THE ESSENTIAL ROLE OF DIVING IN MARINE BIOLOGY

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ABSTRACT

Since the end of the Second World War, scuba diving has given new perspectives to marine sciences and, in particular, to marine biology. Before the advent of diving, our knowledge about biology, ecology and behavior of subtidal organisms and the structure and dynamics of hard bottom communities were very superficial. 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' structures and dynamics. This method has helped to refine the distribution maps of many species and coastal communities. Moreover, scientific diving became an essential tool to explore environments challenging to reach otherwise, as submarine caves. Thanks to non-destructive methods, scientific diving became essential in Marine Protected Areas (MPAs) and, more in general, in field studies promoting conservation purposes. Other opportunities regarded the use of underwater devices as benthic chambers, landers, photo- and cinematographic time-lapse systems, or in situ experimental manipulations aiming at testing scientific hypotheses. The direct access to the underwater habitats determined a scientific revolution, by allowing a considerable advancement of the knowledge about the marine world and constituting an approach that no instrument operated by the surface could ever match. Scientific diving assumed an importance comparable to that of the electron microscope in cell biology, and today it is a standard tool in many marine biological research activities. This work aimed to summarize the history of scientific diving and show its role in the development of marine biology and its importance in opening unexpected horizons in science.

KEYWORDS: History, scientific diving, marine biology, perspectives

A HISTORICAL INTRODUCTION

Diving is probably intrinsic to the spirit of man. For centuries, he has gone underwater for fishing, working for military operations or sabotage. Freediving developed in Stone Age, when people ventured at sea for collecting food, as the kitchen middens of the mesolithic Ertebølle culture in Denmark (ca. 5,300-3,950 B.C.) or the so-called shell heaps present everywhere in the world testify. Moreover, peoples from Arabian Gulf, Egypt, and China dive usually to collect pearl oysters (Ghirardelli, 1970; Cattaneo-Vietti et al., 2015). In the Mediterranean Sea, also the thorny oyster, *Spondylus gaederopus* L., 1758, was fished everywhere, being popular among the different prehistoric coastal human communities as food or trading goods (Windler, 2019).

Diving roots sink into the myth: according to Herodotus (484-430? B.C.) and afterwards Pausanias (110?-180? A.D.), the most famous divers of antiquity were the Greek girl Hydna and her father, Scyllis, who vandalized the Persian King Xerxes naval fleet cutting the moorings and dragging away the submerged anchors during the second Persian invasion of Greece (480 B.C.) (Heberlein, 1972; Marx, 1990). Moreover, Thucydides (460-399? B.C.), told that, during the Peloponnesian war in 415 B.C., divers carried supplies to the Spartans, besieged in Sphacteria Island. Aristotle (384-322 B.C.) claimed that Alexander the Great dived inside a rudimentary bell in the port of Tyre, during the siege of the city, in 332 B.C. to observe underwater works to remove obstacles from the harbor. A famous Mediterranean myth regards Colapesce (Klaus-fish) a Sicilian fisherman. He sacrificed his life to save Sicily by supporting one of the underwater columns on which the island, according to tradition, rested (Cavarra, 1998). In the Mediterranean, fishers dive free for millennia, often deep, to collect red coral or bath sponges as Homer told, three thousand years ago (Tescione, 1973; Pronzato & Manconi, 2008; Voultsiadou et al., 2010). The sponge fishing has lasted for millennia: in 1913, Stathis Hatzis, a sponge fisherman, recovered the Italian battleship *Regina Margherita* anchor, lost at a depth of over 70 m in the waters of Pigadia Bay of Karpathos, an island of the Aegean Sea, in breath-hold and aided only by a flat stone of about 15 kg (Musengo, 1913; Kalafatas, 2003). Indeed, this was not a myth.

Romans used frogmen, called *urinatores*, mainly for military purposes and underwater works. Various epigraphs reported a *corpus urinatores Ostiensium* (the divers guild of Ostia, the harbor of the ancient Roma), while Publius Flavius Vegetius Renatus, a Roman author of the 4th century, mentioned military divers in his *Epitoma rei militaris*.

Diving was also widespread in the Tropics. Marco Polo (1254-1324) told about pearl fishers in India and Sri Lanka diving down to 30 m by using weights and the Muslim Berber-Moroccan scholar and explorer Ibn Battuta (1304-1368?) described the goggles used to fish for pearls in the Strait of Hormuz. Precisely, the same that the Caribbean natives did during the Spanish Conquest in the early 16th century, looking for pearls.

Today, breath-hold diving persists: notable examples are the diving women of the Japanese Ama ethnic group (Maraini, 1960) and the pearl divers in the Red Sea, in the Persian Gulf and the Tuamotu Archipelago (Hong et al., 1991; Hlebica, 2000). For thousands of years, the Korean female divers, called *Jeju haenyeo*, considered by UNESCO in 2016 as Intangible Cultural Heritage of Humanity (Rajagopalan, 2017) and the *Sama-Bajau* fishermen, or Sea Nomads, engaged in breath-hold diving (Ilardo et al., 2018).

The history of the diving techniques' evolution is very complicated and involved great scientists, from Leonardo da Vinci (1452-1519) to Edmond Halley (1656-1742). Already Gaius Plinius Secundus (23-79 A.D.) described some underwater techniques in his *Historia Naturalis*, and Aristotle (384-322 B.C.) wrote about the feat of Alexander in the port of Tyre when he used a rudimentary diving bell to observe the work of divers removing underwater obstacles. Roger Bacon himself (1214-1294), the great medieval English philosopher, wondered what possible equipment could allow the man to dive.

The modern diving techniques back to the early Renaissance, albeit the first diving apparatus, was probably realized in the 12th century. In the modern age, the first tool was the diving bell, used to explore the seafloor since the 16th century. At the beginning of the 17th century, diving bells, exclusively for underwater work, spread throughout Europe and diving techniques developed more and more. Underwater activities became strategical in Europe between the 17th and 18th century, especially in the harbor engineering field. Many efforts were conducted to improve air supply into the diving bell and reduce its weight (Cedrone, 1998). Also, the use of diving suits, connected to the surface by a tube for air supply, although rapidly spreading in underwater work, was rarely used for scientific research. At the beginning of the 20th century, different models of light copper diving helmets with one or two windows at the front, and a rubber hose to carry air from a car tire pump, appeared on the U.S. market. The so-called Dunn (later Miller-Dunn) diving hoods, very easy to use, allowed diving down to about 15 m depth and opened a new path to scientific diving (Gudger, 1918; Conklin, 1933; Lobel & Lobel, 2015). These helmets had significant commercial success in the United States but did not spread to Europe. Interestingly, the European marine biologists, during the 1930s, did not use the device invented by the French Maurice Fernez (1885-1952), a hookah, which, despite allowing great freedom of movement (Rousseau, 2004), was difficult to apply. Only sponge fishers in the Aegean tried to use it for dives down to 60 m deep, thanks to special decompression tables (Ministero dell'Agricoltura e Foreste, 1931).

Finally, in the 30s and 40s of the last century, autonomous breathing systems were developed, mainly for purely military purposes during the Second World War. The first device to be designed was a closed-circuit oxygen apparatus, rather complex to use (*Quick, 1970) and limited by pure oxygen's toxicity* below 10-15 m depth. The employment of this device in the scientific world was also limited by the advent, immediately after the war, of a new revolutionary underwater open-circuit air breathing device, the *Aqua-Lung*, which automatically provided compressed air at ambient pressure to a diver at the slightest intake of breath. This on-demand valve regulator was realized by the French naval lieutenant, Jacques-Yves Cousteau (1910-1997) and by an engineer, Emile Gagnan (1900-1979) in 1942-43 (Olmstead, 2008). In a short time, this regulator became very popular and allowed to dive safely at least down to a depth of 50-60m, breathing compressed air. This self-contained underwater breathing apparatus (scuba) opened new perspectives to the marine sciences generally, and to marine geology, biology and archaeology, in particular.

Before diving, in marine biology, subtidal organisms and communities were studied and known primarily by peering down from the surface or analyzing specimens collected by fishing, dredging, or by grabs and plankton nets. The direct access to underwater habitats determined a scientific revolution, by allowing a considerable advancement of the marine world's knowledge and constituting an approach that no surface-operated instrument can ever match (Witman et al., 2013).

In the last decades, scientific diving became a standard tool in marine biology, as evidenced by the bibliographic analysis conducted on papers published between 1995 and 2006 by Sayer (2007). It indeed assumed importance comparable to that of the electron microscope in cell biology. Diving enabled marine scientists to collect biological and geological samples, observe fish and other organisms and their behavior directly in nature, study species interactions, and evaluate the structures and dynamics of the marine communities. It proved efficient to produce distribution maps for species and communities and assess the main chemical-physical variables along longitudinal and vertical gradients in confined habitats. It was possible to tag specimens for studying their migrations or taking biopsies for genetic analysis. Other activities regarded the use of underwater devices (e.g., benthic chambers, landers, photo- and cinematographic time-lapse systems) and to conduct experimental manipulations *in situ* (with removal and addition actions), for testing scientific hypotheses.

This work aims to show the historical role of scientific diving in the development of marine biology and its importance in opening unexpected horizons in science (Lang et al., 2013; Italian Association for Scientific Divers, 2011). It is well-known that an exhaustive review of all the research conducted using diving would be impossible to do. For this reason, this study does not aim at a detailed description of all the biological studies conducted using diving techniques. Still, it intends to illustrate the essential role diving had in the advancement of most marine biological fields and focus on those characters who, in the various fields of marine biology, were the first or among the first to use this tool.

PEOPLE WHO MADE HISTORY

The history of scientific diving started at the end of the 18° century when in 1785, the Abbot Filippo Cavolini (1756-1810) employed professional divers to obtain material for his study on the gorgonians of the Gulf of Naples (Fresi, 1979) and perhaps, though unconfirmed, he too immersed himself using a diving bell (Riedl, 1980). In 1837, the Scottish David Brewster (1781-1868) wrote a treatise in which he described *instruments for viewing objects underwater to observe the phenomena of aquatic plants; to watch the manners and motions of fishes and other subaqueous animals; in fishing for the pinna marina (the Mediterranean bivalve* Pinna nobilis*) as it is practised on the coast of Naples* (Brewster, 1813).

In 1864, the Austrian Eugen von Ransonnet-Villez (1838-1926), during a journey in Sri Lanka used a diving bell constructed according to his design to take sketches of the underwater life (Jovanovic-Kruspel et al., 2017). In 1878, the Swiss physician Louis Théodore Frederic Colladon (1792-1862) dived with a bell at 10 m deep for an hour at Howth, near Dublin (Ireland). He wrote: *We gathered some fuci (referring to* Fucus jilum, Fucus saccharinus*). We took some marine animals, and obtained several pieces of rock, which suggest some interesting views, explanatory of their formation, which is perhaps owing, as in the case of coral and to certain animals. That part of the bottom of the sea which did not present any rock was composed of sand and pebbles. The current of water was very violent; the color of the water, as seen through the glasses, seemed to us to be of light green* (Colladon, 1821).

