Ocean
and Coastal
Research

REVIEW

http://doi.org/10.1590/2675-2824071.23036tsl
ISSN 2675-2824

Scientific diving in Brazil: history, present and perspectives

Tatiana S. Leite[1]*, Igor E. Pinheiro[2], Flávio Berchez[3], Áthila A. Bertoncini[4], Oswaldo M. Del Cima[5], Irene E. Demetrescu[1], Ronaldo B. Francini-Filho[6], Ruy K.P Kikuchi[7], Arthur A. Machado[7], Rodrigo Maia-Nogueira[8], Flavio L. Martins[9], Liana F. Mendes[10], Gilson Rambelli[11], Claudio L.S. Sampaio[12], Barbara Segal[1], Aline A. Aguiar[13], Augusto S. Auler[14], José Barroco-Neto[15], Roberta M. Bonaldo[16], Francisco S. Buchmann[17], Flavio Calippo[18], Augusto Cesar[19], Matheus A.C. Gama[2], Natalia Ghilardi-Lopes[20], Zelinda M.A.N. Leão[7], Guilherme C. Lessa[7], Carla Menegola[21], Hudson T. Pinheiro[6], Luiz A. Rocha[22], José Sabino[23], José C.S. Seoane[24], Julia Sestokas[1], Cláudio C. Tiago[3], Ewerton Wegner[25], Tito Lotufo[26].

[1] Departamento de Ecologia e Zoologia - Universidade Federal de Santa Catarina (Campus Universitário, s/n, 88040-970 - Florianópolis - SC - Brazil).
[2] Centro de Formação em Ciências Ambientais - Universidade do Sul da Bahia (Campus Sosígenes Costa - Rodovia BR-367 Km 10 Zona Rural - 45810-000 - Porto Seguro - BA - Brazil).
[3] Instituto de Biociências e Instituto de Estudos Avançados - Universidade de São Paulo (Rua do Matão, 05508-090 - São Paulo - SP - Brazil).
[4] Insitituto Meros do Brasil (Rua Benjamin Constant, 67 CJ 1104, 10º. Andar - Centro - 80060-020 - Curitiba - PR - Brazil).
[5] Departamento de Física - Universidade Federal de Viçosa (Av. Peter Henry Rolfs, s/n, 36570-900 - Viçosa - MG - Brazil).
[6] Centro de Biologia Marinha - Universidade de São Paulo (Rodovia Manoel Hypólito do Rego - 11600-000 - São Sebastião - SP - Brazil).
[7] Instituto de Geociências - Universidade Federal da Bahia - Campus Ondina (Rua Barão de Jeremoabo, s/n, 40170-115 - Salvador - BA - Brazil).
[8] EcoBioGeo Meio Ambiente & Mergulho Científico (Colina C, 41680-370 - Salvador - BA - Brazil).
[9] PADI AWARE Foundation (Tomas St. Rancho Santa Margarita, 92688 - CA - USA).
[10] Laboratório do Oceano - Departamento de Ecologia - Universidade Federal do Rio Grande do Norte (59078-900 - Natal - RN - Brazil).
[11] Universidade Federal de Sergipe (Praça Samuel de Oliveira, s/n, 49170-000 - Laranjeiras - SE - Brazil).
[12] Laboratório de Ictiologia e Conservação - Universidade Federal de Alagoas - Unidade Educacional Penedo (Av. Beira Rio, s/n, Centro Histórico - 57200-000 - Penedo - AL - Brazil).
[13] Projeto ilhas do Rio - instituto mar adentro (CEP 22031-012 - Rio de Janeiro - RJ - Brazil).
[14] Instituto do Carste - Carste Ciência e Meio Ambiente (R. Brasópolis, 139, 30150-170 - Belo Horizonte - MG - Brazil).
[15] Lapiás Operações de Mergulho Autônomo (Bonito - MS - Brazil).
[16] Natural History Brazil Produções (Rua Eugênio Passos, 101, 13250-260 - Itatiba - SP - Brazil).
[17] Laboratório de Estratigrafia e Paleontologia - Universidade Estadual Paulista (Praça Infante Don Henrique, s/n, 11330-900 - São Vicente - SP - Brazil).
[18] Universidade Federal do Piauí - Campus Universitário Ministro Petrônio Portella (Av. da Universidade, s/n, 64049-550 - Teresina - PI - Brazil).
[19] Instituto do Mar, Universidade Federal de São Paulo, Rua Carvalho de Mendonça, 11070-100, Santos/SP, Brazil.
[20] Centro de Ciências Naturais e Humanas - Universidade Federal do ABC (Rua Arcturus, 3, 09606-070 - São Bernardo do Campo - SP - Brazil).
[21] Centro de Estudos Costeiros - Limnológicos e Marinhos (CECLIMAR) - Universidade Federal do Rio Grande do Sul (Av. Tramandaí, 95625-000 - Imbé - RS - Brazil).
[22] California Academy of Sciences - Department of Ichthyology (94118 - San Francisco - LA - USA).
[23] Projeto Peixes de Bonito (Rua Praia do Leblon, 272 - Bairro Monte Carlo, 79022-470 - Campo Grande - MS - Brazil).
[24] Departamento de Geologia - Instituto de Geociências - Universidade Federal do Rio de Janeiro (Av. Athos da Silveira Ramos, 274, Sala G-025 - Cidade Universitária, 21941-916 - Rio de Janeiro - RJ - Brazil).
[25] Laboratório de Mergulho Científico - Escola do Mar - Ciência e Tecnologia - Universidade do Vale do Itajaí (Rua Uruguai, 109, 88302-901, Itajaí - SC - Brazil).
[26] Instituto Oceanográfico - Universidade de São Paulo (Praça do Oceanográfico, 05508-120 - São Paulo - SP - Brazil).

* Corresponding author: tati.polvo@gmail.com

Submitted: 03-Mar-2023
Approved: 18-Jul-2023

Editor: Rubens Lopes

ABSTRACT

Scientific diving (SD) is defined as any diving activity that applies scientific procedures to produce subsidies for studies and technical works in underwater environments. The first report of an underwater scientific study in Brazil dates to the 19th century, in the Abrolhos reefs. Currently, in Brazil, scientific diving has been performed in various areas, from shallow coastal regions to remote and sometimes hard-to-reach places, such as oceanic islands, flooded caves, and icy areas like Antarctica. However, the regulation of SD in Brazil still lacks more concrete actions towards an effective and efficient self-regulation that offers physical safety to practitioners and institutional safeguards for organizations that use it in their research projects. Thus, this article aims to contribute to a better understanding of this critical issue in Brazil and to serve as a reference and incentive for the training of professionals and the development of these activities in the country. It includes: 1) a historical review of SD; 2) a diagnosis of the training and application of SD in Brazil; 3) the evolution of marine sciences in Brazil from the perspective of SD; 4) a review of the use of environmental assessment and underwater conservation techniques in oceans and internal waters; 5) an analysis of the evolution of scientific diver training in Brazil, including a diagnosis on training; 6) the history and updates of the rules, regulations, and safety of SD. Given all the potential of diving combined with specific techniques for research, monitoring, and marine and limnic science in Brazil, we aim to understand the evolution of scientific diving teaching and to outline perspectives in the country, as it is crucial for the training of qualified scientists capable of performing these underwater tasks. Finally, we present future plans for the development of this activity in Brazil from the point of view of research and the labor market.

Keywords: Marine science, SCUBA dive, Snorkeling, Underwater survey

INTRODUCTION

Brazil has one of the longest tropical coastlines in the world, with unique oceanographic and historical features and a rich biodiversity (Longo and Amado Filho, 2014). While land regions have been gradually discovered and mapped in detail, underwater ecosystems are still less known, despite their influence and importance on climate and the severe stressors to which coastal and oceanic regions have been subjected in the last century, with only partially known consequences. The submerged regions of the sea are also very poorly known to the public, the media, and policymakers. The constraints on knowledge of marine environments are at least partly related to technological, logistical, and financial constraints, including diving equipment, protocols, and underwater scientific methodologies.

The trajectory of scuba diving around the world and its development as a popular activity have reduced the gap between underwater recreational, scientific, commercial, and military activities (Sayer, 2007). This process was important, leading to the use of diving as a tool in scientific methodology and allowing scientists to extend their research to the underwater realm.

Since ancient times, there have been many historical records related to diving. Scientific diving (SD) is defined as any diving activity that applies scientific procedures to produce subsidies for studies and technical works in underwater environments. This article aims to contribute to a better understanding of SD in Brazil and to serve as a reference and incentive to the training of professionals and the development of these activities in the country. It includes: 1) a history review of SD; 2) a diagnosis of the training and application of SD in Brazil; 3) the evolution of marine sciences in Brazil from the perspective of SD; 4) a review of the use of environmental assessment and underwater conservation techniques in oceans and internal waters; 5) an analysis of the evolution of scientific diver training in Brazil, including a diagnosis on training; 6) the history and updates of the rules, regulations, and safety of SD; and 7) conclusions and future plans to develop this activity in Brazil from the point of view of research and the labor market.

HISTORY OF SCIENTIFIC DIVING IN BRAZIL (20TH AND 21ST CENTURIES)

The first report of an underwater scientific study in Brazil dates from the 19th century, when Charles Frederic Hartt visited the Abrolhos reefs.

He conducted a vertical transect along the wall of the Lixa reef, describing the distribution of the reef fauna in depths up to about 5 m (Hartt, 1870). We do not know what type of diving equipment he used. Only in the 1960s did the first scuba (self-contained underwater breathing apparatus) equipment and divers arrive in Brazil, but not associated with scientific research (Silva, 2020).

The first contributions to the knowledge of marine habitats for taxonomic purposes in the 19th and 20th centuries had dredging as a common sampling approach. The first studies on community structure (Rawitscher, 1944; Joly, 1957; Nonato and Pérèz, 1961) were performed in the intertidal zone. However, pioneering ecological descriptions of the sublittoral zone applied snorkeling for taxonomic samplings, such as the study by Oliveira (1947), who presented the first diagram of zonation patterns of the benthic communities of the rocky shores of Guanabara Bay.

The arrival of young foreign researchers, especially the French couple Jacques Laborel and Françoise Laborel-Deguen in 1961 at the newly created Institute of Marine Biology and Oceanography in Recife, marks the beginning of the use of scuba diving, besides underwater photography, in research along the Brazilian coast. Moreover, by then, Marc Kempf had arrived at the same institution, collecting samples and making records while diving, often in partnership with Jacques Laborel, including an expedition aboard the French research vessel Calypso (Laborel-Deguen et al., 2019).

The Calypso oceanographic campaign from 1961 to 1962 allowed Laborel and Kempf to scuba-dive in the Abrolhos reef region, in the Vitória-Trindade Seamount Chain, as well as in the Jaseur Bank, at 65 m depth. These were the first autonomous and scientific dives performed in Brazilian mesophotic environments. Only recently have these environments been studied using technical diving and rebreathers (Pinheiro et al., 2014; Joyeux, 2015; Guabiroba et al., 2020).

In the late 1970s, a broad and pioneering study using scuba diving and snorkeling for scientific research in the Abrolhos Region was started (Leão, 1982). Zelinda Leão initiated this new phase of Brazilian science, contributing to the dissemination and conservation of the largest and richest reef area in the South Atlantic (Leão et al., 1994). Besides keeping this line of research active until today, Zelinda created the first long-term monitoring program to assess the benthic communities of Brazilian reefs. This project contributed to the training of a new generation of Brazilian scientists who, in association with diving, use nondestructive methods in data collection (Kikuchi et al., 2003; Freitas et al., 2019; Loiola et al., 2019).

Moreover, the Oxford Diving Expedition was a pioneering study in the exploration of sublittoral areas with scuba diving. It assessed the benthic cover in transects at depths of 10, 15, and 20 m in the upwelling sector of Cabo Frio, Rio de Janeiro (RJ) (Maggs et al., 1979), producing vertical transect maps. They also obtained underwater images for analysis via tape recording.

Some years later, Eston et al. (1986) studied the vertical distribution of benthic marine organisms on rocky shores of the Fernando de Noronha Archipelago (Northeastern Brazil), up to 30 m in depth. Moreover, during the 1980s, several researchers used scuba diving for ecological purposes at shallow depths, such as Yoneshigue-Valentin and Valentin (1992), who compared the distribution of organisms in Cabo Frio, RJ, and Oliveira-Filho and Berchez (1993), who described a rocky shore community dominated by seaweeds in Ubatuba, São Paulo (SP).

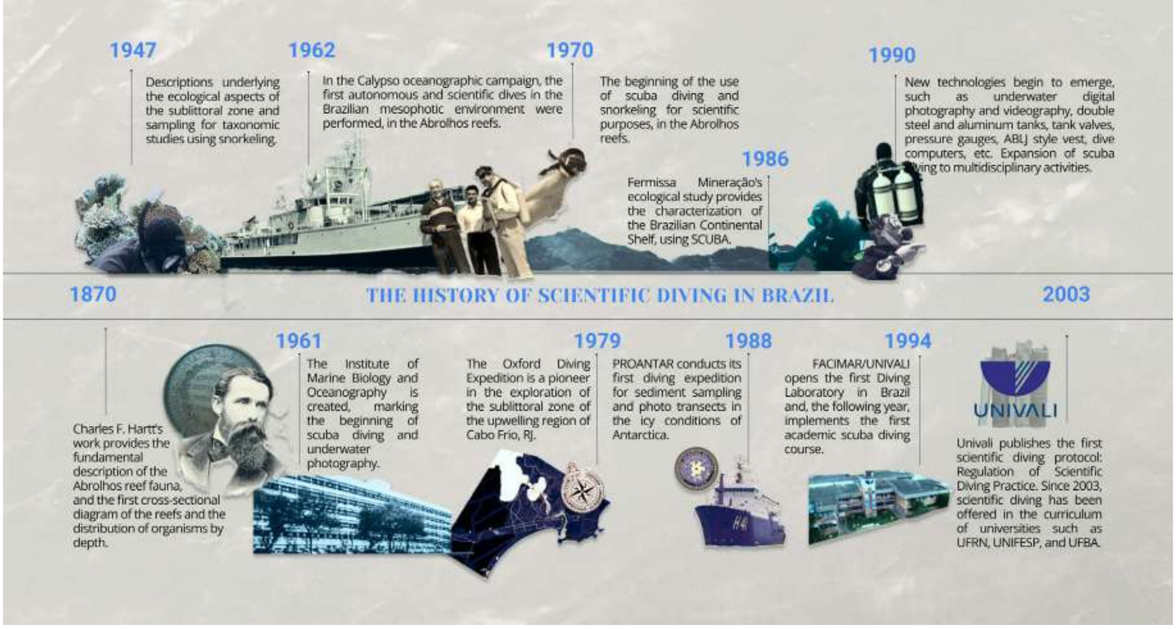
The first ecological study using open sea scuba diving on the Brazilian continental shelf started in 1986 and ended in 1996. The project was related to the Environmental Impact Assessments of the company Fermisa Mineração, which received authorization to mine rhodolith beds. The option for a BACI (before-after control-impact) sampling design, using random sampling elements, and diving in the Brazilian Current, resulted in unprecedented challenges. The results were only partially published with the company's clearance (Berchez et al., 2009).

Another frontier for Brazilian marine sciences was the icy conditions of Antarctica. The Brazilian Antarctic Program (PRONTAR) started in 1975, with Paulo Paiva and Tania Brito conducting the first dives for sediment sampling and photo transects in the austral summer of 1988/1989. Subsequently, many other dives were performed in the following years (Nonato et al., 1992). These dives required dry suits and safety protocols specific to the rapidly changing conditions of the continent.

One of the reasons for the limited performance of scuba diving was the equipment available at the time (70s and early 80s). The diving tank attached to a backpack, the “J” tank valve with the reserve mechanism (30 bar spring force), and the absence of buoyancy compensators made the diver highly limited, requiring mastery of buoyancy techniques and limited bottom time. From the 1990s onwards, new technologies, such as double steel or aluminum tanks, new tank valves, new buoyancy compensators, pressure gauges, and dive computers, allowed the diver to perform multidisciplinary activities safely. At that time, diving schools implemented useful techniques for scientific diving activities, such as underwater orientation, night and deep dives, and underwater photography and videography. The general spread of scuba diving along the Brazilian coast allowed better access to equipment and training, supporting an increment in the sublittoral studies (Villaça and Pitombo, 1997; Creed and Amado Filho, 1999). Many partnerships with diving schools improved efficiency and allowed research to expand.

With the arrival of the new millennium, access to technologies, coinciding with an increase in the number of scientists trained for scientific diving, opened new perspectives for scientific diving in general. Underwater digital photography and videography made it possible to obtain many high-quality and less expensive images, which can be seen immediately, in contrast to the limitation of film cameras. Combining techniques such as drifting footage, drop cameras, or side-scan sonar with scuba diving allowed a more efficient seabed characterization.

The number of lines of research that use scientific diving in Brazil is significant and will be briefly described in the next sections.



1947 Descriptions underlying the ecological aspects of the sublittoral zone and sampling for taxonomic studies using snorkeling.

1962 In the Calypso oceanographic campaign, the first autonomous and scientific dives in the Brazilian mesophotic environment were performed, in the Abrolhos reefs.

1970 The beginning of the use of scuba diving and snorkeling for scientific purposes, in the Abrolhos reefs.

1986 Fermissa Mineração's ecological study provides the characterization of the Brazilian Continental Shelf, using SCUBA.

1990 New technologies begin to emerge, such as underwater digital photography and videography, double steel and aluminum tanks, tank valves, pressure gauges, ABLJ style vest, dive computers, etc. Expansion of scuba ving to multidisciplinary activities.

1870 Charles F. Hartt's work provides the fundamental description of the Abrolhos reef fauna, and the first cross-sectional diagram of the reefs and the distribution of organisms by depth.

1961 The Institute of Marine Biology and Oceanography is created, marking the beginning of scuba diving and underwater photography.

1979 The Oxford Diving Expedition is a pioneer in the exploration of the sublittoral zone of the upwelling region of Cabo Frio, RJ.

1988 PROANTAR conducts its first diving expedition for sediment sampling and photo transects in the icy conditions of Antarctica.

1994 FACIMAR/UNIVALI opens the first Diving Laboratory in Brazil and, the following year, implements the first academic scuba diving course.

2003 Univali publishes the first scientific diving protocol: Regulation of Scientific Diving Practice. Since 2003, scientific diving has been offered in the curriculum of universities such as UFRN, UNIFESP, and UFBA.

Figure 1. Timeline of the main historical milestones and changes in scientific diving in Brazil from 1870 to 2003.

DIAGNOSIS OF SCIENTIFIC DIVING TRAINING AND APPLICATION IN BRAZIL

Understanding the training of scientific divers and the methodologies applied according to the fields of marine science is essential to broaden the knowledge of the activities they currently conduct. Moreover, this knowledge can help establish institutional rules and guidelines to facilitate the training of future diver scientists, improving and standardizing the quality and number of divers. Thus, the Scientific Diving

Working Group (GT Mergulho Científico), under PPGMAR/SECIRM (Comitê Executivo de Pesquisa e pós-graduação em Ciências do Mar/Comissão Interministerial para os Recursos do Mar), elaborated a questionnaire to understand the profile of scientific divers in Brazil. This questionnaire was made available and widely disseminated on the internet in 2014.

A total of 290 participants were validated and analyzed, in a ratio of 70% men and 30% women. Regarding higher education, most participants graduated in Biological Sciences (68.55%), followed by Oceanography (15.19%), Archaeology (3.89%), Fisheries Engineering (3.180%), and Ecology (2.473%). These five majors represent about 93.28% of the answers. Most held a PhD (47.91%), followed by master's degrees (29.51%), undergraduate degrees (18.75%), and specialization degrees (3.12%). Scholars and degree holders are included in each educational stage. Regarding occupation, participants were professors (instructors in the academic field 53.05%), students (undergraduate, master's, and PhD degree 33.69%), and professionals (employees of private and public institutions and postdoctoral fellows 13.26%). Of this total, 31.44% were research leaders (individuals who are autonomous or organize research activities) and 68.55% were researchers (individuals who help conduct research activities).

Experience in scientific diving is an important factor in the quality of data collection, optimization of activities, and safety, minimizing possible risks. Of the 259 participants, 41.3% were divers with less than five years of experience (N=83) (Figure 2), and only a small share had more than 20 years of experience. In all experience groups, men represented a larger share than women.

The questionnaires showed 30 methodologies applied to underwater research (N=250), with 10 methodologies representing 83.55% of the total (Figure 3), and image capture, collection of biological material, visual censuses, and transects accounting for more than 50%. Regarding the maximum depth reached in scientific diving, the most frequent was 10 to 20 m (28.68%; N=74), followed by 20 to 30 m (26.74%; N=69), while the maximum depth reached was 120 m (N=1) (Figure 4). The most explored habitats were coastal waters (up to 10 nautical miles) (40.19%), followed by ocean waters (17.02%), wreck diving (11.51%), and continental waters (rivers, lakes, etc.) (10.21%) (N=278).

