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FOG special volume: Proceedings of the 6th European Conference on Scientific Diving 2021

178 pages, 25 contributions

Preface

We are happy to present the proceedings from the 6th European Conference on Scientific Diving (ECSD), which took place in April 2021 as virtual meeting. The first ECSD took place in Stuttgart, Germany, in 2015. The following conferences were hosted in Kristineberg, Sweden (2016), Funchal, Madeira/Portugal (2017), Orkney, Scotland/UK (2018), and Sopot, Poland (2019), respectively. The 6th ECSD was scheduled for April 2020 but has been postponed due to the Corona pandemic by one year. In total 80 people registered and about 60 participants were online on average during the two days of the meeting (April 21 and 22, 2021). 36 talks and 15 posters were presen-ted and discussed. Some authors and co-authors took advantage of the opportunity to hand in a total of 25 extended abstracts for the proceedings published in the open access journal FOG (Freiberg Online Geoscience).
The contributions are categorized into:

- Device development
- Scientific case studies
- Aspects of training scientists to work under water

The order of the contributions within these three categories is more or less arbitrary.

Please enjoy browsing through the proceedings and do not hesitate to follow up ideas and questions that have been raised and triggered during the meeting. Hopefully, we will meet again in person during the 7th ECSD in France.

The team of the Scientific Diving Center of TUBAF, Freiberg, Germany

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Device development

Scientific diving from early modern period up to the 20th century

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Abstract. In 1967 Rupert Riedl proposed a classification for the development of scientific diving in marine biology into five stages. The stages were based on the respective methods used and the questions posed. Riedl saw the beginning of scientific diving in 1780 in the Gulf of Naples by Filippo Cavolini. If one defined scientific diving more comprehensively than Riedl did, who looked at it only from the biological point of view, remarkable events could have been found much earlier. While the protagonists and developments from the 20th century to the present day are well known, the findings and developments of scientific diving in the early modern period is still unexplored. This is explained here using specific examples. It will be shown that not only SCUBA diving can be interpreted as a paradigm shift, but also that the use of diving bells can already be seen as an important precursor.

Introduction

The zoologist Rupert Riedl (1925-2005) proposed in 1967 (Riedl 1967) a classification for the development of scientific diving in marine biology in five stages. Riedl dated stage one from 1780 to around 1840, and thus before the establishment of marine stations and the development of ecological questions. His stages two and three partially overlap and date to 1942, the introduction of SCUBA diving equipment. This is the beginning of Stage 4. Stage 5 is characterized by the use of unmanned, remote-controlled diving systems. Riedl's classification from 1967 is still used today as a reference for the history of scientific diving (Van Moorsel and Bennema 2015, Cattaneo-Vietti and Mojetta 2021).

Riedl saw scientific diving mainly as a new method for gaining marine biological knowledge, primarily in shore regions. In the meantime, the concepts and targets of scientific diving have become significantly broader. Scientific diving is a well-established approach in eco-, bio- and geosciences or archeology.

In spite of this, there were already approaches to underwater scientific research in the early modern period. The information that scientists gained during their dives not only formed the basis for new biological, physical and medical knowledge, but also fostered further development of diving technology. The diving bell, used during these dives, can therefore be seen as a site of knowledge production.

The current definition of natural science was formerly known as natural philosophy in the early modern period. The scientists of the early modern era were mathematicians, natural philosophers, astronomers and so on.

Antiquity and 16th century

Thousands of years ago, coastal freedivers were the first humans to dive into the sea in search of food such as snails, shells and seaweed as well as to collect pearls, coral and sponges (Fig. 1). They brought the first empirical findings and knowledge from the underwater world (Ioannidou 2014).

The description of Alexander the Great's (356-323 BC) dive is well known (Jung 1999). It is said that he dived down into the sea in a glass diving barrel to marvel at the unknown underwater world. Whether it is a legend or not, in any case, people started thinking about life underwater early on.

Around the same time as Alexander the Great, Aristotle (384-322 BC) and his student Theophrast (c.371-c.287 BC) lived in Greece. The accuracy of Aristotle's research on fish and marine invertebrates indicates that oceanography was part of his research agenda, and some of his information - such as the breeding habits of the octopus - can only have been gathered through observation by divers. In Theophrast's works, he mentions various details of marine plants and this knowledge is credited to sponge divers (Frost 1968).

Aristotle was concerned with the physical difficulties of freediving, and the effects of water pressure on eardrums. He was the first to deal with diving science (Grumach 1962). He suggested that sponge divers should breathe through snorkels, as elephants would, and carry a kettle with them into the deep as an air reservoir. They could dive in it from time to time to breathe. Aristotle may have copied this idea from nature as well. The water spider, for example, can stay underwater for an extensive period of time by attaching an air bladder to an aquatic plant, and occasionally drawing air from it.

The clock must be turned forward many centuries, to the year 1535, in which the first verifiable dive with pure scientific purpose with a diving apparatus took place. In Lake Nemi in central Italy, the architect Francesco de Marchi (1504-1576), wearing an open diving helmet, dived to an Ancient Roman barque resting there.

De Marchi made two dives on July 15, 1535, the first lasting half an hour and the second a full hour. He dove to a depth of almost 14 meters. The barque, about 70 meters long and 20 meters wide, was also walked along and surveyed on the bottom. This achievement was only possible with an air supply. The helmet was possibly supplied with fresh air via a pump from the surface (Jung 2021).

De Marchi cites an interest in archeological research as the reason for the dives. The artefacts he recovered were later examined and exhibited in Rome. In addition to archeological research, he was interested in conducting empirical research on seeing and hearing underwater and documenting it.

Fig.1. Men, already wearing goggles, dive from two fishing boats to collect coral. Engraving by Jan van der Straet (Johannes Stradanus), 1578 (British Museum London, Ref. 1957,0413.57).

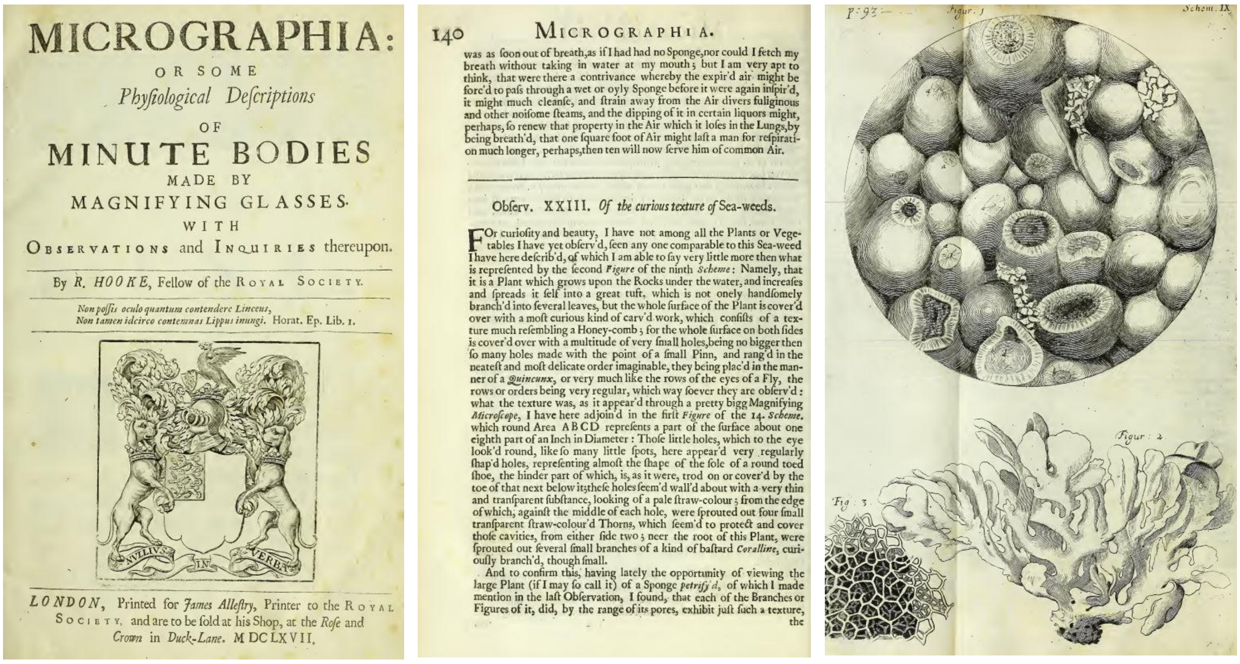
The 17th century

Especially in the 17th century, the development of diving equipment was driven by both economic and scientific interests. A goldrush-like mood gripped Europe as more and more valuable cargoes were recovered from sunken Spanish galleons in the Caribbean. But there were also important successes in salvaging ships in Europe, and especially in Sweden. The most famous example is the work on the wreck of the Swedish warship, *Vasa*, near Stockholm starting in 1662 (Jung 1999).

A consortium was formed to salvage the cannons, which included Matthew Rochford, a native of England. Before the consortium worked on the *Vasa*, they recovered the cannons of the Danish ship, *Sancta Sophia*, at a depth of 33 meters off Gothenburg in 1658. This was a breakthrough as diving work had never been done at such great depths before.

Matthew Rochford produced a report for the Royal Society of London on the diving work, in which he explained how the diving bell was made and used (Rochford 1662). In it, he also reported on how he picked up “some sea-bottom fruits” from the ocean floor. He had sent specimens of these to the Royal Society for examination. In his report he calls them “sea-bottom fruits” and “water fruits”. It was possibly some type of seaweed. It is also interesting that in Rochford’s report we find, for the first time, a description of the changed visual conditions underwater.

Robert Hooke (1635-1703), the curator of the Royal Society, also dealt with the study of seaweed in his work *Micrographia* (1667) (Fig. 2). Perhaps Rocheford’s collection served him as a basis for this. However, it was not until the middle of the 18th century that the Royal Society became systematically involved in the study of underwater fauna and flora. On James Cook’s voyages from 1760 on, collections were made on the barrier reef by Joseph Banks (1743-1820) and Daniel Solander (1733-1782) and brought back to London for further study (Yonge 1980).



MICROGRAPHIA: OR SOME *Phyſiological Deſcriptions* OF MINUTE BODIES MADE BY MAGNIFYING GLASSES. WITH OBSERVATIONS and INQUIRIES thereupon.

By *R. HOOKE*, Fellow of the ROYAL SOCIETY.

Non poſſis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. Lib. 1.

NULLIUS IN VERBA

LONDON, Printed for *James Alleſtry*, Printer to the ROYAL SOCIETY, and are to be ſold at his Shop, at the *Roſe* and *Crown* in *Duck-Lane*. M DC LX VII.

140 MICROGRAPHIA.

was as ſoon out of breath,as if I had had no Sponge,nor could I fetch my breath without taking in water at my mouth; but I am very apt to think, that were there a contrivance whereby the expir'd air might be forc'd to paſs through a wet or oyly Sponge before it were again inſpir'd, it might much cleanſe, and ſtrain away from the Air divers fuliginous and other noiſome ſteams, and the dipping of it in certain liquors might, perhaps, ſo renew that property in the Air which it loſes in the Lungs,by being breath'd, that one ſquare foot of Air might laſt a man for reſpiration much longer, perhaps,then ten will now ſerve him of common Air.

Obſerv. XXIII. *Of the curious texture of* Sea-weeds.

FOr curioſity and beauty, I have not among all the Plants or Vegetables I have yet obſerv'd, ſeen any one comparable to this Sea-weed I have here deſcrib'd, of which I am able to ſay very little more then what is repreſented by the ſecond *Figure* of the ninth *Scheme*: Namely, that it is a Plant which grows upon the Rocks under the water, and increaſes and ſpreads it ſelf into a great tuft, which is not onely handſomely branch'd into ſeveral leaves, but the whole ſurface of the Plant is cover'd over with a moſt curious kind of carv'd work, which conſiſts of a texture much reſembling a Honey-comb; for the whole ſurface on both ſides is cover'd over with a multitude of very ſmall holes,being no bigger then ſo many holes made with the point of a ſmall Pinn, and rang'd in the neateſt and moſt delicate order imaginable, they being plac'd in the manner of a *Quincunx*, or very much like the rows of the eyes of a Fly, the rows or orders being very regular, which way ſoever they are obſerv'd: what the texture was, as it appear'd through a pretty bigg Magnifying *Microſcope*, I have here adjoin'd in the firſt *Figure* of the 14. *Scheme*. which round Area ABCD repreſents a part of the ſurface about one eighth part of an Inch in Diameter: Thoſe little holes, which to the eye look'd round, like ſo many little ſpots, here appear'd very regularly ſhap'd holes, repreſenting almoſt the ſhape of the ſole of a round toed ſhoe, the hinder part of which, is, as it were, trod on or cover'd by the toe of that next below it;theſe holes ſeem'd wall'd about with a very thin and tranſparent ſubſtance, looking of a pale ſtraw-colour; from the edge of which, againſt the middle of each hole, were ſprouted out four ſmall tranſparent ſtraw-colour'd Thorns, which ſeem'd to protect and cover thoſe cavities, from either ſide two; neer the root of this Plant, were ſprouted out ſeveral ſmall branches of a kind of baſtard *Coralline*, curiouſly branch'd, though ſmall.

And to confirm this, having lately the opportunity of viewing the large Plant (if I may ſo call it) of a Sponge *petrify'd*, of which I made mention in the laſt Obſervation, I found, that each of the Branches or Figures of it, did, by the range of its pores, exhibit juſt ſuch a texture, the

Fig.2. Robert Hooke published in *Micrographia* his examinations with his new microscope (Hooke 1667).

Robert Boyle (1627-1691) was very interested in the conditions and life under water, and questioned many divers about their experiences. In his text, *Relations about the bottom of the sea* from 1670, he summarizes his findings (Birch 1772). He was dissatisfied and skeptical of such second-hand testimonies. However, as a nobleman, diving himself seemed to him to be an activity not customary to those of his class. Diving was a dangerous activity done by slaves and the lower classes. This thinking was a general trend among scientists until the 20th century.

