tool for collective intelligence

Collaboration between scientific research and civil society is growing significantly. The general public’s curiosity drives it to engage with the scientific process and culture and the search for solutions to complex issues (economic, social, health, environmental, cultural, educational, or ethical). Digital tools encourage the development of these collaborations, combining artificial and collective intelligence. Thus, participatory research is based on the co-construction of knowledge through cooperation and participation, which aims to understand the scientific, ethical, legal, and technological issues of research more largely. Participatory research represents a significant development in the scientific approach, involving citizens in developing the questions posed and the methodology implemented to answer them. When the action must occur below the surface of seas, lakes or rivers, the major challenge is to penetrate, move, see, and work in an environment that is hostile and physiologically unsuitable to humans. Therefore, using SCUBA diving (and today CCR rebreather diving to enlarge the excursion both in-depth and bottom time) is an essential means of achieving this goal., It requires basic technical skills and a series of training courses adapted to specific issues. Each training course contributes to choosing a particular profile for a specific, more or less complex, role in citizen action in partnership with professional scientific action.

4.2 Occupational Scientific Diving *vs.* Citizen Scientific Diving

Research institutes, universities, museums, etc., are not in the business of teaching basic diving techniques, especially to their employees (researchers, lecturers, professors, technicians, engineers) or PhDs. Furthermore, the scientific community generally does not have the financial resources to design its own special diving equipment, nor develop the basic safety procedures and training required to dive safely with all types of equipment. This is the role of the specialized recreational training agencies (PADI, CMAS, FFESSM - *Fédération française d'études et de sports sous-marins*, BSAC - *British Sub-Aqua Club*, etc.) which issue the basic training certificates. The fact that thousands of people dive safely with these qualifications demonstrates *de facto* their reliability and consistency.

Several European countries have recognized the specificity and usefulness of occupational scientific diving by including this term in their law while associating safety standards concerning the training and practice of underwater techniques. This has meant that those responsible for diving and diving management in scientific or archaeological institutions or university departments must have the training and a defined standard of ability to work underwater. It is then up to the academic and research communities to define the terms and implementation under their authority, if only for insurance purposes (liability of employers). National technical committees are created to conduct the necessary follow-ups concerning the national population of occupational scientific divers, the evolution of techniques, and national and European laws and regulations. As a result, a state or scientific institution may have qualified diving instructors and organize its diving courses for personnel who have already obtained a basic diving certificate that meets the standards of the recreational diving training agencies mentioned above (usually equivalent to a minimum of CMAS two or three stars diver).

In the European system, each country can make its own choices, which also applies to diving at work. However, the significant disparity is detrimental to mobility and international collaboration, as it may limit the possibility of diving at work outside national waters. A minimum of homogeneity is necessary for the mutual recognition of qualifications, hence the need to establish an accepted and shared standard, in the occupational area. We have seen that this work is underway at the state level and that the ESDP standards are included in the legal texts of seven European countries (Table 1). In the face of this, the major recreational diving training agencies suggest that they should be able to define the minimum training standard for a person to qualify as a "scientific diver", or, that they should organize courses in which successful trainees would qualify as "scientific divers", within some days or some weeks. These recreational diving training agencies are responsible for producing recreational divers trained to various defined skill levels. That is all. They may add various modules, and teach people to identify fishes or crustaceans, and give these people badges (CMAS scientific specialty courses - CMAS, 2000b and CMAS, 2018). Such training does not qualify the owner to be contracted and employed as an occupational scientific diver as defined above. Notwithstanding that, these individuals could be labelled without restriction as a Citizen Scientific Diver. Unlike Occupational Scientific Diving, these trainees have a degree obtained after three, five, or more years of study in biology, ecology, geology, physics, or archaeology. They are at the forefront of knowing what is needed to explore, observe, collect, or experiment. The field of practice of recreational diving training agencies is equally important, but it is that of Citizen Science, a field fortunately in constant expansion nowadays.

Experience shows that training in Occupational Scientific Diving and basic technical training should be slow and gradual, at least in the early stages of qualification. This means that a trainee cannot be effective at once. The trainee must be immersed in the problems that will have to deal with. The initial Occupational Scientific Diving training is only a starting point. Released into the field after a training course of a few days will not make an occupational scientific diver. Training within the working community is necessary. This is an essential difference with Citizen Scientific Diving training that prepares for something other than academic science.

4.3 What if we just called things by their name?

Under the auspices of the administration on which they depend, the community of occupational scientific divers can decide on the training and experience needed for the various types of research work. Suppose the recreational diving training agencies allow the "x-stars" qualification level to drop or wish to issue certificates to so-called "scientific divers" who have obtained a certificate below the ESDP standards. In that case, the scientific institutions are free to no longer recognize this training. It is NOT the responsibility of recreational diving training agencies to decide what qualification is acceptable or necessary for research organizations with legal responsibilities. This perfectly agrees with the position stated by CMAS regarding the specialties it teaches amateur divers (CMAS, 2000a and CMAS, 2018). But this contradicts the currently developing ISO Standards of "scientific diving" (ISO TC 228: Tourism and related services, WG1: diving services). The academic community should set the standards and criteria for itself, assessing and choosing among the recreational diving training agencies and the basic certificates they offer, but not allowing itself to be dictated to. Unlike the recreational diving sector, the academic community has no financial incentive to set standards too low. In any case, the potential market for Occupational Scientific Diving will remain small.

Moreover, it is already serviced by the training centers approved by the states that have legislation on Occupational Scientific Diving. Furthermore, organizing specialized courses, for instance, in 3D video photogrammetry, using radioactive chemicals, or acoustic measurements underwater, cannot be designed by amateurs. The use of a single term, *i.e.*, "scientific diving" or "scientific diver" for any so-called scientific activities is to be banned. Getting back to basics in a factual way by distinguishing Occupational Scientific Diving from Citizen Scientific Diving, is as healthy as it is effective and in fact opens a promising avenue for these recreational diving training agencies to have a clear position and offer associated with a language of truth. Operationally, the general scheme should be as follows. Initial SCUBA diving training is the responsibility of the recreational diving sector. Nowadays this also applies to the initial closed-circuit rebreather training. In this latter case the training must also be acknowledged by the manufacturer of this specific breathing apparatus.

The scientific community, under national law, organizes occupational scientific diving training. The Occupational Scientific Diving sector is using the initial SCUBA diving training provided by the recreational diving sector (*i.e.*, CMAS level two or three stars diver or equivalent).

In contrast, the increasingly necessary volunteers are trained by the recreational diving sector and receive the necessary supplements targeted to the project by the competent Occupational Scientific Diving scientific team. Feedback loops may then develop (Figure 1). By maintaining a specific, well-identified system, it can be easy and quick to make decisions, change requirements, and accept or reject trainees who have been trained differently depending on the situation on the field, consistent with the flexibility needed to conduct effective research safely.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The 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.

Publisher's note

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