Considering the participants, the typical scientific diver in Brazil is a young male researcher, usually with a PhD, who conducts research related to biological sciences in coastal waters up to 30 m deep. Although the questionnaire did not assess the socioeconomic aspects of scientific divers, it seems reasonable to think that the dominant profile would be middle class to more affluent strata. In fact, higher education in Brazil still excludes low-income individuals, despite significant changes over the last two decades. Scuba diving can also be considered an expensive activity, requiring equipment and training not offered by public higher education.

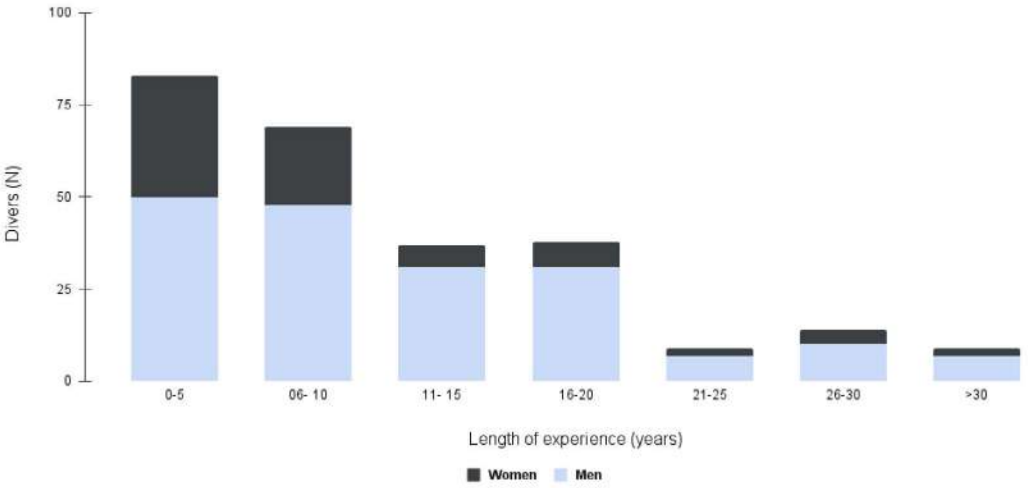


Figure 2. Length of experience (years) as a scientific diver in Brazil and the number of participants in each experience group by sex according to questionnaire applied in 2014 to understand the profile of scientific divers in Brazil.

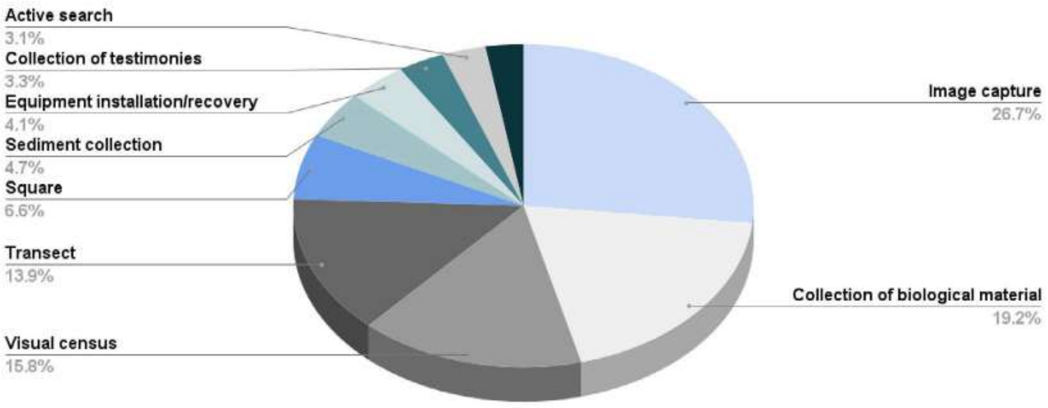


Figure 3. Proportion of types of methodology applied to underwater research in Brazil, grouped and classified by general category, defined by the main objective of the study or its main finding. Each category is expressed as a percentage of the total number (N=290) according to questionnaire applied in 2014 to understand the profile of scientific divers in Brazil. Each participant could choose more than one category.

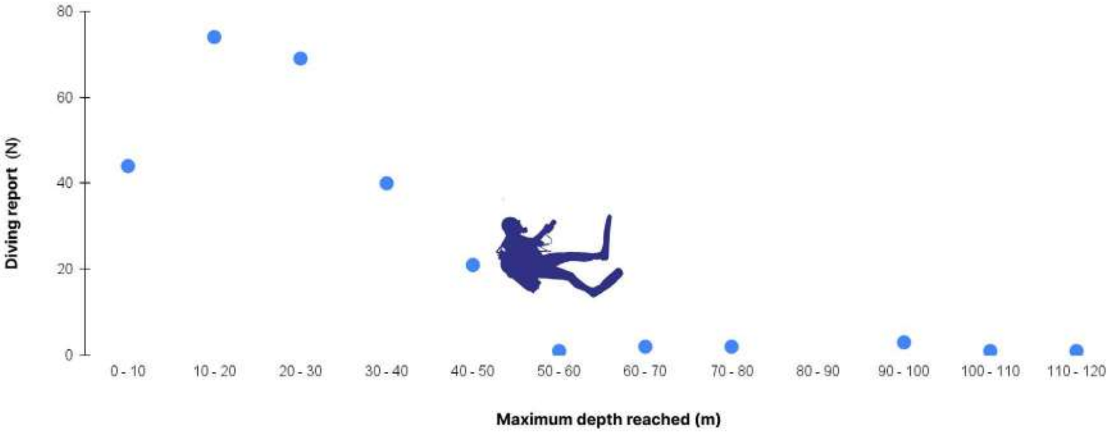


Figure 4. Maximum depth reached by scientific divers in Brazil according to questionnaire applied in 2014 to understand the profile of scientific divers in Brazil.

EVOLUTION OF MARINE SCIENCE IN BRAZIL FROM THE PERSPECTIVE OF SCIENTIFIC DIVING

To assess the evolution of marine science in Brazil, applying scientific diving as a research tool, a bibliographic review was performed in the Web of Science Core Collection and SCOPUS databases with two distinct combinations: 1) “SCUBA” and “BRAZIL”; and 2) “SNORKEL” and “BRAZIL.” For both search combinations, the term “BRAZIL” was entered by field (the search considered title, abstract, and keywords). The search was conducted on all fields related to the terms “SCUBA” and “SNORKEL.” Before downloading the information, all references were checked to avoid data not related to scientific diving. After downloading, the databases were analyzed using the R software (R Core Team, 2022) and the Bibliometrix package (Aria and Cuccurullo, 2017).

The search for the term “SCUBA” found 131 documents in Web of Science Core Collection and 208 in SCOPUS. These documents included articles, review articles, notes, extended abstracts, books, and book chapters published from 1991 to 2022. Before the bibliometric analysis, the databases were combined and 69 duplicates were excluded; therefore, 270 documents were analyzed, with 686 authors. This is a significant number compared with the 442 found by an international study that evaluated bibliographic underwater research supported by scuba diving from 1995 to 2006 (Sayer, 2007). Following the same trend as the information obtained in the interviews, the bibliographic production on scientific diving increased gradually from the 2000s onwards (Figure 5). The documents listed belong to various fields of knowledge, mainly marine biology (86.73%), followed by geology (4.08%), artificial structures (4.08%), ethnoscience (2.01%), anthropology (1.02%), recreational diving (1.02%) and health in diving (1.02%). In the field of biology, the most common studies were on ecological aspects (44.04%), animal behavior (26.19%), taxonomy (10.71%), invasive species records (7.14%), and habitat mapping (5.95%). These topics represent 94.04% of the marine biology line.

For the term "SNORKEL," 31 documents were found in Web of Science Core Collection and seven in SCOPUS. These documents included articles, review articles, and book chapters published from 1998 to 2021. Before the analysis, the databases were combined and two duplicates were excluded. In total, 36 documents were analyzed. In the analyzed documents, 112 authors were identified, with an average of 3.11 authors per document. The field of marine biology also prevailed (92.31%), followed by artificial structures (7.69%). Within biology, the documents were divided into subfields, such as ecology (42.31%), animal behavior (38.46%), human impacts (11.53%), and taxonomy (7%).

These results show an increase in scientific production on scientific diving, thus, they are directly related to the growth in human resources since the 2000s. The numbers also align with the data presented in the previous section, highlighting marine biology research as the main application of scientific diving. The following topics summarize the main lines of research identified and their evolution in terms of results obtained, and methods used.

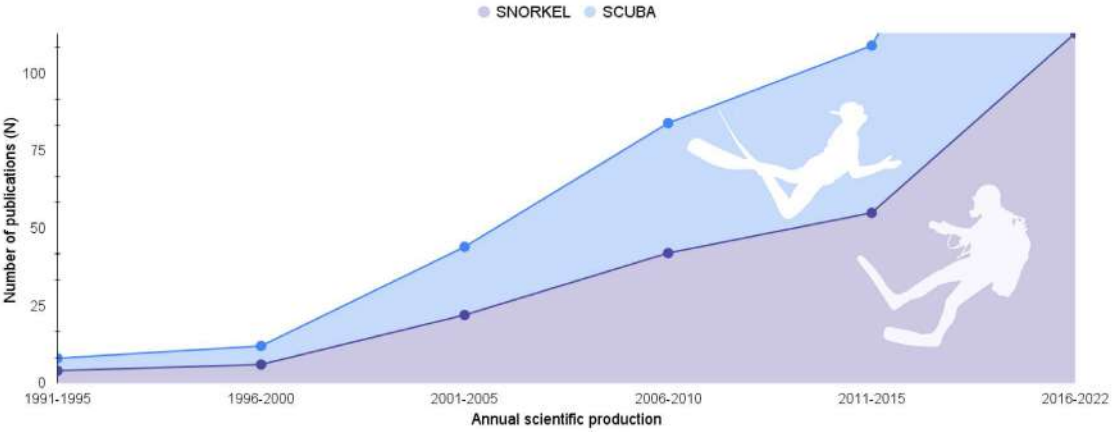


Figure 5. Scientific production using the search criteria "SNORKEL" and "SCUBA" in Brazil (N=270). Documents were found in the Web of Science Core Collection and SCOPUS databases. These documents included articles, review articles, notes, extended abstracts, books, and book chapters published from 1991 to 2022.

USE OF ENVIRONMENTAL ASSESSMENT AND CONSERVATION UNDERWATER TECHNIQUES

AQUATIC ECOLOGY AND BIODIVERSITY

The use of diving in biological research began in Brazil with the participation of foreign researchers and initially involved biodiversity surveys of fauna and flora and general ecological aspects of marine ecosystems. One of the pioneering contributions is the work *Les Peuplements de Madréporaires des Côtes Tropicales du Brésil* (Laborel, 1970). This monograph was recently translated and reviewed in the book *Recifes Brasileiros: O Legado de Laborel* (Laborel-Deguen et al., 2019), considered a milestone, a guideline in the ecological knowledge of Brazilian reef environments. At the same time, Henry Matthews, a Brazilian malacologist and professional diver, began his scientific career, contributing with sampling and scientific publications that expanded the knowledge of the diversity of marine mollusks in Northeastern Brazil and becoming one of the biggest names in marine science in Brazil (Rocha-Barreira et al., 2016).

In the 1970s, another foreign oceanographic expedition, conducted by Oxford University, promoted dives for scientific purposes in Brazil. Since then, Brazilian researchers have published studies using biological material collected in these first expeditions, such as Mothes de Moraes (1985), who described the fauna of marine sponges in the upwelling region of Cabo Frio, RJ. Moreover, educational institutions and research focused on marine areas began to grow and, due to this combination of factors, the scientific production and training of researchers in marine biodiversity in Brazil has advanced significantly.

Studies on the development and reproduction of aquatic organisms became more viable due to the manual collection of live specimens in good condition by scuba diving. For instance, Petersen and Ditadi (1971) described aspects of the reproductive biology of *Glossobalanus crozieri* (Hemichordata) collected by diving in the sublittoral zone. Regarding phycology, studies on algae have broadened, no longer focusing exclusively on taxonomic and distribution aspects, but delving into biological, ecological, and biochemical aspects, thus requiring dives to obtain samples and *in situ* records (Oliveira-Filho, 1977).

The diversification of research increased further since the 1980s, when scientific publications on aquatic and marine biodiversity using diving intensified in Brazil. Diving techniques applied in sampling allow direct contact between the researcher and the environment, organisms, and communities studied, enabling the collection of vital information for the description of species and their habitats, such as daily habits, coloration, and socialization with other organisms. Direct access to the environment and the use of submersible devices also allow the ecophysiological study of organisms *in situ*, such as the evaluation of the photobiological behavior of corals (holobionts), their adaption to natural light, the reaction of calcification to temperature and natural light, and community structuring in response to turbidity (Suggett et al., 2012; Freitas et al., 2019; Loiola et al., 2019), but also contributed to great advances in the knowledge of biogeographic patterns for shallow habitats such as the coral reefs along the Brazilian coast (Castro and Pires, 2001).

With the advancement and development of underwater research, as new species are described and new records are made, knowledge of biodiversity has continued to grow, even for conspicuous organisms, such as fish (Moura et al., 2001), crustaceans (Teschima et al., 2012), and cephalopods (Leite et al., 2008, 2021), making it clear that there is still much to learn about the oceans, especially in previously unexplored places. In a recent publication, Pinheiro et al. (2020) recorded 41 new fish occurrences in the Saint Peter and Saint Paul Archipelago. Many of these records were made by applying scientific diving techniques to reach deeper waters with rebreathers in surveys from 2009 to 2018 (see details in the next section).

The use of diving is also associated with advances in understanding species and interactions in continental aquatic environments. Due to the shallow depth and low visibility of rivers and streams, where most studies requiring diving are conducted, biodiversity studies traditionally used snorkeling instead of scuba diving. Studies using scuba diving are usually performed in caves, in the field of speleology and fossil collecting (Parisi et al., 2016). In this field, studies on the natural history and behavior of freshwater fish stand out as they continue to contribute to recent publications on ecological interactions and the habitat effects on stream fauna (Casatti and Castro, 1998; Sabino et al., 2011; Teresa et al., 2011; Nunes et al., 2020).

Another critical aspect of scientific knowledge and conservation is the possibility of recording and monitoring fauna of commercial interest, rare or threatened species, using nondestructive sampling surveys (Giraldes et al., 2015). Thus, international protocols have been established for the use of scuba diving in various environments. In Brazil, Reef Check and the AGRRA (Atlantic and Gulf Rapid Reef Assessment) protocol stand out as monitoring networks for rocky and coral reefs (Kikuchi et al., 2003; Ferreira and Maida, 2006), as well as SeagrassNet for monitoring seagrass banks (Short et al., 2006) and ReBentos for monitoring benthic habitats (Turra and Denadai, 2015). Besides monitoring the biome, human activities, such as diving and its effects on the environment, have also been monitored, especially to observe the behavior of divers (Giglio et al., 2016, 2019). These monitoring protocols also allow the involvement of individuals in recreational diving, presenting an excellent interface between scientific promotion and citizen science focused on the conservation of marine environments.

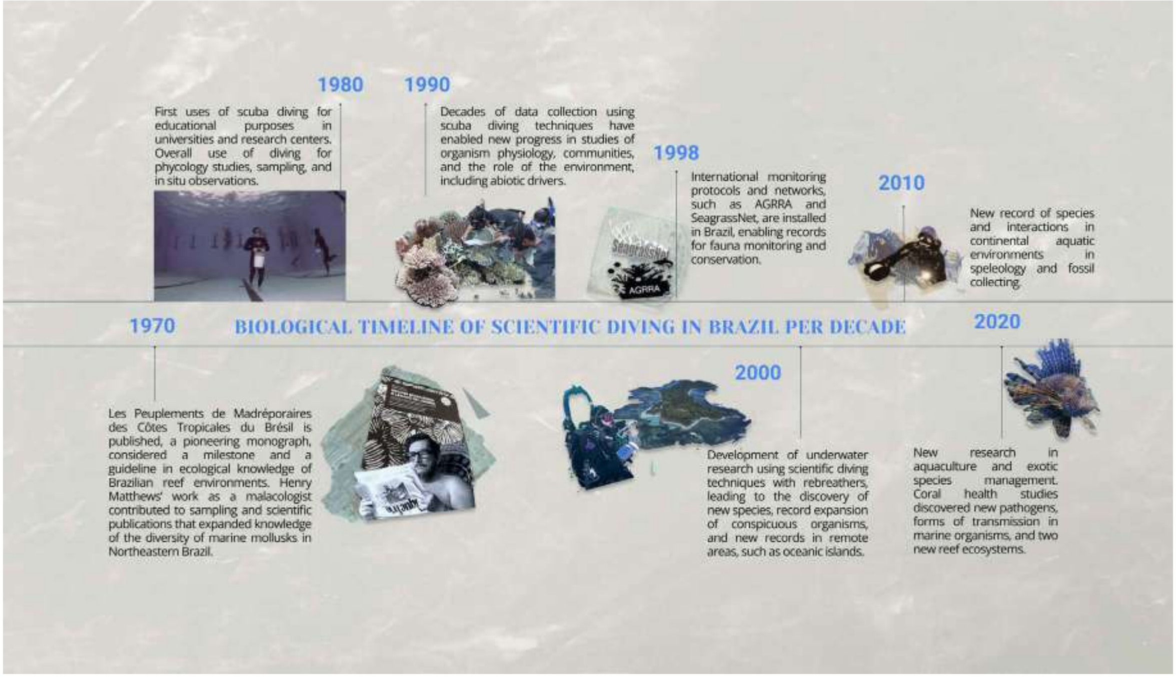
Scientific diving has also brought important advances in understanding the ecological interactions, natural history, life history, and behavior of aquatic organisms. Knowledge of the ecological interactions between fish and their relationship with habitat changes has tremendous implications for the management and conservation of these ecosystems. Describing the complex interactions of cleaning and its role in reefs, which are the most diverse marine environments, is only possible with detailed *in situ* observation (Quimbayo et al., 2018). Studies on the behavior of several invertebrate groups have led to the discovery of new interactions between species (Felinto et al., 2020) and important aspects of the life history of species of commercial interest, such as octopuses (Leite et al., 2009a; Batista and Leite, 2016), allowing useful information to be obtained to subsidize both fisheries management actions (Leite, et al., 2009b) and new research in the field of aquaculture. The discovery of new pathogens and even forms of transmission of marine organisms is also a recent example of the great importance of diving in studies on coral health in Brazil (Moreira et al., 2014).

A recurring issue in aquatic ecosystems is the introduction of invasive species. In some cases, the economic damage is particularly significant, such as that caused by the golden mussel *Limnoperna fortunei*, which creates a crust on the turbines of hydroelectric power plants (Pestana et al., 2010). In coastal marine environments, the increase in invasive species has been affecting natural communities, especially the orange cup coral of genus *Tubastraea* (Creed et al., 2017) and, more recently, red lionfish *Pterois volitans* (Luiz et al., 2021).

The use of scientific diving or the observations recorded from it have been of great relevance in studies and practical actions focused on monitoring and managing invasive species (Crivellaro et al., 2021). Thus, the potential for advances in knowledge and management by the application of citizen science strategies stands out. In fact, recent records of lionfish were obtained in collaboration with fishermen, which made it possible to trace the route of biological invasion in the southwestern Atlantic (Luiz et al., 2021). In the marine environment, invasive species are a topic of great interest and enticement to society, facilitating a practical interaction between the layperson and scientific production by citizen science projects. In the light of the Sun Coral Project in Rio de Janeiro and the recent lionfish monitoring campaign in Fernando de Noronha, the potential of using citizen science to increase the interaction between science and society and promote better management of coastal marine environments in Brazil is noticeable. In terms of ecosystem research, we highlight the recent reassessment of mesophotic reefs in the mouth of the Amazon River (Francini-Filho et al., 2018) and the discovery of a biogenic reef at 12 m depth on Queimada Grande Island, SP (Pereira-Filho et al., 2019, 2021). Notably, the coast of São Paulo is one of the most sought-after regions for scientific research, including for large public selections and programs, such as BIOTA/FAPESP. However, scientific diving has recently led to this great discovery: a reef ecosystem on this little-known and little-studied coast.

Currently, there are several experimental research laboratories where studies in the field of ecology, ecophysiology, ecotoxicology, etc. have been conducted thanks to the conservation of hand-collected specimens by scuba diving (Moura et al., 2001; Sánchez-Jérez et al., 2001; Teschima et al., 2012; Giraldes et al., 2015; Medeiros et al., 2021). This type of sampling has been fundamental to mesocosm experiments. Thus, scientific diving has improved experimental research by providing vital information on the response of species to environmental stimuli in constant anthropogenic change (Sánchez-Jérez et al., 2001; Suggett et al., 2012) and studies assessing the feasibility of farming species to restore coral reef environments (Oliveira et al., 2008). Today, these studies can predict ecosystemic changes and mitigation, acclimatization, and protection efforts (Figure 6).

With the advancement of knowledge and the increasing popularity of scientific diving, many short-, medium-, and long-term programs and projects have emerged, with snorkeling and diving activities that go beyond the academic scope, also including conservation actions and research performed by third sector companies and public agencies such as ICMBio (Instituto Chico Mendes de conservação da Biodiversidade). Information on the main initiatives concerning the broader territorial and scientific range and reach is compiled (Table S1) with records of crucial funding and results or products obtained to date. This information was obtained by searching the official websites or, failing that, by consulting the main published contributions.