The salvage work in Sweden had an important impact on the development of scientific diving not only through Matthew Rocheford, but also through a second person in the consortium, the Scotsman James Maule. He dove on a wreck of the Spanish Armada at Tobermory (Isle of Mull, Scotland) three years after his operations in Sweden.

The Scottish professor at the University of Glasgow, George Sinclair (d. 1696), took advantage of this opportunity, and dived in the bell with Maule in 1665. His book *Ars Nova et Magna Gravitatis et Levitatis* (1669) contains the most comprehensive and detailed treatise on the diving bell to date. Sinclair was, with Robert Boyle, whom he had visited in London, one of the earliest British authors in the field of hydrostatics. In his second book *The Hydrostaticks* (1672), Sinclair proposes eight scientific experiments that could be performed underwater in a diving bell. From his accounts, it can be seen that Sinclair himself made air pressure measurements and other experiments in the diving bell at a depth of about 10 meters. His measurements were amazingly correct. Sinclair confirmed Boyle’s law of 1662 by practical experiments underwater.

Sinclair’s descriptions and conclusions on diving physics were superior for their age. If one considers that he also dove himself, and worked with scientific precision, this is a particularly worthy achievement that has not yet been recognized. Sinclair combines in his person diving science and scientific diving.

As unknown as Sinclair was until today, as well known is the astronomer Edmond Halley (1656-1742). In 1689 he dealt with the theory of the diving technique, and held lectures on it at the Royal Society. In 1691, when a frigate carrying a valuable cargo of elephant teeth and gold was shipwrecked on the Sussex coast, Halley put his knowledge into practice and built a diving bell (Jung 1999).

Halley worked on the wreck every summer until 1696 and reported on his work and his observations during the dives in several lectures and papers. His observations consisted, on the one hand, of understanding the effects of pressure on the diver’s ears. Halley also described that every time the bell was lifted out of the water, the air inside it abruptly turned into a white fog.

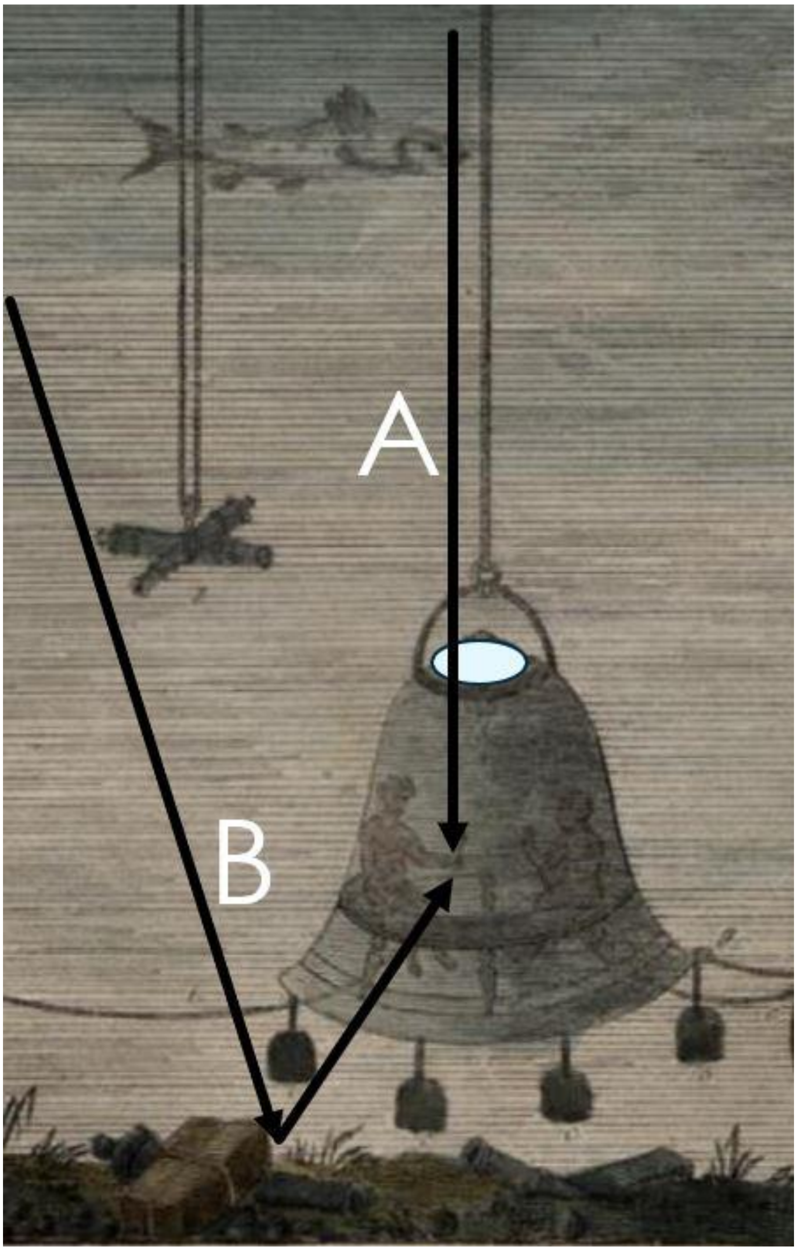


Fig.3. Edmond Halley’s Diving Bell. The sunlight within the diving bell enters through the glass window (A) and is reflected from the ground (B) (Karlsruher Unterhaltungs-Blatt, No. 46, 1829, p. 184 modified).

An even more important scientific observation by Halley was that brightness and colors change with depth. Halley had reported this to Isaac Newton (1643-1727), who was especially interested in the observation of different colors within the diving bell. Halley had a glass window installed in the upper part of his bell. This allowed sunlight to enter. If Halley held his flat hand in the sunlight, the hand had a reddish color on the upper side and a greenish color on the lower side, where the light was reflected by the water under the bell (Fig. 3).

Newton included this observation in his book *Opticks* (1704). He shows the correct basic understanding, according to which colors are selectively filtered in water, but his conclusion, according to which the blue colors are reflected and only the red colors pass through the water is incorrect. Newton could have avoided this wrong conclusion if he had made the observations himself underwater instead of taking them at face value without double-checking.

The 18th century

Although critical new scientific findings had already been made in some cases with the diving bell, it was not able to gain widespread circulation as a new research method. Its use was too costly, and the diver was not mobile enough. Hans Sloane (1660-1753) and Luigi Ferdinando Marsigli (1658-1730) collected during their voyages a considerable number of shells, corals, sponges (‘submarines’ as they were collectively known) and fish. Many of these served as working objects for naturalists and taxonomists (Delbourgo 2011).

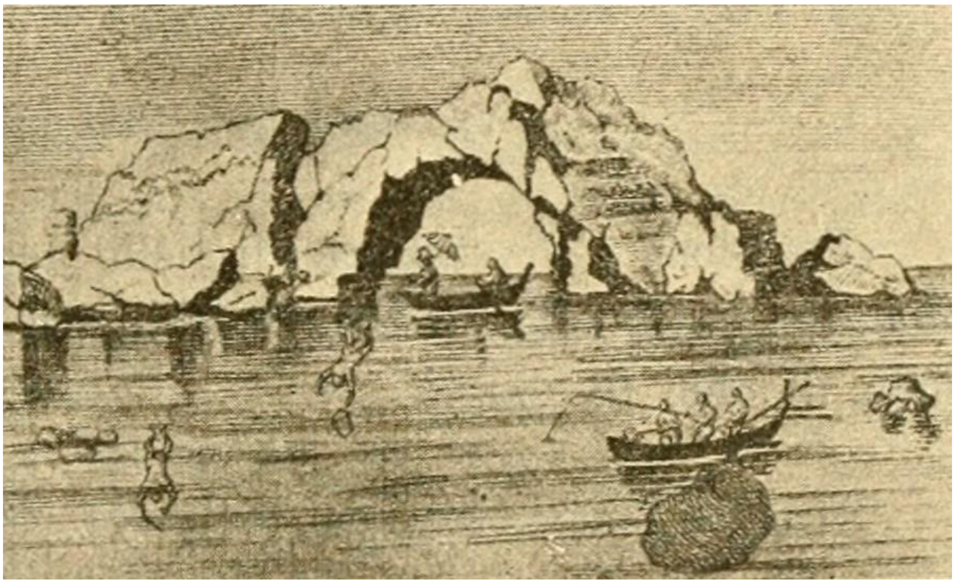


Fig.4. Filippo Cavolini, sitting on his boat with an umbrella which protects the scientist from the sun, gave instructions to the freedivers about which objects they should bring to the surface for him at the Gaiola Island near Naples (Delle-Chiaie 1853).

Furthermore, freedivers were used as in the classical antiquity for collections from the seabed, such as by marine biologist, Filippo Cavolini (1756-1810). In the 1780s, Cavolini employed freedivers to obtain material for his study on the gorgonians of the Gulf of Naples (Delle-Chiaie 1853) (Fig. 4). This was the classic type of early submarine research, where the researcher was still outside the study area and had helpers who made the collections on the seabed. From 1785 to 1792, Cavolini published three well-received books describing the underwater fauna and flora of the Gulf.

During the same time as Cavolini made his collections in Naples, the Edinburgh merchant Charles Spalding (1738-1783) made some interesting biological observations, as he dived with his diving bell: “I was agreeably surprised to find a large grove of tall weeds, all of them from six to eight feet high, with large tufted tops, mostly growing in regular ranges, as far as my eye could reach; a variety of small lobsters, and other shell-fish swimming about in the intervals” (Spalding 1783).

A few years later, the lecturer Adam Walker (1731-1821), reported observations made during a night dive from the diving bell. The purpose of the dive was to investigate the life underwater at night (Walker 1802).

The 19th and 20th century

In the early 19th century, more and more scientists decided to participate in a dive with a diving bell and conduct research. In 1818, during a visit to Plymouth, the mechanical engineer Charles Babbage (1791-1871) had an opportunity of going down in a large diving bell. He measured on the ground his body temperature and examined whether a compass needle still worked underwater inside the diving bell. Other experiments by Babbage concerned the transmission of sound underwater, and the formation of fog in the diving bell as it rises (Babbage 1864).

Another diving attempt in connection with marine exploration took place two years later near Dublin. The botanist, Louis Theodore Colladon (1792-1862), submerged in a diving bell 10 meters deep. During an hour’s stay underwater he observed and measured the ground. He did not only take an interest in technical data concerning the diving bell and the workers, but he also collected seaweed and some animals from the ground, maybe also shells and snails (Colladon 1821; Heberlein 1980). Even if Colladon does not explicitly reference the possibilities of using the diving bell for research and science, he practically carried out his diving descent into the almost unknown underwater world in this way.

The scientist Michael Faraday (1791-1867) accompanied the Civil Engineer Marc Isambard Brunel (1769-1849) in May 1827 to the bottom of the River Thames in a diving bell. Faraday observed that Brunel could disappear out of the bell, into the cold, black and polluted water of the River Thames, for a whole two minutes at a time. Brunel was examining the river bed at the site of the flooding of the Thames Tunnel (Timbs 1860).

In the mid-19th century, marine biologists and archeologists began to use open diving helmets with air supply attached by a pump on the boat. These were *scaled-down diving bells* that allowed the diver greater mobility. The open diving helmet was a light, simple and inexpensive diving equipment. They were used repeatedly for scientific diving, especially in the warm waters of the Caribbean and the Mediterranean, until the first decades of the 20th century, for example by the Zoologists William Beebe (1877-1962) and Hans Hass (1919-2013). Henri Milne-Edwards (1800-1885), during his scientific journey to Sicily in 1844, used such an open helmet to pursue marine animals. He dived in the port of Milazzo for 30 minutes at a depth of 4 meters and in the bay of Taormina for 45 minutes at a depth of up to 8 meters (Milne-Edwards 1845).

In 1942, Hans Hass (1919-2013) was the very first scientist who combined swim diving with an autonomous diving apparatus as a new research method and opened a new and paradigmatic path to scientific diving (Hass 1948; Hass 1954; Scheer 1967). He used a modified Draeger Oxygen rebreather, fins and a mask for his dives (Fig. 5). The independent movement in three-dimensional space became possible. The use of compressed air or mixed gas were later qualitative improvements of the new method.

Hass could now also dive into submarine caves and make collections there. The aquatic invertebrates (Bryozoans) collected on this expedition 1942 to the Sporades islands were the basis for his “summa cum laude” doctoral thesis. He was able to trace the growth laws back to mathematical principles. A year later, Hass was at the University of Vienna assisted by a young student in making sections of this invertebrates with the microtome. The name of the student was Rupert Riedl (Jung 2019). Riedl conducted his own research underwater from the end of the 1940s onwards.

Fig.5. Hans Hass examines during his expedition 1942 in the Aegean Sea equipped with his swim diving device *Sabella spallanzanii* on the sea floor. (Hass 1954).

Conclusion

Taking into account our present state of knowledge on the historical development of scientific diving, it seems appropriate, to revise Rupert Riedl’s classification, especially as far as the dating of the beginning of scientific diving is concerned. As it can be shown, the history of scientific diving did not begin in 1780, as often presented. From a historical point of view, the first stage should include at least the early modern period.

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A Miniature Wireless Device for Long-term Underwater Data Acquisition

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Abstract. Monitoring an athlete's performance during a match or competition benefits both the athlete and the coach. We were interested in monitoring performance of underwater rugby players. Since no suitable device was found, which could measure parameters we are interested in, such as depth and acceleration, a novel, Bluetooth LE capable, underwater data logger, named pete3d was developed. The device is cylindrical, with a 28mm diameter and 12mm height. The electronics consist of a microcontroller, pressure and temperature sensor, an accelerometer, RTC and a flash storage. An Android application serves as the user interface to read out and visualize the data. A concept for simultaneous data read-out from multiple devices during a match is also introduced. Furthermore, a statistical analysis of the UWR dive logs that were gathered in 2019 and 2020 is presented.