However, diving bells were too cumbersome and complicated to use and, in the mid 19th century, marine biologists began to use diving rubberised canvas suits and copper helmets (Fig. 1). In the Mediterranean Sea, Henri Milne-Edwards (1800-1885), during his scientific journey to Sicily in 1844 with his fellows Armand de Quatrefages (1810-1892) and Emile Blanchard (1819-1900), used a metallic helmet with a long flexible tube connected to an air pump *to pursue marine animals into their hidden retreats* (Milne-Edwards, 1845; Ott, 1973; Mojetta, 2019). This simple device had been conceived by Colonel Gustave Paulin, the commander of the Paris firefighters, for an entirely different purpose. Milne-Edwards was probably the first marine biologist to observe the underwater world directly. In 1879, the Italian Navy loaned a diving suit to the Zoological Station of Naples, and the algologist Gottfried Berthold (1854-1937) along with the zoologist August Weismann (1834-1914) made several dives to observe the marine life of the Gulf (Groeben, 2002), probably using a helmet placed on their shoulders and called “open helmet”. The founder of the Zoological Station himself, Anton Dohrn (1840-1909), made some dives, underlining the importance this technique could impose on understanding the underwater environment (Dohrn, 1880; Riedl, 1978). Similarly at Banyuls-sur-Mer in France, the marine biologist and underwater photographer Louis Marie-Auguste Boutan (1859-1934) used a diving suit in 1886 to study the Mediterranean limpets for his thesis: *Recherches sur l'anatomie et le développement de la fissurelle. Comparaison de la fissurelle avec les types voisins*.

Figure 1. Funny 19th century print of a diver observing marine organisms with a magnifying glass (Courtesy of Federico De Strobel).

In some cases, marine scientists used local divers to collect samples: in this way, Ernst Haeckel (1834-1919) obtained a collection of corals from the Red Sea near Tor (Egypt) in 1873 (Haeckel, 1876). However, the direct observation remained the priority, although throughout the 19th-century diving was not so popular among marine scientists, with rare exceptions. In the 1880s, the Swiss naturalist, Hermann Fol, used a diving suit off Nice several times to examine the sea bottom. He made interesting observations about the extinction of the light under the sea, probably the first direct observations about color loss underwater (Murray & Hjort, 1912). In 1890, he also stated the principles of scientific diving as he wrote: *Science, however, could derive no profit from the reports of professional divers; their veracity is below everything that could be imagined, and then they look without seeing... Of the scientific observations which I have been able to make with the diving-dress, I will speak only of those of a physical order; a book would not be sufficient to describe my zoological observations... In this matter, the diver is in a condition to gain valuable information by which new avenues may be opened for the study of the phenomena of Nature* (Fol, 1890).

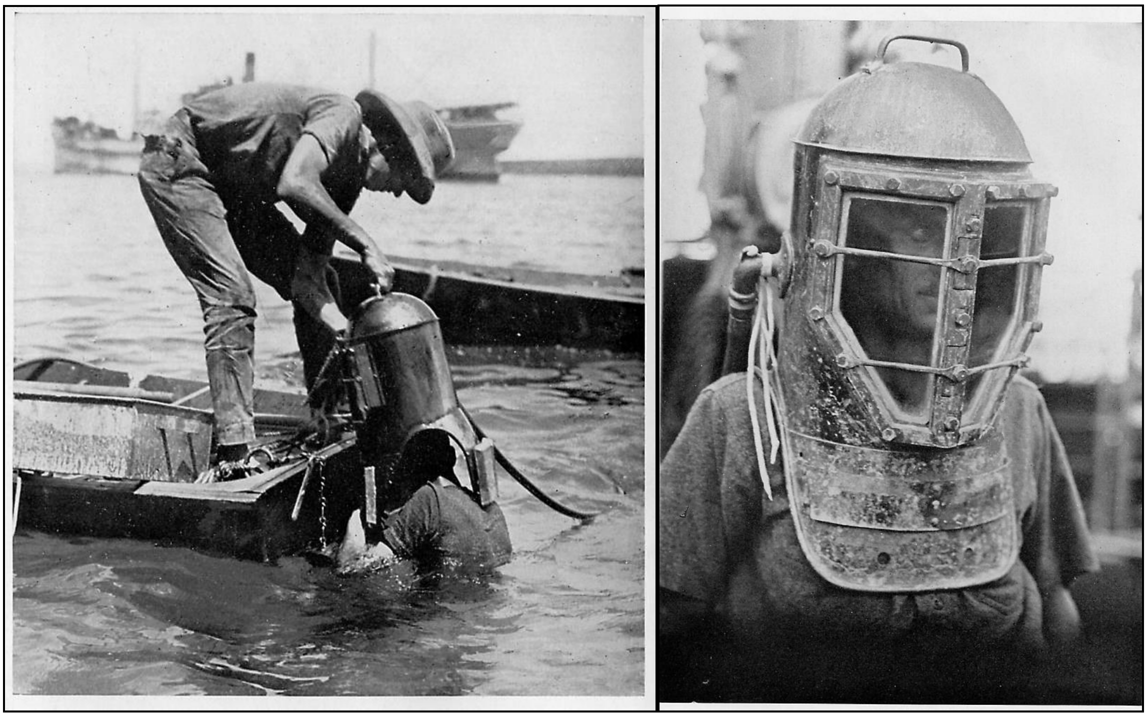

Figure 2. William Beebe used a diving helmet during the scientific cruises of the r/v *Arcturus* in 1925.

In 1903-05, Alfred Goldsborough Mayor (formerly Mayer) (1868-1922) built and directed the Dry Tortugas Laboratory of the Carnegie Institution in Loggerhead Key, Florida. For the first time, he observed corals using a diving hood. He would soon dive in the Pacific, off Pago Pago in American Samoa (Stephens & Calder, 2006). Other biologists used diving helmets at Loggerhead Key as the sponge expert, Max Walker de Laubenfels (1894-1960), and the gorgonian specialists, Lewis Cary (Cary, 1918) and William Longley (1881-1937). They also studied the color patterns of the reef fishes, their behavior and the interactions between different species (Longley & Hildebrandt, 1941). At the same time, Roy Waldo Miner (1875-1955), from the American

Museum of Natural History of New York, spent 13 years to study the Bahamas fauna and became a pioneer of the scientific diving (Miner, 1934). William Beebe (1877-1962), another leading scientist in diving explorations (Fig. 2), in 1925 used the commercial diving hood during his scientific cruises on board of the R/V Arcturus in the Galapagos Islands and Haiti (Beebe, 1926; 1928).

In Australia, Sir Charles Maurice Yonge **(**1899-1986), from the University of Cambridge, and his colleagues during the first Great Barrier Reef Expedition in 1928 used diving equipment housed at the Museum of Tropical Queensland, in Townsville. Yonge himself described it as *a dustbin with a handle at the top and plate glass windows in front* (Yonge, 1930). During this expedition, Anne Stephenson, wife of Thomas Alan Stephenson (1898-1961), dived with a helmet and hence probably she could be considered the first woman to dive for scientific purposes.

In those periods, many scientists also built craft tools for their work: Vernon E. Brock (1912-1971), an ichthyologist from California, made a prototype mask consisting of a casted aluminum tube with front glass and a rubber inner tube which provided water-tightness to the face. The mask weighed 90% less than the helmets and gave much more freedom. In the 1940s, Cheng Kui Tseng, a Chinese graduate student at Scripps Institute of Oceanography at San Diego (California), used a commercial diving suit to collect agar-producing *Gelidium* seaweed for cultivation (Fig. 3). In contrast, Frank Haymaker used a diving helmet to study the benthic communities of the Scripps Canyon in 1947. In the late 1940s, the Scripps Institution was among the first to adopt diving for supporting scientific projects, using the Gagnan-Cousteau *Aqua-Lung*, which entered the market in 1947. *Besides, several scientific institutions also started to study the benthic communities of the tropical environments using diving devices* (Loya et al., 2018).

Figure 3. Cheng Kui Tseng used a commercial diving suit to collect seaweed for cultivation studies in the early 1940s at the Scripps Institute in La Jolla. He became a pioneer in ocean farming in China.

In Europe, the cnidariologist Paul Kramp (1887-1975) used a full diving suit in 1925 to observe and sample marine organisms in Denmark, while the Swedish Torsten Gislen conducted remarkable quantitative benthic analyses inside the Gullmarsfjorden (Gothenburg) (Gislen, 1929-30), repeated 60 years after (Svane & Gröndahl, 1988). Other pioneers were the Dutch Hilbrand

Boschma (1893-1976), Philip H. Kuenen (1902-1976) and Jan Verwey (1899-1981) (Godfried van Moorsel and Bennema, 2015). In the United Kingdom, Kitching et al. (1934) used a diving helmet to describe the different rocky associations down to 3 m deep in Wembury Bay (South Devon), while the algologist Lilian Lyle (1864-1936) used divers in 1929 for collecting macroalgae from the scuttled off warships in Scapa Flow (Lyle, 1929). At the Scottish Millport Marine Station, Bainbridge (1952) used a Siebe-Gorman apparatus to study the behavior of some planktonic items in the Firth of Clyde, while George Robert Forster (1928-2020) used scuba diving to study the hard-bottom communities in Devon and Dorset, at the Marine Biological Association of Plymouth (Forster, 1954; 1955; 1961).

Nevertheless, at the turn of the Second World War, the underwater activity was almost exclusively conducted for military interest or sporting purposes related to fish hunting. Later, the pleasure turned into naturalistic interest, also thanks to the rapid spread of the *Aqua-Lung*. However, diving was viewed with suspicion by part of the academic world. At the end of the 1940s, the first scuba scientists were received at the Zoological Station of Naples with distrust. Rupert Riedl (1925-2005), from the Zoologishes Institut der Universitat in Vienna (Fig. 4), remembered: *in those days the establishment was represented by Reinhard Dohrn* (1888-1962), *Anton's son: he told me that I could not disturb a scientific Institute, like the Zoological Station, asking for funding for a sport activity* (Riedl, 1978). However, not everyone thought the same. In California, the invertebrate zoologist Wesley Roswell Coe (1869-1960), from the Scripps Institution, said to a student: *Son, you go on out there. You will learn more in an hour [underwater] than you'll learn in ten hours with books* (Hanauer, 2003). At the same time, Hans Hass (1919-2013), an Austrian student from the Faculty of Biology of Berlin, spent several months at the Zoological Station of Naples to study bryozoans for his doctoral thesis in zoology, also diving in the Grotta Azzurra marine cave of the Capri Island (Hass, 1949). Probably his thesis was one of the first scientific studies realized using diving equipment.

French scientists were among the first marine biologists adopting scuba diving techniques. In particular, researchers from the University of Marseille and the Marine Station of Endoume, this latter founded at Marseille in 1889. At the end of the 1940s, Pierre Drach (1906-1998), future director of the *Observatoire océanologique de Banyuls-sur-Mer*, started underwater investigations of the structure of the coralligenous, the carbonate bioconstructions formed by the activity of red coralline algae (Laborel, 1958, 1961), and marine cave communities (Drach, 1948). In the same years, Jean-Marie Pérès (1915-1998), director of the Endoume Marine Station in Marseille from 1948 to 1983, much favored the underwater research and a marine biology school of considerable scientific importance was born, laying the basis for the study of the benthic bionomy in the Mediterranean. In the same years, the algologist Roger Molinier (1927-1991) devoted himself to the study of *Posidonia* meadows and biogenic concretions (Molinier, 1952; 1955), while Jacques Laborel (1934-2011) began to study the sciaphilous habitats, particularly the coralligenous. Laborel also began to study the underwater marks of the Holocene sea-level changes (Laborel & Laborel-Deguen, 1994), working in Brazil and Africa for many years. Still in Marseille, in the immediate aftermath, Jean André Vacelet began his research on sponges (Vacelet, 1964), Jean-Georges Harmelin on bryozoans (Harmelin, 1969) and Helmut Zibrowius on serpulids and *scleractinians (Zibrowius, 1968). In* 1952, the Austrian Rupert Riedl organized the *Österreichischen Tyrrhenia-Expedition* to study marine caves (AA.VV., 1959), mainly thanks to diving activities. Among the young scientists, Klaus Rützler conducted his PhD thesis dealing with sponges' systematics and ecology in Mediterranean marine caves (Russ & Rützler, 1959; Rützler, 1996).