BIOLOGICAL TIMELINE OF SCIENTIFIC DIVING IN BRAZIL PER DECADE

1970

Les Peuplements de Madréporaires des Côtes Tropicales du Brésil is published, a pioneering monograph, considered a milestone and a guideline in ecological knowledge of Brazilian reef environments. Henry Matthews' work as a malacologist contributed to sampling and scientific publications that expanded knowledge of the diversity of marine mollusks in Northeastern Brazil.

1980

First uses of scuba diving for educational purposes in universities and research centers. Overall use of diving for phycology studies, sampling, and in situ observations.

1990

Decades of data collection using scuba diving techniques have enabled new progress in studies of organism physiology, communities, and the role of the environment, including abiotic drivers.

1998

International monitoring protocols and networks, such as AGRRA and SeagrassNet, are installed in Brazil, enabling records for fauna monitoring and conservation.

2000

Development of underwater research using scientific diving techniques with rebreathers, leading to the discovery of new species, record expansion of conspicuous organisms, and new records in remote areas, such as oceanic islands.

2010

New record of species and interactions in continental aquatic environments in speleology and fossil collecting.

2020

New research in aquaculture and exotic species management. Coral health studies discovered new pathogens, forms of transmission in marine organisms, and two new reef ecosystems.

Figure 6. Timeline of the main historical milestones and changes in marine biology using underwear methodologies from 1970 to 2020.

SCIENTIFIC TECHNICAL DIVING FOR MARINE BIOLOGY RESEARCH IN BRAZIL

Although recreational scuba diving allows researchers to perform a wide range of activities underwater, certain situations require more advanced techniques, known as "technical diving." In particular, deeper habitats and challenging environmental conditions (e.g. open blue water and icy environments) usually require the diver to be properly trained and use specialized equipment to perform the research tasks safely. In this context, cave and polar diving also demand an important set of technical knowledge and equipment, but these will be addressed in another section.

Throughout the history of scientific-technical diving in Brazil, the most frequent challenge for marine scientists was to reach deeper habitats (> 30 m) and conduct research while controlling the risks associated with the diving operation. Some challenges of deep diving include narcosis and toxicity caused by nitrogen and oxygen, respectively, as well as the need for decompression in longer dives to avoid seasickness and a fixed cable to guide divers and perform occasionally long decompressions (up to four hours). Different gases can be used during ascent/descent and at the bottom, and total equipment can weigh up to 100 kg.

Possibly, some researchers performed deep diving using multiple tanks and standard scuba equipment in Brazil earlier on, without any formal record. From our point of view, the first scientific deep dives in Brazil were conducted in 1979 in the Saint Peter and Saint Paul Archipelago. At the time, researchers dived with air tanks to a depth of 60 m, discovering two new endemic reef fish species found exclusively on deep reefs (Lubbock and Edwards, 1981). Brazilian scientists only started performing deep diving activities almost 20 years later, from April 1997 to April 1999, in the northeastern region, at depths up to 70 m (Rocha et al., 2000; Feitoza et al., 2005). At this point, there was no infrastructure for deep technical diving in Brazil, and only air tanks with adapted equipment were available for bottom time and decompression. These first dives produced new records for the southwestern Atlantic and allowed the first ecological assessment of a Brazilian reef fish community beyond 30 m depth, shedding light on the role of the deep reefs connecting the northeastern Brazilian coast to the Caribbean.

At the end of the 1990s, other deep dives were conducted in Fernando de Noronha, using the same protocol as the tourists, with double tanks and compressed air along with a stage tank, and no bottom or decompression mixture (Francini-Filho et al., 2000; Menezes et al., 2003). Decompressive dives also became more frequent, using air tanks to reach depths of 50 to 70 m in other areas of Brazil, such as the Abrolhos Bank, the Trindade and Martin Vaz islands, seamount chains, and oil platforms, allowing the discovery of new fish species and ecological studies (Pinheiro et al., 2009, 2011). With the development of nonscientific technical diving community in Brazil and the availability of new equipment and training, researchers also took the opportunity to use these techniques in scientific research. As a result of these improvements, a series of deep dives (up to 90 m) were performed from 2010 to 2014 in the Abrolhos Bank, aiming to assess potential sites for the expansion of the Marine Protected Areas network and biodiversity assessments (Simon et al., 2016). By this time, scientists were already trained to use gas mixtures, such as TRIMIX as a bottom mixture and NITROX/O2 for decompression, greatly increasing bottom time and decreasing decompression time. During this transition, decompressive dives using air tanks became progressively less frequent.

The next step in the development of deep diving techniques involved the dissemination and use of the different types of closed-circuit rebreathers. Rebreathers revolutionized scientific diving by giving divers unprecedented autonomy, allowing longer bottom time and safe access to deeper sites by shortening decompression intervals. As rebreathers are “bubble-free,” they also avoid noise and thus allow sampling without scaring fish away. Jean-Christophe Joyeux led the first scientists trained to use Megalodon rebreathers in Brazil, enabling them to collect fish and explore the Vitória-Trindade seamount chain (VTC) (Pinheiro et al., 2014, 2015). On that occasion, in 2011, these scientific divers were able to dive to a depth of 84 m, discovering new ecosystems and two new fish species in the VTC. Rebreathers have also been used in research projects in the Abrolhos Bank and, more recently, in the Saint Peter and Saint Paul Archipelago and the Fernando de Noronha Archipelago (Pimentel et al., 2020; Pinheiro et al., 2020), and in shallower areas of the southern Brazilian coast. These authors explored reef walls and canyons down to 130 m depth, discovering six new fish species and producing many new records from these oceanic locations.

Other types of technical diving have the potential to be further developed in Brazil. For instance, blue-water dive, performed in open ocean waters, has not often been used to collect and document pelagic life. Moreover, scientists have frequently studied wrecks and their associated organisms (Lira et al., 2010; Simon et al., 2015), although they do not usually perform deep dives that require specific protocols. From the point of view of archeological diving, the particularities will be discussed in a separate section.

Although technical diving is developing slowly in Brazil, a recently funded project resulting from a partnership between the Center for Marine Biology (CEBIMar) of the University of São Paulo (USP) and the California Academy of Sciences aims to develop infrastructure and training for technical diving exploration in the country. CEBIMar will host a deep diving team and offer logistics for technical diving operations on the coast of São Paulo. The development of technical deep diving in Brazil should result in the discovery of many new species and the possibility of more advanced studies in the field of biogeography, conservation, ecology, and evolution.

DIVING IN MARINE GEOLOGY: TECHNIQUES AND METHODS

In Brazil, underwater geology is developed in both marine and limnic environments. The latter, mainly lakes and caves associated with rivers, will be discussed in section 4.5. The most frequent studies are related to sedimentology, paleontology, micropaleontology, paleoceanography, and, more recently, geotourism.

Regarding seabed mapping, activities such as visual description and photography and videography (Cruz et al, 2008) (Figure 7A), and the collection of samples, sediments, and rocks are complementary to the use of satellite remote sensing (Vianna et al., 1991; Kikuchi and Leão, 1997; Testa and Bosence, 1999; Santos et al., 2007) and, in particular, the results obtained by echo sounders (single- or multi-beam) and side-scan sonar, among others (Kikuchi and Leão, 1998; Buchmann and Tomazelli, 2003; Seoane et al., 2012; Gomes, 2015; Araújo and Amaral, 2016; Nascimento Silva et al., 2018) grouped under the name ground truth verification. Aspects of underwater geology and geomorphology have also been used by geotourism to guide divers in mapping the underwater relief, allowing a more interpretative diving approach and promoting awareness of the fragility of the site is to reduce the impact of tourist diving activities (Vale et al., 2021).

Recently, visual documentation of the environment has advanced significantly with the development of image recording equipment onboard remotely operated vehicles (ROV) or autonomous underwater vehicles (AUV). These devices have broadened the scope of research and are essential at depths greater than 30 m, where safety conditions and bottom time become more critical for divers. However, this does not limit the possibility of research in depths greater than 50 m, such as in the study performed with regular air in carbonate and reef environments in the continental shelf of northern Bahia (BA) (Kikuchi and Leão, 1998) or in technical dives with TRIMIX gas mixture in Abrolhos (Bastos et al., 2013) and the Rocas Atoll (Amado-Filho et al., 2016).

Surface and core sediment sampling in oceanography and limnology are traditionally performed with remotely operated devices, such as the Van Veen grab sampler, gravity corers, and box corers. However, there are advantages to working directly with scuba diving in depths down to 30 m. Direct sampling by divers, for example, is effective in all situations and allows the selection and description of the site and seabed shapes (e.g. wave patterns and sinkholes) when visibility permits. It can be performed by snorkeling in shallow depths and with good visibility, such as in reef ecosystems. Regarding gravity and box coring, the operation requires large vessels with cranes hindered in depths of 10 to 20 m. Thus, scuba diving allows sampling core sediments a few inches long at depths of about 2 m.

First used in 2003 (Santedicola, 2008), underwater coring of corals and reefs has been conduct to obtain samples to understand the mechanism of coral calcification (Oliveira et al., 2008; Kikuchi et al., 2013), paleoceanographic studies (Santedicola, 2008; Kikuchi et al., 2013; Pereira et al., 2015, 2018), sea level reconstruction, and reef evolution (Bastos et al., 2018). The techniques used in these studies are underwater navigation, operating percussion, and pneumatic (Santedicola, 2008; Kikuchi et al., 2013; Pereira et al., 2015, 2018) or hydraulic drilling accessories and equipment. *In situ* studies on coral calcification were conducted by coral skeleton staining (Kikuchi et al., 2013), while studies on reef sedimentation rates (Dutra et al., 2006; Segal and Castro, 2011) required choosing suitable sites to install sediment traps and returning periodically to replace the devices.

Obtaining longer core samples, at depths down to 1 m, requires pneumatic or hydraulic equipment (Figure 7B). This involves adapting power drills to cylinders attached to tanks that are taken to the bottom to be operated (Pereira et al., 2015, 2018). Another alternative to pneumatic (Santedicola,

2008) or hydraulic equipment are compressors or pumps installed on vessels.

In the field of scientific diving, another line of research on underwater outcrops is underwater paleontology. An important example is the frequent presence of fossils of extinct giant mammals with underwater rock formations on the continental shelf of Rio Grande do Sul (Buchmann and Tomazelli, 2003). Giant sloths and armadillos, mastodons, saber-toothed tigers, and their fossils were deposited in ancient lagoons at a sea level 20 to 100 m lower than today during the Last Glacial Maximum. These paleolagoons and their fossils may be 120 to 600 thousand years old (Lopes et al., 2010), and these deposits have been eroded by storm waves and washed ashore (Cruz et al., 2016).

DIVING IN ENVIRONMENTAL CONSULTING AND OCEANOGRAPHIC INSTRUMENTATION

Monitoring for environmental consulting in Brazil began in the late 1990s, coinciding with the development of recreational diving in the country and the popularization of nondestructive visual census methods to collect data on the aquatic biome. This growth allowed the emergence of specialized environmental companies offering these services, which were also incorporated into commercial diving companies, specializing in the installation and maintenance of this underwater equipment. Although they represent most of the technical work, diving activities are primarily based on scientific methodology and need this knowledge to be applied. Thus, although commercial divers receive robust training, most lack training in scientific areas crucial to perform the activity. Moreover, the equipment commonly used by these divers, such as umbilicals, does not allow the application of most scientific methods.

The data collected are used to diagnose the quality of the environments and allows decisions that enable environmental monitoring, mitigating or elimination of impacts, and restoration of damaged areas (Holland et al., 2009; Lessa et al., 2019; Schettini et al., 2020), such as services associated with the environmental licensing process, which is a relevant instrument for the National Environmental Policy (Act 6.938 of August 31, 1981), whose studies are conditional to obtaining environmental licenses by potentially impacting enterprises.

Scientific diving activities with oceanographic instrumentation stand out in the field of environmental consulting due to the possibility of using techniques, technologies, and tools that allow the application of safe, fast, efficient, and nondestructive methods to obtain physicochemical data by the sampling of different environmental matrices, such as water and sediments, and its relationship with biome composition.

Scientific diving activities in the field of oceanographic instrumentation primarily involve the installation, maintenance, and recovery of oceanographic equipment, whose data are used for environmental monitoring and scientific research. Currently, oceanographic equipment for monitoring coastal areas is increasingly compact. The main equipment used are waverider buoys; multiparameter probes to measure conductivity (salt levels), temperature, depth, dissolved oxygen, pH, turbidity, and chlorophyll; acoustic Doppler current profiler (ADCP) (Figures 7C–D); CTD (conductivity, temperature, and depth); video recorders; and meteooceanographic buoys. This equipment records many variables, such as statistical parameters of surface waves, current speed and direction, salt levels, temperature, pressure, turbidity, pH, chlorophyll, colored dissolved organic matter (CDOM), dissolved oxygen levels, and partial pressure (Costa and Möller, 2011; Dally, 2018; Franz et al., 2021).

Diver efficiency requires training, safe conditions, appropriate tools, reliable instruments that can be easily adjusted, and a well-designed dive plan. This planning for the installation of equipment considers: i) the operating depth of the instruments, with their operational limits and the difficulty of underwater operations; ii) oceanographic conditions, such as typical sea wave patterns at the site, water turbidity, and current speed; iii) the nature of the seabed, whether muddy, sandy, or rocky; and iv) existing fishing activities and vessel traffic and their intensity at the site.

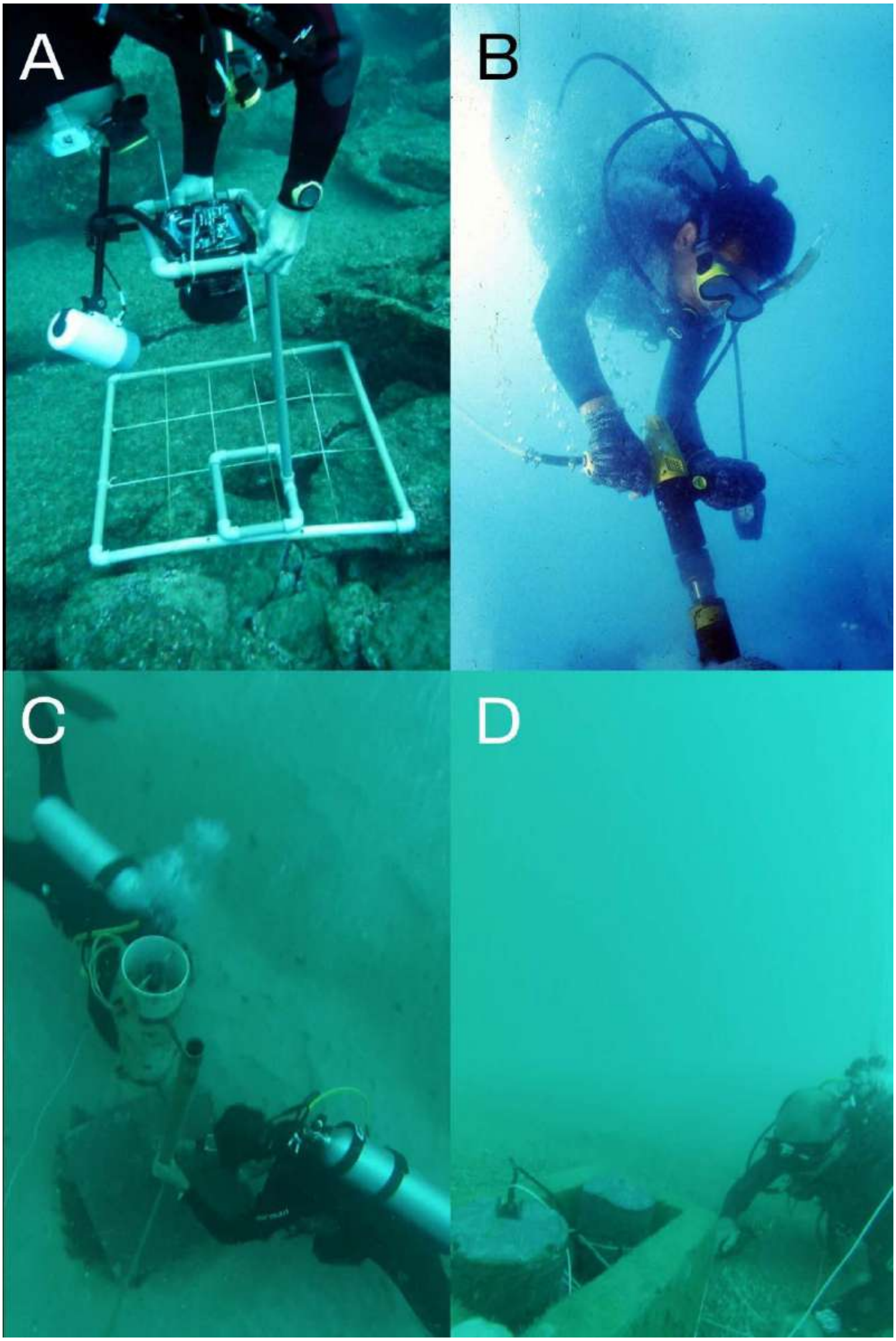


Figure 7. A) Photographic documentation in marine geology using photographic quadrants (Photo: Francisco Buchmann); B) Rock drilling with a pneumatic drill (Photo: Leo Dutra); C) The Sea-Bird HydroCAT-EP multiparameter probe measures conductivity (salt levels), temperature, depth, dissolved oxygen, pH, turbidity, and chlorophyll (Photo: Arthur A. Machado); D) ADCPs (acoustic Doppler current profiler) (Photo: Arthur A. Machado).

CAVE DIVING IN BRAZIL: HISTORY AND SCIENCE

Cave diving is a potentially dangerous specialized activity involving several techniques and equipment associated with the experience of highly skilled divers (Iliffe and Bowen, 2001). Scientific cave diving is even more complex, as mastery of this activity must be coupled with the collection of robust data and adherence to reproducible protocols based on relevant and well-founded projects.

One of the first steps for any type of research is to become familiar with the study site by exploration diving, which precedes or is part of underwater mapping. The first cave dives in Brazil were performed in 1981 in sandstone caves in the Vila Velha State Park, in Ponta Grossa, Paraná (PR), by the Bandeirantes do Mar diving school, from São Paulo, SP. In 1987, for the first time, speleologist Sérgio Beck (Centro Excursionista Universitário – CEU/USP) went beyond the Menezes Gallery in the Santana Cave, in Iporanga, SP. These pioneering works produced exploration outlines. The first systemic underwater topography took place in Bonito, Mato Grosso do Sul (MS), in 1991 and 1992 in expeditions of the Bambuí Speleological Research Group, Minas Gerais (MG), in collaboration with French cave divers. Over time, cave diving in Brazil reached extremely high technical levels, reflected in remarkable results in terms of cave penetration and depth. The dives conducted in Gruta da Bananeira (Santa Maria da Vitória, BA) and Lago Azul (Niquelândia, MG) are, to this day, internationally recognized achievements.

On the other hand, sump diving, where the speleologist has to be prepared to explore dry and flooded areas with their own equipment and often has to pass through narrow passages or chasms, is little known, despite its relevant potential. The most remarkable example of this type of exploration occurred in 2013 in the São Mateus System – Imbira, in São Domingos, Goiás (GO). Diving in a sump of less than 10 m long allowed connecting two caves over 10 km long. The result was the third largest cave in Brazil (Rubbioli et al., 2019). There are still many other caves with potential for underwater exploration.

Scientific activities using cave diving started in Brazil in the 1990s, with the increase in research focused on the paleontology, geology, and bioecology of the hypogean fauna. Mainly in the Bodoquena Plateau, MS, and the Chapada Diamantina, BA, cave divers reported to the scientific community the discoveries made during their expeditions. Since then, a new field of research has been opened. The first studies focused on the biology and ecology of the cave-dwelling catfish *Rhamdiopsis krugi* in Poço Encantado, Chapada Diamantina (Mendes, 1995a, 1995b), and the population ecology of the troglobite crustacean *Potiicoara brasiliensis,* in caves in Mato Grosso do Sul (Morachiolli, 2002).

Sampling in underwater hypogean environments by diving can include the use of usual methodologies of visual censuses performed in open water, adapted to cave environments. For instance, visual censuses can be conducted in population studies by applying methodologies such as fixed transects and roving diver surveys (Hill and Wilkinson, 2004). It can also adapt methods from classical behavioral studies, such as focal animal (Lehner, 1996) and others. The discovery and recording of new taxa can also occur during exploration diving or even recreational cave diving. Moreover, recording taxa while exploring flooded galleries helps extend the area of occurrence of cave-dwelling populations, provided that these are reliable records, such as photographs or a physical sample of specimens.

Regarding paleontology studies, the relatively frequent occurrence of megafauna fossil deposits in Quaternary deposits in Brazilian caves is remarkable, although they have already been recorded in flooded areas of underground environments. Then, mainly since the 2000s, scientific studies have been performed in association with fossil collecting. Therefore, protocols for manual collection of large bones and an airlift system with sieving of small fragments were implemented (Salles et al., 2001, 2006), which allowed obtaining a vast palaeontologic collection. The studies cover aspects of taxonomy, taphonomy, and paleoenvironmental reconstruction of various taxa, including the description of new Quaternary megafauna species.