Introduction

Athletes and coaches benefit from feedback showing the performance status during training and competition. Comprehensive measurements, often in real-time, provide unambiguous and objective information about the status of the athlete. Especially valuable are measurements not taken in a laboratory, but in a real-world sports environment. This is the major motivation for wearable technologies in sports. Major requirements for such systems in general are minimum weight, small form factor, low power consumption, safety, security, reliability, sufficient sampling rate, adequate and stable data acquisition, easy calibration, configuration and handling. Typical wearables in sports are motion sensors like inertial measurement units (IMUs) based on micro electromechanical sensors (MEMS) technology (Adesida et al. 2019).

In team disciplines, ideally several athletes can be monitored in parallel. Wireless data transmission of data is of special importance, being unobtrusive and leading to better compliance of the athletes. The use of wearables has widely replaced video monitoring systems, which have restrictions when several athletes should be monitored at the same time. Nevertheless, wearable systems have to be validated against existing optical systems (Adesida et al. 2019).

In addition to the assessment of the skill level, performance and expertise of athletes the prevention of accidents and health issues is of prime importance. Therefore, the additional use of sensors for physiological parameters is beneficial (Yetisen et al 2018). State-of-the-art sensor data fusion provides a comprehensive overview of the athlete's status. Extensive data analysis using machine learning techniques can detect human activities and even falls from ECG signals (Butt et al 2021).

Smart sensors can be connected in sensor networks with various communication protocols. Classical protocols are IEEE802.15.4/Zigbee and Bluetooth Low Energy (BLE). BLE has the large advantage of being available in a plethora of end devices, e.g. smart phones and embedded systems. Performance and the suitable number of devices have to analysed (Reich et al 2020).

Safety, Security and Reliability are of special importance for the use of wearables in sport activities. Because of the possibility of accidents during training and competition wearables fall into the category of Safety Critical Systems (SCS) requiring the use of proper development methods, fulfilling national and international safety standards (Leveson et al 2011). Security and data protection add the necessity of further development procedures, which have to be integrated (Friedberg et al 2017). Reliability is required for practical purposes and compliance of athletes and coaches alike.

Region of Interest

We were interested in performance measurement of players in underwater rugby (UWR), in particular diving depth, dive duration and surface interval.

UWR is a two-team sport, played in a 3,5m to 5m deep pool. On the bottom of the pool, two baskets are mounted on the opposite ends. The players try to score a goal by placing a saltwater-filled ball into the basket of the opposing team. The players' equipment consists of a team-coloured swimsuit and cap with earmuffs, diving mask, snorkel, and fins. Other equipment, such as a wrist-worn dive watch, is not permitted, as it poses an injury threat due to sharp edges. There are 12 players per team, of which 6 are in the water. The players in the water exchange with those on the bench. These players can either be attackers, defenders, or goalkeepers. UWR is a strenuous sport, as it requires the players to perform many dives to the bottom of the pool in a short period of time. A match usually lasts for two 10 to 15 minutes halves, depending on the competition level.

Our approach was to estimate the players performance by recording and analyzing their dive profiles, as well as their underwater activity (i.e. how much they move). Besides, quasi real time monitoring of such data simultaneously from multiple players is also of interest. Real time monitoring of the divers is not simple. Communication technologies like Bluetooth or WiFi do not work well underwater, since the signal attenuation limits their wireless range to a few centimetres underwater. Alternative technologies, such as acoustical transition, would not work well if many transmitters are present in the same pool. Low-frequency (<250kHz) transmitters would work well underwater, but would require more power, and thus, a larger device.

To obtain such the depth and acceleration, a rule-conformant wearable is needed, that can be safely placed on the player, and would not pose an injury risk. Additionally, a device with a wireless capability is needed, so that the data can be read out during a match. In search of such a device, several data loggers were evaluated. Due to their large size, low sampling rate, or lack of wireless capability, none of those devices were suitable for our study.

Methods

As described above, commercially available data loggers, like dive watches or other depth data loggers cannot be used in underwater rugby. One location, where a data logger can be placed, is inside the protective earmuff that most athletes use (Schuster 2014). In a previous study, such a miniaturized depth data logger was developed, however it did not feature wireless connectivity.

Within this study, a new device was developed, which includes a high accuracy depth sensor, 3D accelerometer and a Bluetooth LE modem. This data logger was named pete3d. Pete3d can be fitted in the caps' earmuff, and this way, it does not pose a danger to the players.

The device performs periodic depth and acceleration measurement. The data is stored in the flash storage, and can later be accessed via an Android application. The Bluetooth LE aspect of the pete3d enables a quasi live-monitoring of the diver, by having the Bluetooth LE link active once the player is on the surface in between dives.

A brief overview of the various aspects of the device and the application in given in the following subchapters.

Hardware Design Overview

The core of our design is the BGM123A System on Chip (SoC) by Silicon Labs, which is capable of wireless communication. The SoC handles sensor data readout, manages flash storage, and handles the BLE connectivity with the Android app. The SoC communicates with the pressure and temperature sensor, the accelerometer and the Real Time Clock (RTC) via I2C interface. A flash storage chip with 4 Mbyte storage is connected via SPI interface.

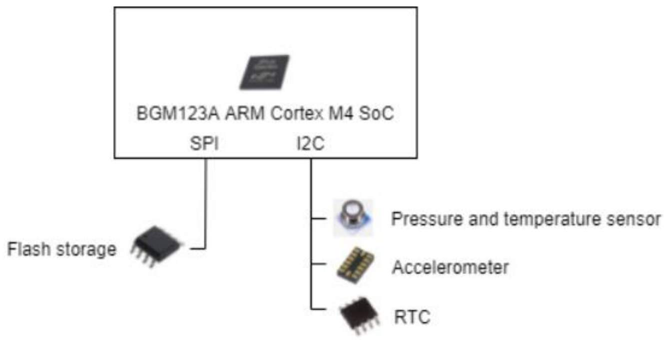

Fig.1. Pete3d hardware components

Electronics

For the depth measurement, the MS5837-30BA pressure and temperature sensor by Measurement Specialists was chosen. It has a measurement range of 0-30 bar, and a resolution of 24 bits. With a depth resolution of 0.2cm, it is a common choice for dive computers. It has an accuracy of +-50 mBar, which might seem low. In our use case, this is of no significance, since we are interested in depth. Depth, a relative value, is the difference of the surface pressure and the current pressure. The integrated temperature sensor allows for 2nd order temperature compensation. It has a typical standby current of 0.02uA, and has an average current consumption of 12.5uA for one measurement per second and oversampling rate enabled. I2C is the protocol used to communicate to this sensor.

ADXL345, a low-power, 3-axis MEMS accelerometer by Analog Devices, was also utilized in our device. It is a sensor with a high resolution (13-bit) and a four sensitivity ranges to up to +-16g. The +-2g range is used in this design. This device is suitable for measurement of dynamic acceleration, such as motion or shock. When our device is in measurement mode, the accelerometer is constantly sampling with a frequency of 50Hz. The values are stored in a FIFO buffer. When the depth data is read out, this data array is read out as well, and a median average of the values is calculated. Acceleration data and pressure data are then timestamped and stored in the SPI flash memory. I2C is the protocol used to communicate to this sensor.

To store the measured data, and firmware update for the bootloader, AT25SF161, a 4Mbyte flash memory by Adesto is used. It guarantees 100,000 program/erase cycles per page. In Ultra-Deep Power-Down State, this IC consumes 2uA. A page read consumes 4mA, and program and write operations consume 10mA typically. The flash storage has a page size of 256 bytes. To reduce the number of write cycles to this IC, the firmware allocates a temporary page in RAM, which is filled with timestamped data during measurement. Once the RAM page is full, we store the content of this page in external flash. The device can store up to 500 thousand samples in the storage.

To obtain accurate timestamp values and to generate periodic measurement interrupts, the PCF8563, an external real-time clock by NXP is used. It is a device optimized for low-power consumption, with a power consumption of 0.25uA. The timer function is used to generate a hardware interrupt connected to a GPIO of our microcontroller which wakes the application up when it is time to read out the data.

A low-power microcontroller was needed to interface with the aforementioned ICs. It must be Bluetooth LE capable, have a small size factor, and preferably be easily programmed and integrated in the design. Due to the processing power needed for the Bluetooth LE functionality, most of these devices have an integrated Cortex M4 core. There are several potential devices on the market by semiconductor manufacturers such as Silicon Labs and Dialog Semiconductor. For this design, the BGM123A microcontroller by Silicon Labs was picked, due to several reasons. It is a high-performance 32-bit 38.4 MHz ARM Cortex M4 System-on-Chip (SoC). Aside from the standard MCU components, the SoC contains a Bluetooth 4.2 LE stack, and an integrated antenna. With dimensions of 6.5x6.5mm, and no requirements for decoupling condensators, it is small, which makes it suitable for wearables. It has 256kB flash storage for the application image, and 32kB RAM. Power consumption is low as well, with 2.1 uA in EM3 state, where RAM is still powered, allowing for a fast wakeup. This mode will be used as the sleep mode. In the active mode, it needs 5mA. Bluetooth peak current for TX/RX is 8.7mA. The device performs periodic depth and acceleration sensor readout.

To power the electronics, CR2450N.FH.LF button-cell battery by Renata, with a capacity of 540mAh was used. Its standard discharge current is 0.8mA, with a maximum continuous discharge current of 3.0mA. It has two PCB-pin terminals, which makes it easy to solder to our PCBA.

To guarantee a stable power supply during the peak current draw times, which occur when writing and reading from the flash, and sending BLE messages, a 100uF capacitor was placed in parallel to the battery. During the peak current draw times, the capacitor serves as a primary power source, while for the low current periods, the battery acts as the primary power source and the capacitor charger.

Firmware

The firmware for the BGM123A SoC was written in C. To facilitate the development and programming of the device, Silicon Studio IDE by Silicon Labs was used. The firmware we wrote consists of the second stage bootloader, and the application.

On power up, the bootloader will check the SPI flash storage for a new application image. If an update is present, it will be validated and installed, by replacing the application image in the microcontroller EEPROM with the image from the flash storage. After this, the application will start.

Once the application starts, system health is checked, by checking the SoC supply voltage, initializing, and reading out the sensors, and checking the sensor values for plausibility. Besides, flash memory is checked as well. If a problem is detected, such as an implausible sensor value, or lack of communication with the flash storage, the device will reset up to three times, and check again. If the corrupt state persists, the device will shut down.

After initialization, standby mode is started. In this state, power is kept to a minimum, by utilizing the sleep modes of the hardware components. A BLE advertising package is sent in a 3s interval.

To determine the surface pressure, and thus to detect if the device is submerged due to a sudden pressure increase, the pressure sensor is read in 8s interval, and a running average of 5 pressure values is calculated. Once the newly measured pressure value is higher than the average by a margin set by the user, the devices switches to measurement state.

In the measurement state, the pressure and accelerometer and RTC values are read out with a frequency of 2Hz. The read-out signal is generated by the RTC. The data is timestamped and stored in RAM. Once the RAM page is full, its content is written to the flash storage. Once the pressure hasn't changed for a certain amount of time, the measurement state is stopped, and the firmware switches back to standby mode.

If the device has not been in the measurement mode for more than 1 day, the BLE advertising in the standby mode is deactivated to save power. It will be reactivated once the device is submerged, i.e. once it exits the next measurement state.

Housing and Assembly

The housing for the electronics is cylindrical with a diameter of 28mm and a height of 12mm. Underwater electronics, such as a dive computer is usually housed in a water and pressure proof housing. Such housings are expensive, and increase the size of the device. An alternative to a costly CNC machined or injection moulded housing is using a 3D printed case, in which the electronics is encapsulated and protected from water with silicone gel. This method was used for pete3d, where a thin-walled 3D printed case was utilized. The case consists of two parts. In one bucket-like part, the electronics are encapsulated in silicone gel. This part is then covered with a lid. Once the silicone gel cures, the electronics are waterproof, with a maximum operable depth of 300 meters. A bungee cord is used to fasten the device to the caps' earmuff.

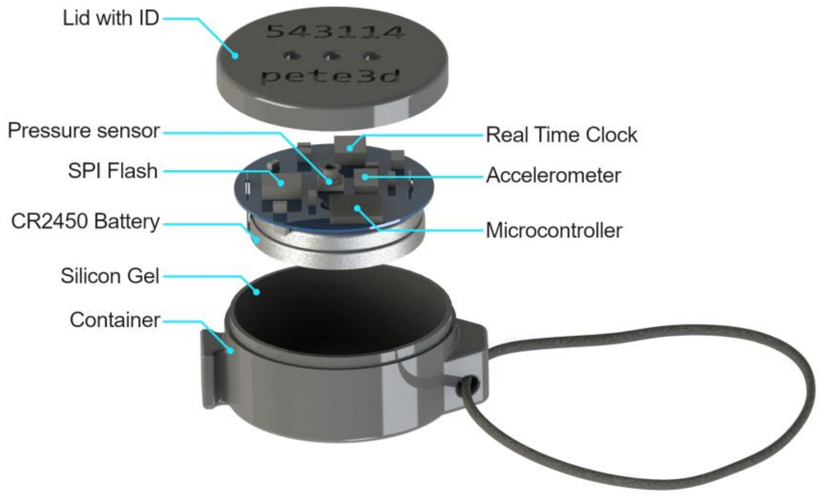

Fig.2. Hardware stack and assembly

Android Application

An Android application was developed, to provide a user interface for the device. Android programming language and the Android Studio IDE was used to develop this software.

The application has several screens: configuration, read-out, visualization and multi device screen.

In the configuration screen, the user can set their personal settings and the device settings. The personal settings include name, weight, gender, team name, and team position. The device settings include the measurement start depth threshold, sampling rate, and the measurement stop criteria (surface timeout). The application connects to the device, reads out the settings, and allows the user to update them.

In the read-out screen, the app connects to the device, and reads out the logs present on the device. Once the data is read out, the data on the device is deleted. The application contains a logbook of all the read-out logs. The user can navigate to the visualization screen by selecting one of the logs.