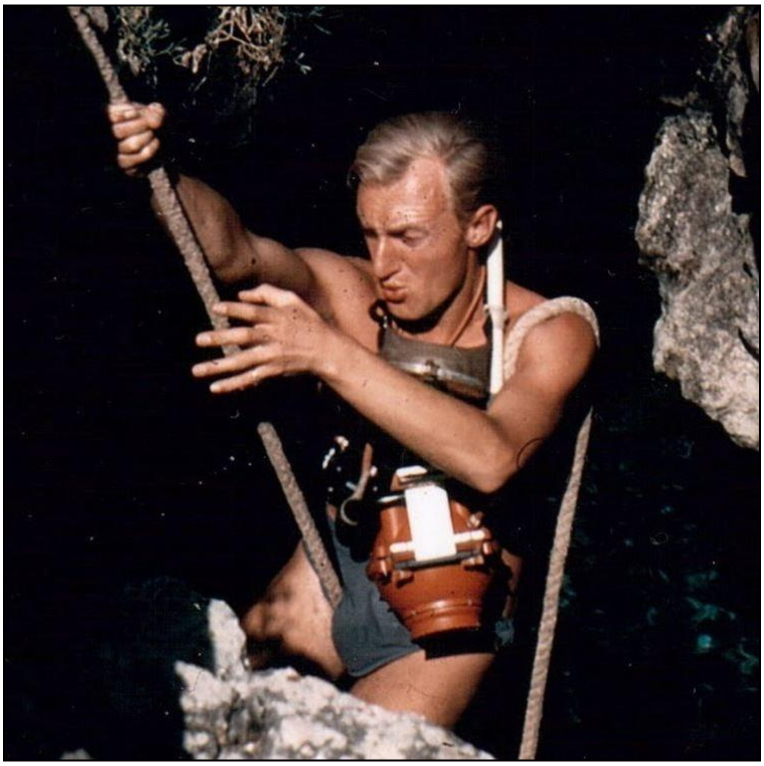

Figure 4. Rupert Riedl studied the marine caves' biology and ecology during the *Österreichischen Tyrrhenia-Expedition* in the Gulf of Naples in 1952.

In the same period, scientific diving started in Italy thanks, among other reasons, to the success and fame obtained by the Italian expedition in the Red Sea to explore the Dahlak Islands underwater habitats (1953) and organized by Bruno Vailati (1919-1990). The most famous Italian divers of the time attended, along with scientists such as Francesco Baschieri Salvadori (1921-2000), who collected *scleractinians*, now hosted in the Civic Museums of Zoology of Rome and Milan (Epiceno & Paggetti, 2014). A few years later, Enrico Tortonese (1911-1987), director of the Natural History Museum of Genoa and Lucia Rossi (1913-2006) from the University of Turin asked to several scuba pioneers (Gianni Roghi, Cino Motta, Duilio Marcante) and to the newborn group of Carabinieri Subacquei in Genoa (1953) to collaborate for taking specimens and coralligenous samples (Fig. 5) from the Ligurian Sea (Tortonese 1958; 1961; Rossi, 1959; Pastorino & Canu, 1965; Luciano & Roero, 2008; Gatti et al., 2015). Between 1956 and 1957, with the support of the Institute of Zoology of the University of Turin, the Piedmontese Underwater Society organized a cycle of researches and collections in the waters of Cervo Ligure (Ligurian Sea) and western Sardinia directed, for the scientific part, by Menico Torchio (1932-2001) (Marcante & Muccioli, 1986). In the 1960s, the algologist Giuseppe Giaccone (1936-2018), a pioneer of deep diving, started to study the dim-light algal communities in Sicily and Roberto Marchetti (1930-1995) described the red coral populations present in the Ligurian and Tyrrhenian seas (Marchetti, 1965a,b). In the same years, the spongiologist Michele Sarà (1926-2006), with the help of Gustavo Pulitzer-Finali (1915-2006), introduced the phytosociological method, a technique already applied to marine benthos by French scholars such as Roger Molinier and Charles-François Boudouresque, in the study of the spatial and temporal variation of shallow-water encrusting sponge assemblages and in particular in shallow semi-submerged caves, an easily accessible habitat (Sarà, 1958; 1964). Always in Italy, since 1969, the Laboratory of Benthic Ecology of the Zoological Station on the Island of Ischia started with important underwater projects regarding the seagrass meadows (*Posidonia*, *Cymodocea* and *Zostera*), hard bottoms (including caves), soft-bottoms, shallow hydrothermal sites, lagoons, rocky reefs laying the groundwork for an Italian school of scientific diving, including that formed under the guidance of Michele Sarà at the University of Genoa (Balduzzi et al., 1983).

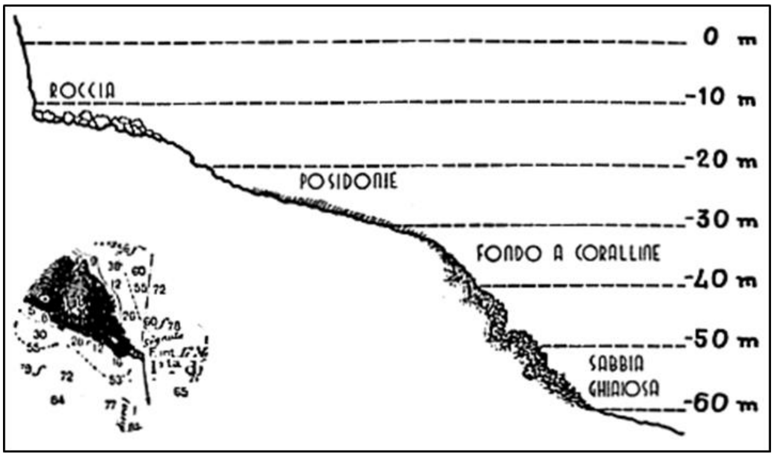

Figure 5. A first sketch of the coastal benthic communities' distribution along the Portofino Promontory cliff (Italy) made by divers at the end of the 1950s. Roccia = Rock; Posidonie = *Posidonia oceanica* meadow; Fondo a coralline = Coralline algae seabed; Sabbia giaiosa = Gravel sand.

Between the 1960s and 1970s, at the request of the ecologist Ramon Margalef (1919-2004), an important development of the marine biology studies began in Spain that had no equal in Europe. Thanks to Juan-Domenic Ros's coordination, dozens of researchers have dedicated themselves to studying the marine fauna and flora of the Iberian Peninsula. They made significant progress, and a Spanish school was created in a few years, mainly at the Centre d'Estudis Avançats de Blanes and at the University of Barcelona, composed primarily by scientific divers (Ros *et al*., 1984, 1985). A few years later, relevant biological studies started in Greece from the School of Biology of the Aristotle University of Thessaloniki and continued at the Hellenic Centre for Marine Research and the Department of Marine Sciences of the University of the Aegean (Koukouras et al., 1985, 1992, 1996).

Since the 1970s, diving sciences have spread widely, and today, there is no significant scientific institution in the world that does not have at least one diving laboratory or does not use divers to carry out research. Our knowledge about the marine biosphere expanded also owing to new methods such as the accessibility to mixed-gas diving and closed-circuit rebreather systems which have enabled scientists to reach and also study the deep mesophotic habitats, reaching 100-

120 m depth (Heine, 2011). In particular, the rebreather absorbing the carbon dioxide of a user's exhaled breath does not discharge the exhaled gas. Thus, this device is very silent and allows to approach many organisms without frightening them with the emission of air bubbles or diving for a long time in shallow waters.

BIODIVERSITY AND HARD-BOTTOM LITTORAL COMMUNITIES

Scuba diving revolutionized marine botanical and zoological sciences. The current knowledge on biological richness, species abundance, presence of non-indigenous species, structure and dynamics of hard-bottom communities in shallow waters are mostly due to scuba activities (Bakus, 2007). Until the spread of this method, our knowledge of the hard-bottom communities was limited to samplings carried out from the surface, using trawlers, dredges and grabs, useful tools in the study of soft-bottom communities, but definitively unsuitable for operating on hard bottoms.

Figure 6. A scientific diver samples organisms in the Mediterranean coralligenous assemblage (Courtesy of Roberto Pronzato).

Scuba diving provided the most accurate method to describe the coastal benthic communities (Bianchi et al., 2004). Several underwater protocols were adopted to gain information (Fig. 6), including visual census, transect lines, photo-quadrats, methods based on the counting and measuring of animals or plants species (Bianchi et al., 2003). In the same way, underwater visual transects permitted the establishment of quantitative assessments of erect and massive species both on rocky and sandy bottoms.

Figure 7. A diver using a sucking pump to collect vagile organisms in a Mediterranean algal community (Courtesy of Roberto Pronzato).

All this information can be summarized in habitat mapping, a prime necessity for environmental planning and management (Bianchi et al., 2012b). These maps provide an inventory of habitat types and their extent, illustrate the location of environmentally sensitive areas, and identify hot spots of biodiversity. Maps also allow to detect changes in biotic cover, allow boundary demarcation of multiple-use zoning schemes, and help quantify ecosystem services (Mumby & Harborne, 1999).

In shallow soft bottoms, where sampling from small boats is complicated, several scientific divers have put in place different systems, as hydraulic diver-operated dredge-sieves, to suck up the sand or the mud of a metallic cylinder forced into the sediments (Brett, 1964; Barnett & Hardy, 1967; Emig & Lienhart, 1967) for operating in the infra- and circumlittoral zones.

Quantitative studies on the motile benthos in rocky communities are challenging to do, as this type of fauna escapes the usual sampling methods. Good results were obtained using small nets or sucking pumps (Giangrande et al., 1986), both directly operated underwater (Fig. 7). These samplings, albeit accurate, are often too limited and point-like. Using traps placed directly on the bottom as "continuous benthic recorders", it has been possible to evaluate the motile fauna's seasonal abundances, mainly crustaceans, or to quantify the amounts of sediment rolling down along a cliff (Bavestrello et al., 1991, 1995) (Fig. 8).

Figure 8. A trap to collect sediments rolling down the cliff.

In situ observations helped shed light on the early life cycle of subtidal marine invertebrates, such as spawning periods, reproductive strategies, unpredictable recruitments, settlement moments, and slow growth rates. At the same time, tagging studies have permitted to identify dispersal and migration mechanisms, patch distribution, and habitat selection by juveniles and adults.

The possibility of reaching environments that were difficult to sample with other techniques or of modest extents, such as, for example, caves or deep shoals, has allowed us to evaluate better the distribution of many species and their real rarity. A species is often considered rare because it has a short life cycle or its distribution range is limited or lacks precise information about its ecological habitats. For example, until the 1950s, the nudibranch *Peltodoris atromaculata* Bergh, 1880 was considered very rare (Pruvot-Fol, 1954): thanks to diving now is possible to consider it one of the most common nudibranchs of the coralligenous community.