A line of research involving physical speleology in underwater environments concerns uranium-series dating of calcite crusts formed in underground flooded environments. Dating these crusts (as well as stalactites and stalagmites in flooded environments) allows the determination of the chronology of cave flooding, enabling important inferences about the evolution of the cave and the region (Sallum-Filho, 2005). The main caves studied are Gruta do Ioiô and Gruta do Impossível (Castro et al., 2014; Eltink et al., 2020) and Poço Azul (Cartelle et al., 2008), in Chapada Diamantina, BA, and Nascente do Formoso, Buraco do Japonês, and Gruta das Fadas (Salles et al., 2006; Oliveira et al., 2017), in the Bodoquena Plateau, MS.

UNDERWATER ARCHAEOLOGICAL RESEARCH

History has recorded facts related to diving and Archeology. It began in 1960, when a young American archaeologist, George Fletcher Bass, decided to learn to dive to investigate the remains of a 12th century BC vessel at Cape Gelidonya, Turkey. At the early days of underwater research, the integration between professional researchers and amateur divers was standard, but Bass's pioneering spirit reinforced the importance of archaeologists to diving. Still, 60 years later, some divers insist on exploring submerged archeological sites on their own, especially those with the remains of shipwrecks, which promote the idea of lost treasures in the collective unconscious, feeding the fantasy of easy enrichment. This lack of understanding of this cultural heritage led international bodies such as UNESCO to elaborate documents to help protect these sites, such as the Convention on the Protection of the Underwater Cultural Heritage (Paris, 2001), allowing integration between researchers worldwide.

In Brazil it was no different. The first dives to locate submerged vessels and artifacts were performed by divers and enthusiasts who intended to create private collections, commercialize and obtain artifacts to display without any archeological concern. Brazil has a tragic maritime history, and from a formal point of view, the results of these surveys produced only inaccurate reports and, in a few cases, catalogs of the removed pieces that were preserved and displayed. Although these early interventions contributed to awakening interest in maritime heritage, they did not adopt the perspectives of underwater archeology and the protection of underwater cultural heritage. More than simply recovering pieces and associating them with traditional history, archeology seeks to produce narratives from the evidence identified by the systematic study of vessels and artifacts, *in situ*, in their proper contexts (Rambelli and Funari, 2007).

This scenario of shipwreck intervention, based more on the tradition of rescuing objects lost at sea, continued until the 1990s. At that time, Brazilian archeologists learned to dive and began to conduct underwater research, treating these submerged testimonies as archeological sites and applying the theoretical, methodological, and technical aspects intrinsic to the science of underwater archeology. The first Brazilian research that effectively applied academic perspectives to underwater archeological sites was conducted on the southern coast of São Paulo, under the Ribeira Valley Program (PABVR/MAE/USP). This project led to several submerged academic investigations, which resulted in the implementation and development of different scientific diving techniques (such as low-visibility diving and underwater survey) for the archaeological study of shipwrecks, submerged prehistoric sites, fortifications, anchorages, and harbors (Rambelli, 1998, 2003; Bava de Camargo, 2002; Calippo, 2006, 2009, 2011; Duran, 2008; Guimarães, 2009).

In 2004, this context also allowed the creation of the Center for Nautical and Underwater Archeology Studies (CEANS/UNICAMP) (Rambelli and Funari, 2007). Thanks to CEANS, the first underwater archeology projects in a remote zone (shipwreck in the Saint Peter and Saint Paul Archipelago) were developed (Calippo et al., 2013), adapting the archaeological charting technique to an underwater context (Amazonian archeological sites with submerged rock carvings) (Pereira et al., 2009) and developing new strategies and techniques for assessing and monitoring the impacts of terrestrial archeological sites that have been submerged as a result of dams construction. This wet archeology allowed the development of the practice of diving with enhanced safety, which requires the diver (archeologist or volunteer) to have prior training and specific training in underwater archeology.

From the academic recognition of the results of underwater archeological research obtained in Brazil, new projects and research groups have started to adapt, develop, and consolidate scientific diving methods and techniques in underwater archeology. Using the scientific methods of underwater survey offsets, ties/trilateration, underwater photography, etc., new research has been developed, such as the study of slave ships (Rambelli, 2006); anchorage and port areas (Bava de Camargo, 2017); underwater ritual sites (related to African traditions) (Ribeiro, 2020); historical shipwrecks of different types of vessels, such as Clipper (Gusmão, 2015), Galleon (Torres et al., 2016; Bandeira, 2021), Brig (Calippo et al., 2021), and other shipwrecks not yet confirmed (Souza, 2007; Noelli et al., 2009; Duran et al., 2010). Underwater geophysical methods (such as side-scan sonar and magnetometer) were also used whenever possible in all these types of research (Rambelli, 2003; Freire, 2020; Calippo et al., 2021). Recently digital methods based on underwater 3D photogrammetry have been increasingly adopted (Figures 8A–B) (Torres et al., 2017; Freire, 2020; Calippo et al., 2021).

Figure 8. A and B) 3D model built (by Adriano Oliveira/UFC) from the underwater 3D photogrammetry technique applied to the archaeological record of Palpite brig (19th century) (Photo: F. Calippo).

ENVIRONMENTAL EDUCATION AND SCIENTIFIC DIVING

Environmental education's (EE) conceptual issues profoundly influenced the Rio-92 Treaty on Environmental Education for Sustainable Societies and Global Responsibility, which are highlighted by the Brazilian National Curriculum Guidelines for Environmental Education (DCNEA) (Resolution CNE/CP 2/2012, Diário Oficial da União, Brasília, June 18, 2012, Section 1, p. 70). This implies a holistic view of EE, ultimately related to changes in values, principles, and attitudes (La Trobe and Acott, 2000), with an emancipatory character.

Interdisciplinarity is fundamental to achieve a holistic EE, reinforced by both DCNEA and the Brazilian Guidelines and Bases of Education (LDB; 1996), and this concept could be extended to transdisciplinarity (Berchez et al., 2019). If we transfer this idea to activities in the marine environment, understanding our influence on the ocean and vice-versa makes more sense within what we call Ocean Literacy Framework (UNESCO, 2020; Cava et al., 2005).

Since the early 2000s, several experiences have shown that diving can be used as an integrative phenomenon, "phenomenon-based education" (Berchez et al., 2019), useful for all levels of formal education and particular initiatives, such as those conducted in marine protected areas. This activity can potentially promote the fundamental gains expected from an educational activity. Scientific diving itself can be a way to promote scientific literacy in practice, since the activity of producing scientific knowledge can help divers understand scientific concepts related to the marine environment, scientific data collection procedures, the nature of scientific knowledge, the importance of the marine environment for scientific discoveries, among others. One way to promote scientific literacy in diving is the use of citizen science, a process of public participation in the construction of scientific knowledge (Pimentel et al., 2019).

In Brazil, the first initiatives that applied diving in environmental education date back to the 1980s, with the increase in scuba diving schools. Although without a scientific base and relying on empiric experience, these actions were key to the development of a conservation-oriented diving ethics in Brazil (Berchez et al., 2007).

More structured activities emerged around the beginning of the millennium. Guided trails for the general public were based on snorkeling and scuba diving or the use of underwater viewers along a sequence of interpretation sites. Additional equipment was produced, such as rafts to aid flotation or PVC submersible cards for visual identification of organisms. Although universities developed and implemented part of these initiatives, several others were led by local associations or city halls (Wegner and Polette, 2003; Berchez et al., 2005, 2007, 2015; Pedrini et al., 2016). Among them, the USP (Universidade de São Paulo) Underwater Trail has endured for 20 years, from 2002 until now, having guided around 30,000 people and trained 733 educators.

Another example is the Outside Water Diving Trail (Berchez et al., 2007; Ursi et al., 2013), a sequence of interdisciplinary panels, diving equipment, and experiments that use the concepts, knowledge, and skills related to diving in the education of primary school students. Moreover, EE activities initiated by briefings can potentially have a positive short-term impact on the health of marine biodiversity. With the development of diving tourism, especially in marine protected areas with reef environments, known for their biodiversity and fragility, a delicate situation arose due to the impact caused by divers on reef organisms. Recently, Giglio et al. (2018) showed the importance of briefings before dives using standardized educational material to reduce negative impacts.

UNDERWATER PHOTOGRAPHY AND VIDEOGRAPHY IN MARINE SCIENCE

Photography was introduced to scientific diving as a record of evidence, something extremely valuable to science, which until then relied solely on drawings to depict aquatic organisms. The first attempts at underwater imaging date back to the 1850s, by William Thompson (1822–1879), who carried equipment to a depth of 5.5 m in an intertidal zone in Weymouth Bay (south coast of England) using ropes (Martínez, 2014).

Until 1890, essential advances were made by trial and error by several people, such as Jacob Ellsworth Reighard (1861–1942) and the Brazilian diver Henrique Adolfo Boiteux (1862–1945) (Martínez, 2014). However, the image that became known at the time as the first underwater photo was taken by the French marine biologist Louis Marie-Auguste Boutan (1859–1934) in Banyuls-Sur-Mer, France (Boutan, 1900). Some years later, John Ernest Williamson (1881–1966) filmed the first underwater moving pictures, *Thirty Leagues Under the Sea* (1914) and *Twenty Thousand Leagues Under the Sea* (1916), using a long rigid tube called photosphere (Cattaneo-Vietti and Mojetta, 2021).

In Brazil, the first records of underwater photography used for scientific purposes occurred in the expeditions of Jacques Laborel and Marc Kempft in reef environments in the northeastern region (see section USE OF ENVIRONMENTAL ASSESSMENT AND CONSERVATION UNDERWATER TECHNIQUES REGARDING IN OCEANS AND INTERNAL WATERS). Later, underwater images illustrated the article by Paiva et al. (1973) on experimental lobster fishing in Ceará and depicted the behavior of gillnets on various bottom areas, especially areas of calcareous algae. After the 1980s, photography, and later videography, became more widely used in studies of animal behavior in freshwater environments and, after the 1990s, in studies of systematics, animal behavior, and natural history of marine and freshwater organisms.

Underwater photography has played a crucial role in the description of reef species, such as *Elacatinus figaro* (Sazima et al., 1997), *Platygillellus brasiliensis* (Feitoza, 2003), *Octopus insularis* (Leite and Mather, 2008), *Latrunculia janeirensis* (Cordonis et al., 2013), *Coenocyathus sebroecki* (Kitahara et al., 2020), among others. Carvalho-Filho et al. (2020) recently recorded the cryptic fish genus *Malacoctenus,* describing *M. lianae* and *M. zaluari*, two new endemic species from the Brazilian coast, and solving an identification problem that persisted for years in studies with underwater visual census. As well as the recent description of *C. sebroecki* (Kitahara et al., 2020), an image of an azooxanthellate coral species was obtained in Rasa Island, RJ, which was crucial for the identification of the species distribution.

Photography and videography have also been widely used to conduct fish species surveys (Monteiro-Neto et al., 2013; Pimentel et al., 2020), benthic composition (Aued et al., 2018; Matheus et al., 2019), and behavioral studies (Sabino, 1999, 2009; Leite et al., 2009a). Moreover, photos and videos are used to describe new behavioral records in natural history and ethology studies in Brazilian reefs (Krajewski and Bonaldo, 2005; Bonaldo et al., 2007; Krajewski et al., 2009). Studies on feeding associations in reef environments often use photography and videography in sampling, both for data collection and to illustrate the interactions described, as well as studies on cleaning symbiosis (Sazima et al., 2000; Grossman et al., 2006; Bertoncini et al., 2009), nuclear-follower feeding associations (Sazima et al., 2006, 2007, 2010), Batesian mimicry (Krajewski et al., 2009), commensalism between dolphins and fish (Sazima et al., 2003, 2013), among others. More recently, researchers have also been using remote video recorders to measure ecological interactions such as herbivory (Longo et al., 2019; Nunes et al., 2020) and antagonistic interactions (Fontoura et al., 2020) of fish and other reef species.

Studies involving citizen science methodology, especially by engaging the public via social media, also use photographic and video records made not only by researchers, but also by the lay public (e.g. tourists, locals, workers) visiting sites of interest to the study. Some examples of Brazilian initiatives are (see some of this projects in Table S1): #DeOlhoNosCorais Project, which aims to involve the public in activities that allow the monitoring of coral colonies on the Brazilian coast; Budiões Project, which aims to record seven species of parrotfish on the Brazilian coast (https://budioes.org/participe); a study on the interactions between octopuses and marine litter based on photos and video available on social media or sent by photographers (Freitas et al., 2022); and Meros do Brasil Project, which aims to better understand the distribution patterns of groupers (*Epinephelus itajara*) by photo identification (Bertoncini et al., 2013) on the Brazilian coast.

Photography and videography are fundamental tools for scientific promotion. In scientific meetings and especially in the dissemination of studies to the lay public, the use of images can be a great ally to make the intended message clearer, more interesting and impactful, besides allowing studies to be presented in media outlets where the image is crucial, such as TV programs, e.g. Mar Sem Fim (https://marsemfim.com.br/), Domingão Aventura (http://gshow.globo.com/programas/domingao-do-faustao/noticias/domingao-aventura/1.html), and the documentaries Blue Planet (https://www.bbc.co.uk/programmes/b008044n), Blue Planet II (https://www.bbc.co.uk/programmes/p04tjbtx), and Vida no Azul (https://www.discoverybrasil.com/animal-planet/vida-no-azul). The use of images in scientific promotion has become even more relevant since the popularization of accessibility, especially due to the Internet and social media.

Technology has also made imaging in research more accessible. Since the introduction of mini cameras (e.g. GoPro) with 11 megapixel sensors and FullHD videos, constant technological advances took equipment to a level of producing 5K videos and 20 megapixel photos in just over a decade. This is associated with excellent results even in low light, which represents a significant challenge in underwater environments. Extremely compact and affordable underwater video equipment in underwater housings has led to a significant increase in research possibilities involving scientific diving and testing of scientific hypotheses (Koenig and Stallings, 2015; Paula et al., 2018; Fontoura et al., 2020; Guabiroba et al., 2020; Garcia et al., 2021).

Today, there is a wide range of photography and videography equipment (Figures 9A–D), of varying cost and features, which require careful consideration. Thus, it is always up to the scientific diver to assess the objectives in the field. Whether documenting the environment or the object of study, there are essential issues such as the type of lenses (macro or wide-angle), the need for artificial lighting (flashlights or detachable camera flash), assessment of conditions of use of the equipment considering the size of the final set, which always affects diving performance, especially in terms of buoyancy and drag.

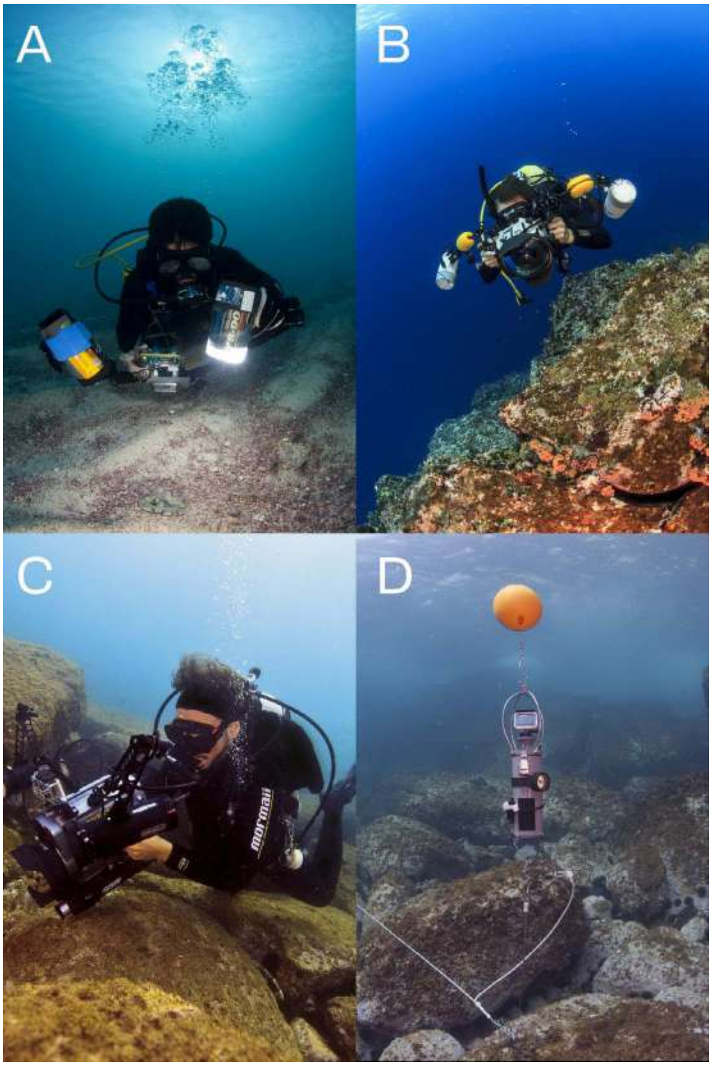


Figure 9. Different sets of photographic and videographic equipment used by divers. A) compact camera with detachable flash; B) DSLR camera with wide-angle dome; C) video camera with lighting; F) compact camera for remote images (SRV) (Koenig and Stallings, 2015).

Finally, despite the constant development in image capture, organizing their image database remains an obstacle that many divers need to overcome. Although several software (e.g. Adobe Lightroom CC, CyberLink PhotoDirector, ACDSee Photo Studio) for sorting images are available in the market, there is still no culture of how the material should be organized or development of an essential mindset of backing up this material and securing the data. Such an image database could allow easy access to these data for future research and comparison and provide material to illustrate scientific studies and material for scientific education and promotion (Segal et al., 2017; Bertoncini et al., 2019).

THE SCIENCE OF DIVING PHYSIOLOGY: BUBBLE DYNAMICS AND DECOMPRESSION THEORY

Besides the aforementioned underwater techniques, Brazil has also conducted research on diving physiology, which is crucial for the technological development and advancement of the activity itself, thus preventing accidents. Simply put, diving is the immersion of a body into a liquid fluid. However, when the body is a fully equipped diver, whether free, open-, or closed-circuit or surface supplied, diving has become a multi-phenomenon complex activity involving several laws of physics and biochemistry (Wienke, 1994, 2016), subjecting divers to various physical and physiological effects.

The hyperbaric nature of diving—absolute ambient pressure higher than atmospheric pressure at sea level—produces significant physiological changes in the body, which are also due to the increased partial pressure of the gases in the mixture used by the diver. The most common incidents in diving are barotraumas, especially pulmonary hyperdistention, decompression sickness (DCS), and arterial gas embolism (AGE), all effects associated with the presence of dissolved gas in blood and body tissues or cavities (Vann et al., 2011; Pollock, 2020; Mauvecin and Espinosa, 2022).

While the laws of classical mechanics and fluid dynamics dictate the movement of the diver, the laws of thermodynamics, gases, fluid dynamics, and electromagnetism are primarily involved in the hyperbaric physiological processes and the operation and performance of diving equipment. In these fields, experimental and theoretical research on bubble dynamics and decompression theory, and the elaboration of decompression protocols for open and closed-circuit diving (rebreather) have been developed in Brazil since the last decade (Wienke et al., 2008; Del Cima et al., 2017, 2018; Schirato et al., 2018).

In 1896, Wilhelm Ostwald presented a phenomenon in which small crystals in solution dissolve and redeposit onto larger crystals (Ostwald, 1897), a mechanism well-known as Ostwald ripening. Recently, an experiment was performed at the Department of Physics (DPF) of Universidade Federal de Viçosa (UFV), where Ostwald ripening was also observed among gas bubbles in liquid fluids, in which smaller bubbles feed larger ones (Del Cima et al., 2017, 2018). Thus, it proved that for gas bubbles in liquid fluids, Ostwald ripening consists of the transfer of gas from smaller to larger bubbles by diffusion in liquid fluids, increasing the radius of the larger bubbles by decreasing the number of smaller bubbles.

DCS (Vann et al., 2011; Pollock, 2020; Mauvecin and Espinosa, 2022) and AGE are a hazard that divers, astronauts, aviators, and workers in pressurized environments are exposed to when under hyperbaric or hypobaric conditions and therefore subject to compression and decompression. Lesions caused by gas bubbles (N_2, He, O_2, CO_2, H_2O vapor) can trigger, for example, DCS due to the formation and growth of intravascular and extravascular bubbles.

Preliminary experimental studies (Del Cima et al., 2017, 2018) on Ostwald ripening, performed for an air bubble system of air bubbles (bubble chamber) in liquid fluids under some rheological parameters (density and surface tension) of human blood (Wienke, 2009), but with higher viscosity (7.8 times the average viscosity of human blood) to reduce coalescence, showed an increase in the average bubble radius size, while the number of bubbles decreased over time. Consequently, the Ostwald mechanism leads to an increase in larger bubbles while the smaller ones disappear.

Therefore, smaller bubbles (asymptomatic) feed the larger ones (potentially symptomatic). Based on this phenomenon, Ostwald ripening probably contributes to an increased risk of decompression, as the average bubble radius size may increase over time due to gas diffusion between the bubbles and not only by decompression (decrease in ambient pressure) or outgassing—effects proven to be significant in the manifestation of DCS symptoms. Finally, an empirical model was proposed from the experimental data for the time evolution of the average radius size and the number of bubbles (Del Cima et al., 2017, 2018).