The visualization screen shows the logs' metadata, such as time and date, and presents the depth and acceleration data as graphs. The user can browse through the graphs, zoom in and out, and even perform statistical analysis on the selected areas of the graphs, to get values such as the average dive duration, number of dives, average surface time, etc.

The following Figure will provide the reader with three application screenshots.

Fig.3. pete3d Android application screenshots. The first on the left shows a list of dive logs. The middle screenshot provides the metadata of one of the dive logs. Besides, it provides a statistical analysis of a selected dive log part. The screenshot on the right provides the visualisation of the depth, and the "effort" – which is a part of an ongoing research.

Simultaneous Read-Out of Multiple Devices

The multidevice screen allows the app to connect to multiple devices at the same time. This is the mode used to read out the data while the match is still ongoing. The application can connect to up to eight pete3d devices, and read out the data from these devices simultaneously. The setup is as follows: During a match, or a training session, all of the players are assigned a device to use. An Android phone running the application is placed on the edge of the pool, where the Bluetooth signal is strong enough to communicate to all of the devices in the pool. The application is actively scanning for devices. Once the player surfaces and the device in the earmuff is above the surface, a connection is established between the application and the device. If the player spends enough time on the surface for a connection to be established, the data, starting from the timestamp of the last readout, will be read out. This is a part of an ongoing research, where the Bluetooth practicality in a Wireless Body Area Network is additionally evaluated.

Results

We were successful in the development of our data logger. The device is cylindrical, with a 28mm diameter and 12mm height. It weighs 21g. During standby, where a pressure measurement is performed every 8 seconds, and periodic BLE advertising packets are sent, 17uA are consumed on average. If no BLE advertising packages are sent, i.e. the device has not been submerged for more than a day, the standby current drops to 5uA. With a pressure sensor sampling frequency of 2 Hz, and accelerometer sampling frequency of 50Hz, the average power consumption rises to 196uA.

With a capacity of 540mAh, the battery can last for more than 10 years in standby mode with no BLE activity. The battery can last for more than 1500 dive hours, including reading out the data.

Once the battery is depleted, it can be easily replaced, by taking electronics out of the housing, removing the silicon gel, and replacing the battery. The device can then be resealed and used again.

In total, 64 units were manufactured and distributed to various UWR players worldwide. 1257 dive logs were collected from 37 individuals. From this data set, the logs where subject metadata like gender and position was missing, logs where less than 5 dives were performed and logs where the maximum depth was less than 3 meters were removed. We were left with 528 dive logs with 630,8h of recorded dive time containing 17171 dives, performed by 30 divers. 20 of them were male, and 10 were female. Each dive log contains multiple dives.

The depth and acceleration data of one such dive log is presented in the following Figure.

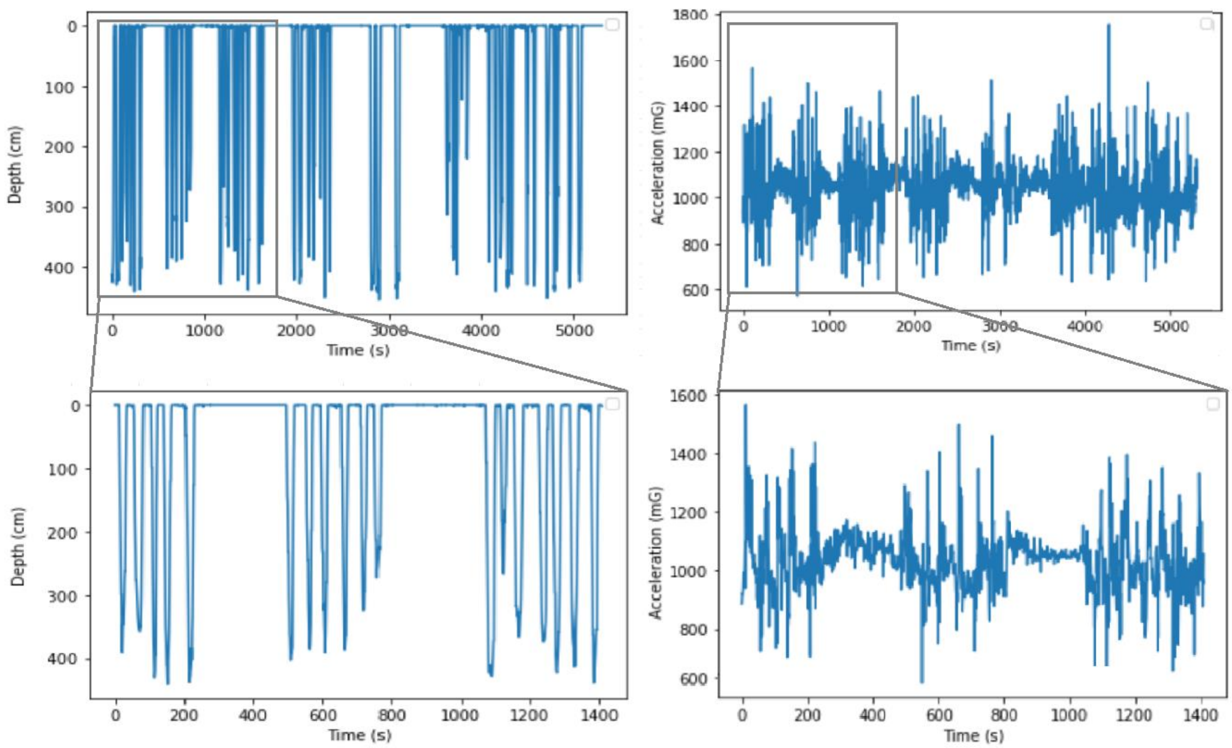

Fig.4. A 91 minutes long depth and acceleration profile, typical for an UWR training. The upper left graph represents the full-length depth profile. The upper right graph represents the full-length acceleration profile. The lower left graph represents the first 23 minutes of the depth profile, where three groups of up to 7 dives are visible. The lower right graph represents the first 23 minutes of the acceleration profile.

In the following table, the statistics about the dive logs that were gathered is presented.

Table 1. Underwater time and surface time duration in all of the 528 dive logs

Gender	Position	Number of players	Number of dive logs	Underwater time duration and standard deviation	Surface time duration and standard deviation
Male	Attacker	5	114	9,31 ± 4,90	13,63 ± 6,55
Male	Defender	9	93	11,15 ± 5,55	13,05 ± 6,80
Male	Goalkeeper	6	128	10,57 ± 5,13	13,07 ± 6,64
Female	Defender	5	110	11,41 ± 4,88	13,07 ± 6,13
Female	Goalkeeper	5	82	9,53 ± 4,87	15,28 ± 7,53
All	All	30	528	10,30 ± 5,13	13,60 ± 6,97

The average underwater duration of all of the dives was 10,30s, with a standard deviation of 5,13s. The average surface duration for all logs was 13,60s with a standard deviation of 6,97. No significant difference was found between male and female players. Worth noticing is that the defenders remain slightly longer underwater compared to attackers and goalkeepers. For a more graphical representation, a histogram of underwater time and surface time duration for all of the 528 logs was made.

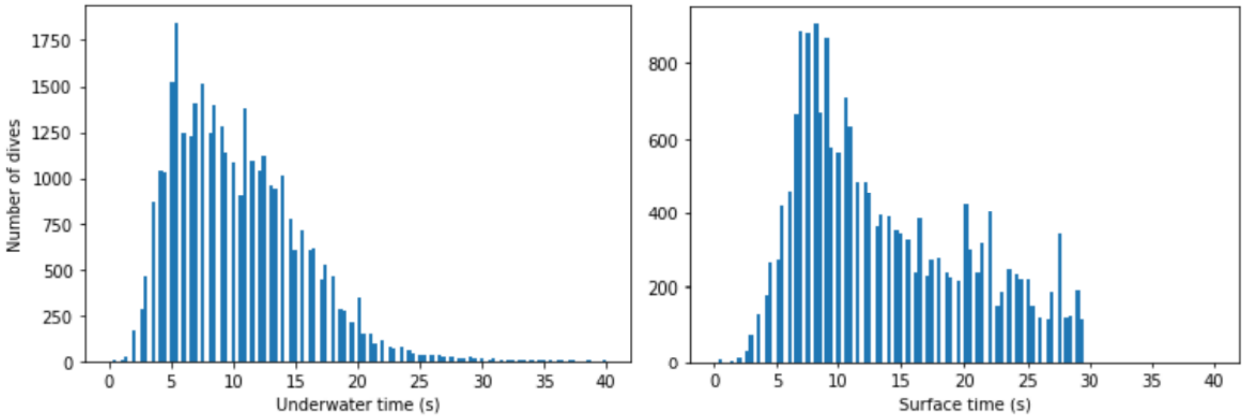

Fig.5. Underwater time histogram and surface time histogram for the 528 dive logs

The analysis of the acceleration profiles is part of an ongoing research.

Conclusion

A miniaturized depth and activity logger was developed that fits into the earmuff of the personal protective equipment of underwater rugby players. At this location it can be worn by the diver, where it can gather depth and acceleration data. Due to its small size, it does not pose an additional injury risk to the diver. Dive profiles as well as activities were successfully recorded from multiple divers during training as well as competition.

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DORIS: Diver carried Oceanographic Recording InstrumentS

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Abstract. The aim of the project was to develop a miniaturised and cost-optimised autonomous CTD instrument that could be carried or deployed by divers to provide accurate, precise and georeferenced physico-chemical measurements. The device (160 mm in length and 25 mm in diameter) consisted of an ARM Cortex M4 microprocessor with floating point unit, a two-electrode conductivity measurement system, a GPS module and three temperature sensors. All data were stored in an internal memory with user configurable sample rates between 1 s and 60 s. GPS coordinates were captured automatically on surfacing and an integrated WiFi modem (ESP8266) permitted configuration of the device via a smartphone. Once the device was in reach of a known WiFi network, data were automatically uploaded either via MQTT protocol or FTP. The device was successfully tested in laboratory pressure chambers and during sea dives.

Introduction

In-situ data are essential to monitor oceanographic conditions, supplement satellite sea surface temperature data and validate ocean models. There is a lack of depth-resolved coastal temperature data and the potential for using measurements downloaded from dive computers has been considered (Wright et al. 2016). It is estimated that there are 6–10 million recreational divers globally (Wright et al. 2016) and it is assumed that the use of dive computers may be approaching 100% (Azzopardi and Sayer 2010). Most modern dive computers record profiles of temperature and depth and could produce significant oceanographic datasets if managed within coordinated citizen science programmes.

Whereas selecting specific models of dive computer can generate datasets that could contribute to ocean monitoring, they are currently limited to measuring temperature only at relatively low quality (Marlowe et al. 2021). The aim of the current work was to develop a miniaturised and cost optimised CTD instrument that could be carried or deployed by divers to provide accurate, precise and georeferenced measurements of conductivity, temperature, and pressure (depth). The main design criterion was that the instrument would have the capability of being totally autonomous and turn on, record and transmit data with zero or minimal input from the diver. The citizen scientists would, therefore, be collecting data while carrying out their normal recreational diving activity. In addition, the instruments would provide low-cost options for scientific divers or other users requiring depth resolved CTD data.

Sensor technologies

DORIS used the MS583730 pressure sensor from TE Connectivity, which has a measurement range of 0-30 bar. This pressure sensor is used mainly in dive computers and has a high resolution of 24 bit. The integrated temperature sensor allowed a 2nd order temperature compensation. The depth resolution was 0.2 cm. According to the datasheet, the absolute accuracy of the sensor was ±200 mbar. This seemed to be a rather low accuracy; however, we tested a batch of 100 sensors in the laboratory and they all delivered results within ±10mbar. Nevertheless, absolute pressure accuracy is not that important, as the pressure readings at depth are always referred to the surface pressure. This means that absolute pressure errors will cancel out. Sensor drift and stability were also important and so for this device, long term stability was specified to < ±30 mbar year^{-1}.

The temperature sensor integrated into the pressure sensor was not suitable for temperature measurement in a scientific instrument like a CTD, as the accuracy was only specified to be ±4 °C. Therefore, two additional temperature sensors were integrated into the design. The MAXIM MAX30205 was chosen because of the high resolution of 16 bits and an excellent accuracy of ±0.1 °C. An additional NTC temperature sensor, housed in a 1 mm glass tube, was integrated in the design as well. While it does not have a high accuracy and requires calibration, it is, with a t90 of less than 10 s, a very fast responding sensor which is especially suitable for when DORIS passes through a thermocline.

For conductivity measurements, the golden standard is a four-electrode measurement array. However, such circuitry was too expensive for a low-cost device. Therefore, a two-electrode design was favoured. Many designs for conductivity meters are published and many designs are based on a 555-timer circuit, where a capacitor is charged and discharged via the two electrodes immersed in water. As conductivity increases, the capacitor is charged and discharged faster, and the output frequency of the timer IC increases. Typically, in such designs, this frequency is then measured with a microcontroller. Many designs also incorporate capacitors that are connected in series with the electrodes to avoid any DC voltage on the electrodes, which would otherwise lead to accelerated electrode degradation. The main advantage of 555-timer-IC based conductivity measurement circuitry is the simplicity of the design. However, in such designs, the peak AC voltage on the electrodes is two thirds of the supply voltage. Even when using a 555-type timer IC with a very low supply voltage of 1 V, like the TLC551CD from Texas Instruments, the peak AC voltage is 0.66 V. Using such voltages in sea water will result also in electrolysis and the calibration curve becomes highly non-linear. Therefore, we concluded that the 555-timer based circuitry was not suitable for a CTD for sea water.

Instead, we used the analogue peripherals of the STM32L452 Microcontroller from ST Microelectronics together with two operational amplifiers for a two-electrodes measurement set up (Fig. 1). The DAC of the microcontroller was used to generate a sine-wave signal with a peak-to-peak amplitude of 150 mV. This signal was high pass filtered and fed into the positive input of an operational amplifier used as voltage follower. Thus, a signal of ±150 mV in respect to the internal voltage reference V_REF of 1.65 V was applied to the first electrode. The second operational amplifier was used as a current amplifier. The voltage output of the second operational amplifier equaled the input current on Electrode 2 multiplied by the Resistor R2. The output signal was sampled with the ADC of the microcontroller.