COASTAL HABITATS AND THEIR DYNAMICS

The underwater activity gave a formidable impulse to the research of the littoral hard-bottom communities. Firstly, diving allowed to develop the study of the tropical coral reefs, some of the world's most diverse ecosystems. Since the Great Barrier Reef Expedition (Yonge, 1930), coral reefs were under constant observation in many tropical countries as they play an essential role in the conservation of biodiversity, are a source of food, are a formidable barrier to coastal erosion, provide jobs for local communities, and offer opportunities for recreation and tourism (Knowlton & Jackson, 2001).

The same applies in the Mediterranean Sea for seagrass meadows, particularly *Posidonia oceanica* ones, whose role is essential in the ecological balance of littoral habitats (Montefalcone, 2009; Marba et al., 2014). Charles-François Boudouresque was among the firsts to devote himself to the study of the *Posidonia* meadows. In the last decades, these studies led to the description of the distribution and structure of the seagrass meadows present along the Mediterranean coasts. Among the firsts, Colantoni et al. (1982) described the *Posidonia* beds distribution around the Island of Ischia (Naples), using underwater techniques.

Another habitat of great ecological importance because of its complex structure and high diversity is kelp forests that characterizes both the subtidal temperate-cold coasts of the Pacific and Atlantic oceans. Thanks to underwater observations, Aleem (1956) was among the first to assess the standing crops inside a *Macrocystis pyrifera* (Linnaeus) C. Agardh forest, while the specific richness and the ecology of this habitat were described in-depth by Dayton (1985).

In the Mediterranean Sea, the rocky subtidal zone from 15 to 120 m depth is often characterized by carbonate bioherms, the coralligenous habitats, which reach thicknesses ranging from 25 cm to more than 2 m (Ballesteros, 2006; Ingrosso et al., 2018; Çinar et al., 2020). These bioherms, dating back to 8000 YBP, form a secondary carbonate substrate that constitutes a highly biodiverse habitat, characteristic of the Mediterranean, whose study has been improved by the progress of diving techniques (Laborel, 1961; Laubier, 1966; Bertolino et al., 2017a, 2017b, 2019).

The same is true for the so-called 'mesophotic' or 'twilight' zones which develop on continental slopes or the top of seamounts at depths between 60 and 100-120 m (Lesser et al., 2009). These habitats are still difficult to access today by conventional diving techniques and remain partially unknown. However, as early as the 1960s, Giuseppe Giaccone studied the forests characterised by *Laminaria rodriguezii* Bornet, 1888 in the Strait of Messina and on the Banco Apollo (Ustica Island), an Atlantic enclave in the Mediterranean Sea and a hot spot of biodiversity (Giaccone, 1967).

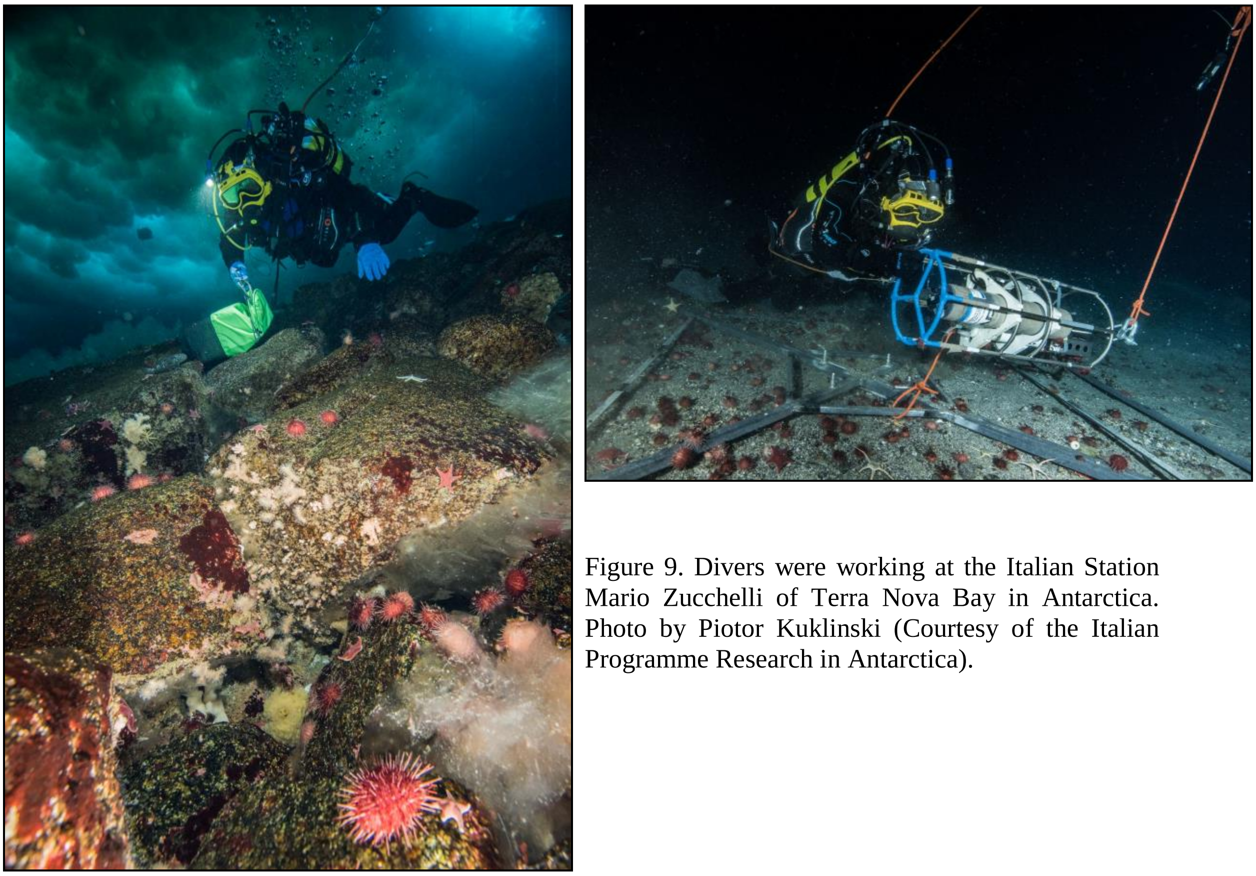

Figure 9. Divers were working at the Italian Station Mario Zucchelli of Terra Nova Bay in Antarctica. Photo by Piotor Kuklinski (Courtesy of the Italian Programme Research in Antarctica).

Diving has also allowed conducting selective and non-destructive samplings of one of the less known marine fauna components, the meiofauna or organisms that live between the interstitial spaces of marine sediments and whose dimensions vary between 45 µm and 1 mm (Mare, 1942).

Seascape ecology attempts to synthesize all the variables that drive organism distributions and their movements, showing critical ecological thresholds, and abrupt shifts in their abundances. In this context, the benthic community structure analysis received a tremendous impulse thanks to underwater studies, allowing the perception of the seascape that would be otherwise unreachable without direct underwater activities. In this regard, investigations at the seascape level became fundamental for the assessment of the ecological quality of coastal habitats, according to the E.U. Directive (Cánovas Molina et al., 2016). All this information allowed producing thematic maps at different scales, showing the density of engineering or critical species and their covering capacity.

Underwater observations are also essential to verify the effects of underwater artificial reefs deployed everywhere in the world. They are artefacts, often modular, immersed at shallow depths to increase fish production through increased survival and growth of juveniles, enhance habitat complexity, favor the aggregation of scattered specimens and as mechanical deterrents to illegal trawling (Firth et al., 2016).

Extensive use of diving was also applied in the study of benthic communities in polar waters, particularly Antarctica, where open-circuit scuba dives started in 1958 (Peckman, 1964; Neushul, 1965; Brueggeman, 2003), investigating species distribution and abundances (Fig. 9). One of the pioneers was Paul Dayton, from the Scripps Institution of Oceanography. His scuba observations have allowed mainly to describe the under-ice benthic communities in McMurdo Sound and define the main characteristics of the Antarctic marine ecology (Dayton et al., 1974).

Studying the hard-bottom communities, one of the scientific problems that the diving activity helped solve was the minimal area, i.e., the minimum sampling surface representing a marine rocky bottom community (Fig. 10). The minimum area is mostly practical and fundamentally concerns the cost-benefit analysis between the amount of information collected and the effort to obtain it (Boudouresque, 1971; Weinberg, 1978). Thanks to the sampling of contiguous and growing surfaces of rocky surfaces, it was possible to construct curves of the number of species vs surface. The method is costly and requires a considerable analysis effort in the laboratory, and also many species are not easily removed from the substrate or are extremely difficult. A much hastier method to describe the structure of benthic macro-communities, although inevitably less accurate, is the direct visual counting within delimited areas, permitting to analyse the distribution of benthic species, their spatial extension, heterogeneity, patchiness, fragmentation and ecological connectivity (Boero & Fresi, 1986; Boström et al., 2011).

Figure 10. A scientific diver collects organism to evaluate their area minima inside a Mediterranean coralligenous assemblage (Courtesy of Roberto Pronzato).

MARINE CAVE STUDIES

At the beginning of its diffusion in the scientific world, diving became an essential tool to explore environments that were difficult to reach otherwise, as submerged caves. The underwater caves were an unknown environment that only thanks to diving could be explored and studied (Barbieri, 2014; Cicogna et al., 2003). The first studies on the structure and dynamics of this unique environment in the Mediterranean Sea are due to the French school of Marseille that led to the description of the biocoenoses of semi-dark and dark caves (Pèrés & Picard, 1949; Laborel & Vacelet, 1958; Vacelet, 1964; Ledoyer, 1968).

In 1957, Pietro Parenzan (1902-1992) explored the underwater section of the Zinzulusa Cave (Castro Marina, Apulia, Italy) (Parenzan, 1958). He followed the example of Rupert Riedl from Vienna University who organized a series of expeditions to study the marine caves in the Sorrentine and Istria Peninsulas (AA.VV., 1959), trying, above all, to investigate the role of hydrodynamics in the distribution of biota. The synthesis was published in *Biologie der Meereshöhlen* by Rupert Riedl (1966). Since the 1970s, contributions also come from Italian researchers (Sarà, 1970; Balduzzi et al., 1982) and, from the 1980s, thanks to the Spanish (Gili et al., 1986; Bibiloni et al., 1984; Zabala et al., 1989) and Greek schools (Gerovasileiou & Voultsiadou, 2012). Taxonomic and flora-faunal studies in shallow marine caves evidenced the rarity of exclusive species (troglobionts) but the presence of many bathyphilic and 'cryptobiotic' species, which have found, in the marine caves, conditions similar to those of bathyal and cryptic environments, respectively (Harmelin et al., 1985; Vacelet et al., 1994). This phenomenon was defined as "secondary troglobiosis" by Cattaneo & Pastorino (1974). Easily accessible to scuba divers, this "bathyal island" offered exceptional opportunities to study deep-sea biology. The presence of relict species such as *Petrobiona massiliana* Vacelet & Lévi, 1958, a sponge belonging to a family thought to be extinct at the end of the Cretaceous (Vacelet & Levi, 1958; Vacelet, 1964) of bathy-abyssal affinity hexactinellid *Oopsacas minuta* Topsent, 1927 (Vacelet et al., 1994) or carnivorous sponges belonging to the Cladorhizidae family (Hestetun et al., 2016). All these pieces of evidence suggest the exceptional nature of this habitat and its scientific importance (Harmelin et al., 1985; Vacelet & Boury-Esnault, 1995; Vacelet, 2007).