Later, based on the empirical model, Ostwald ripening—the mechanism of gas diffusion between bubbles—was implemented in RGBM (RGBM-Ostwald) (Wienke et al., 2008; Del Cima et al., 2018; Wienke, 2019). The contribution of gas diffusion between bubbles (Ostwald ripening) to RGBM is evident even in less exposed dives.

Ever since John Scott Haldane proposed the first decompression model in 1908, scientists have searched for new models to describe the behavior of gases in the body to reduce the risks associated with harmful effects under pressure variations. Thus, other decompression models were developed, such as single-phase models (dissolved gas) and two-phase models (gas bubbles) (Yount and Hoffman, 1986; Wienke, 1990). Recently, Ostwald ripening was implemented to RGBM (Wienke et al., 2008; Del Cima et al., 2018; Wienke, 2019).

Currently, a physical and computational finite element model is in the final stage of development by the Decompression Theory Group at DPF/UFV, which aims to study the evolution kinetics of gas bubbles in a liquid fluid (Del Cima et al., 2017; Oliveira, 2022) to later develop a diving decompression model and subsequent validation tests using dry diving (hyperbaric chamber) and *in situ*.

SCIENTIFIC DIVING TEACHING IN BRAZIL: THE EVOLUTION OF SCIENTIFIC DIVER TRAINING IN BRAZIL

Once all the potential of the use of diving, coupled with specific techniques for research, monitoring, and marine and limnic science in Brazil, is contemplated, we aim to understand the development of scientific diving teaching and outline perspectives in the country, since the training of qualified scientists capable of conducting these underwater surveys is crucial.

The first assessment on the state of the art of scientific diving in Brazil, recently published by Maia-Nogueira (2021), suggests guidelines for training aimed at developing more efficient and safer scientific diving. However, this assessment focuses only on nonscience related diving techniques. Several certification programs require scuba diving training for scientific divers, although European standards do not require traditional recreational diving training in all member states for performing scientific study activities (Feral, 2017; Maia-Nogueira, 2021). A diver scientist can master various techniques and specialties, from freediving and scuba diving to technical diving, thus broadening their range of action in the environment, with a greater likelihood of working safely in various underwater and hyperbaric scenarios (Figures 10A–D).

Scientific diving is not a specialty of recreational diving (Maia-Nogueira, 2021). The first efforts to teach scientific diving in scientific institutions occurred at Universidade Federal do Rio Grande (FURG) in 1978, with the creation of the subject "Underwater Diving Techniques," which had a duration of 60 hours in one academic period and was included in the curriculum of the Oceanology course. This subject was offered for 10 years and was discontinued in 1988.

In 1994, the School of Marine Sciences of Universidade do Vale do Itajaí (FACIMAR/UNIVALI) created the Diving Laboratory to support research activities. From 1995, the Oceanography course of this university implemented the subject "Scuba Diving," and the Diving Laboratory supported research, extension, and teaching activities. In 2003, UNIVALI published its first scientific diving protocol: Regulation of Scientific Diving Practice, and these initiatives resulted in the creation of the Scientific Diving Center of UNIVALI in 2004, in partnership with the Confédération Mondiale des Activités Subaquetiques (CMAS). Thus, the subject "Scientific Diving" was included in the curriculum of Oceanography and Biology courses.

In 2006, this subject, currently called “Underwater Study Methods,” was implemented by the Department of Oceanography of the Universidade Federal do Rio Grande do Norte (DOL/UFRN) (https://sigaa.ufrn.br/sigaa/link/public/curso/curriculo/10336000). Since 2012, the subject “Underwater Sampling Techniques” has been offered by the Sea Institute of Universidade Federal de São Paulo (https://www.unifesp.br/campus/san7/graduacao/cursos/bacharelado-interdisciplinar-em-ciencia-e-tecnologia-do-mar) and, in 2018, “Scientific Diving” was included in the Oceanology curriculum of the Universidade Federal do Sul da Bahia (https://ufsb.edu.br/cfcam/pt-br/graduacao/oceanologia).

From a future perspective, we understand that scientific diving teaching should establish a theoretical reference to support the integration of diving methods, scientific methodology, and the techniques from The American Academy of Underwater Sciences (AAUS) standards (2013). Thus, a basic curriculum should include principles of physics applied to understanding the underwater environment; human physiology; diving safety concepts and fundamentals; underwater orientation and navigation; diving equipment; planning of diving operations; rules, regulations, environment, safety, and legal aspects related to diving. Regarding the scientific aspect, courses should address content related to scientific studies, including scientific research methods and, ideally, environmental education and conservation.

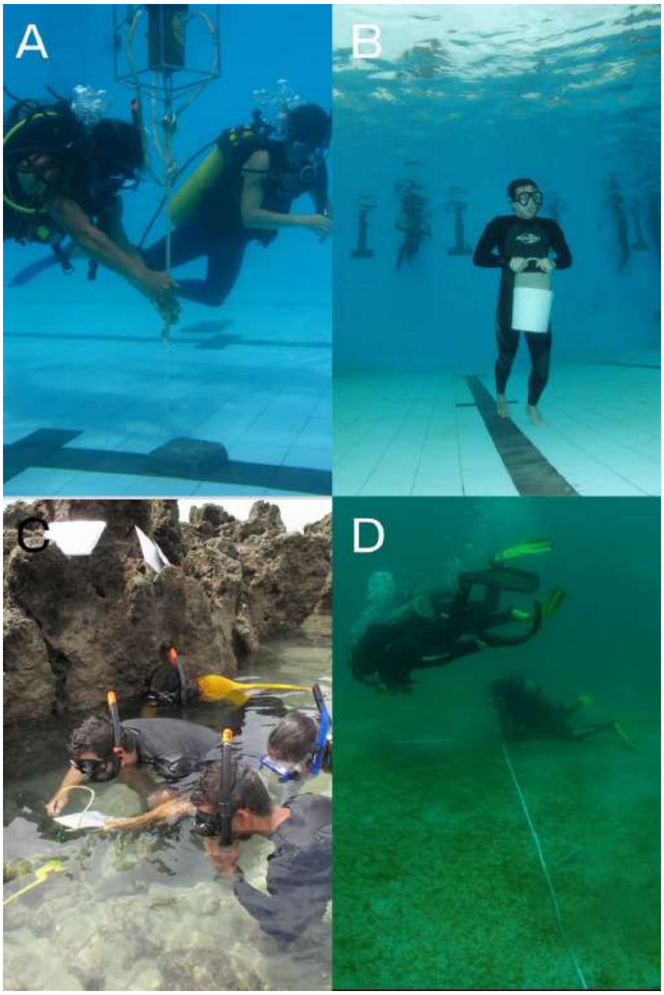


Figure 10. A and B) Pool training to level up practical autonomous and freediving abilities (Photo: Ewerton Wegner); C and D) Training in scientific data collection in a natural environment using freediving and scuba diving (Photos: Liana Mendes and Tiego Costa).

SCIENTIFIC DIVING SAFETY AND REGULATION IN BRAZIL: PROTOCOLS, CURRENT SITUATION AND FUTURE PERSPECTIVES

The excellent history of scientific diving was due to the continuous effort of supervision and guidance (Dardeau et al., 2012). Internationally, scientific diving has a significantly lower accident rate than other diving modalities, including recreational diving. A 10-year review of AAUS members' diving records from 1998 to 2007 analyzed 1,019,159 scientific dives and yielded an overall incident rate of 0.93/10,000 person-dives. Of these, 33 cases of decompression illness (DCI) were identified, encompassing both DCS and air embolism (Dardeau et al., 2012). The rate of DCI was 0.324/10,000 person-dives, which was lower than the rate of 0.9–35.3/10,000 published by this study on recreational, instructional, or guided, commercial, or military diving. Another study reviewed three scientific diving databases, which included 508,771 dives and 28 severe cases, split between 21 cases of DCI and seven deaths (Sayer, 2005). The rate found was 0.6 and 0.4, respectively, for serious incidents and cases of DCI per 10,000 dives. Currently, in Brazil, scientific diving is often performed in remote and sometimes hard-to-access areas, such as oceanic islands, flooded caves, and icy areas like Antarctica (Nonato et al., 1992). Sites such as the Saint Peter and Saint Paul Archipelago and the Trindade Island are located hundreds of miles from the coast, with no airports available (Mohr et al., 2009). The concept of remote location may include isolated sites, such as those aforementioned, but it can also mean far from adequate medical assistance. Thus, even locations relatively close to metropolitan areas may be classified as remote due to the lack of medical resources for adequate diagnosis and treatment.

Although there are more than a hundred hyperbaric medical services in Brazil, only a fraction is prepared to manage a diving emergency. In the last decades, hyperbaric oxygen therapy (HBOT) has gained other important medical applications, and the treatment of DCI is no longer part of the medical practice. In diving, conditions can be severe and occur outside the working hours of these services. Dive planning should consider these factors and the whole team should understand and acknowledge these difficulties.

Safety risks may also be present in the learning process. The loss of knowledge across generations can compromise a work in progress. Issues that required attention from previous generations may not receive the necessary care from younger generations. Diver training has changed progressively as equipment has become more reliable and easier to use. Even though these changes may reduce the time necessary to master basic skills, they may also reduce efforts to develop the student's problem-solving skills. Time pressure is another challenge for scientific divers. The ever-growing demand for academic scientific production, coupled with the high cost of diving courses, has led researchers to bring students from various levels of training, sometimes even without adequate training and experience, onto the dive team. As a result, there is a vicious cycle of turning out individuals who fall short of the required training.

The lack of someone to assume the advisor role may be a problem caused by efforts to reduce training time, curriculum, support team, and the academic network. The advisor role allows the group to learn each other's skills and mistakes. This may have a huge positive impact on the advisor's performance and help minimize the issue of loss of knowledge across generations of researchers (Pollock and Godfrey, 2007).

Appropriate protocols and regulations could further enhance safety in scientific diving. Many attempts to regulate scientific diving activities have been made by external actors, including the commercial diving workers' union and the Brazilian Navy (Marinha do Brasil, Diretoria de Portos e Costas, 2011). The last attempt, from the partnership between the GT Mergulho Científico and the Directorate of Ports and Coasts (DPC), was made by publishing NORMAM-15 – Atividades Subaquáticas (Marinha do Brasil, Diretoria de Portos e Costas, 2016). It was recently rectified in its third revision (NORMAM-03, DPC/DGN/MB Ordinance No. 73 of April 20, 2023), which included in Chapter 1, item 0142, the externality of scientific diving in its scope. This definition by the maritime authority, completely separating scientific from commercial diving, was a remarkable achievement for scientific diving in Brazil and needs to be maintained.

The low accident rate of scientific diving compared with other diving modalities, including recreational diving, has given the activity the space to exercise self-regulation without external control. Maintaining this status requires the commitment of each individual involved in the activity or responsible for any aspect of scientific diving. Safety programs are more efficient when all levels, institutions and individuals, actively support the initiatives.

In scientific diving, a possible direction for Brazil would be the organization of an association with experts in diving operations and safety, focused on developing general standards for proper working practices. The documents produced by this group of experts would serve as terms of reference for the activity in the country. Each institution can revise the terms of reference and amend them according to the demands of operational conditions. Since most institutions do not have the necessary expertise, this council would usually act by a diving safety supervisor, sometimes assisted by external experts, who take responsibility for ensuring safety measures. The main responsibilities of the institution would be to ensure the availability of trained staff and appropriate safety equipment, to develop its own standards, and to provide adequate support so that all staff may effectively respect these standards.

The regulation of scientific diving (SD) is a topic that has been discussed for some years, but still lacks more concrete actions towards an effective and efficient self-regulation that offers physical safety to those who practice it and institutional safeguard to the organizations that use it in their research projects.

The growing need for better knowledge of Brazilian underwater environments and the advancement of research to generate this knowledge bring close the inevitable regulation of SD in Brazil, promoting numerous future benefits for the activity. However, it may also present challenges, leading the Brazilian SD community to adequate self-regulation before the imposition of external actors with little technical-scientific knowledge of the activity.

Universities and research institutions often rely on the basic training of divers with recreational diver training protocols, especially regarding basic skills and knowledge required of divers. Once they have mastered basic diving skills, they begin to acquire and train specific techniques needed to perform tasks related to underwater scientific work. The parameters of this training end up being the responsibility of each institution or university. Thus, most institutions that use diving as a tool for scientific research rely on the rules and procedures of recreational diving training organizations and the international standards NBR ISO to guide the training of their scientists in the fundamentals of diving, complementing their training with the fundamentals of scientific activity and using their own procedures and standards. The standards are: NBR ISO 21416:2020 Recreational diving services – Requirements and guidance on environmentally sustainable practices in recreational diving; NBR ISO 21417:2020 Recreational diving services – Requirements for training on environmental awareness for recreational divers; NBR ISO 11121:2019 Recreational diving services – Requirements for introductory programs to scuba diving; NBR ISO 24803:2019 Recreational diving services – Requirements for recreational diving providers; NBR ISO 24802-1:2019 Recreational diving services – Requirements for the training of scuba instructors – Part 1: Level 1; NBR ISO 24802-2:2019 Recreational diving services – Requirements for the training of scuba instructors – Part 2: Level 2; NBR ISO 24802-3:2019 Recreational diving services – Requirements for the training of scuba instructors – Part 3: Level 3 – Diving leader; NBR ISO 24801-1:2018 Recreational diving services – Requirements for the training of recreational scuba divers – Part 1: Level 1 – Supervised diver; NBR ISO 24801-2:2018 Recreational diving services – Requirements for the training of recreational scuba divers – Part 2: Level 2 – Autonomous diver; NBR ISO 13293:2018 Recreational diving services – Requirements for gas blender training programs; NBR ISO 11107:2012 Recreational diving services – Requirements for training programs on enriched air nitrox (EAN) diving; NBR ISO 13289:2012 Recreational diving services – Requirements for the conduct of snorkeling activities; NBR ISO 13970:2012 Recreational diving services – Requirements for the training of recreational snorkeling guides.

Some countries are more advanced in their SD regulations. We will mention and discuss here three examples where SD already has a regulation in force, and then evaluate them to elaborate our own rules.

In the United States, two distinct regulation systems coexist: state and private standards. The Occupational Safety and Health Administration (OSHA), the government agency that regulates labor issues, has a set of occupational standards and regulations. However, in the Guidelines for Scientific Diving of its Occupational Safety and Health Standards (1910), in general terms, the agency only determines which scientific diving programs can be exempt from the mandatory requirements for commercial diving. On the other hand, in 1982, after several requests from scientists across the country, including AAUS, OSHA exempted scientific diving from commercial diving regulations under certain conditions. Final resolutions on the exemption came into effect in 1985 (Federal Register, Vol. 50, No. 6, p. 1,046). OSHA recognizes AAUS as an organization that defines scientific diving standards and procedures.

In South Africa, a decree (Occupational Health and Safety ACT, 1993; Diving Regulations, 2001) regulates almost all professional diving activities. In this case, SD runs significant risks of having its activities directly affected by the strict regulation of commercial diving, which could lead to the impracticability of its activities.

On the other hand, Australia is the least clear and specific of the three. The Model Work Health and Safety Regulations also provides specific regulations for commercial diving, but excludes and defines limited scientific diving work as "limited scientific diving work means general diving work that: a) is carried out for the purpose of professional scientific research, natural resource management or scientific research as an educational activity; and b) involves only limited diving."

These examples show how SD can be misunderstood by labor authorities, who are often unfamiliar with underwater work, in particular underwater scientific research. Although well-intentioned, the regulations imposed by these authorities can seriously harm the activity, since many of the requirements for commercial diving are costly and difficult to implement in the field, but totally unnecessary and even detrimental to underwater scientific work. A break between SD and commercial diving becomes indispensable to ensure that scientific activities continue and thrive in the future. Therefore, a set of rules and standards is essential to ensure effective self-regulation of the activity, thus avoiding regulatory efforts by government agencies or other private organizations.

We envision other alternatives for SD self-regulation in Brazil. There are some different ways in which an industry or activity can create a set of rules or standards that will self-regulate the industry or activity. We present here two of them, which we believe are the most feasible, considering the characteristics and particularities of Brazilian SD:

1. Industry standards follow the American model. A private entity can represent the SD community by creating and maintaining the standards of the activity, and thus being recognized as the official regulatory agency. In general, these entities consist of a group of people or organizations specialized in the activity represented and that meet regularly to discuss and approve changes and updates to the standards previously created. In the previous example, the organization in question is AAUS. The recreational diving community also has a similar entity called the World Recreational Scuba Training Council (WRSTC).

Even though this is accepted and respected, it still lacks a public identity, as knowledge of its existence outside the diving and SD community is quite limited, which allows attempts to regulate SD by external actors, such as unions and commercial diving organizations.

2. Another alternative is using international and national technical rules. Several industries

> worldwide use technical rules extensively, and generally show a greater maturity of the industries and countries adopting them. An advantage of this alternative to self-regulation is the greater knowledge of these rules by authorities at various levels, including labor, legal, etc. In this type of regulation, each country has its own representation in an international agency, the International Organization for Standardization (ISO). ISO is an independent, nongovernmental international organization that sets standards to ensure the quality, safety, and efficiency of products, services, and systems. Experts in each area of interest are part of its work groups, as well as a coordinator (usually also an expert) and a secretary.

Another important feature of these standards is that, although they are internationally approved, each country may approve its own rules if necessary. The Brazilian representative in ISO is the Brazilian Association of Technical Standards (ABNT). Currently, there are no specific rules for SD in ISO or any of its members, but the thirteen rules published for recreational diving can serve as bases for SD rules.

CONCLUSIONS AND FUTURE PERSPECTIVES FOR SCIENTIFIC DIVING IN BRAZIL

The results of this review show the importance of SD for underwater research in Brazil, making it clear that there still is much to be explored in underwater environments, especially in deeper and/or remote areas. According to Cattaneo-Vietti and Mojetta (2021), “diving enabled marine scientists to collect biological and geological samples, observe organisms and their behavior directly *in situ*, study species interactions, and evaluate the marine communities’ structure and dynamics.” An increase in research and consulting on human impact on the marine environment and invasive species management is also evident, requiring SD. This tool also allows research to have less impact on marine life, especially due to advances in underwater photography and videography, preventing several organisms from being captured and sacrificed for studies. This feature helped advance studies on conservation and preservation and endangered fauna.

The relative scarcity of scientific research involving underwater archaeology, cave diving, and diving at depths greater than 50 m in Brazil reflects the small number of scientists with the technical training to do so. As in other countries, this reality may be related to the difficult in taking technical courses, buying sophisticated and expensive equipment, and maintaining a training routine. This is also coupled with the fact that these dives present life-threatening risks for the researcher due to their complexity. Besides the aforementioned aspects, the complicated bureaucracy for obtaining research licenses also contributes to the scenario.

SD attracted interest from educational and research institutions, companies, and the third sector. This increasing interest alerts to the urgent need to recognize and regulate this activity in Brazil, on the part of educational institutions, where these activities – such as maintaining hazard pay – are already present; and of the scientific sector (CNPq, CAPES, SECIRM), that should recognize this activity as an important tool for the development of marine science in Brazil. Moreover, financial contributions and support are needed, including investments directed to vessels that may be modified to include SD in their activities.

However, the current situation in Brazil reflects the lack of specific funding for the structuring of research institutions and the training of scientific divers, as well as a lag in the process of regulating SD, which has led to the activity being performed without proper training, risking the lives of students and researchers, or even compromising the quality of results. These issues have hampered the ongoing training of diver scientists and hindered the development of underwater research in the country.

Having a set of rules and self-regulation in SD makes it easier to obtain the necessary resources for this progress, resulting in greater safety for all those involved in the activity. This includes not only the physical safety of the researchers directly involved in the dive, but also the institutional safeguarding for the organizations involved.

Moreover, it allows a better understanding of the activity by the managers and directors of these organizations, who are not always familiar with the details of scientific diving, which can harm researchers who depend on the permission from these managers.

We end this article by pointing that in 2021, IOC/UNESCO proclaimed the United Nations Decade of Ocean Science for Sustainable Development(https://www.oceandecade.org/). This key instrument aims to develop ocean science, helping countries, decision-makers, and citizens to develop concepts and make decisions about our ocean. Thus, scientific diving has increased knowledge for present and future education and science.

ACKNOWLEDGMENTS

All authors thank PPG-Mar/CIRM (Interministerial Commission on Marine Resources), especially coordinator Prof. Dr. Krug, for supporting the Brazilian Scientific Dive Working Group (GT Mergulho Científico), the National Council for Scientific and Technological Development (CNPq) and the Coordination of Superior Level Staff Improvement (CAPES), for supporting several scientific diving researchers with grants and research funding, and ICMBio for supporting and encouraging scientific divers within marine protect areas in Brazil. We also thank Eleonora Trajano and Ezio Luiz Rubiolli for their review and collaboration with the Cave Diving section, and the anonymous reviewers who contributed to this publication. HTP thanks the São Paulo Research Foundation (FAPESP) for research funding and scholarship (grants 2019/24215-2 and 2021/07039-6); RBFF thanks the research productivity scholarship provided by CNPq (#309651/2021-2); AC thanks the research productivity scholarship provided by CNPq 305417/2019-3); and CM thanks the Bahia Research Foundation (FAPESB) and Petrobras Ambiental (Rede Temática Taxonomia de Porifera do Brasil).