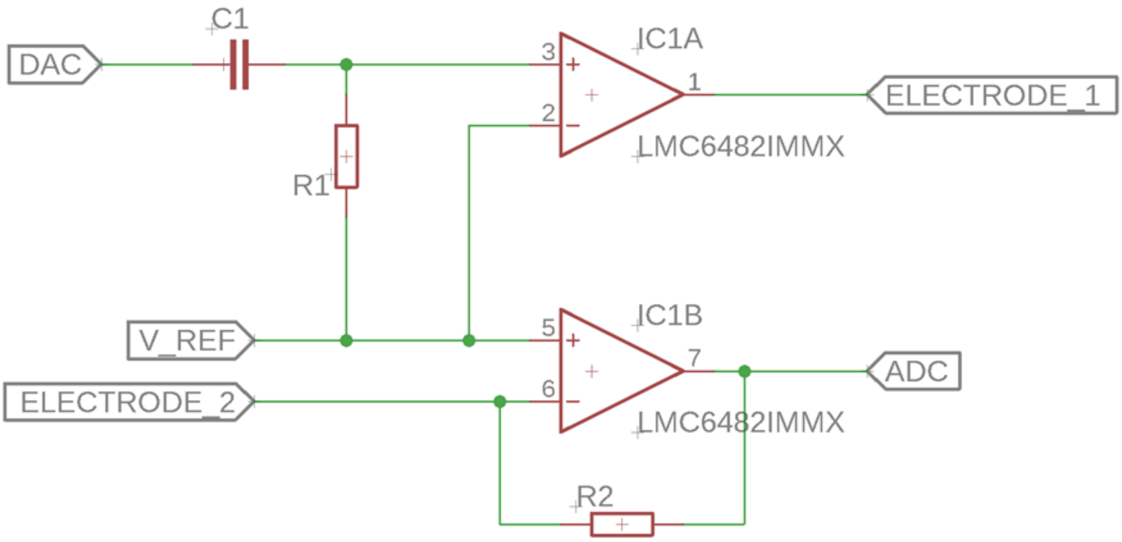

Fig. 1. The two-electrode conductivity measurement circuit

System design

The overall system design is shown in Fig. 2. The ESP8266 microcontroller module from Espressif, with its integrated WiFi modem, was the core component of DORIS. It handles measurement data storage in the internal 4 Mbyte FLASH Memory, WiFi connectivity, GPS module readout as well as data visualization on a small RGB TFT Display with 160x80 pixel resolution.

The ESP8266 does not have an integrated DAC and its ADC is not suited for fast precision measurements. Therefore, the above-mentioned STM32L452 ARM Cortex M4 microcontroller was integrated in the design. It features a 12-Bit ADC and 12-Bit-DAC, a floating-point unit and multiple digital interfaces to connect sensors. The pressure sensors and the digital temperature sensors are read out with one I2C interface. The sine wave excitation signal for electrode 1 is generated with the DAC in combination with the integrated DMA (Direct Memory Access). The ADC channel connected to the current amplifier IC1B is also read out with a DMA channel.

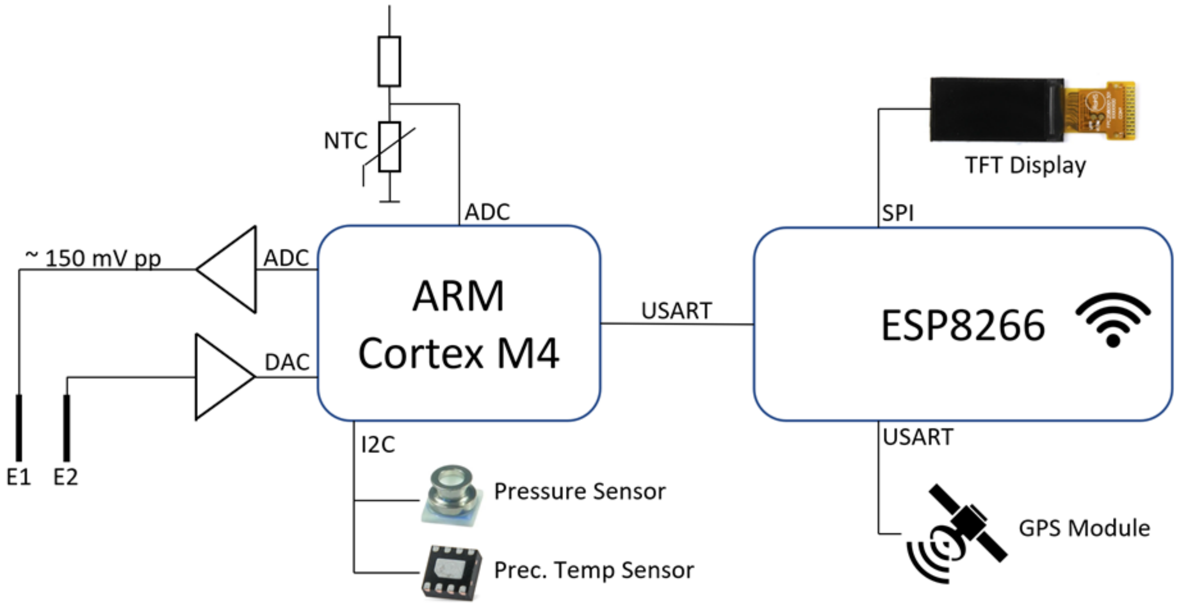

Fig.2. Overall system design

Housing

The electronics were housed in a Polycarbonate tube with an outer diameter of 25 mm and a wall thickness of 3 mm. The end caps are machined from black PVC. The pressure resistance of the housing was simulated in Autodesk Fusion 360. For an ambient pressure of 50 bar, the maximum stress in the polycarbonate was 23 MPa, which generated a safety factor of 2.7 (Fig. 3).

In most underwater equipment, like for instance dive computers, pressure sensors are situated inside a pressure proof housing and the port of the pressure sensor is O-ring sealed against the housing. For this device, we have chosen a different method to facilitate prototyping. The PCB with the microcontrollers and all the circuitry is mounted in a slot of one end cap, where it is sealed with Epoxy resin. Thus, one side of the PCB, where the pressure sensor, the two conductivity electrodes and the temperature sensors are located, is outside of the housing (Fig. 4). An additional end cap was designed and 3D-printed to ensure the sensors were fully open to the ambient water but protected from accidental abrasion; the final prototype design is shown in Fig. 5.

Firmware

The firmware of the STM32L452 Microcontroller was developed in C within the STM32CubeIDE from ST Microelectronics. The firmware for the ESP8266 module was developed within the Arduino framework. The device is designed to work fully autonomously once it is set up correctly. There is a magnet switch located on the PCB. Bringing a magnet in close vicinity of that switch starts the configuration and data download portal. In this mode, the ESP8266 is set up as Server and WiFi access point, which can be accessed with any browser. It allows changing the user settings as well as downloading manually the measurement data.

During standby mode, where most of the peripherals are switched off to reduce the power consumption to a minimum, the system wakes up in a predefined interval between 10 and 60 s and measures the conductivity between the electrodes. If the conductivity is below a certain value, the device wakes up and enters measurement mode, where conductivity raw data, pressure values and temperature values are stored in a measurement file. Once out of the water, the module activates the GPS module, stores the location at the end of the measurement file and enters standby mode again.

If the module is configured for autonomous operation, then the module will automatically perform a scan for wireless networks in predefined intervals. When a known wireless network is found, it connects and automatically uploads the measurement data either using FTP or MQTT.

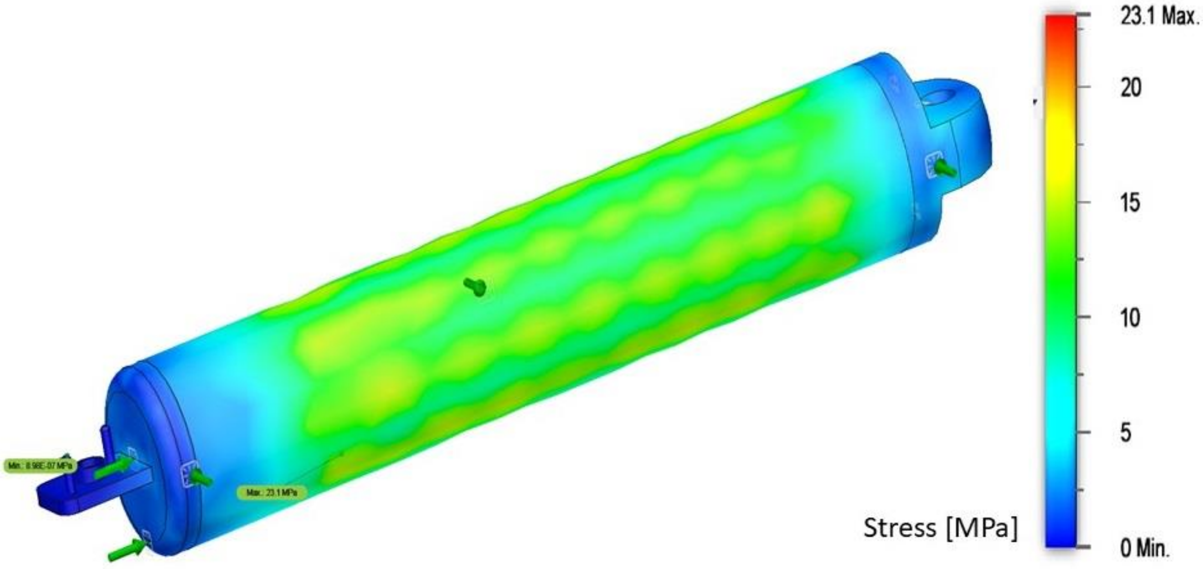

Fig. 3. Simulated pressure resistance of the housing (colour scale in MPa; range 0 to 23).

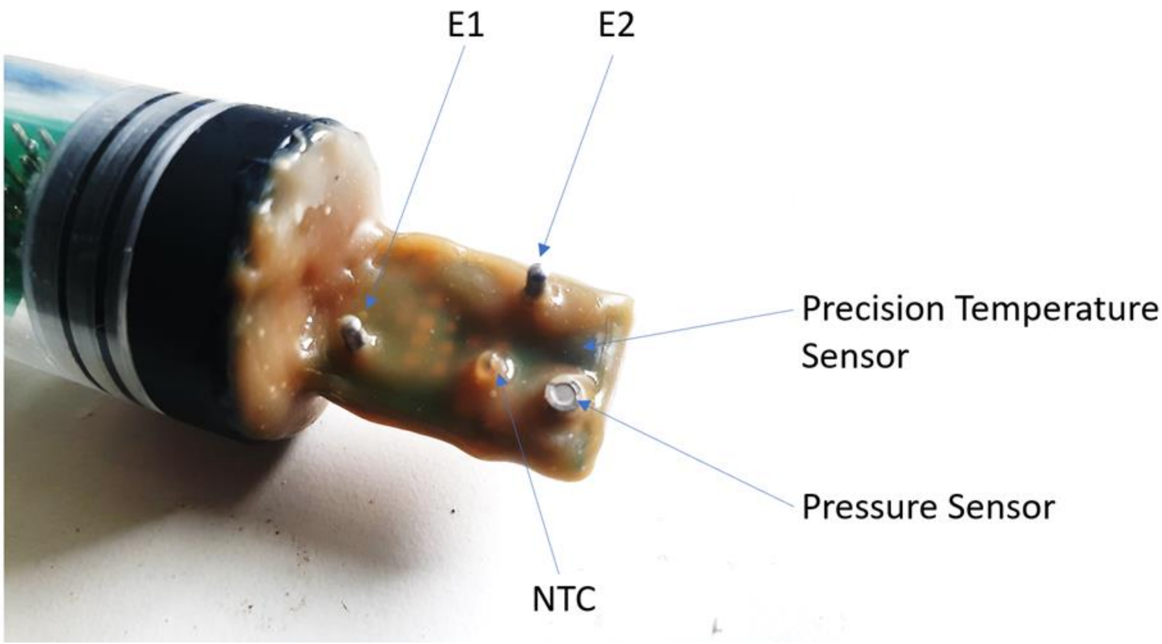

Fig. 4. Details the end cap with the integrated PCB. E1 and E2 are the two conductivity electrodes.

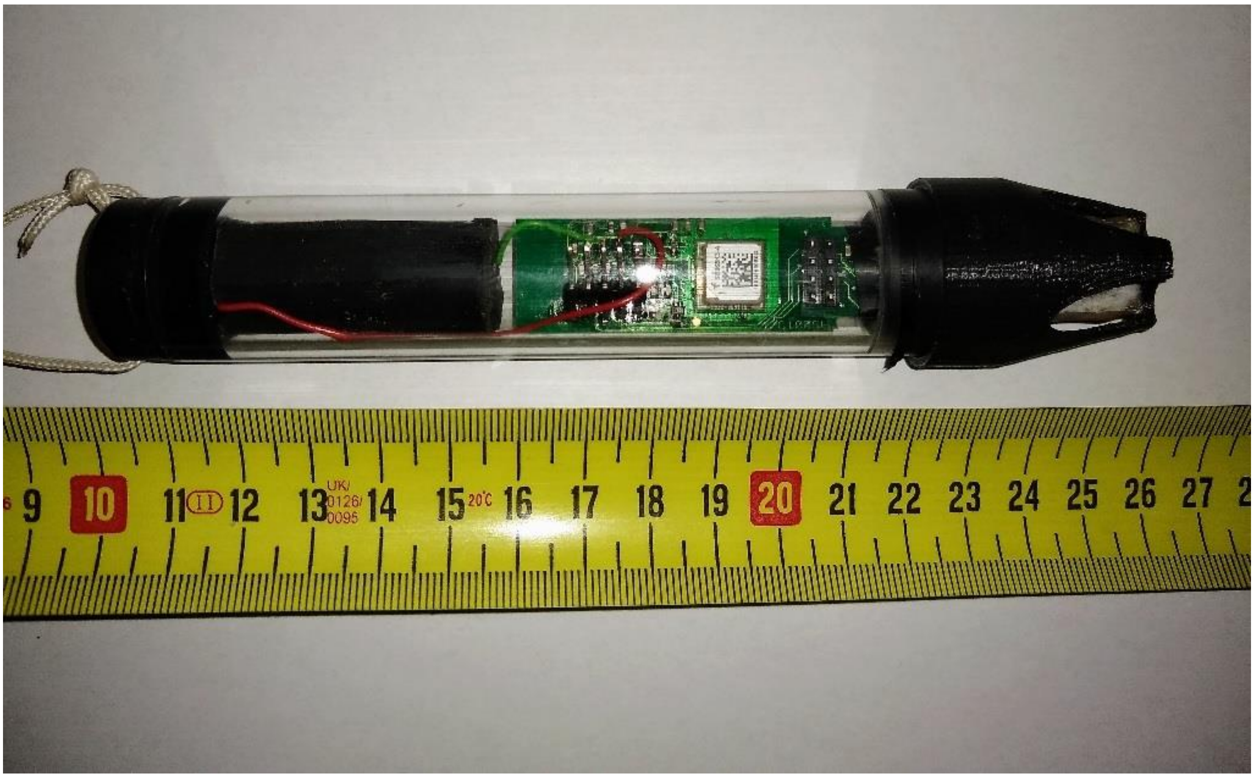

Fig. 5. Final design of the initial prototype instrument.