In the 1980s, marine caves became a "natural laboratory" on a small scale and easily accessible to study the role of light and hydrodynamics in driving the sessile benthic communities (Riedl, 1978; Balduzzi et al., 1982; 1989; Boury-Esnault et al., 1993). In a horizontal cave, light and hydrodynamic intensities, as well as trophic inputs and other environmental gradients, change within a few meters. They are much more easily measurable than in the external environment, where these variables change in the extent of hundreds of meters.

Scientific divers also studied the functioning of the cave system, the flow of organic matter mainly due to the nycthemeral migrations of crustaceans and fish inside and outside the cave, and proposed a theoretical model (Ott & Svoboda, 1976). In the mid-1980s, the exploration of the cave complex of Capo Palinuro (South Tyrrhenian Sea) (Fig. 11) permitted to identify a peculiar habitat. It was characterized by hot sulfur resurgences that favor the development of large bacterial populations (*Beggiatoa*), whose chemosynthetic activity permits to act as the primary producer of organic matter, supporting a rich fauna (Morri et al., 1994; Benedetti-Cecchi et al., 1996). A phenomenon that recalls what happens in the oceanic hydrothermal vents.

Figure 11. A diver inside a sulphurous cave (Snow Hall, Grotta Azzurra Cave, Palinuro Cape, Italy). The chemocline, due to sulphur-water springs, and floating bacterial mats are evident (Courtesy of Fabio Barbieri, Palinuro Diving Center, Italy).

Recently many studies mainly carried out by French, Italian and Greek scientists, allowed to know much more about the biodiversity and the functioning of the Mediterranean marine cave ecosystems, just thanks to the possibility to visit them by diving (Bussotti et al., 2006; Chevaldonné & Lejeusne, 2003; Dimarchopoulou et al., 2018; Gerovasileiou & Voultsiadou, 2012; Gerovasileiou et al., 2015, 2016, 2017; Rastorgueff et al., 2015; Montefalcone et al., 2018a).

Different is the case of the anchialine caves present along the coast without a direct connection with the sea, maintaining salty or brackish waters, often with low concentrations in dissolved oxygen. Specialized cave diving technology is essential also to explore these environments inhabited by endemic, cave-adapted species often considered "living fossils" (Iliffe, 1992; Iliffe & Kornicker, 2009).

PREY-PREDATOR INTERACTIONS, COMPETITION AND COOPERATION

Studies regarding the intra- and interspecific interactions among marine organisms, in terms of both spatial and temporal variability and competition and cooperation (Fig. 12), received a significant impulse thanks to the possibility to observe the distribution and growth rates of sessile benthic species, mainly sponges and bryozoans, directly underwater (Sarà, 1970). Scuba diving has allowed observing *in situ* the complex hierarchy networks that drive the structure and dynamics of the coastal benthic communities, identifying the relationship between prey and predator and the foundation or engineering species that play key roles in the maintenance of biodiversity by facilitating the persistence of the habitat (Dayton, 1971; 1972; Wulff & Buss, 1979). Scuba-based research also favored the study of the top-down effects inside the benthic food webs, evaluating the role of animal behavior in driving trophic cascades in different habitats. These studies became popular in marine ecology and, thanks to underwater observations, the direct and indirect effects of the herbivory and predation along the trophic levels were possible to understand (Paine, 1966; Siddon & Witman, 2004). Moreover, consumer-prey interaction studies became essential to evaluate the effects of the implementation of an MPA or intensive resource exploitation (Pinnegar et al., 2000). Other fundamental studies on the role of herbivorous or predators in limiting and controlling the abundance of the macroalgae or single preys were done with techniques of removal and addition of specimens and species. In this way, it was possible to manipulate the macroalgae-herbivores or prey-predator relationships using cages, showing how the densities could explode in the absence of predation or vice-versa. For example, the effects of grazing by sea urchins as a leading cause of deforestation due to their blooms following the disappearance of large populations of sea-otters, the main sea urchin predators, represent a classic model in marine ecology (Paine & Vadas, 1969; Estes & Palmisano, 1974). Mediterranean scientists used observational diving and experimental approaches to study the trophic cascades in rocky reefs, recording data on fish, algae and invertebrates and evaluating the effects of changes in the composition of the various trophic components (Sala et al., 1998).

DIVING, SEA-TRUTHING AND GLOBAL THREATS

Underwater diving allows real-time, detailed and large-scale assessments, integrating details that, without direct observations, can lead to misconceptions. Also, the monitoring and evaluation of the global threat to marine ecosystems due to habitat loss, pollution, over-exploitation, climate change, and the effectiveness of the natural response require diver intervention. Changes in global climate occur in the sea and, in the field of global change, underwater investigations were essential (Bianchi et al., 2012a; Longobardi et al., 2017). Ocean acidification, anthropogenic carbon dioxide increase, and coral bleaching processes are only examples of changes, and scuba diving has provided a large amount of observational data with minimal disturbance, contributing significantly to the vast body of knowledge on the subject, over several decades (Hall-Spencer et al., 2008). Long-series of data on coral reefs collected with scientific diving permitted to evaluate the effects of global warming and bleaching and define the trajectories of change due to the synergic effects of local and large-scale human pressures in the Anthropocene (Montefalcone et al., 2018b).

Changes in community structure are also exacerbated by the introduction of alien species, which are considered one of the leading causes of biodiversity loss (Galil, 2000). Scientific divers are the most competent to detect the presence of potentially invasive species and in some cases, can provide a quick response (Katsanevakis et al., 2020).

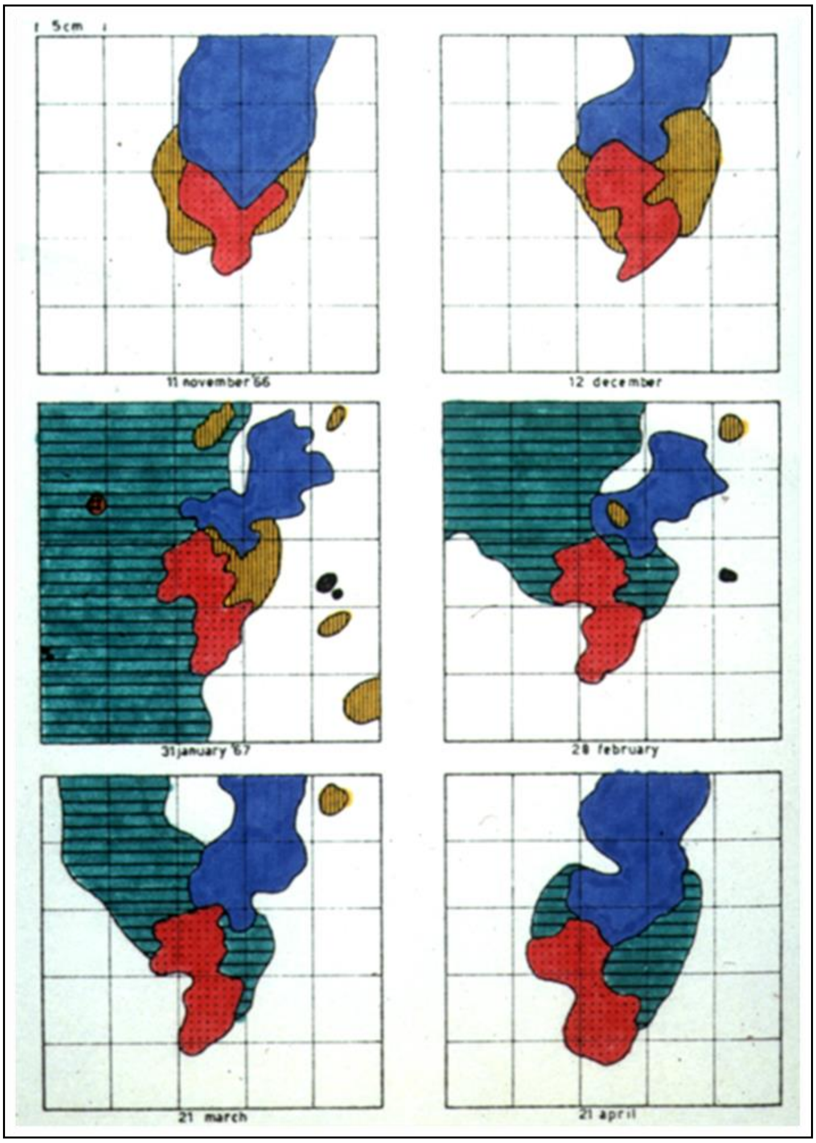

Figure 12. Contours of encrusting sponges made over time by Michele Sarà to study their spatial variability realized from November 1966 to April 1967.

FISH VISUAL CENSUS

Since Vernon E. Brock (1954) firstly proposed underwater transects to census reef fish populations, visual census (UVC) has been a crucial non-destructive tool for fish ecologists because of the minimal impact on the fish behavior (Harmelin-Vivien & Francour, 1992; Guidetti, 2000, 2002). Thanks to direct underwater observations, our knowledge on the distribution and abundance of many species improved significantly and today is, on a worldwide scale, one of the most used techniques for studying coastal fish communities, delivering a significant contribution especially for conservation issues. In the Mediterranean, the first studies were conducted in the Port-Cros MPA (Harmelin-Vivien et al., 1975, 1985). These results have changed our knowledge about the coastal fish fauna, their behavior, and their links with well-defined habitats. Before diving, our understanding mainly came from fishing activities, which inevitably used very selective capture systems (nets, long lines, traps, and so on). Thanks to this technique, it is possible to acquire and evaluate the distribution and structure of coastal fish communities, record information about the members and size of a given population, and verify the protection and spill-over effects within MPAs (Guidetti, 2000, 2002).

Moreover, this technique fostered significant advances in understanding the different fish behavior during the diel cycle, thanks to nocturnal observations by scuba diving (Helfman, 1993; Azzurro et al., 2007). The results obtained by the UVC, today widely standardized, have assumed crucial importance in the management of MPAs and are decisive in suggesting to managers, stakeholders and policymakers correct policies related to a sustainable economy and biodiversity conservation. However, UVC studies could underestimate the diversity and density of small, benthic fishes whose behavior is often very elusive (Willis, 2001), considering the disturbance due to the observer's presence and noisiness.

BLUEWATER DIVING

The zooplankton communities have always been investigated using nets, drawn horizontally or vertically and whose meshes varied according to the dimension of the target items. However, nets are unsuitable for studying gelatinous zooplankton, easily damaged or destroyed by nets or trawls. On the contrary, scuba observations opened a new approach and permitted *in situ* studies of the gelatinous zooplankton in the upper layers of the open tropical, temperate, and polar oceans (Hamner, 1975). This approach produced information and images about the real morphology of many zooplanktonic and nektonic species, often very large, elucidated behavioral patterns, and helped understand marine snow dynamics. The blue-water dive technique opened to marine biologists, one of the largest and least known habitats on Earth, populated by diverse, abundant, and mostly unknown animals (Madin et al., 2013). In this context, the so-called "blackwater diving" is becoming increasingly popular among the underwater photographer community. It is a special kind of night dive off the coast with divers tethered to floating or anchored facilities who can take photos of zooplankton and other invertebrates that are frequent in the superficial layers of the waters only during the night.