We dedicate this article *in memorian* of Sergio Viegas, for his important collaboration in the GT Mergulho Cientifico, helping us on the topic of scientific diving safety and regulation, and to Thione Simon, for his dedication and discoveries about marine fish in the mesophotic reefs around the Brazilian oceanic islands.

AUTHOR CONTRIBUTIONS

T.S.L.: Conceptualization; Supervision; Project Administration.

A.B., A.A.M., B.S, C.L.S.S., F.B., F.M., G.R., I.E.P, L.F.M., M.O.DC., R.F-F, R.K., T.M.C. L., T.S.L.: Investigation; Writing – original draft.

A.B., A.C., A.A.M., A.S.A., B.S, C.L.S.S., C.M., F.C., E.W., F.B., F.M., F.S.B., G.C.L., G.R., H.T.P., I.E.P, J.B-N., J.C.S.S., J.SA., J.SE., L.F.M., L.A.R., M.A.C.G., M.O.DC., N.G-L., R.F-F, R.M.B., R.K., T.M.C. L., T.C.G., T.L., T.S.L., Z.M.AN.N.L.: Writing – review & editing.

REFERENCES

Amado-Filho, G. M., Moura, R. L., Bastos, A. C., Francini-Filho, R. B., Pereira-Filho, G. H., Bahia, R. G., Moraes, F. C. & Motta, F. S. 2016. Mesophotic ecosystems of the unique South Atlantic atoll are composed by rhodolith beds and scattered consolidated reefs. *Marine Biodiversity*, *46*(4), 933–936. DOI: https://doi.org/10.1007/s12526-015-0441-6

Araújo, P. & Amaral, R. F. 2016. Mapping of coral reefs in the continental shelf of Brazilian Northeast through remote sensing. *Revista de Gestão Costeira Integrada*, *16*(1), 5–20. DOI: https://doi.org/10.5894/rgci629

Aria, M. & Cuccurullo, C. 2017. Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975*.* DOI: https://doi.org/10.1016/j.joi.2017.08.007

Aued, A., Smith, F., Quimbayo, J., Cândido, D., Longo, G., Ferreira, C., Witman, J., Floeter, S. & Segal, B. 2018. Large-scale patterns of benthic marine communities in the Brazilian Province. *PLOS ONE*, *13*(6), e0198452. DOI: https://doi.org/10.1371/journal.pone.0198452

Bandeira, B. F. 2021. Updated Archaeological Documentation of the Shipwreck Galeão Santíssimo Sacramento (1668). *The SHA Newsletter*, *54*(2), 32–35.

Bastos, A., Moura, R., Amado-Filho, G., D'agostini, D., Secchin, N., Francini-Filho, R., Güth, A., Sumida, P., Mahiques, M. & Thompson, F. 2013. Buracas: Novel and unusual sinkhole-like features in the Abrolhos Bank. *Continental Shelf Research*, *70*, 118–125. DOI: https://doi.org/10.1016/j.csr.2013.04.035

Bastos, A., Moura, R., Moraes, F., Vieira, L., Braga, J., Ramalho, L., Amado-Filho, G., Magdalena, U. & Webster, J. 2018. Bryozoans are Major Modern Builders of South Atlantic Oddly Shaped Reefs. *Scientific Reports*, *8*(1), 9638. DOI: https://doi.org/10.1038/s41598-018-27961-6

Batista, A. & Leite, T. 2016. Octopus insularis (Cephalopoda: Octopodidae) on the tropical coast of Brazil: where it lives and what it eats. *Brazilian Journal of Oceanography*, *64*(4), 353–364. DOI: https://doi.org/10.1590/s1679-87592016123406404

Bava de Camargo, P. 2017. Arqueologia portuária em Sergipe: teoria e metodologia. Vestígios. *Revista Latino-*

Americana de Arqueologia Histórica, *11*, 28–51. DOI: https://doi.org/10.15210/lepaarq.v14i27.9833

Bava de Camargo, P. F. 2002. *Arqueologia das fortificações oitocentistas da planície costeira Cananéia/Iguape,SP* (mathesis). Museu de Arqueologia e Etnologia, Universidade de São Paulo, São Paulo.

Berchez, F., Carvalhal, F. & Robim, M. 2005. Underwater interpretative trail: guidance to improve education and decrease ecological damage. *International Journal of Environment and Sustainable Development*, *4*(2), 128–139. DOI: https://doi.org/10.1504/ijesd.2005.007235

Berchez, F., Ghilardi, N., Robim, M., Pedrini, A., Hadel, V., Fluckiger, G., Simões, M., Mazzaro, R., Klausener, C., Sanches, C. & Bespalec, P. 2007. Projeto Trilha Subaquática: sugestão de diretrizes para a criação de modelos de educação ambiental em unidades de conservação ligadas a ecossistemas marinhos. *OLAM Ciência & Tecnologia*, *7*(3), 181–209. DOI: https://doi.org/10.11606/issn.1982-900X.olamtecnol.2007.82665

Berchez, F., Ghilardi-Lopes, N., Raimundo, S. & Saraiva, A. 2019. Integrating Emerging Pedagogies and Technologies in Environmental and Formal Basic Education. *In*: Ghilardi-Lopes, N. & Berchez, F. (eds.), *Coastal and Marine Environmental Education* (pp. 53–67). Berlim: Springer. DOI: https://doi.org/org/10.1007/978-3-030-05138-9

Berchez, F., Mansilla, A., Ghilardi-Lopes, N., Schwindt, E., Leite, K. & Rozzi, R. 2015. Ecology and Education in Marine Protected Areas: Insights from Brazil and South America. *In*: Rozzi, R., III, F. S. C., Callicott, J. B., Pickett, S. T. A., Power, M. E., Armesto, J. J., & Jr, R. H. M. (eds.), *Earth Stewardship* (Vol. 2, pp. 351–366). Springer International Publishing. DOI: https://doi.org/10.1007/978-3-319-12133-8_23

Berchez, F., Tiago, C., Rosso, S., Dias, G. & Oliveira, E. 2009. Structure of a coralline algal bed in southeastern Brazil. *Brazilian Journal of Ecology*, *13*, 49–57. DOI: https://doi.org/10.1590/S1679-875920160932064sp2

Bertoncini, A. A., Moraes, F., Borgonha, M., Aguiar, A. & Duarte, B. 2019. *Guia de Biodiversidade Marinha e Mergulho das Ilhas do Rio*. Rio de Janeiro: Museu Nacional.

Bertoncini, Á., Giglio, V., Alves, J., Grossman, A., Matheus, Z. & Ferreira, B. 2013. Projeto Meros Do Brasil Photo-ID: First Insights of Goliath Grouper (Epinephelus itajara, Epinephelidae) Population and Movements at Fernando de Noronha National Marine Park. *In*: *66th Gulf and Caribbean Fisheries Institute* (pp. 279–300). Corpus Christi.

Bertoncini, Á., Machado, L., Barreiros, J., Hostim-Silva, M. & Verani, J. 2009. Cleaning activity among Labridae in the Azores: the rainbow wrasse*Coris julis*and the Azorean blue wrasse*Centrolabrus caeruleus*. *Journal of the Marine Biological Association of the United Kingdom*, *89*(4), 859–861. DOI: https://doi.org/10.1017/s002531540900040x

Bohnsack, J. A. & Bannerot, S. P. 1986. A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes. *NOAA Technical Report NMFS*.

Bonaldo, R. M., Krajewski, J. P., Sazima, C. & Sazima, I. 2007. Dentition damage in parrotfishes feeding on hard surfaces at Fernando de Noronha Archipelago, southwest Atlantic Ocean. *Marine Ecology Progress Series*, *342*, 249–254. DOI: https://doi.org/10.3354/meps342249

Boutan, L. 1900. *La photographie sous-marine et les progrès de la photographie*. Paris: Schleicher Fréres.

Buchmann, F. S. & Tomazelli, L. J. 2003. Southern Brazil: origin and effects on nearby modern beaches. *Journal of Coastal Research*, *35*, 318–322.

Calippo, F. 2009. The submerged shell mounds of Cananéia, São Paulo, Brazil: a case study of underwater archaeology. *In*: *Proceedings XVth UISPP World Congress* (Vol. 22).

Calippo, F. R. 2006. Os sambaquis submersos de Cananéia: um estudo de caso de arqueologia subaquática. *In*: *Proceedings of the XVth Congress of the UISPP, Colloquia Coastal Geoarchaeology*. Universidade de Sao Paulo, Agencia USP de Gestao da Informacao Academica (AGUIA). DOI: https://doi.org/10.11606/d.8.2004.tde-27062006-143634

Calippo, F. R. 2011. Sociedade sambaquieira, comunidades marítimas. *Revista de Arqueologia*, *24*(1), 82–101. DOI: https://doi.org/10.24885/sab.v24i1.316

Calippo, F. R., Bastos, A. C., Braga, M. D. & Oliveira, A. A. 2021. Collaborative Research Project "Identification of the Shipwreck Known as Barco do Acaraú, Itarema, Ceará. *The SHA Newsletter*, *54*, 31–32.

Calippo, F. R., Rambelli, G. & Camargo, P. F. B. de. 2013. Por uma arqueologia subaquática que vai além dos naufrágios: o caso do arquipélago de São Pedro e São Paulo. *Ciência e Cultura*, *65*(2), 33–36. DOI: https://doi.org/10.21800/s0009-67252013000200013

Cartelle, C., De Iuliis, G. & Pujos, F. 2008. A new species of Megalonychidae (Mammalia, Xenarthra) from the Quaternary of Poço Azul (Bahia, Brazil). *Comptes Rendus Palevol*, *7*(6), 335–346. DOI: https://doi.org/10.1016/j.crpv.2008.05.006

Carvalho-Filho, A., Sazima, I., Lima, S., Almeida, D., Mendes, L., Dias, R., Britto, M. & Gasparini, J. 2020. Review of the genus Malacoctenus (Actinopterygii: Labrisomidae) from the Southwestern Atlantic, with description of two new species. *Zootaxa*, *4819*(3), 499–520. DOI: https://doi.org/10.11646/zootaxa.4819.3.4

Casatti, L. & Castro, R. M. C. C. 1998. A comunidade de peixes de um riacho de Floresta com Araucária, alto rio Iguaçu, sul do Brasil. *Ichthyology Explore Freshwaters*, *9*(3), 229–242. DOI: https://doi.org/10.1590/s0101-81752008000200012

Castro, C. B. & Pires, D. O. 2001. Brazilian coral reefs: what we already know and what is still missing. *Bulletim of Marine Science*, *69*(2), 357–371.

Castro, M., Montefeltro, F. & Langer, M. 2014. The Quaternary vertebrate fauna of the limestone cave Gruta do Ioiô, northeastern Brazil. *Quaternary International*, *352*, 164–175. DOI: https://doi.org/10.1016/j.quaint.2014.06.038

Cattaneo-Vietti, R. & Mojetta, A. 2021. The essential role of diving in marine biology. *Bulletin of Environmental and Life Sciences*, *3*, 1279. DOI: https://doi.org/10.15167/2612-2960/BELS2021.3.1.1279

Cava, F., Schoedinger, S., Strang, C. & Tuddenham, P. 2005. Science Content and Standards for Ocean Literacy : A

Report on Ocean Literacy. *In*: *Proceedings of MTS/IEEE*. DOI: https://doi.org/10.1109/OCEANS.2005.1639840

Cordonis, C., Moraes, F. & Muricy, G. 2013. A new species of Latrunculia (Biannulata) (Porifera: Demospongiae) from Rio de Janeiro, south-eastern Brazil. *Marine Biodiversity*, *43*(2), 105–111. DOI: https://doi.org/10.1007/s12526-012-0132-5

Costa, R. L. & Möller, O. O. 2011. Estudo da estrutura e da variabilidade das correntes na área da plataforma interna ao largo de Rio Grande, Brasil. *Revista de Gestão Costeira Integrada*, *113*, 273–281.

Creed, J. C. & Amado Filho, G. M. 1999. Disturbance and recovery of the macroflora of a seagrass (Halodule wrightii Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. *Journal of Experimental Marine Biology and Ecology*, *235*(2), 285–306. DOI: https://doi.org/10.1016/s0022-0981(98)00188-9

Creed, J., Fenner, D., Sammarco, P., Cairns, S., Capel, K., Junqueira, A., Cruz, I., Miranda, R., Carlos-Junior, L., Mantelatto, M. & Oigman-Pszczol, S. 2017. The invasion of the azooxanthellate coral Tubastraea (Scleractinia: Dendrophylliidae) throughout the world: history, pathways and vectors. *Biological Invasions*, *19*(1), 283–305. DOI: https://doi.org/10.1007/s10530-016-1279-y

Crivellaro, M., Silveira, T., Custódio, F., Battaglin, L., De Sá Dechoum, M., Fonseca, A. & Segal, B. 2021. Fighting on the edge: reproductive effort and population structure of the invasive coral Tubastraea coccinea in its southern Atlantic limit of distribution following control activities. *Biological Invasions*, *23*(3), 811–823. DOI: https://doi.org/10.1007/s10530-020-02403-5

Cruz, I. C. S., Kikuchi, R. K. P. & Leão, Z. M. A. N. 2008. Use of the video transect method for characterizing the Itacolomis reefs, Eastern Brazil. *Brazilian Journal of Oceanography, 564*, 271-280. DOI: http://dx.doi.org/10.1590/S1679-87592008000400002

Cruz, E., Dillenburg, S. & Buchmann, F. 2016. Description and controls on distribution of Pleistocene vertebrate fossils from the central and southern sectors of the Coastal Plain of Rio Grande do Sul, Brazil. *Revista Brasileira de Paleontologia*, *19*(3), 425–438. DOI: https://doi.org/10.4072/rbp.2016.3.08

Dally, W. 2018. Comparison of a mid-shelf wave hindcast to ADCP-measured directional spectra and their transformation to shallow water. *Coastal Engineering*, *131*, 12–30. DOI: https://doi.org/10.1016/j.coastaleng.2017.10.009

Dardeau, M. R., Pollock, N. W., Mcdonald, C. M. & Lang, M. A. 2012. The incidence of decompression illness in 10 years of scientific diving. *Journal of the South Pacific Underwater Medicine Society*, *42*(4), 195–200.

Del Cima, O. M., Oliveira, P. C., M, R. C., Silva, H. S. & Teixeira, A. V. N. C. 2017. Gas diffusion among bubbles and the DCS risk. *In*: *Proceedings from the International Conference on Underwater Education (ICUE 2017)*. Long Beach.

Del Cima, O., Rocha, C., Teixeira, A. & Wienke, B. 2018. Ostwald ripening for air bubbles and decompression illness: phenomenological aspects in diving. *ArXiv: Fluid Dynamics*. DOI: https://doi.org/10.48550/arXiv.1806.05673

Diretoria de Portos e Costas. 2011 Normas das Autoridade Marítima para atividades subaquáticas - NORMAN-15/ DPC 1ºrevisão. avalible on: http://www.sintasa.org.br/antigo/galeria/normas/nr_15_new.pdf

Diretoria de Portos e Costas. 2016 Normas das Autoridade Marítima para atividades subaquáticas - NORMAN-15/ DPC 2ºrevisão. avaliable on: https://www.marinha.mil.br/dpc/sites/www.marinha.mil.br.dpc/files/normam15.pdf

Duran, L. D. 2008. Whaleboats, Trypots, and Blubber: Underwater Archaeology in the Study of the Whaling Station on the Island of Bom Abrigo, Southern Coast, State of São Paulo. *Revista de Arqueología Americana*, (26), 223–240.

Duran, L. D., Camargo, P. B. de, Calippo, F. R. & Juliani, L. 2010. O naufrágio das nozes (Palhoça, SC): um estudo de caso de Arqueologia Subaquática de Contrato no Brasil. *Vestígios - Revista Latino-Americana de Arqueologia Histórica*, *4*(1), 10–33. DOI: https://doi.org/10.31239/vtg.v4i1.10698

Dutra, L. X. C., Kikuchi, R. K. P. & Leão, Z. M. A. N. 2006. Effects of Sediment Accumulation on Reef Corals From Abrolhos, Bahia, Brazil. *Journal of Coastal Research*, *2*(39), 633–638.

Eltink, E., Castro, M., Montefeltro, F. C., Dantas, M. A. T., Scherer, C. S., Oliveira, P. V., & Langer. 2020. Mammalian fossils from Gruta do Ioiô cave and past of the Chapada Diamantina, northeastern Brazil. *Journal of South American Earth Sciences*, *98*, 102–379.

Eston, V., Migotto, A., Oliveira Filho, E., Rodrigues, S. & Freitas, J. 1986. Vertical distribution of benthic marine organisms on rocky coasts of the Fernando de Noronha Archipelago (Brazil). *Boletim Do Instituto Oceanográfico*, *34*, 37–53. DOI: https://doi.org/10.1590/s0373-55241986000100004

Feitoza, B. 2003. Platygillellus brasiliensis n. sp. (Perciformes: Dactyloscopidae), the third species of the genus from the Atlantic. *Revista Brasileira de Entomologia*, *65*(3), 21–28. DOI: https://doi.org/10.1590/1806-9665-RBENT-2021-0059

Feitoza, B., Rosa, R. & Rocha, L. A. 2005. Ecology and zoogeography of deep-reef fishes in northeastern Brazil. *Bulletin of Marine Science*, *763*, 725–742.

Felinto, A., Mota, and E. L. S. & Rosa, R. de S. 2020. Observations of the Reef Fish Alphestes Afer (actinopterygii, Epinephelidae) Following the Octopus Insularis (cephalopoda, Octopodidae) in a Tropical Reef System. *Oecologia Australis*, *24*(1), 173–178. DOI: https://doi.org/10.4257/oeco.2020.2401.14

Feral, J. 2017. SD European Standards. *European Scientific Diving Panel*. DOI: https://doi.org/10.13140/RG.2.2.18525.05604

Ferreira, B. & Maida, M. 2006. *Monitoramento dos Recifes de Coral do Brasil: Situação Atual e Perspectiva. MMA/ Brasília*. Brasília, DF: Ministério do Meio Ambiente. DOI: https://doi.org/10.7476/9788598729251.0013

Fontoura, L., Cantor, M., Longo, G. O., Bender, M. G., Bonaldo, R. M. & Floeter, S. R. 2020. The macroecology of reef fish agonistic behaviour. *Ecography*, *43*(9), 1278–1290. DOI: https://doi.org/10.1111/ecog.05079

Francini-Filho, R., Asp, N., Siegle, E., Hocevar, J., Lowyck, K., D'avila, N., Vasconcelos, A., Baitelo, R., Rezende, C., Omachi, C., Thompson, C. & Thompson, F. 2018. Perspectives on the Great Amazon Reef: Extension, Biodiversity, and Threats. *Frontiers in Marine Science*, *5*. DOI: https://doi.org/10.3389/fmars.2018.00142

Francini–Filho, R. B., Moura, R. L., & Sazima, I. 2000. Cleaning by the wrasse Thalassoma noronhanum, with two records of predation by its grouper client Cephalopholis fulva. Journal of Fish Biology, 56(4), 802-809.

Franz, G., Garcia, C., Pereira, J., De Freitas Assad, L., Rollnic, M., Garbossa, L., Da Cunha, L., Lentini, C., Nobre, P., Turra, A., Trotte-Duhá, J., Cirano, M., Estefen, S., Lima, J., Paiva, A., Noernberg, M., Tanajura, C., Moutinho, J., Campuzano, F., Pereira, E., Lima, A., Mendonça, L., Nocko, H., Machado, L., Alvarenga, J., Martins, R., Böck, C., Toste, R., Landau, L., Miranda, T., Dos Santos, F., Pellegrini, J., Juliano, M., Neves, R. & Polejack, A. 2021. Coastal Ocean Observing and Modeling Systems in Brazil: Initiatives and Future Perspectives. *Frontiers in Marine Science*, *8*. DOI: https://doi.org/10.3389/fmars.2021.681619

Freire, L. F. 2020. *Vapor de transporte Madeira: Arqueologia marítima histórica da Revolta da Armada de 1893.* (phdthesis). Universidade Federal de Sergipe, São Cristóvão.