Dive trials

A series of test dives were conducted near Oban, Scotland, in February 2020. The recording devices were set to autonomous mode with a sampling rate of 10 s. The prototype was simply attached to a diver who was conducting routine science equipment maintenance dives. An example from the dive series is shown in Fig. 6 and consisted of a dive to approximately 30 msw. In February in Scotland, surface seawater temperatures are approximately 1 °C colder than at 30 msw, with a small thermocline at between 6 and 10 msw. Fig. 6 shows the depth/time profile derived from the pressure reading and the recordings from the three temperature measurement methods. All three methods detected the thermocline and displayed the 1 °C difference but there was a range between the absolute recorded temperatures of approximately 1 °C. The conductivity recording for the same dive is shown in Fig. 7 and showed some variation with depth and the possible detection of a slight halocline. If true, the halocline was also at between 6 and 10 msw, although some of the deflection may have been caused by changes in water temperature (see below). In all the dive trials, the GPS signature recorded at the end of each dive was closely aligned to the GPS record made from the dive support boat when retrieving the divers from the water.

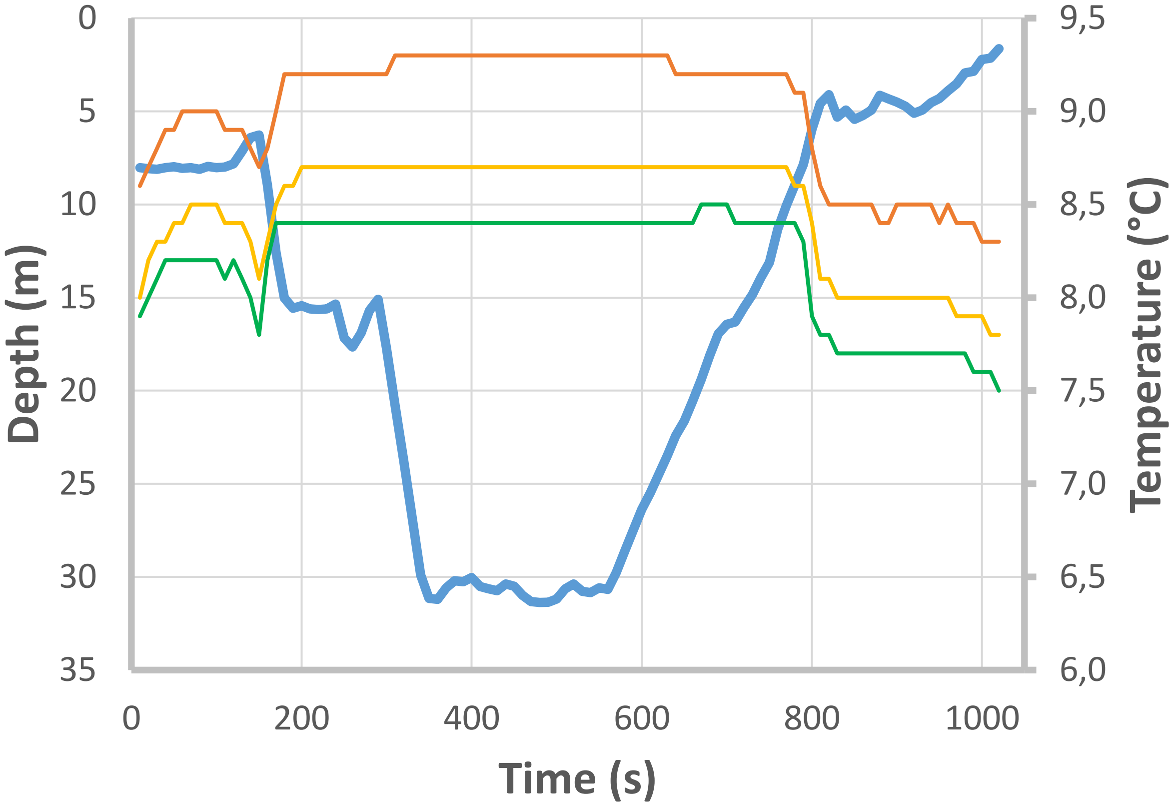

Fig. 6. An example from one of the dive trials to approximately 30 msw. The three temperature records were generated from the sensor integrated with the pressure sensor (red), the NTC temperature sensor (yellow) and the MAXIM MAX30205 sensor (green).

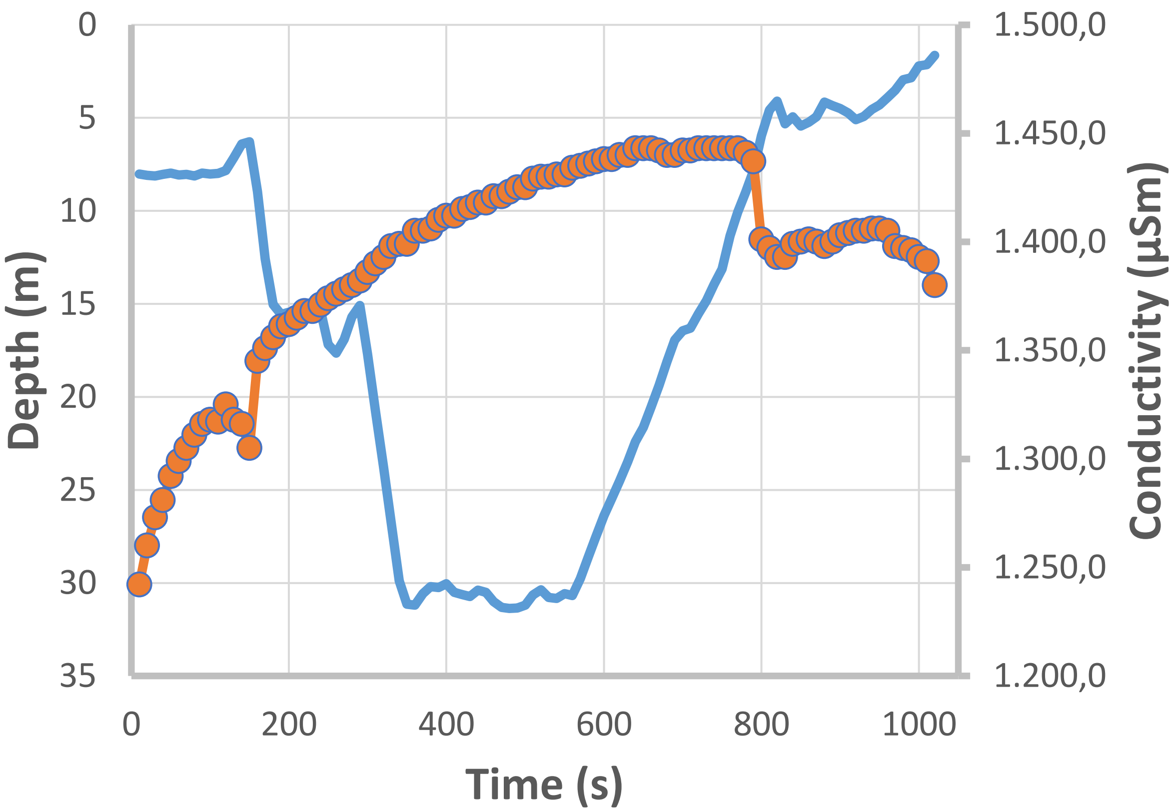

Fig. 7. Conductivity data (orange circles) against depth for the same trial dive as shown in Fig. 6.

Chamber trials

A series of trials was conducted in a compression chamber under controlled conditions to simulate passing through a significant thermocline. The objective was to examine the different reaction times and profiles of temperature changes recorded by DORIS and dive computers.

One example (3 replicates were performed), illustrated here, consisted of two containers within the chamber holding water at two temperatures (approximately 38 °C and 13 °C). The DORIS prototype was placed into the 38 °C water along with a nominal dive computer (the *SUUNTO D4i*). The chamber was compressed initially to 15 msw. At that depth, the dive computer and DORIS were transferred immediately into the 13 °C water. The compression continued to 30 msw. After about 4 min, the chamber was brought back to surface with another stop at 15 msw, where the two devices were switched back to the 38 °C water.

The rates and scales of the temperature changes recorded by the three DORIS sensors were almost identical and are not shown. Fig. 8 shows that the DORIS response was completed within 40 s on the descent when moved between 8 °C and 13 °C, and within 30 s on the ascent when transferred from 13 °C to 38 °C; the corresponding dive computer times were 400 and 340 s respectively. The minimum and maximum temperatures recorded once equilibrium had been reached were 12.0 °C and 35.3 °C respectively for DORIS; the comparative values for the dive computer were 13 °C and 34 °C, respectively.

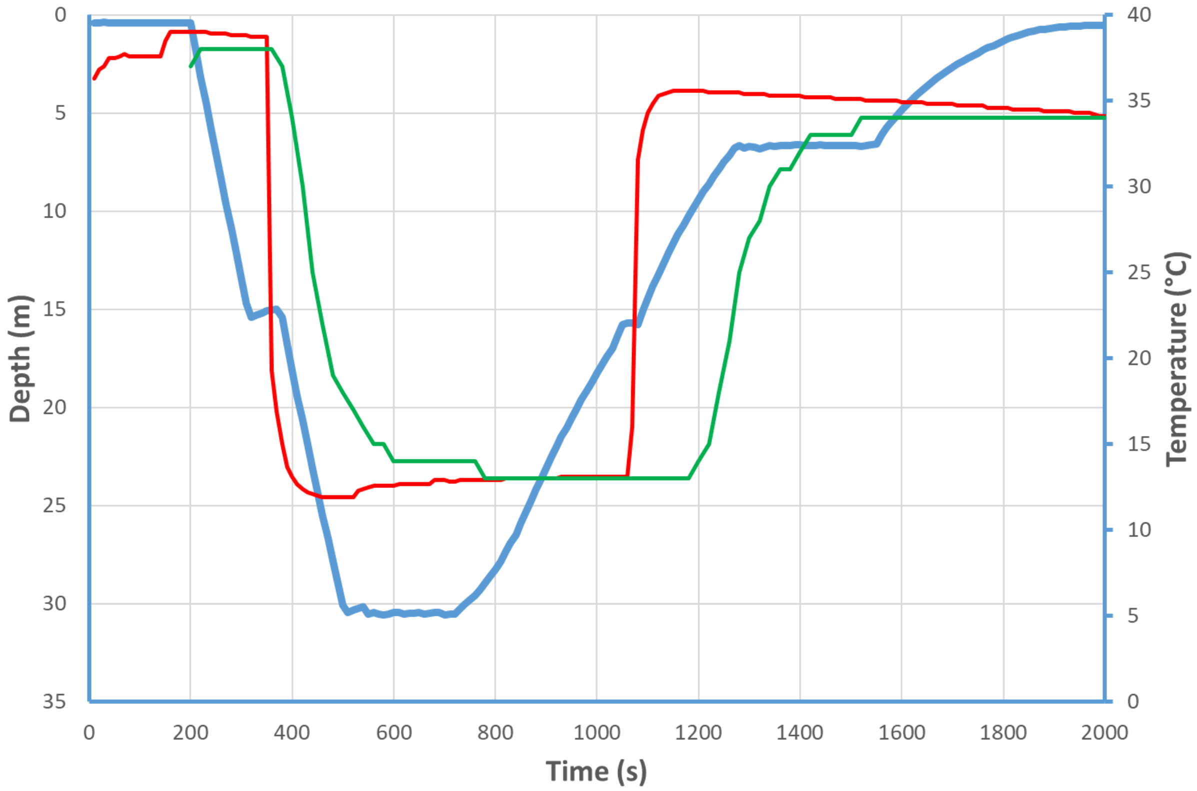

Fig. 8. An example of a thermocline simulation experiment with recorded responses from DORIS (red) and *SUUNTO D4i* (green)

Discussion

This account is based on the operation of prototype devices and presents raw data only at this stage of development. Ongoing research will produce fully calibrated devices that will be capable of real-time conversions of pressure to depth as modified by the water conductivity. The design of the method of conductivity measurement will be revised to improve the robustness of e recordings. Measuring dissolved oxygen will increase the unit costs but may be possible in future models.

Preliminary trials show that low-cost autonomous remote CTD recording would be possible at acceptable levels of accuracy. High-resolution CTD data are standard measurements for monitoring variation and trends in ocean temperatures. However, routine CTD sampling is costly and time-consuming if needed to acquire broadscale data of the marine environment of interest. A citizen science programme based on recreational diving, and using autonomous instruments such as DORIS, would provide a global platform for obtaining significant quantities of high-quality depth-resolved data for a relatively small overall cost. In addition to the numbers of divers available, recreational diving tends to be carried out at similar dive sites and so there is opportunity for high levels of replication in the data on both intra- and inter-annual scales.