Moreover, surface-towed nets proved inadequate to quantify the meroplanktonic community present in the water column, immediately above rocky and sandy bottoms. With the development of scientific diving, some nets were mounted on underwater scooters, or demersal plankton traps were placed *in situ* and operated via scuba, for assessing the dynamics and behavior of the zooplankton near the seafloor (Hobson & Chess, 1976; Potts, 2009). In other cases, the vertical and temporal distribution and biomass of zooplankton over a coral reef were evaluated using underwater plankton pumps, sampling throughout the diel cycle (Heidelberg et al., 2010).

These techniques were particularly crucial, indicating that most of the zooplankton is resident and migrates vertically off at dusk and comes back at dawn. In conclusion, the use of underwater traps or plankton nets operated by divers showed that the results obtained using standard sampling techniques greatly underestimated plankton abundance over coral reefs (Alldredge & King, 1977).

BIOREMEDIATION AND TRANSLOCATION

The underwater activity has also given a significant boost to "gardening" operations aimed at restoring degraded marine coastal habitats or translocate species of ecological importance, in response to specific conservation problems. In particular, worldwide coral gardening projects towards the reef and species recovery have been put in place to encourage reef re-development, showing that these techniques can be essential for reef rehabilitation (Rinkevich, 2005; Lirman & Schopmeyer, 2016). In particular, coral restoration projects focused primarily on fast-growing branching corals (Bostrom-Einarsson et al., 2020).

The first seagrasses transplantation attempts were made in the 1950s in North America, using *Zostera marina* (Phillips, 1974; McRoy & McMillan, 1977). Also, the rapid decline of the *Posidonia* meadows in the Mediterranean Sea (Leriche et al., 2006; Marba et al., 2014) and Western Australia (Bastyan & Cambridge, 2008), attributed to a wide variety of human activities, suggested several attempts of reforestation (Paling et al., 2009).

In the Mediterranean basin, already in the 1970s, George Cooper implemented the first transplantation attempt in the Gulf of Giens (Toulon) (Cooper, 1976) and was subsequently followed by other researchers (e.g. Augier et al., 1996; Cinelli, 1980; Balestri et al., 1998; Bacci et al., 2014). The results proved the potential of the approach, which is now operated on a large scale, although these transplants' success is still in discussion (Meinesz et al., 1991; 1993).

Aquaculture of species of commercial interest involves mainly fish, shellfish, crustaceans, corals and seaweed. In these rearing activities, scientific diving is essential. In the Mediterranean Sea, underwater interventions for a re-location or farming of species which have suffered sharp reductions due to the substantial impact of the pollution or excessive fishing pressure were conducted with different success rates. Most of them concerning species of economic or ecological significance, such as the precious red coral *Corallium rubrum* (Linnaeus, 1758) (Bavestrello et al., 2001), the bath sponges *Spongia officinalis* Linnaeus, 1759 and *S. lamella* (Schulze, 1879) (Pronzato, 1999; Corriero et al., 2004), the noble pen or fan mussel *Pinna nobilis* Linnaeus, 1758 (Cabanellas-Reboredo et al., 2019; Bakran-Petricioli et al., 2019) or brown algae of the genus *Cystoseira* (Susini et al., 2007).

Coral farming for commercial purposes or for restoring reefs is now widespread in tropical waters (Pomeroy et al., 2006; Hernández-Delgado et al., 2018). However, underwater farming techniques were also investigated for some sponges that produce biologically active metabolites of considerable interest in pharmacology (Duckworth & Wolff, 2007; Duckworth, 2009; Padiglia et al., 2018).

Diving into the Past

Coralline algae, *scleractinians*, serpulids and bryozoans can, on geological time scales, lead to the formation of massive carbonate bioconstructions which are present everywhere, mainly in shallow tropical and temperate seas. According to several variables such as temperature, salinity, turbidity, and sedimentation rates, their growth rate varies. Thanks to different coring techniques, scuba diving permitted to study structural changes of these paleo-communities over time, their species richness, the history of the rising sea-level, and hypothesize the paleoclimate (Bertolino et al., 2017a, 2017b). Cores permitted to describe previously dominant species and their replacement by other species, and natural and anthropogenic perturbations. In an age of global change and ocean acidification, understanding the different biocalcification processes and these habitats' dynamics is critical to assess their vulnerability and interpret the effects of climate change, supporting future environmental evolution predictions.

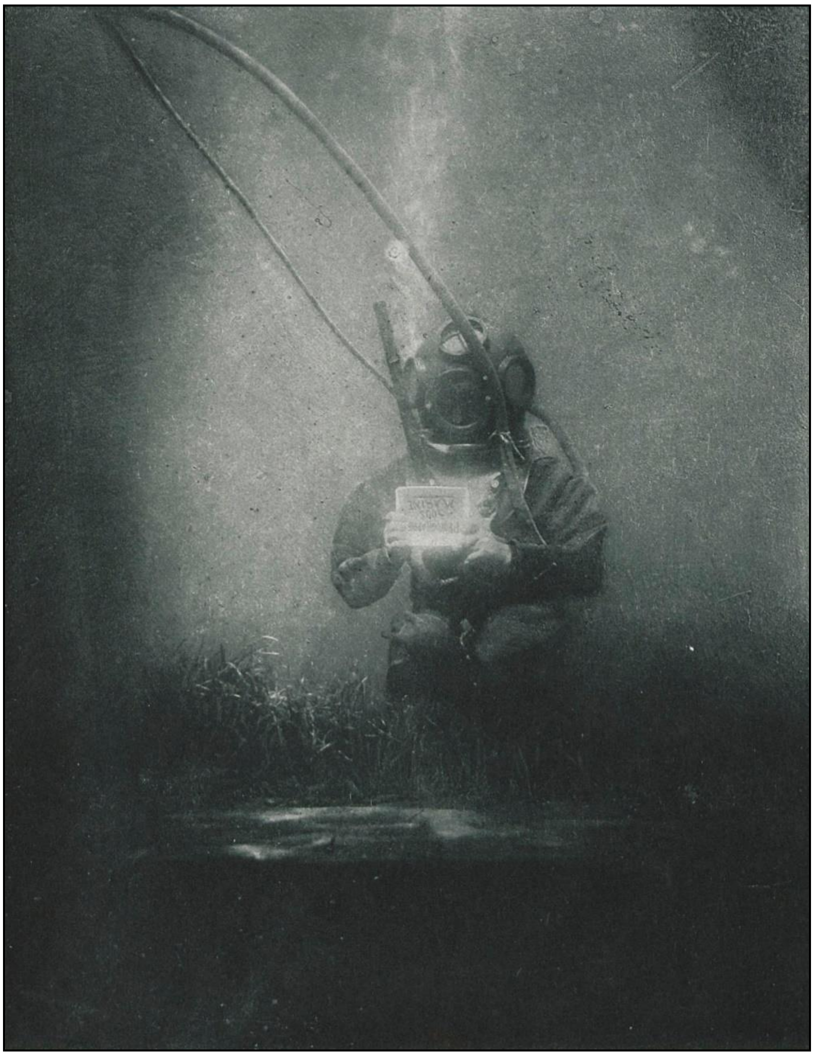

Figure 13. Emile Racovitza, vice director of the Observatoire océanologique de Banyuls-sur-Mer or perhaps Joseph David, a Boutan's collaborator, sitting in a Posidonia meadow with a commercial diving suit, photographed by Louis Marie-Auguste Boutan in 1898.

UNDERWATER PHOTOGRAPHY

Before the advent of underwater photography, the oceans' world and their inhabitants were represented only by drawings. In many cases, they were of extraordinary precision. The scientific and artistic value was evident in the tables of famous volumes like those of *Fauna und Flora des Gulf von Neapel,* published by the Stazione Zoologica Anton Dohrn of Naples or the *Résultats des Campagnes Scientifiques du Prince Albert 1er de Monaco* and the immense archives of images of the Natural History Museum of London and Smithsonian National Museum of Natural History. Almost all of the marine animals' drawings were realized copying dead or fresh specimens collected with various tools. However, in the 19^{th} century, the Austrian artist-explorer Eugen von Ransonnet-Villez (1838-1926), during a journey in Egypt and Arabia in 1862, sketched some underwater landscapes observing the world of corals through the water. Two years later, he was in Sri Lanka and used a diving bell constructed according to his design. Sitting in this bell, he observed the underwater world and took sketches to describe the life beneath the water (Jovanovic-Kruspel et al., 2017).

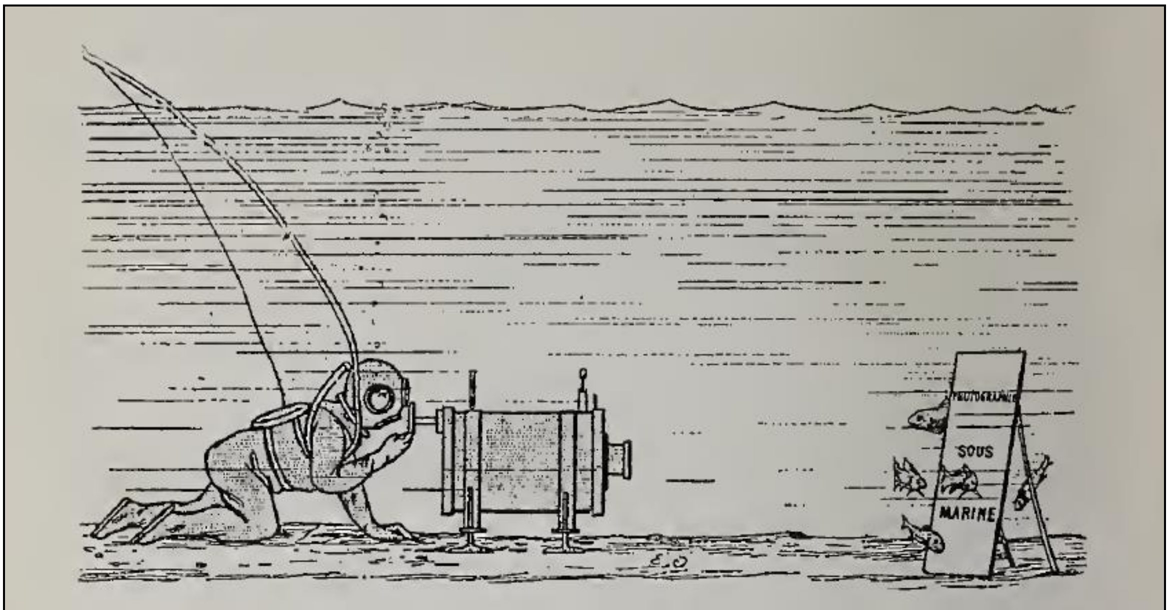

FIG. 23. — Scaphandrier prenant une photographie instantanée.

Figure 14. Boutan for the improved study of fish movements attracted them in front of a clear panel that allows a faster photographic exposure (from Boutan, 1900).