Freitas, L., Oliveira, M., Leão, Z. & Kikuchi, R. 2019. Effects of turbidity and depth on the bioconstruction of the Abrolhos reefs, Brazil. *Coral Reefs*, *38*, 241–253. DOI: https://doi.org/10.1007/s00338-004-0446-2

Freitas, T., Leite, T., Ramos, B., Di Cosmo, A. & Proietti, M. 2022. In an octopus's garden in the shade: Underwater image analysis of litter use by benthic octopuses. *Marine Pollution Bulletin*, *175*, 113339. DOI: https://doi.org/10.1016/j.marpolbul.2022.113339

Garcia, G., Dias, M. & Longo, G. 2021. Trade-off between number and length of remote videos for rapid assessments of reef fish assemblages. *Journal of Fish Biology*, *99*(3), 896–904. DOI: https://doi.org/10.1111/jfb.14776

Giglio, V., Luiz, O. & Schiavetti, A. 2016. Recreational Diver Behavior and Contacts with Benthic Organisms in the Abrolhos National Marine Park, Brazil. *Environmental Management*, *57*(3), 637–648. DOI: https://doi.org/10.1007/s00267-015-0628-4

Giglio, V., Ternes, M., Kassuga, A. & Ferreira, C. 2019. Scuba diving and sedentary fish watching: effects of photographer approach on seahorse behavior. *Journal of Ecotourism*, *18*(2), 142–151. DOI: https://doi.org/10.1080/14724049.2018.1490302

Giraldes, B., Coelho Filho, P. & Smyth, D. 2015. Decapod assemblages in subtidal and intertidal zones—Importance of scuba diving as a survey technique in tropical reefs, Brazil. *Global Ecology and Conservation*, *3*, 163–175. DOI: https://doi.org/10.1016/j.gecco.2014.11.011

Gomes, M. 2015. The investigation of a mixed carbonate-siliciclastic shelf, NE-Brazil. *Italian Journal of Geosciences*, *134*, 9–22. DOI: https://doi.org/10.3301/IJG.2014.08

Grossman, A., Sazima, C., Bellini, C. & Sazima, I. 2006. Cleaning Symbiosis Between Hawksbill Turtles and Reef Fishes at Fernando de Noronha Archipelago, off Northeast Brazil. *Chelonian Conservation and Biology*, *5*(2), 284–288. DOI: https://doi.org/10.2744/1071-8443(2006)5[284:csbhta]2.0.co;2

Guabiroba, H., Santos, M., Pinheiro, H., Simon, T., Pimentel, C., Vilar, C. & Joyeux, J.-C. 2020. Trends in recreational fisheries and reef fish community structure indicate decline in target species population in an isolated tropical oceanic island. *Ocean and Coastal Management*, *191*, 105194. DOI: https://doi.org/10.1016/j.ocecoaman.2020.105194

Guimarães, R. 2009. *A arqueologia em sítios submersos: estudo do sítio depositário da enseada da praia do Farol da ilha do Bom Abrigo - SP* (mathesis). Universidade de Sao Paulo, Agencia USP de Gestao da Informacao Academica (AGUIA), São Paulo. https://doi.org/10.11606/d.71.2010.tde-01032010-164713

Gusmão, D. M. 2015. *Sítios arqueológicos de naufrágios da Baía de Todos os Santos, Salvador-BA: estudo de caso do Clipper Blackadder* (mathesis). Universidade Federal de Sergipe, São Cristóvão.

Hartt, C. F. 1870. Geology and physical geography of Brazil. *In*: Agassiz, L. (ed.) *Thayer Expedition: Scientific results of a Journey in Brazil*. Boston: Field Osgood and Co.

Hill, J. & Wilkinson, C. 2004. *Methods for ecological monitoring of coral reefs*. Townville: Australian Institute of Marine Science.

Holland, K. T., Vinzon, S. B. & Calliari, L. J. 2009. A field study of coastal dynamics on a muddy coast offshore of Cassino beach, Brazil. *Continental Shelf Research*, *29*(3), 503–514. DOI: https://doi.org/10.1016/j.csr.2008.09.023

Iliffe, T. & Bowen, C. 2001. Scientific Cave Diving. *Marine Technology Society Journal*, *35*(2), 36–41. DOI: https://doi.org/10.4031/002533201788001901

Joly, A. B. 1957. Contribuição ao conhecimento da flora ficológica marinha da Baía de Santos e arredores. *Boletim Da Faculdade de Filosofia, Ciências e Letras*, *14*, 7–27. DOI: https://doi.org/10.11606/issn.2318-5988.v14i1p7-237

Joyeux, J. 2015. Fish biodiversity of the Vitória-Trindade Seamount Chain, southwestern Atlantic: an updated database. *PloS ONE*, *10*, 3. DOI: https://doi.org/10.1371/journal.pone.0118180

Kikuchi, R. K. P. & Leão, Z. M. A. N. 1998. The Effects of Holocene Sea Level Fluctuation on Reef Development and Coral Community Structure, Northern Bahia, Brazil. *Anais Da Academia Brasileira de Ciências*, *70*(2), 159–171.

Kikuchi, R. & Leão, Z. 1997. Rocas (Southwestern Equatorial Atlantic, Brazil): An atoll built primarily by coralline algae. *In*: *Proceedings of 8th International Coral Reef Symposium* (pp. 731–736). Panamá.

Kikuchi, R., Leao, Z., Testa, V., Dutra, L. & Spano, S. 2003. Brazil. Rapid Assessment of the Abrolhos Reefs, Eastern Brazil (Part 1: Stony Corals and Algae). *Atoll Research Bulletin*, *496*(9), 172–187. DOI: https://doi.org/10.5479/si.00775630.496-9.172

Kikuchi, R., Oliveira, M. & Leão, Z. 2013. Density banding pattern of the south western Atlantic coral Mussismilia braziliensis. *Journal of Experimental Marine Biology and*

Ecology, *449*, 207–214. DOI: https://doi.org/10.1016/j.jembe.2013.09.019

Kitahara, M., Capel, K. & Migotto, A. 2020. Coenocyathus sebroecki sp. nov.: a new azooxanthellate coral (Scleractinia, Caryophylliidae) from southeastern Brazil. *Marine Biodiversity*, *50*(4), 59. DOI: https://doi.org/10.1007/s12526-020-01077-5

Koenig, C. & Stallings, C. 2015. A new compact rotating video system for rapid survey of reef fish populations. *Bulletin of Marine Science*, *91*(3), 365–373. DOI: https://doi.org/10.5343/bms.2015.1010

Krajewski, J., Bonaldo, R., Sazima, C. & Sazima, I. 2009. Octopus mimicking its follower reef fish. *Journal of Natural History*, *43*(3–4), 185–190. DOI: https://doi.org/10.1080/00222930802450965

Krajewski, J. P. & Bonaldo, R. 2005. Spawning out of aggregations: Record of a single spawning dog snapper pair at Fernando de Noronha Archipelago, equatorial western Atlantic. *Bulletin of Marine Science*, *77*(1), 165–167.

La Trobe, H. & Acott, T. 2000. A Modified NEP/DSP Environmental Attitudes Scale. *The Journal of Environmental Education*, *32*(1), 12–20. DOI: https://doi.org/10.1080/00958960009598667

Laborel, J. 1970. Les peuplements de madréporaires des cotes tropicales du Brésil. *Annales de l'Université d'Abidjan*, *23*, 1–260. DOI: https://doi.org/10.1590/S0373-55241982000100006

Laborel-Deguen, F., Nunes, F., Castro, C. & Pires, D. 2019. *Recifes brasileiros: o legado de Laborel*. Rio de Janeiro: Museu Nacional.

Leão, Z. M. A. N., Hetzel, B. & Castro, C. B. 1994. Corals Of Southern Bahia (pp. 179–181). Nova Fronteira.

Leão, Z. M. de A. N. 1982. Morphology, Geology And Developmental History Of The Southernmost Coral Reefs Of Western Atlantic, Abrolhos Bank, Brazil.

Lehner, P. N. 1996. *Handbook of ethological methods* (2nd ed.). Cambridge: Cambridge University Press.

Leite, T., Haimovici, M. & Mather, J. 2009a. Octopus insularis (Octopodidae), evidence of a specialized predator and a time-minimizing hunter. *Marine Biology*, *156*(11), 2355–2367. DOI: https://doi.org/10.2307/1542128

Leite, T., Haimovici, M., Molina, W. & Warnke, K. 2008. Morphological and genetic description of Octopus insularis, a new cryptic species in the Octopus vulgaris complex (Cephalopoda: Octopodidae) from the tropical southwestern Atlantic. *Journal of Molluscan Studies*, *74*(1), 63–74. DOI: https://doi.org/10.1093/mollus/eym050

Leite, T. & Mather, J. 2008. A new approach to octopuses' body pattern analysis: A framework for taxonomy and behavioral studies. *American Malacological Bulletin*, *24*(1), 31–41. DOI: https://doi.org/10.4003/0740-2783-24.1.31

Leite, T., Vidal, E., Lima, F., Lima, S. & Dias, R. 2021. A new species of pygmy Paroctopus Naef, 1923 (Cephalopoda: Octopodidae): the smallest southwestern Atlantic octopod, found in sea debris. *Marine Biodiversity*, *51*, 51–68. DOI: https://doi.org/10.1007/S12526-021-01201.Z

Lessa, G., Mariani, R. & Fonseca, L. 2019. Variability of the Thermohaline Field in a Large Tropical, Well-Mixed Estuary: the Influence of an Extreme Draught Event. *Estuaries and Coasts*, *42*(8), 2020–2037. DOI: https://doi.org/10.1007/s12237-019-00641-y

Lira, S., Farrapeira, C., Amaral, F. & Ramos, C. 2010. Sessile and sedentary macrofauna from the Pirapama Shipwreck, Pernambuco, Brazil. *Biota Neotropica*, *10*(4), 155–165. DOI: https://doi.org/10.1590/s1676-06032010000400021

Loiola, M., Cruz, I., Lisboa, D., Mariano-Neto, E., Leão, Z., Oliveira, M. & Kikuchi, R. 2019. Structure of marginal coral reef assemblages under different turbidity regime. *Marine Environmental Research*, *147*, 138–148. DOI: https://doi.org/10.1016/j.marenvres.2019.03.013

Longo, G., Hay, M., Ferreira, C. & Floeter, S. 2019. Trophic interactions across 61 degrees of latitude in the Western Atlantic. *Global Ecology and Biogeography*, *28*(2), 107–117. DOI: https://doi.org/10.1111/geb.12806

Longo, L. & Amado Filho, G. 2014. O conhecimento da fauna marinha bentônica brasileira através dos tempos. *História, Ciências, Saúde-Manguinhos*, *21*(3), 995–1010. DOI: https://doi.org/10.1590/s0104-59702014000300011

Lopes, R., Oliveira, L., Figueiredo, A., Kinoshita, A., Baffa, O. & Buchmann, F. 2010. ESR dating of pleistocene mammal teeth and its implications for the biostratigraphy and geological evolution of the coastal plain, Rio Grande do Sul, southern Brazil. *Quaternary International*, *212*(2), 213–222. DOI: https://doi.org/10.1016/j.quaint.2009.09.018

Lubbock, R. & Edwards, A. 1981. The fishes of Saint Paul's Rocks. *Journal of Fish Biology*, *18*(2), 135–157. DOI: https://doi.org/10.1111/j.1095-8649.1981.tb02810.x

Luiz, O. J., Santos, W. C. R. dos, Marceniuk, A. P., Rocha, L. A., Floeter, S. R., Buck, C. E., Klautau, A. G. C. M. de & Ferreira, C. E. L. 2021. Multiple lionfish (Pterois spp.) new occurrences along the Brazilian coast confirm the invasion pathway into the Southwestern Atlantic. *Biological Invasions*, *23*(10), 3013–3019. DOI: https://doi.org/10.1007/s10530-021-02575-8

Maggs, C. A., Milner, A. A., Watts, W. & Whittle, M. R. 1979. The Oxford diving expedition to Cabo Frio, Brazil. *Bulletin of the Oxford UniversityExploration Club*, *4*, 13–40.

Maia-Nogueira, R. M. 2021. *Mergulho científico, estado da arte e formação básica.*

Martínez, A. 2014. A souvenir of undersea landscapes: underwater photography and the limits of photographic visibility (1890-1910). *História, Ciências, Saúde - Manguinhos*, *21*(3). DOI: https://doi.org/10.1590/S0104-59702014000300013

Matheus, Z., Francini-Filho, R., Pereira-Filho, G., Moraes, F., Moura, R., Brasileiro, P. & Amado-Filho, G. 2019. Benthic reef assemblages of the Fernando de Noronha Archipelago, tropical South-west Atlantic: Effects of depth, wave exposure and cross-shelf positioning. *PLOS ONE*, *14*(1), e0210664. DOI: https://doi.org/10.1371/journal.pone.0210664

Mauvecin, G. & Espinosa, C. 2022. *Buceo: aspectos médicos y fisiológicos.* Mar del Plata: Medicina Hiperbárica.

Medeiros, S. L. de S., Paiva, M. M. M. de, Lopes, P. H., Blanco, W., Lima, F. D. de, Oliveira, J. B. C. de, Medeiros, I. G., Sequerra, E. B., Souza, S. de, Leite, T. S. & Ribeiro, S. 2021. Cyclic alternation of quiet and active sleep states in the octopus. *IScience*, *24*(4), 102223. DOI: https://doi.org/10.1016/j.isci.2021.102223

Mendes, L. F. 1995a. *Ecologia populacional e comportamento de uma nova espécie de bagre cavernícola da Chapada Diamantina, Brasil.* (mathesis). Universidade de São Paulo, São Paulo.

Mendes, L. F. 1995b. Observations on the ecology and behaviour of a new species of a troglobitic catfish from Northeastern Brazil. *Mémoires de Biospéologie*, *22*, 99–101.

Menezes, N. A., Buckup, P. A., De Figueiredo, J. L. & De Moura, R. L. 2003. *Catálogo das espécies de peixes marinhos do Brasil*. São Paulo: Museu de Zoologia da Universidade de São Paulo.

Mohr, L. V., Castro, J. W. A., Costa, P. M. S. & Alves, R. J. O. V. 2009. *Ilhas Oceânicas brasileiras: da pesquisa ao manejo* (2nd ed.). Brasília, DF: Ministério do Meio Ambiente.

Monteiro-Neto, C., Bertoncini, Á. A., Chaves, L. de C. T., Noguchi, R., Mendonça-Neto, J. P. & Rangel, C. A. 2013. Checklist of marine fish from coastal islands of Rio de Janeiro, with remarks on marine conservation. *Marine Biodiversity Records*, *6*, 1–13. DOI: https://doi.org/10.1017/s1755267213000973

Morachiolli, N. P. 2002. *Estudo dos Spelaeogriphacea brasileiros, crustáceos Peracarida subterrâneos* (phdthesis). Instituto de Biociências, Universidade de São Paulo, São Paulo.

Moreira, A. P. B., Tonon, L. A. C., Pereira, C. do V. P., Alves, N., Amado-Filho, G. M., Francini-Filho, R. B., Paranhos, R. & Thompson, F. L. 2014. Culturable Heterotrophic Bacteria Associated with Healthy and Bleached Scleractinian Madracis decactis and the Fireworm Hermodice carunculata from the Remote St. Peter and St. Paul Archipelago, Brazil. *Current Microbiology*, *68*(1), 38–46. DOI: https://doi.org/10.1007/s00284-013-0435-1

Mothes de Moraes, B. 1985. Sponges collected by the Oxford diving expedition, to the Cabo Frio upwelling area (Rio de Janeiro, Brasil). *Studies on Neotropical Fauna and Environment*, *20*(4), 227–237. DOI: https://doi.org/10.1080/01650528509360694

Moura, R. I., Figueiredo, J. L. & Sazima, I. 2001. A new parrotfish (Scaridae) from Brazil, and revalidation of Sparisoma amplum (Hanzani, 1842), Sparisoma frondosum (Agassiz, 1831) Sparisoma axillare (Steindachner, 1878) and Scarus trispinosus (Valenciennes, 1840). *Bulletin of Marine Science*, *68*(3), 505–524.

Nascimento Silva, L. L., Gomes, M. P. & Vital, H. 2018. The Açu Reef morphology, distribution, and inter-reef sedimentation on the outer shelf of the NE Brazil equatorial margin. *Continental Shelf Research*, *160*, 10–22. DOI: https://doi.org/10.1016/j.csr.2018.03.011

Noelli, F. S., Viana, A. & Moura, M. L. 2009. Praia dos Ingleses 1: Arqueologia subaquática na Ilha de Santa Catarina, Brasil (2004/2005/2009). *Revista Do Museu de Arqueologia e Etnologia*, (19), 179. DOI: https://doi.org/10.11606/issn.2448-1750.revmae.2009.89883

Nonato, E. F., Brito, T. A. S., Paiva, P. C. & Petti, M. A. V. 1992. *Atividades subaquáticas realizadas na Baía do Almirantado a partir da VI Expedição (1988).* (resreport). São Paulo: Interno do Instituto Oceanográfico.

Nonato, E. F. & Pérèz, J. M. 1961. Observation sur quelques peuplements interdidaux de substrat dur dans la region d'Ubatuba. *Cahiers de Biologie Marine*, *2*, 263–270.

Nunes, L., Morais, R., Longo, G., Sabino, J. & Floeter, S. 2020. Habitat and community structure modulate fish interactions in a neotropical clearwater river. *Neotropical Ichthyology*, *18*(1), 1–19. DOI: https://doi.org/10.1590/1982-0224-2019-0127

Occupational Safety and Health Administration. 1998. Standard number 1910, Subpart T, Commercial Diving Operations. DOI: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartTAppB

Oliveira, A. M., Becker-Kerber, B., Cordeiro, L. M., Borghezan, R., Avilla, L. S., Pacheco, M. L. A. F. & Santos, C. M. D. 2017. Quaternary mammals from central Brazil (Serra da Bodoquena, Mato Grosso do Sul) and comments on paleobiogeography and paleoenvironments. *Revista Brasileira de Paleontologia*, *20*(1), 31–44. DOI: https://doi.org/10.4072/rbp.2017.1.03

Oliveira, L. 1947. Distribuição geográfica da fauna e flora da Baía de Guanabara. *Memórias Do Instituto Oswaldo Cruz*, *45*(3), 709–734. DOI: https://doi.org/10.1590/s0074-02761947000300013

Oliveira, M., Leão, Z. & Kikuchi, R. 2008. Cultivo de Millepora alcicornis como uma ferramenta para Restauração e Manejo dos Ecossistemas Recifais do Nordeste do Brasil. *Revista de Gestão Costeira Integrada*, *8*(2), 183–201. DOI: https://doi.org/10.5894/rgci148

Oliveira, P. C. 2022. Modelos quase-bidimensionais para a evolução de bolhas de gás em líquidos (MSc thesis). Departamento de Física, Universidade Federal de Viçosa, Viçosa, Minas Gerais. https://doi.org/10.47328/ufvbbt.2022.250

Oliveira-Filho, E. 1977. *Algas marinhas bentônicas do Brasil. Tese (Livre Docência em Ficologia) - Instituto de Biociências* (PhD Thesis). Instituto de Biociências, Universidade de São Paulo, São Paulo, São Paulo. https://doi.org/10.11606/T.41.2013.tde-14032013-171424

Oliveira-Filho, E. & Berchez, F. 1993. Resource biology of Pterocladia capillacea (Gelidiales, Rhodophyta) populations in Brazil. *Hydrobiologia*, *260*(1), 255–261. DOI: https://doi.org/10.1007/bf00049026

Ostwald, W. 1897. Studien über die Bildung und Umwandlung fester Körper. *Zeitschrift Für Physikalische Chemie*, *22*, 289–330.

Paiva, M. P., Alcantara Filho, P., Matthews, H. R., Mesquita, A. L. L., Ivo, C. T. C. & Costa, R. S. 1973. Pescarias experimentais de lagostas com redes de espera, no Estado do Ceará (Brasil). *Arquivos de Ciências Do Mar*, *13*(2), 121–134.

Parisi, D., Missagia, R., F, P., Cozzuol, M., Gasparini, G., P, G. & L, S. 2016. Fossil peccaries of late Pleistocene/ Holocene (Cetartiodactyla, Tayassuidae) from underwater caves of Serra da Bodoquena (Mato Grosso do Sul State, Brazil). *Historical Biology*, *29*(1), 1–8. DOI: https://doi.org/10.1080/08912963.2015.1125898

Paula, Y., Schiavetti, A., Sampaio, C. & Calderon, E. 2018. The effects of fish feeding by visitors on reef fish in a Marine Protected Area open to tourism. *Biota Neotropica*, *18*(3). DOI: https://doi.org/10.1590/1676-0611-bn-2017-0339

Pedrini, A., Brotto, D., Santos, T., Lima, L. & Nunes, R. 2016. Percepção ambiental sobre as mudanças climáticas globais numa praça pública na cidade do Rio de Janeiro (RJ, Brasil). *Ciência & Educação*, *22*(4), 1027–1044. DOI: https://doi.org/10.1590/1516-731320160040012

Pereira, E. da S., Rambelli, G., Camargo, P. F. B., Calippo, F. R. & Barbosa, C. A. P. 2009. Arqueologia subaquática na Amazônia – documentação e análise das gravuras rupestres do sítio Mussurá, rio Trombetas, Pará, Brasil. *Revista de História Da Arte e Arqueologia*, (11), 109–126.