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Radon as natural tracer for submarine groundwater discharge

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Abstract. Submarine groundwater discharge besides river discharge is an important part of groundwater flow towards oceans and not well quantified. In particular in karst groundwater point discharge is common and subject of investigation and documentation for scientific divers. Besides temperature and electric conductivity radon is a potential natural tracer. A self-build water-gas equilibrium chamber and a low-cost indoor radon monitor were used to investigate both submarine groundwater water samples and seawater from the bay of Sweta Marina (Croatia). The results of the prototype are promising. Gas was equilibrated within short time with the water samples and provided reliable results. However, further improvement of the device is needed.

Introduction

River water discharge, which is partly surface drainage and partly drainage of groundwater into a river, can be rather easily determined with accuracy of few percent. On contrary direct submarine groundwater discharge (SGD) into ocean water is not easy to monitor. One precondition is a groundwater tracer and second preconditions are information about flow of ocean water in coastal areas driven be tides, density of water and wind (Grünenbaum et al. 2020). Tracers for SGD are manifold. Easily to be measured and commonly used are temperature, electric conductivity (EC), density differences visible as shimmering and radon(Taniguchi et al. 2019).

All parameters have certain advantages and disadvantages. Temperature is rather easy to measure under water with sensors having a quick response time (Tan et al. 2008) either by scientific divers and rovers or by remote sensing, if the discharging groundwater is warmer or less dense based on water constituents than ocean water and upwells to the surface. However, temperature can only be used in times of the year when groundwater and ocean water temperatures are significant different and temperature may be biased quickly by sun radiation within short time. A further drawback is often the low range of values (e.g. 10 or 20 °C). EC is easy to read with a handheld device in situ by scientific divers and underwater rovers in a 3d water volume and offers excellent resolution due to the huge value range with typically < 1 mS/cm in groundwater and about 50 mS/cm in ocean water. Density differences which is an important issue with respect to seawater intrusion and dynamic tidal effects along a coastline can be easily seen with naked eye if it occurs spot-wise, however, quantitative determination of density differences under water is not simple (Werner et al. 2013).

Radon is dissolved as gas in water and offers a large value range as well with very low values in ocean water and rather high values in groundwater. This is based on the fact that most rocks contain considerable amounts of uranium and thus as well small amounts of radium which decays to radon (mainly ^{222}Rn). Furthermore, it is based on the fact that radon is a gas and thus extremely mobile in rocks and additionally highly soluble in water. Besides tidal and wind induced transport of ocean water in coastal and bay areas the degassing of radon from the ocean surface has to be considered as well (Hartman and Hammond 1985).

On contrary to EC radon cannot be read online with a sensor but requires water sampling and rather expensive equipment for radon determination in water. To measure radon in water usually commercial devices are used. The first step of measuring radon dissolved in gas is separating gas from a water samples by applying a vacuum and then introduce the extracted gas in the measuring device (Jobbágy et al. 2017). Other gas water separation techniques are spray, diffusion along a membrane and bubbling of air through water to obtain equilibrium between gas and water. These techniques have the big advantage on contrary to applying a vacuum since they can be used for continuous monitoring as well (Vyletělová and Froňka 2019). Devices are rather expensive (> 5000 €) and therefore the aim of the research was to use a low-cost indoor radon detector (< 400 Euro) and an equilibrium gas-water chamber instead of the common degassing technique by applying a vacuum.

Materials and methods

A low-cost indoor radon detector with a dual structured pulsed-ionization chamber system and a highly accurate detection circuit (RadonEye RD200) was used in combination with a self-build water-gas equilibrium chamber to measure radon in water samples taken in the bay of Sveta Marina, Croatia, in September 2019. At spots where temperature, EC and visual anomalies were detected water samples were taken by scientific divers in 500 ml PE bottles by replacing the tap water at the sampling point with air by means of a sniffer and then filling the bottle completely with water. Location and time were documented. Immediately after the dive the water sample bottles were attached to the water-gas equilibrium unit and a constant gas circulation initialized.

The RD200 continuously measures with a dual structured pulsed-ionization chamber (scintillation chamber) and a highly accurate detection circuit. The RD200 takes averaged readings every 10 minutes (Fig. 1).

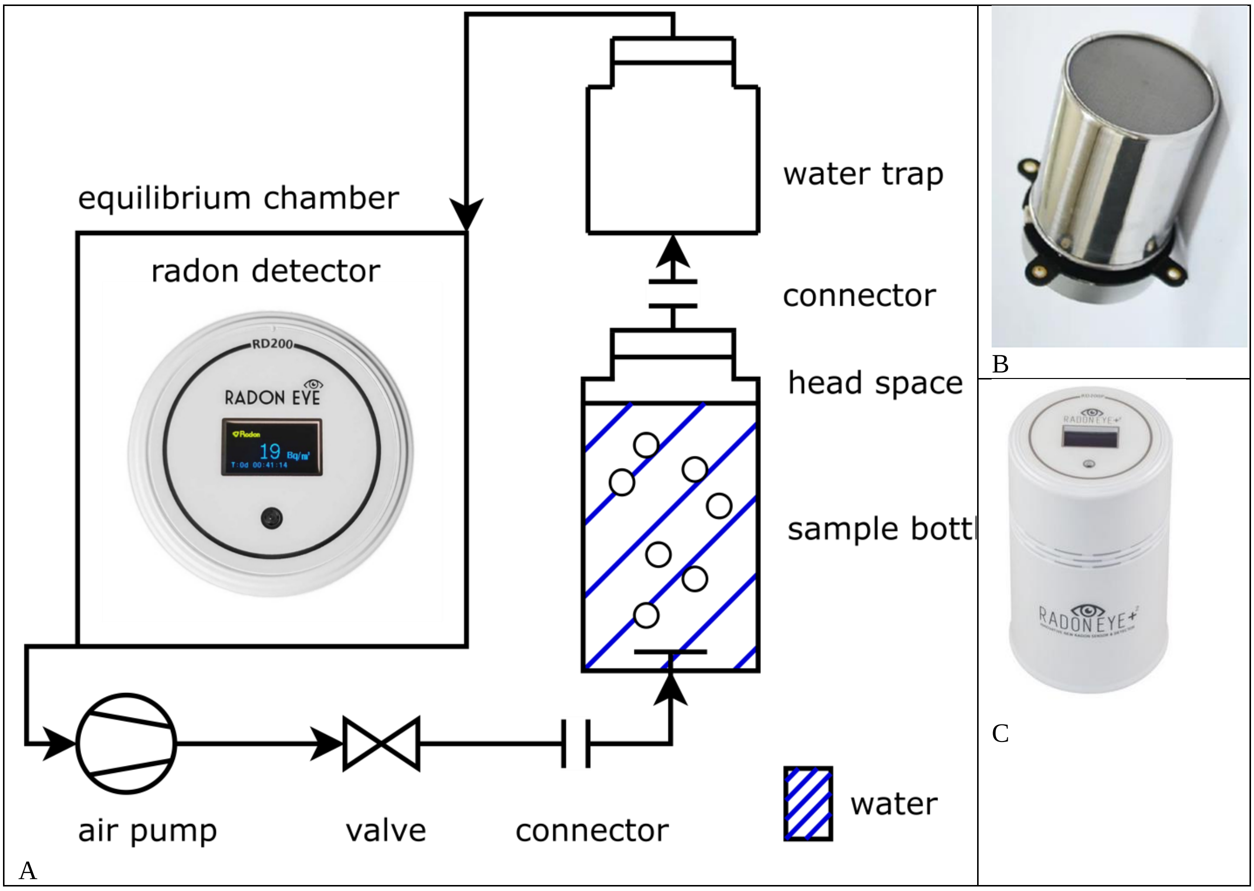

Fig.1.A: Sketch of the measuring setup comprising a pump, the bubble bottle, a water vapor trap and the RD200 in the gas-chamber. **B:** scintillation sensor. **C:** Indoor radon monitor (RadonEye+)

A membrane pump (left lower corner) is used to bubble air through the sample bottle, then into a water trap and finally into a chamber with the Radon Eye inside. The sample bottle is kept cooler (e.g. by latent heat of evaporation) than the ambient air: thus, the relative humidity of the circulating air is always above the water temperature and the dew point is never exceeded. Thus, condensation is avoided, which is obligatory.

A new measurement starts with filling the gas loop with Radon free atmospheric air with Radon concentrations less than 2 Bq/m3. If the ambient air is above this level, it is recommended to use compressed air which has been kept in the tank for at least 4 weeks.

Then gas is cycled for 60 minutes to reach equilibrium between gas and water. The radon concentrations are continuously measured and mean values are displayed and written to the build in memory every 10 minutes. After one hour more or less constant values are reached. Total measuring times of 2 to 3 hours with ongoing gas circulation per sample provided repeated measurements. Data from the Radon Eye are read from the internal memory via Bluetooth and a smart phone App, which comes with the commercial device.

The Radon concentration in water is calculated from the measured Radon concentration in the gas (equation 1).

$$Cw = Kg\ Cg\ \frac{Vw}{Vg} \qquad \text{eq.1}$$

With Cg and Cw: Concentration in gas and water
Vg and Vw: Volume of gas and water
K: gas/water partitioning coefficient

The gas/water partitioning coefficient of Radon which accounts for 4.43 at 25°C in distilled water
The temperature of water is taken into account by equation 2 (Kiliari and Pashalidis 2008).

$$\frac{1}{K} = 0.105 + 0.405e^{-0.0502T} \qquad \text{eq. 2}$$

With T: temperature of water

Furthermore, the salinity of the water can be used for a correction of the air/water partitioning coefficient. (Schubert et al. 2012). Additionally, one has to consider of course the time between sampling and measurement and thus taking care for the decay of radon in the time between sampling and measuring the Radon concentration by applying the well-known radioactive decay.

Temperature and EC were read and water samples were taken by scientific divers. For sampling 500 ml PE bottles filled with tap water were used by replacing the tap water at the sampling point with air by using a sniffer and then filling the bottle completely with outflowing karst water. Using this 500 ml bottle has the advantage that possible degassing can be minimized. Alternatively, water samples of submarine karst discharges or elsewhere were taken by means of large syringes (450 ml) which were then transferred in the 500 ml bubble bottle with a hose in the 500 ml “bubble” bottle. In case of small karst groundwater outlets syringes have the advantage that the karst water can be pointedly sucked in with the aid of a hose.

Location and time were documented. Within a few hours after sampling the water samples were investigated and the time gap between sampling and measurement was documented and used for correction.

Results

Based on the water and gas volume, salinity temperature and the air/water partitioning coefficient with the radon concentration in gas was used to calculate the radon concentration in water (between 2 and 810Bq/m^3). These values were compared with in situ temperature and EC readings at focused SGD points and the water in the bay of Sveta Marina, respectively. It could be shown that the low-cost prototype delivered plausible and reliable results (Fig.2).

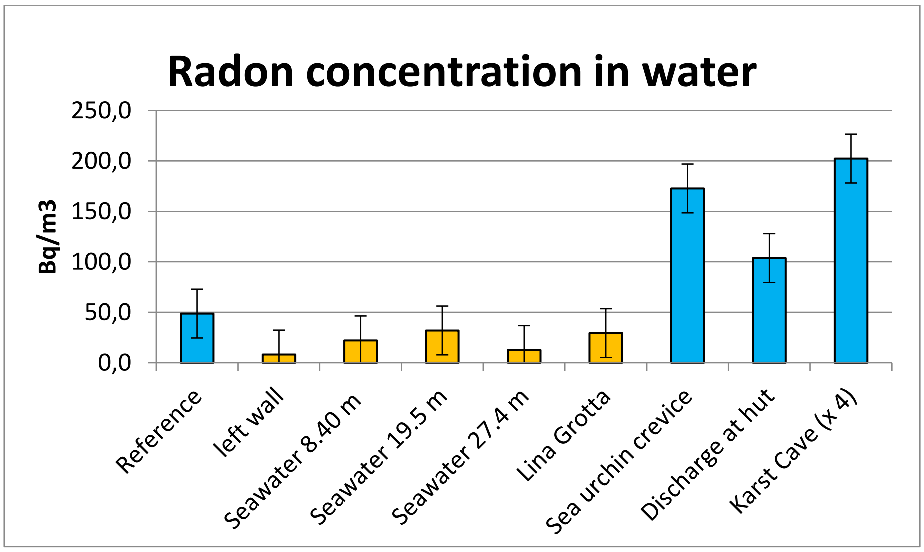

Fig.2. Radon concentration in Bq/m^3 water. Pure karst water samples are shown in blue. The value of Karst Cave has to be multiplied by 4. The yellow sampling points are distributed along the coastline and not taken at focused karst discharge point.

All samples were measured between 3 and 7 times. The error bar displays the standard deviation of repeated readings after equilibrium has been reached. This shows that the precision is not very high and has to be improved during further experiments.

Conclusion

A low cost commercial indoor radon monitor was successfully combined with an air/water equilibrium prototype. With Radon concentrations in water, EC and temperature these three parameters in combination with numerical transport modeling tools and additional data offer a valuable suite of information to learn more about the dynamics of tidal and wind impacted SGD in an area of interest.

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RoBiMo – The tasks of scientific divers for robot-assisted fresh-water monitoring

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Abstract. As part of the RoBiMo project, a measuring system for holistic, spatially resolved recording of the condition and processes in inland waters is to be developed. This system should measure regular, continuous and spatially resolved parameters of water quality in stagnant inland waters. For that, the swimming robot "Elisabeth" from the TU Bergakademie Freiberg will be enhanced and used. The measurements are recorded and placed on a winch system using a measuring chain of sensor elements (like temperature, conductivity, turbidity). The ingress of groundwater should also be detected like the respiration process of the lakes. The navigation of the swimming robot takes place autonomously from a base station on the bank due to a network-independent connection. For the evaluation and visualization of the measurement results, the methods of artificial intelligence and virtual reality are used. Local and seasonal changes in the water body can be documented.
With scientific divers, a comparison of the measured values "ground truth" with water samples and in-situ measurements should be realised. For that, an intensive investigation is necessary. Furthermore, the scientific divers can manipulate the sensors in a targeted manner and check the functionality in situ. For obstacle detection the photogrammetry process and reconstruction are used and shown in an example of the Flodden quarry in Meissen, Saxony. The following text should give an overview of the project after 1 year and the work of the scientific divers.