Today, although scientific illustration retains its importance, underwater photography is a fundamental means of documentation for most researchers (Bohnsack, 1979; Boyer, 2014). First underwater photographic images date back to 1856 when William Thompson (1822-1879) placed a waterproof cased camera at few meters deep in Weymouth Bay (South England) (Martinez, 2014). However, the first, most famous underwater photographs were obtained by the French marine biologist Louis Marie-Auguste Boutan (1859-1934) at Banyuls-sur-Mer (France) in 1893-98, while he was working at the *Observatoire Océanologique*, founded in 1881 by Henri de

Lacaze-Duthiers (1821-1901). Boutan is considered the founder of underwater photography also because he is the author of the first manual, *La photographie sous-marine*, published in 1900. One of his more renowned photos shows the Romanian oceanographer and biologist Emil Racovitza (1868-1947), vice director of the Laboratoire, underwater, in a diving suit (Figs. 13-14). A few years later, John Ernest Williamson (1881-1966) using a long rigid tube, called "*photosphere*" realized the first underwater movies as *Thirty Leagues Under the Sea* (1914) and *Twenty Thousand Leagues Under the Sea* (1916). In 1926, Charles Martin (1877-1977), a genius in applied chemistry to photography and the first director of the *National Geographic Photo Lab*, made several underwater autochrome photographs (they are believed to be the first), documenting the life of the coral reefs of the Dry Tortugas, in collaboration with the ichthyologist William H. Longley (Longley & Hildebrant, 1941) (Fig. 15). Ten years earlier, Englishman Francis Ward photographed freshwater fish in color in Great Britain (Weinberg et al., 1993).

Figure 15. Two of the underwater photographs shot by Charles Martin documenting the Dry Tortugas' life (Florida Keys) coral reefs at 1,3 m depth in 1926.

After the Second World War, in 1951, Hans Hass (1919-2013) created the Rolleimarin waterproof case to house the Rolleiflex 6x6 camera and underwater photography became quite popular (Fig. 16). In 1956, Jean de Wouters d'Oplinter developed the Calypso-Pho, an amphibious 35 mm camera produced by Spirotechnique. Acquired by Nikon, it became the most famous underwater film camera in the world under the Nikonos brand, achieving a real revolution. At an affordable price, Nikonos contributed fundamentally to the development of underwater photography. In the 1970s, underwater photography and video became common practice: millions of photographers, amateurs and professionals began documenting the life forms present at sea. Thanks to their activity, thousands of marine species have been photographed in their natural environment. They provide a fundamental contribution to the knowledge of marine biodiversity in all seas of the world. Biological specimens were photographed, labelled *in situ* and collected for identification, allowing to correlate their image with the certainty of classification for species that cannot be easily classified exclusively by a photograph (Pansini, 1983). Taking photo-samples, using rectangular frames to demarcate a part of the substrate for detailed analysis along transects, permitted accurate and efficient quantification of the abundance and coverage of the most conspicuous sedentary species within coralligenous assemblages (Çinar et al., 2020), marine caves (Gerovasileiou et al., 2017) as well as photophilic communities (Longobardi et al., 2017).

Pansini & Pronzato (1990), using fixed squares photographed over time, evaluated the dynamics of Mediterranean sponge communities.

Moreover, stereo-photographic methods, matching pairs of photographs to create a stereoscopic effect, were developed (Lundalv, 1976; Done, 1981; Gibson et al., 2016). Underwater stereophotogrammetry, digital photography, computer processing power and specialized software (Marre et al., 2019) have been emerging instruments for the study of marine habitats and species, providing improved detail resolution, three-dimensional perspective, and a means of determining the shape and dimension of objects at different distances from the camera focal plane (Japp, 1986). Today, the availability of digital cameras for underwater use renders the collection of such observations extremely easy and effective and permits evaluations across time.

Figure 16. The Italian Gianni Roghi, in the late 1950s with a Rolleimarin waterproof case created to house the Rolleiflex 6x6 camera.

Thanks to the development of underwater photogrammetry, it was possible to create photomosaics to describe large surfaces, allowing, for example, to evaluate tropical scleractinians' growth rate (Fryer & Elfick, 1981). As a natural evolution of simple counting specimens along transects or quadrats, scientific divers moved to the use of photos and videos in underwater visual census techniques (UVC) at shallow waters (Leonard & Clark, 1993; Langlois et al., 2010; Hill & Wilkinson, 2004; Parravicini et al., 2009) to collect quantitative data, without altering the marine habitat. The subsequent step was to develop digital models for seafloor mapping and monitoring

(Dumas et al., 2009; Teixidò et al., 2011; Kipson et al., 2011). Underwater scientific photography also permitted to evaluate the progress of slow biological processes through time-lapse cameras (Machan & Fedra, 1975; Fedra & Machan, 1979; Pronzato, 1997). In 1985, Fabio Cicogna (1926-2008) and Roberto Pronzato realized a time-lapse camera (Cicogna & Pronzato, 1985). Thanks to this system, they studied the morphological variations of the sponge *Clathrina clathrus* (Schmidt, 1864) (Gaino et al., 1991), the behavior and diel activity of the Mediterranean red coral (Santarelli et al., 1999), and that of the anemone *Halcampoides purpureus* (Studer, 1879) inside a marine cave (Boero et al., 1991).

UNDERWATER HUMAN HABITATS OR LABORATORIES

The idea to build saturated underwater habitats used primarily by scientists to make *in situ* observations and maximise their underwater observational time arose at the beginning of the 1960s. These projects involved scientific purposes and the oil industry, which at the same time began exploring the continental shelf in search of oil fields. A first experiment (*Conshelf* or *Precontinent I*) was conducted in 1961 by Jacques-Yves Cousteau when two divers lived in a small underwater habitat at 10 m deep for one week, off Marseille. Later, in 1963, eight divers participated in the *Conshelf II Project* (*Precontinent II*) in the Red Sea, at Sha'ab Rumi off Sudan, living for a month in an underwater "village", studying shark behavior and venturing out into cages as deep as 50 m. In 1965, *Conshelf III Project* took six aquanauts to 100 m for three weeks near Cap Ferrat, between Nice and Monaco. In the same time, Edwin Link (1904-1981) organized the *Man in Sea Project* at Villefranche-sur-Mer by with the help of the underwater archaeologist Robert Stènuit who spent 24 hours at a depth of 64 m using an atmosphere wholly saturated with a mixture of oxygen and helium (heliox). In 1964, Link conducted the second *Man in Sea* experiment in the Bahamas waters when two divers (R. Stènuit and Jon Lindbergh) stayed for 49 hours at a depth of 132 m, still breathing heliox (Rambelli, 2006, 2008). The saturation diving path was paved. During 1965-1969, the U.S. Navy used different *Sealab* habitats for research on diving physiology directed by Captain George Foote Bond (1915-1983), U.S. Navy physician and father of the saturation diving. From their home base, the divers could swim out daily to make observations and to carry out underwater experiments. Many underwater habitats were constructed everywhere to test the viability of deep-water habitats and the health effects of prolonged living in submerged structures and, in some cases, to explore the marine environment (Ott, 1973). Among others, scientists of the *Tektite I, II and III Projects* at the Virgin Islands, off Grand Bahama Island, and *Edalhab* in Florida studied the coral reef fishes' ecology and behavior (High & Ellis, 1973).

Today, the *Aquarius* underwater laboratory, first in St. Croix (Virgin Islands) (1987-1989), then off Key Largo (Shepard et al., 1996) has been dedicated to science and education by the Florida International University in Miami and is still in active use. However, the high management costs and the subsequent loss of interest by the oil industry, aimed at using more and more robotic systems, have decreed the end of these experiences.

DIVING AND SCIENTIFIC COMMUNICATION

In 1949, Charles Maurice Yonge published *The Sea Shore*, probably the first guide to the underwater world. In 1950, Roy Waldo Miner, a pioneer of the scientific diving, published a *Field book of seashore life*, describing many animals in their natural surroundings. In 1949, Rachel Carson (1907-1964), the author of the famous bestseller *Silent Spring* (1962) against the intensive use of pesticides in agriculture, joined a University of Miami expedition and used a Miller-Dunn helmet to observe the reefs (Lobel & Lobel, 2015). Deriving from this experience, she wrote two famous books, *The Sea Around Us*, and *The Edge of the Sea*, written respectively in 1951 and 1955. Another excellent scientific communicator is Sylvia Alice Earle, who spent a lot of her life protecting the ocean and its wildlife. In 1970, she led the first all-female team in the *Tektite II* experiment at the Virgin Islands, studying pollution's effects on the local coral reefs.

Other books also included underwater hunting manuals which, albeit with a particular vision, treated the ichthyological component describing the various species and some aspects of their ecology and ethology. We should mention here the works of Luigi Miraglia a forerunner of spearfishing (Miraglia, 1935), and those of Gianni Roghi (Roghi, 1955). In the 1960s, when diving was still developing, the curiosity of those who went underwater stimulated the publication of books dedicated to the identification of marine organisms. Among these, we have to remember *Die Unterwasserfauna der Mittelmeerküsten: Ein Taschenbuch für Biologen und Naturfreund (Guide to the coastal marine fauna of the Mediterranean* (1961) by the German Wolfgang Luther and Kurt Fiedler, *Fauna und Flora der Adria* published by Rupert Riedl in 1963, and *Aquarianer Fangen Meerestiere* (*Aquarists catch marine animals*), a manual for collecting the small fauna by Wilfried Weigel (1969). These books became benchmarks for similar books and have been translated into several languages.

In 1973, Giulio E. Melegari published *Portofino Sub*, the first naturalistic diving guide in the Mediterranean. In 1981, four distinguished Italian experts (Francesco Cinelli, Maria Cristina Gambi, Eugenio Fresi, Piero Solaini) published *La vita nel Mediterraneo (The life in the Mediterranean)*, a guide of great format useful at home, but not during a dive: a problem solved later by Angelo Mojetta and Andrea Ghisotti (1951-2010) (1994) with a pocketbook which was an example for many similar, more illustrated and complete books printed afterwards (Trainito, 2005; Rinaldi, 2017).

In addition to popular books, specialized magazines have also significantly contributed to the growth of interest in marine biology. In 1951, *Skin Diver Magazine*, subtitled *A magazine for skin divers and spearfishermen*, was born in California. Among the first, the Italian *Mondo Sommerso* appeared in 1959 and became a gym for several marine biology writers, among which, by way of example, Giorgio Bini (1906-1973) to whom we also owe the monumental work *Atlas of fish of the Italian coasts*. In Italy, subsequently, pages and pages of marine biology, sometimes dedicated to research projects, appeared in other magazines such as *Il Subacqueo*, *Sub*, *Sesto Continente* and *Aqua*. They were among the first to propose *Citizen Science* projects by launching the idea of monitoring (sharks, nudibranchs, *Posidonia* meadows distribution) open to divers' collaboration.

Documentaries and movies additionally contributed to the dissemination of knowledge of the marine world. Hans Hass was among the first to explore the Red Sea. In 1950, he made a film, with his wife Lotte (1928-2015), *Abentuer im Roten Meer* (*Under the Red Sea)*, which introduced the wonders of the underwater world to the general public and won the first award at the 2ª Mostra Internazionale del Film Scientifico of Venice in 1951. In 1952, during the Österreichischen Tyrrhenia-Expedition organized by Rupert Riedl, Kurt Schaefer made a color movie, *Lights Under Water - Wonders of the Sea*, in underwater caves of Sorrento and was one of the first-ever underwater color films.

In the same year, Cousteau bought the 400-ton former mine-sweeper *Calypso,* which converted into a famous research vessel, thanks to a series of underwater documentaries and movies. In 1956, Jacques-Yves Cousteau and his young assistant Louis Malle (1932-1995) shot *The Silent World* (*Le Monde du silence*), one of the first films to use underwater cinematography to show the ocean depths in color and winner of the Palme d'Or for the best film at the 9th Cannes Film Festival and an Oscar from the Academy Awards (1957), for the best documentary. Afterwards, Cousteau documented his *Conshelf II Project* in the Red Sea, producing *Le monde sans soleil* (1964), a documentary again the winner of an Oscar. Moreover, being elected to the Secretary-General of the Mediterranean Science Commission (CIESM), Jacques-Yves Cousteau favored the diving studies by activating a specific scientific committee, known as *Pénétration de l'Homme sous la Mer*.