Pereira, N., Sial, A., Kikuchi, R. K. P., Ferreira, V. P., Ullmann, C., Frei, R. & Cunha, A. M. C. 2015. Coral-based climate records from tropical South Atlantic. *Anais Da Academia Brasileira de Ciências*, *87*(4). DOI: https://doi.org/10.1590/0001-3765201520150072

Pereira, N., Sial, A., Kilbourne, K., Liu, S.-C., Shen, C.-C., Ullmann, C., Frei, R., Korte, C., Kikuchi, R., Ferreira, V. & Braga, B. 2018. Carbon stable isotope record in the coral species Siderastrea stellata: A link to the Suess Effect in the tropical South Atlantic Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *497*, 82–90. DOI: https://doi.org/10.1016/j.palaeo.2018.02.007

Pereira-Filho, G. H., Mendes, V. R., Perry, C. T., Shintate, G. I., Niz, W. C., Sawakuchi, A. O., Bastos, A. C., Giannini, P. C. F., Motta, F. S., Millo, C., Paula-Santos, G. M. & Moura, R. L. 2021. Growing at the limit: Reef growth sensitivity to climate and oceanographic changes in the South Western Atlantic. *Global and Planetary Change*, *201*, 103479. DOI: https://doi.org/10.1016/j.gloplacha.2021.103479

Pereira-Filho, G. H., Shintate, G. S. I., Kitahara, M. V., Moura, R. I., Amado-Filho, G. M., Bahia, R. G., Moraes, F. C., Mitrano, N. L., Francini, C. l. B., Gibran, F. Z. & Motta, F. S. 2019. The southernmost Atlantic coral reef is off thesubtropical island of Queimada Grande (24°S), Brazil. *Bulletin of Marine Science*, *952*, 277–287.

Pestana, D., Ostrensky, A., Tschá, M. & Boeger, W. 2010. Prospecção do molusco invasor Limnoperna fortunei (Dunker, 1857) nos principais corpos hídricos do estado do Paraná, Brasil. *Papéis Avulsos de Zoologia*, *50*(34), 553–559. DOI: https://doi.org/10.1590/s0031-10492010003400001

Petersen, J. & Ditadi, A. 1971. Asexual reproduction in Glossobalanus crozieri (Ptychoderidae, Enteropneusta, Hemichordata). *Marine Biology*, *9*(1), 78–85. DOI: https://doi.org/10.1007/bf00348821

Pedrini, A.G., Brotto, D. S., Santos, T. V., Lima, L. & Nunes, R. M. 2016. Percepção ambiental sobre as mudanças climáticas globais numa praça pública na cidade do Rio de Janeiro, Brasil. *Ciência & Educação (Bauru), 22*(4), 1027–1044. DOI: https://doi.org/10.1590/1516-731320160040012

Pimentel, C., Rocha, L., Shepherd, B., Phelps, T., Joyeux, J., Martins, A., Stein, C., Teixeira, J., Gasparini, J., Reis-Filho, J., Garla, R., Francini-Filho, R., Delfino, S., Mello, T., Giarrizzo, T. & Pinheiro, H. 2020. Mesophotic ecosystems at Fernando de Noronha Archipelago, Brazil. *Neotropical Ichthyology*, *18*(4). DOI: https://doi.org/10.1590/1982-0224-2020-0050

Pimentel, D. de S., Pedrini, A. de G., Kawabe, L. de A., Robim, M. de J., Berchez, F. A. de S. & Meireles, C. P. 2019. Opportunities and Challenges to Implement Environmental Education in Brazilian Coastal and Marine Protected Areas. *In*: *Coastal and Marine Environmental Education* (pp. 103–117). Springer International Publishing. DOI: https://doi.org/10.1007/978-3-030-05138-9_7

Pinheiro, H., Camilato, V., Gasparini, J. & Joyeux, J.-C. 2009. New records of fishes for Trindade-Martin Vaz oceanic insular complex, Brazil. *Zootaxa*, *2298*(1), 45–54. DOI: https://doi.org/10.11646/zootaxa.2298.1.3

Pinheiro, H., Ferreira, C., Joyeux, J.-C., Santos, R. & Horta, P. 2011. Reef fish structure and distribution in a south-western Atlantic Ocean tropical island. *Journal of Fish Biology*, *79*(7), 1984–2006. DOI: https://doi.org/10.1111/j.1095-8649.2011.03138.x

Pinheiro, H., Macena, B., Francini-filho, R., Ferreira, C., Albuquerque, F., Bezerra, N., Carvalho-filho, A., Ferreira, R., Luiz, O., Mello, T., Mendonça, S., Nunes, D., Pimentel, C., Pires, A., Soares-gomes, A., Viana, D., Hazin, F. & Rocha, L. 2020. Fish biodiversity of Saint Peter and Saint Paul's Archipelago, Mid-Atlantic Ridge, Brazil: new records and a species database. *Journal of Fish Biology*, *97*(4), 1143–1153. DOI: https://doi.org/10.1111/jfb.14484

Pinheiro, H., Mazzei, E., Moura, R., Amado-Filho, G., Carvalho-Filho, A., Braga, A., Costa, P., Ferreira, B., Ferreira, C., Floeter, S., Francini-Filho, R., Gasparini, J., Macieira, R., Martins, A., Olavo, G., Pimentel, C., Rocha, L., Sazima, I., Simon, T., Teixeira, J., Xavier, L. & Joyeux, J.-C. 2015. Fish Biodiversity of the Vitória-Trindade Seamount Chain, Southwestern Atlantic: An Updated Database. *PLOS ONE*, *10*(3), e0118180. DOI: https://doi.org/10.1371/journal.pone.0118180

Pinheiro, H. T., Joyeux, J.-C. & Moura, R. L. 2014. Reef oases in a seamount chain in the southwestern Atlantic. *Coral Reefs*, *33*(4), 1113–1113. DOI: https://doi.org/10.1007/s00338-014-1211-9

Pollock, N. 2020. Decompression Illness. *In*: *Divers Alert Network (DAN).*

Pollock, N. W. & Godfrey, J. M. 2007. Diving for Science. *In*: *Diving for Science. Proceedings of the American Academy of Underwater Sciences 26th Symposium*. Dauphin Island.

Quimbayo, J. P., Schlickmann, O. R. C., Floeter, S. R. & Sazima, I. 2018. Cleaning interactions at the southern limit of tropical reef fishes in the Western Atlantic. *Environmental Biology of Fishes*, *101*(7), 1195–1204. DOI: https://doi.org/10.1007/s10641-018-0768-5

R. CORE TEAM. 2022. A language and environment for statistical computing.

Rambelli, G. 1998. *A arqueologia subaquática e sua aplicação à arqueologia brasileira: o exemplo do baixo vale do Ribeira de Iguape.* (mathesis). Universidade de São Paulo, São Paulo.

Rambelli, G. 2003. *Arqueologia subaquática do baixo Vale do Ribeira - SP* (phdthesis). Universidade de São Paulo, São Paulo.

Rambelli, G. 2006. Arqueologia de naufrágios e a proposta de estudo de um navio negreiro. *Revista de História Da Arte e Arqueologia*, (6).

Rambelli, G. & Funari, P. P. A. 2007. Patrimonio arqueológico subacuático en Brasil: pensamientos varios. *Memorias: Revista Digital de Historia y Arqueología Desde El Caribe*, *14*, 13–48.

Rawitscher, F. K. 1944. Algumas noções sobre a vegetação do litoral brasileiro. *Boletim Da Associação Dos Geógrafos Brasileiros*, *4*(5), 13–28.

Ribeiro, A. 2020. *Estudo dos Processos de Formação de sítios arqueológicos em ambientes aquáticos associados a terreiros de Candomblés da Grande Salvador (Séculos XIX a XXI)* (phdthesis). Universidade Federal do Rio de Janeiro, Rio de Janeiro. https://doi.org/10.31239/vtg.v15i2.32436

Rocha, L., Rosa, I. & Feitoza, B. 2000. Sponge-dwelling Fishes of Northeastern Brazil. *Environmental Biology of Fishes*, *59*(4), 453–458. DOI: https://doi.org/10.1023/a:1026584708092

Rocha-Barreira, C., Cascon, H. & Rabay, S. 2016. Coleção Malacológica "prof. Henry Ramos Matthews" da Universidade Federal do Ceará: 50 anos de história e contribuições ao conhecimento dos moluscos do Nordeste brasileiro. *Arquivos de Ciências Do Mar*, *49*(supl), 9–16. DOI: https://doi.org/10.32360/acmar.v49i0.6121

Rubbioli, E. L., Auler, A., Menin, D. & Brandi, R. 2019. *Cavernas Atlas do Brasil Subterrâneo*. Belo Horizonte: Grupo Bambuí de Pesquisas Espeleológicas.

Sabino, J. 1999. Comportamento de peixes de riachos brasileiros: métodos de estudos para uma abordagem naturalística. *Oecologia Brasiliensis*, *6*, 183–208.

Sabino, J. 2009. Técnica e ética da fotografia do comportamento animal: dos pioneiros à era digital. *Oecologia Brasiliensis*, *13*(1), 209–221. DOI: https://doi.org/10.4257/oeco.2009.1301.17

Sabino, J., Andrade, L., Sazima, I., Teresa, F., Floeter, S., Sazima, C. & Bonaldo, R. 2011. Following fish feeding associations in marine and freshwater habitats. *Marine and Freshwater Research*, *68*(2), 381–387. DOI: https://doi.org/10.1071/mf15294

Salles, L. O., Cartelle, C., Guedes, P. G., Boggiani, P. C., Janoo, A. & Russo, C. A. M. 2006. Quaternary mammals from Serra da Bodoquena, Mato Grosso do Sul, Brazil. *Boletim Do Museu Nacional*, *521*, 1–12.

Salles, L. O., Libertino, A., Russo, C. A. M., Cartelle, C., Toledo, P. M., Guedes, P. G., Carvalho, G. A. S., Santos, H. G., Werneck, M., Fonseca, R. & Pontual, F. 2001. Recovering fossils from underwater caves. *In*: *Proceedings 13th International Congress of Speleology* (pp. 254–255). Brasília.

Sallum-Filho, W. 2005. *Geomorfologia e geoespeleologia do carste da Serra da Bodoquena, MS* (phdthesis). *MS. Tese Doutorado - Instituto de Geociências-USP*. Universidade de Sao Paulo, Agencia USP de Gestao da Informacao Academica (AGUIA), São Paulo, 212 pp. https://doi.org/10.11606/t.44.2005.tde-19112015-093950

Sánchez-Jérez, P., Cesar, A., Cortez, F., Pereira, C. & Silva, S. 2001. Spatial distribution of the most abundant sea urchin populations on the southeast coast of Sao Paulo (Brazil). *Ciencias Marinas*, *27*(1), 139–153. DOI: https://doi.org/10.7773/cm.v27i1.371

Santedicola, P. M., M. C. R. ,. Kikuchi, R. K. P. ,. Cunha, M. P. ,. Domingues, R. M. ,. Gonçalves. 2008. Pilot Study on Ca/Sr, Ca/Mg & Ca/Ba Ratios in Skeletons of Mussismilia Brasiliensis as SST Proxy in the Coast of Bahia, Eastern Brazil. *In*: *III Simpósio Brasileiro de Oceanografia*.

Santos, H., C. L. A. and Vital, Amaro, V. & Kikuchi, R. 2007. Mapping of the submerged reefs in the coast of the Rio Grande do Norte, near Brazil: Macau to Maracajau. *Revista Brasileira de Geofisica*, *25*(Supl 1), 27–36.

Sayer, M. 2005. The international safety record for scientific diving. *SPUMS Journal / South Pacific Underwater Medicine Society*, *35*(3).

Sayer, M. 2007. Scientific diving: a bibliographic analysis of underwater research supported by SCUBA diving, 1995-2006. *Underwater Technology*, *27*(3), 75–94. DOI: https://doi.org/10.3723/175605407783360035

Sazima, C., Krajewski, J. P., Bonaldo, R. M. & Guimaraes, P. R. 2007. The goatfish Pseudupeneus maculatus and its follower fishes at an oceanic island in the tropical west Atlantic. *Journal of Fish Biology*, *69*(3), 883–891. DOI: https://doi.org/10.1111/j.1095-8649.2006.01166.x

Sazima, C., Krajewski, J. P., Bonaldo, R. M. & Sazima, I. 2006. Nuclear-follower foraging associations of reef fishes and other animals at an oceanic archipelago. *Environmental Biology of Fishes*, *80*(4), 351–361. DOI: https://doi.org/10.1007/s10641-006-9123-3

Sazima, C., Krajewski, J. P., Bonaldo, R. & Sazima, I. 2010. Associações alimentares do tipo nuclear-seguidor entre peixes e outros animais em Fernando de Noronha. *Boletim Sociedade Brasileira de Ictiologia*, *100*, 45–48.

Sazima, I., Krajewski, J. P., M, B. R. & Sazima, C. 2013. *A vida dos peixes em Fernando de Noronha*. Campinas: Terra da Gente.

Sazima, I., Moura, R. & Rosa, R. S. 1997. Elacatinus figaro sp. n. (Perciformes: Gobiidae), a new cleaner goby from the coast of Brazil. *Aqua, Journal of Ichthyology and Aquatic Biology*, *23*, 33–38.

Sazima, I., Sazima, C., Francini-Filho, R. B. & Moura, R. L. 2000. Daily Cleaning Activity and Diversity of Clients of the Barber Goby, Elacatinus figaro, on Rocky Reefs in Southeastern Brazil. *Environmental Biology of Fishes*, *59*(1), 69–77. DOI: https://doi.org/10.1023/a:1007655819374

Sazima, I., Sazima, C. & Silva, J. M. 2003. The cetacean offal connection: Feces and vomits of spinner dolphins as a food source for reef fishes. *Bulletin of Marine Science*, *72*(1), 151–160.

Schettini, C., Asp, N., Ogston, A., Gomes, V., Mclachlan, R., Fernandes, M., Nittrouer, C., Truccolo, E. & Gardunho, D. 2020. Circulation and fine-sediment dynamics in the

Amazon Macrotidal Mangrove Coast. *Earth Surface Processes and Landforms*, *45*(3), 574–589. DOI: https://doi.org/10.1002/esp.4756

Schirato, S. R., El-Dash, I., El-Dash, V., Natali, J. E., Starzynski, P. N. & Chaui-Berlinck, J. G. 2018. Heart rate variability changes as an indicator of decompression-related physiological stress. *Undersea & Hyperbaric Medicine : Journal of the Undersea and Hyperbaric Medical Society, Inc*, *45*(2), 173–182.

Segal, B. & Castro, C. B. 2011. Coral community structure and sedimentation at different distances from the coast of the Abrolhos Bank, Brazil. *Brazilian Journal of Oceanography*, *59*(2), 119–129.

Segal, B., Freire, A. S., Lindner, A., Krajewski, J. P. & Soldateli, M. 2017. *MAArE Monitoramento Ambiental da Reserva Biológica Marinha do Arvoredo e Entorno*. Florianópolis: UFSC/MAArE.

Seoane, J. C. S., Arantes, R. C. M. & Castro, C. B. 2012. Benthic habitat mapping at Recife de Fora, Brazil:Imagery and GIS. *In*: *Proceedings of the 12th International Coral Reef Symposium*. Cairns.

Short, F. T., Koch, E. W., Creed, J. C., Magalhães, K. M., Fernandez, E. & Gaeckle, J. L. 2006. SeagrassNet monitoring across the Americas: case studies of seagrass decline. *Marine Ecology*, *27*(4), 277–289. DOI: https://doi.org/10.1111/j.1439-0485.2006.00095.x

Silva, F. 2020. Conheça a História do Mergulho no Brasil e no mundo. Accessed: https://www.evidive.com.br/conheca-a-historia-do-mergulho-no-brasil-e-no-mundo/

Simon, T., Joyeux, J.-C. & Pinheiro, H. 2015. Fish assemblages on shipwrecks and natural rocky reefs strongly differ in trophic structure. *Marine Environmental Research*, *90*, 55–65. DOI: https://doi.org/10.1016/j.marenvres.2013.05.012

Souza, C. C. R. 2007. Identificação arqueológica de um naufrágio na área do Lamarão Externo do Porto do Recife, PE, Brasil. *CLIO Arqueológica*, (22), 233–245.

Suggett, D. J., Hall-Spencer, J. M., Rodolfo-Metalpa, R., Boatman, T. G., Payton, R., Pettay, D. T., Johnson, V. R., Warner, M. E. & Lawson, T. 2012. Sea anemones may thrive in a high CO 2 world. *Global Change Biology*, *18*(10), 3015–3025. DOI: https://doi.org/10.1111/j.1365-2486.2012.02767.x

Teresa, F. B., Romero, R. de M., Casatti, L. & Sabino, J. 2011. Habitat simplification affects nuclear-follower foraging association among stream fishes. *Neotropical Ichthyology*, *9*(1), 121–126. DOI: https://doi.org/10.1590/s1679-62252011005000009

Teschima, M. M., Júnior, E. F. & Freire, A. S. 2012. New records of marine mantis shrimp, crabs and lobsters (Crustacea) from Santa Catarina State, southern Brazil (27°15'S 48°25'W). *Marine Biodiversity Records*, *5*. DOI: https://doi.org/10.1017/s1755267212000760

Testa, V. & Bosence, D. W. J. 1999. Physical and biological controls on the formation of carbonate and siliciclastic bedforms on the north-east Brazilian shelf. *Sedimentology*, *46*(2), 279–301. DOI: https://doi.org/10.1046/j.1365-3091.1999.00213.x

The American Academy of Underwater Sciences (AAUS). 2013. Standards for scientific diving. Available on: https://www.aaus.org/diving_standards

Torres, R., Opdebeeck, J., Coenen, T. & Manders, M. 2016. A shipwreck of the Dutch admiralty in the Baía de Todos os Santos, Brazil. *In*: Brouwers, W. F. G. J. & Manders, M. R. (eds.), *The Utrecht (1648). Cultural Heritage Agency of the Netherlands* (pp. 25–29). Utrecht: Cultural Heritage Agency of the Netherlands.

Torres, R., Yamafune, K., Castro, F. & Ferreira, S. 2017. Mapeando em profundidade: a integração de técnicas digitais para a pesquisa arqueológica de sítios de naufrágios históricos. *Vestígios - Revista Latino-Americana de Arqueologia Histórica*, *11*(1), 107–134. DOI: https://doi.org/10.31239/vtg.v11i1.10553

Turra, A. & Denadai, M. R. 2015. *Protocolos para o monitoramento de habitats bentônicos costeiros - Rede de Monitoramento de Habitat Bentônicos Costeiros - ReBentos*. São Paulo: Instituto Oceanográfico da Universidade de São Paulo. DOI: https://doi.org/10.7476/9788598729251

Ursi, S., Towata, N., Katon, G. F. & Berchez, F. de S. 2013. Influência de exposição interativa sobre ambiente marinho e sua biodiversidade nas concepções de meio ambiente de estudantes do ensino fundamental. *Enseñanza de Las Ciencias: Revista de Investigación y Experiencias Didácticas*, (extra), 3575–3580.

Vale, T., Albani, and R., Moreira, J., & and. 2021. The opinion of divers on the interpretation of marine geology in the archipelago of Fernando de Noronha, Brazil. *Journal of the Geological Survey of Brazil*, *4*(SI 1). DOI: https://doi.org/10.29396/jgsb.2021.v4.si1.6

Vann, R. D., Butler, F. K., Mitchell, S. J. & Moon, R. E. 2011. Decompression illness. *The Lancet*, *377*(9760), 153–164. DOI: https://doi.org/10.1016/s0140-6736(10)61085-9

Vianna, M., Solewicz, R., Cabral, A. & Testa, V. 1991. Sandstream on the northeast Brazilian shelf. *Continental Shelf Research*, *11*(6), 509–524. DOI: https://doi.org/10.1016/0278-4343(91)90008-t

Villaça, R. & Pitombo, F. 1997. Benthic communities of shallow-water reefs of Abrolhos, Brazil. *Revista Brasileira de Oceanografia*, *45*(1–2), 35–43. DOI: https://doi.org/10.1590/s1413-77391997000100004

Wegner, E. & Polette, M. 2003. Proposta metodológica para a implantação de trilhas subaquáticas na ilha João da Cunha, Porto Belo – SC. *Turismo Visão e Ação*, *5*(3), 323–324.

Wienke, B. 1990. Reduced gradient bubble model. *International Journal of Bio-Medical Computing*, *26*(4), 237–256. DOI: https://doi.org/10.1016/0020-7101(90)90048-y

Wienke, B. 1994. *Basic Diving Physics and Applications*. Flagstaff: Best Publishing Company. DOI: https://doi.org/10.1201/b18528

Wienke, B. 2009. Diving decompression models and bubble metrics: Modern computer syntheses. *Computers in Biology and Medicine*, *39*(4), 309–331. DOI: https://doi.org/10.1016/j.compbiomed.2008.12.013

Wienke, B. 2016. *Biophysics and Diving Decompression Phenomenology*. Sharjah: Bentham Science Publishers.

Wienke, B. 2019. *Technical And Research Diver Reference Manual*. New York: Springer.

Wienke, B., O'Leary, T. R. & Del Cima, O. M. 2008. Empirical bubble broadening and effects ondecompression schedules. *Journal of Applied Biotechnology & Bioengineering*, *5*(3), 189–195.

Yoneshigue-Valentin, Y. & Valentin, J. L. 1992. Macroalgae of the Cabo Frio Upwelling Region, Brazil: Ordination of Communities. *In*: Seeliger, U. (ed.), *Costal plant communities of Latin América. Academic Press, San Diego.* (pp. 31–50). Academic Press.

Yount, D. E. & Hoffman, D. C. 1986. On the use of a bubble formation model to calculate diving tables. *Aviation, Space and Environmental Medicine*, *57*(2), 149–156.