In 1952, Folco Quilici (1930-2018) shot *Sesto Continente* in the Red Sea during the Italian Underwater Expedition which won the Special Award at the Venice Film Festival in 1954.

In 1958, the U.S. television series *Sea Hunt* began, introducing scuba diving to the television audience. In the 1970s, Bruno Vailati was the director of many television series dedicated to sea and its life. In the same period, Gianni Roghi (1927-1967) was a great popularizer of the underwater environment, particularly in malacology. In America, Ramón Bravo (1925-1998), a Mexican photographer, filmmaker and diver, showed the beauty of the undersea world through his numerous underwater films, photography, and books. He discovered the famous "caves of the sleeping sharks" off Isla Mujeres (Yucatan Peninsula) in the Caribbean, favoring the studies of Eugene Clark (1922-2015), an ichthyologist known for her research on shark behavior. In the underwater documentary field, since 1974, the *Festival mondial de l'imagine sous-marine*, which for years will be held in Antibes in France, will collect the best expressions in this sector.

In the 1970s-80s years, the Scientific Research and Underwater Research Group (GRSTS) of Florence, founded in 1966 by Alessandro Olschki (1925-2011), organized several research initiatives in the Red Sea, Galapagos, Antarctic Peninsula, and Great Barrier Reef, carrying out numerous publications and underwater research (Olschki, 2007). In 1978, Fabio Cicogna (1926-2008) founded the CLEM (Centro Lubrense Esplorazioni Marine), a non-profit organization promoting marine science. In those years, Cicogna organized workshops and field activities to favor the study of marine caves (Cicogna et al., 2003), the protection of the red coral populations (Cicogna & Cattaneo-Vietti 1993; Cicogna et al., 1999) as well as the establishment of the first MPAs in Italy.

Scientific diving schools and the Citizen Science

After the First World War, the diving helmet had great success and became very popular in the U.S. In the 1930s, the University of Miami began to organize scientific diving courses to explore the reefs of the Bahamas and those of Dry Tortugas reefs 70 miles west of Key West, (Florida), and within the Fort Jefferson National Monument designated in 1935. The 1950s and

1960s saw the birth of several scuba diving training activities in response to rising accident rates for scuba divers. In 1952, Duilio Marcante (1914-1985) and Luigi Ferraro (1914-2006), forerunners of closed-circuit oxygen apparatus, started to organize courses in Genoa (Italy), to which several young researchers also attended. *British Sub Aqua Club* (BSAC) was formed in 1953 and Conrad Limbaugh (1924-1960), from the Scripps Institution, organized the first civilian course of scuba diving in the U.S., developing standards and writing the first Scientific Diving Manual in 1954. In 1958, the *Confédération Mondiale des Activités Subaquatiques* (CMAS) (*World Underwater Federation*) was founded in Brussels, and the *American Academy of Underwater Sciences* (AAUS) followed in 1977. In 1984, the *International Academy of Underwater Sciences and Techniques* was established in Rome at the CMAS headquarters. All these academies brought together those who had carried out meritorious activities in scientific, technical, technological and hyperbaric underwater fields, or had merits in the popular, artistic, sports, and exploratory areas. In 1989, a group of diving scientists from various universities and other research institutions founded the *International School for Scientific Diving "Anna Proietti Zolla*" (ISSD) (Cinelli et al., 2011). In 1997, a European Scientific Diving Course was held at Elba Island (Italy), giving one of the first impulses to the strategy of the *European Scientific Diving Committee* (ESDC). Three years later, a draft standard for European Scientific Divers and Advanced European Scientific Divers was formalized during a workshop of the ESDC. This latter was succeeded by the *European Scientific Diving Panel* (ESDP) to advance underwater scientific excellence, promote, implement and harmonize a practical support framework for scientific diving in Europe. Many Universities, Research Centers and Associations around the world annually organize underwater scientific researcher courses. In general, the topics extend to the geomorphology of the environment in which these courses are carried out and the structural characteristics of the local benthic photophilic and sciaphilous communities, with particular focus on the environmental gradients that drive their structure and dynamics. The definition of experimental techniques for topographic surveys, organisms sampling and monitoring benthic organisms and ecosystems along the main environmental gradients, such as hydrodynamics, light and trophic status are also discussed. Students carry out practical activities along transects or gradients during the dives, making quali-quantitative samplings, visual census techniques, and *in situ* measurements of environmental variables. Many courses also cover diving protocols and rules of different national legislation, safety protocols, guidelines and good practice.

Many enthusiast divers in marine biology also participate in these courses, and they will also contribute over time through Citizen Science projects. Since the 1990s, the collaboration between science and the general public has progressively grown, overcoming the doubts of a part of the scientific world concerning non-professional divers. The cornerstone of this change, particularly in the Mediterranean Sea, should be searched in the bulk of information recorded by amateur divers regarding the distribution of the green alga *Caulerpa taxifolia*, the so-called "killer alga" (Meinesz, 2007), which invaded the north-western coast of the Mediterranean. Due to the high impact on the public, a monitoring program started very soon within the framework of a European program (Life DGXI - Control of the *Caulerpa taxifolia* extension in the Mediterranean Sea). It led to regular surveys during three campaigns from 1993/1994 until 1998/1997, printing thousands of information leaflets in French, English, Italian, Spanish, Arabic and Croatian (Cottalorda et al., 2008).

Since those years, several Citizen Science projects (e.g. Reef-Check, CIGESMED for divers) provided reliable data in the collection of scientific data, mainly regarding the presence and distribution of some marine organisms, possible anomalies, new fauna and flora entries or counts of species of conservation interest (Cerrano et al., 2016). In many Nations, enthusiastic scuba divers contribute to cleaning the seabed by collecting the trash present or controlling and removing alien species as in the case of the Indo-Pacific lionfishes in the Caribbean (Fadilah et al., 2013). In particular, Citizen Science contributes to the knowledge of the presence of non-indigenous species and is a valuable help for social media groups, platform and Facebook pages such as *Observadores del Mar*, *LifeWatch Alien Species VRE*, *Oddfish - Seawatchers - Exotic species*, *Doris*, *Seawatchers Italia Alghe Aliene*, *Aliens Fish* or *Aliens in the Sea* (Servello et al., 2019; Tiralongo et al., 2019).

The contribution of Citizen Science, if well organized, can be significant, considering that recreational diving engages 20 million people worldwide. Most of the literature refers to tropical destinations, but at least 1 million dives per year occur in Mediterranean MPAs, determining a significant economic flux (Lucrezi et al., 2017).

However, a high number of dives per site may negatively affect its underwater habitat (Sala et al., 1996; Betti et al., 2019). This impact has been extensively studied in the most popular tropical coral reefs, and there are known adverse effects due to inadequate skills and lack of environmental awareness, which can be addressed by training and education. If effectively engaged, amateurs can contribute to science, territorial management and more (Lucrezi et al., 2018).

The Future

Since its advent in the past century, scientific diving developed quickly everywhere globally, becoming an essential technique for exploring the continental shelf and obtaining new knowledge in marine biology. The most profound contribution of scuba to science is the otherwise unobtainable insights provided by direct observation. Today, thousands of researchers are engaged in observing and collecting scientific information, and their work is undoubtedly valuable. There are no difficulties in operating safely with proper technical equipment and under favorable conditions (weak currents and good visibility). Scientific diving can be safe even in low visibility conditions and intense currents, but proper training is the key here. Notably, the spread of rebreather diving systems will bring many advantages to scientific activities compared to conventional open-circuit systems. They offer much higher gas efficiency combined with lack of noise and visual disturbance by exhalant air bubbles.

Scientific diving is carried out to support large marine research programs and provides scientists with the capacity for direct observation and experimental manipulation in underwater research (Fig. 17). However, today, below 40-50 m of depth, there is a tendency to use ROVs that have become economically affordable. We would like to remind that, in the 1960s, on-board the research boat *Colapesce* of the Institute of Zoology of the University of Messina (Bolognari & Cavallaro, 1969) an underwater television system allowed a prolonged observation of the seabed up to 150 meters.

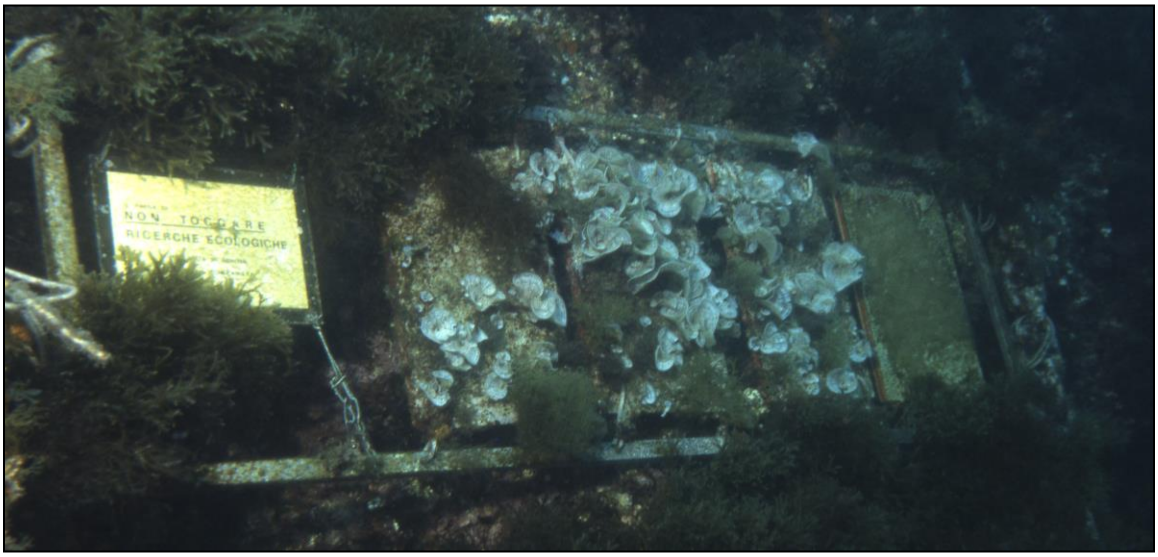

Figure 17. Experimental panels to study the photophilic assemblage succession in the Mediterranean Sea (Courtesy of Roberto Pronzato).

Today, marine biological research deals with different topics (Sayer, 2007) as follows:

To describe the biodiversity and composition of the coastal communities and the open waters, taxonomic, floristic, and faunal research.

To determine community distribution, structure and dynamics, and analyse the different roles and variations of environmental parameters that drive the communities' structure and dynamics.

To conduct experimental research *in situ* with manipulations, for testing ecological hypotheses.

To develop conservation research dedicated to the study of the impact of human activities.

To evaluate the increasing frequency of mass mortalities in benthic communities and the arrival of alien species.

To study amateur divers' impact on coastal environments, such as coral reefs, submerged caves, and several Mediterranean habitats.

Finally, scientific diving will help render more efficient the underwater instruments placed on the seabed, as the autonomous observational platforms, recording physical, chemical or biological activities, CTDs, benthic chambers, and photo- cinematographic time-lapse systems. In this way, in the future, these apparatuses will work wholly independent from the divers. However, man's presence and ability to discern will always be fundamental in considering and evaluating biological phenomena and processes in depth.

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