Keywords:
- water monitoring
- photogrammetry
- autonomous swimming robot
- artificial intelligence
- scientific diver

Introduction

Numerous dams, reservoirs and other inland waters in Germany and Saxony serve for drinking and process water, fishing, tourism and the ecological status. The last dry years 2018 and 2019 tested the function and security of supply of the water system. The growing number of flooded post mining lakes also cases significant challenges for their sustainable use due to recurring acidification processes. Previous water monitoring is done with a high level of personnel expenditure and the associated costs at regular time intervals. The projects RoBiMo (robot-assisted inland water monitoring) with the partner project AIRGEMM (Artificial Intelligence and Robotics for Geo Environmental Modelling and Monitoring) at the Technical University Bergakademie Freiberg want to contribute to a significant improvement of the water management and to reduce previous restrictions of the frequency and to provide assistance to overcome the intensity of the monitoring services. All the process is done in the context of global change and a better way of use.

Project goal und structure

RoBiMo combines six different institutes and five different disciplines. Part of the project are the institute for sensor materials, the institute for thermal engineering and technical thermodynamics, the interdisciplinary ecological centre, the chair for hydrogeology and hydrochemistry, the institute for informatics und the scientific diving centre. The project started in January 2020 und has a duration of three years.

The main aim is to improve the fresh water monitoring of dams and new lakes. These are like in the introduction named a big part of Saxony and become of greater importance due to the flooding of disused opencast mines and changing environmental conditions because of the climate change.

The main idea of the project is shown by **Fig.1**. An automatically controlled swimming robot, which is equipped with a high-resolution sonar and a multi-parameter sensor chain, is to be used to measure inland waters completely and with a resolution of the depth. In addition, not only the water subsoil but also the deeply resolved water parameters should be measured online. These data are visualized online and processed using artificial intelligence for virtual reality and a just-in-time display at the edge of the water. In addition to the depth-resolved water parameters, temperature, conductivity and turbidity, the outgassing and respiration of greenhouse gases and the influence of ground water flows should be investigated. For this purpose, a gas measurement on the water surface is to be carried out stationary with the swimming robot.

The obstacle detection is realized by the sonar system during the autonomous journey and used for the path planning. Communication takes place between the swimming robot and a base station, which is the interface for the user.

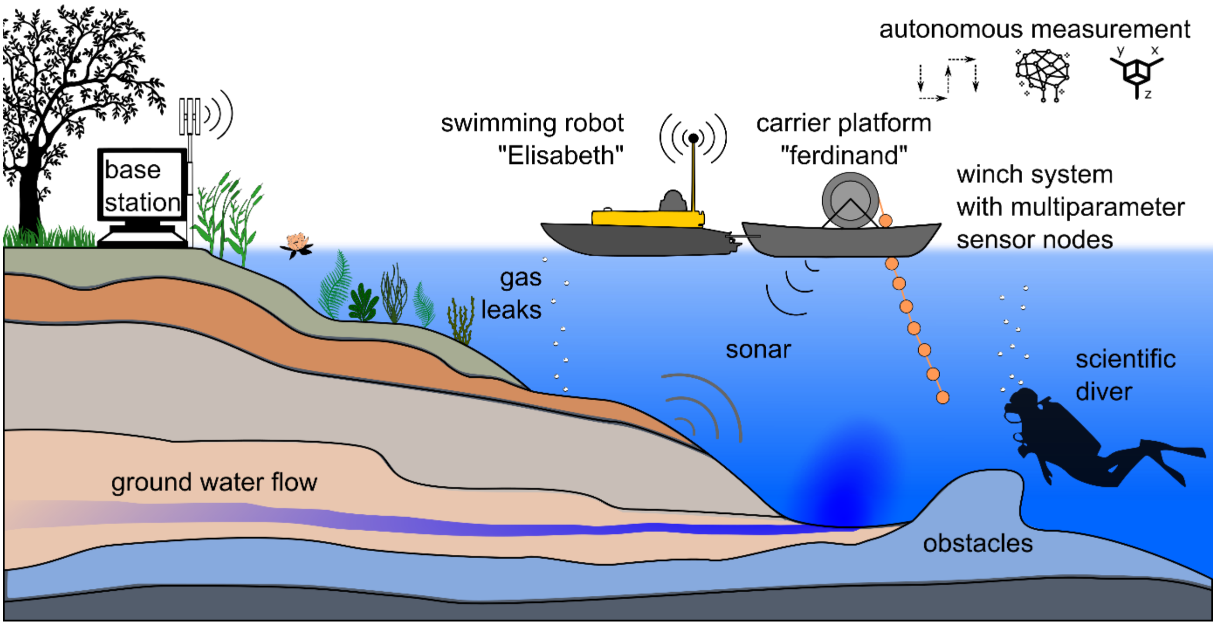

Fig.1. Schematic representation of the investigations with the swimming robot "Elisabeth" and the platform “Ferdinand” with an autonomous, three-dimensional, multisensory recording of inland waters, the detection of groundwater ingress, measurement of water respiration, validation of the results by scientific divers and presentation of the results using methods of artificial intelligence (Jarosch et al. 2020)

At the project start an all in on platform with a measurement of the water parameter, the underwater bathymetry and the respiration should be developed. Because of the different boundary conditions of the different measurement tasks, it was decided to split the measurement program. The investigation was split in to three parts, the sonar sampling, the water parameter measurement and the respiration measurement.

Sonar sampling is used for the underwater bathymetry and obstacles. These cases can run with a higher speed of the swimming robot than the measurements and generate so the first results. These are the base for further investigations und provides a high-resolution map for the investigation with the sensor chain. It also helps the scientific divers to prepare their dives and locate the taken samples and in situ parameter.

For measurement of the water parameter, a maximum speed of 0.5 m/s of the swimming robot is expected. So, we have a reproducible flow around the sensor and not so much flow resistance. The first prototype of the sensor node develop by the institute of electronic and sensor materials includes the acceleration, water temperature, pressure, turbidity and conductivity. The next generation should also include further parameters like the pH-value or oxygen and use another shape for better flow performance.

The gas exhaustion measurement is done by the interdisciplinary ecological centre and needs up to 30 minutes on one local place to calculate the CO_2 and Methane concentration and equilibrium. So, it is possible to investigate the potential of greenhouse gases absorption or emission of a lake or dam.

For the whole investigation an additional simulation by artificial intelligence to react of errors and environmental influences, like wind or waves, is done by the institute of computer science. For the first tests, path planning and operations a Kingfisher Clear Path swimming robot is used. It includes an automated operation system and an autopilot. This system is light, easy to use and a plug and play solution. The sonar system is a multi-frequent system with 1024 beams called Sonic 2020. It can generate sonar and backscatter data at once and measures with frequencies between 200 – 400 kHz.

Because of the different measurement cases and the boundary conditions it is necessary to use a custom build swimming platform, called “Ferdinand”. It uses the same operation and control system like “Elisabeth” but offers a cluster load system and a better performance. Herewith, a higher load and speed and a better control of the system is possible.

a) **b)**

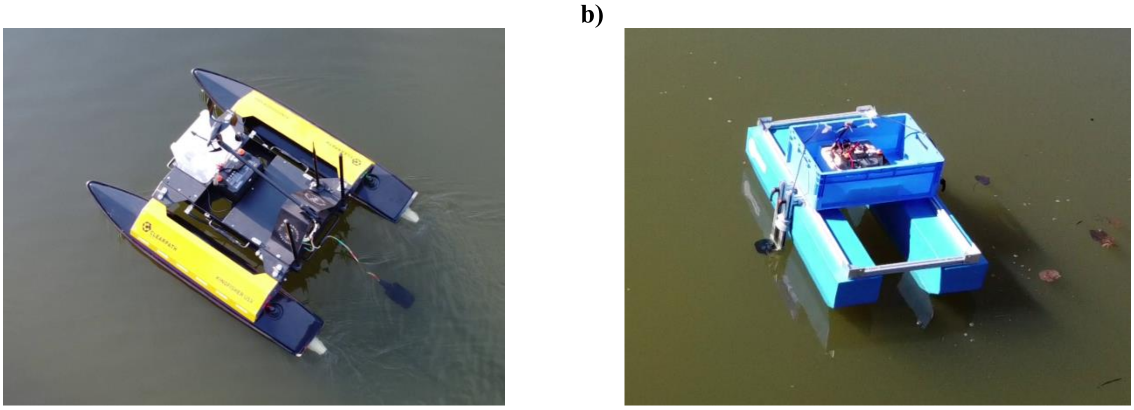

Fig.2 image of the two swimming robots “Elisabeth” a) and first prototype “Ferdinand” b) which are part of the project RoBiMo

The individual measuring systems can be exchanged on the platform by the frame. In the further it should be possible to use all three systems at the same time, thus enabling quick and effective measurement. The individual systems are currently being assembled and then tested with one platform. The validation is part of the 2021 measurement campaign.

The following part is limited to the measurement of the depth-resolved water parameters. A specific winch system has to be developed for the accommodate the sensor chain with the individual sensor nodes. This is done by the scientific diving centre. The functionality of the sensor elements and a reliable mounting must be taken into account, as well as a variable mounting of the sensor elements on the holder and guide rope. Furthermore, a space-saving storage and an effective positioning of the sensor nodes at depth must be observed during the measurement. For this purpose, the deflection of the sensor elements as a function of the speed as well as the basic weight must be considered. **Fig.2** shows the results as a function of speed. This deflection was calculated on the basis of a static system, taking into account the buoyancy and weight of the sensor elements as well as the basic weight and the speed-dependent drag force of the water.

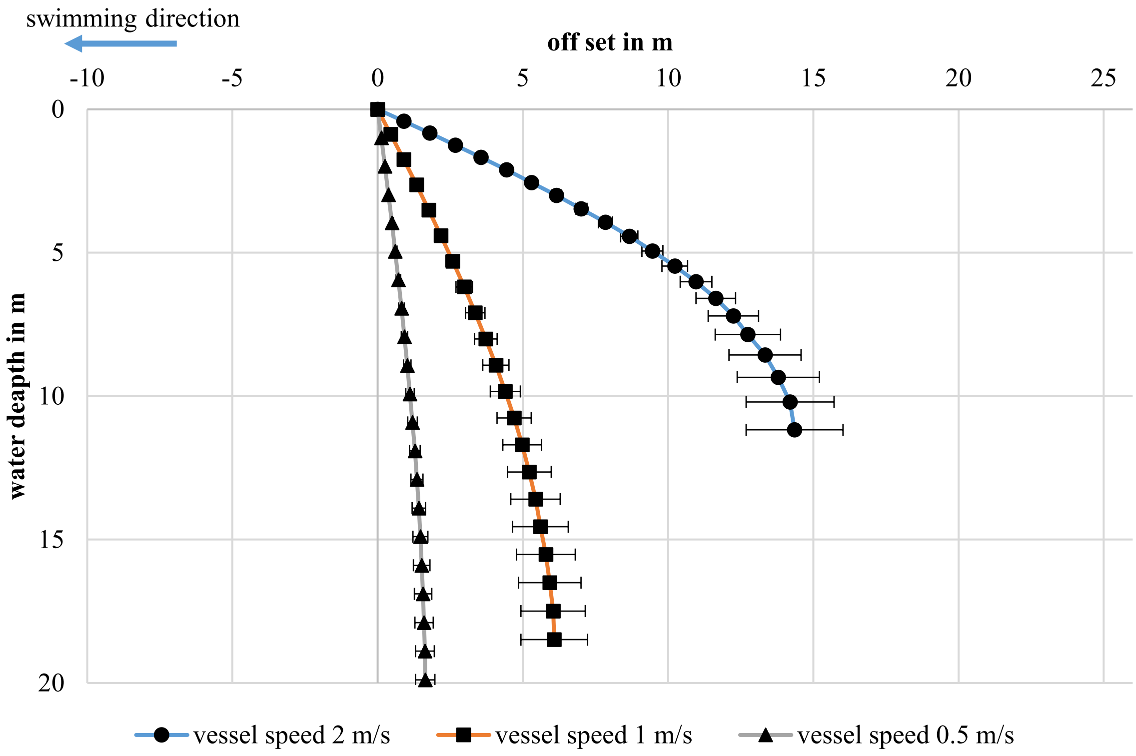

Fig.3. Drag of the sensor chain by the calculated vessel speed of 0.5, 1 and 2 m/s of a 20 m sensor chain with 20 sensor elements, an appr. 50N ground weigh and 5N sensor weight

This resulted in a speed of 0.5 m/s for a measurement of the water parameters. During the measurement, an exact depth determination by the pressure sensor and the acceleration sensor is planned.

Further tasks of the scientific diving centre are the validation of the measurement results. This is possible through a comparison with existing data, the measurement of in-situ parameters and the taking of samples, as well as a targeted manipulation of the sensors. For this purpose, depth profiles, e.g. temperature and conductivity, are recorded by the scientific divers and compared with the measuring system. The same can be achieved with further parameters in which water samples are taken from different depth layers and then examined in the laboratory by the Chair of Hydrogeology.

In addition to the water and sediment samples, samples are also required for artificial intelligence and the simulation of obstacles. For this purpose, three-dimensional point clouds and models are generated by the scientific diving centre with the help of photogrammetry. In this way, training data for the algorithms can be generated and the simulation environment can be prepared on real objects. An explanation of the photogrammetry process and some first results are given in the next chapter.

Photogrammetry process and results

The process of photogrammetry describes the reconstruction and calculation of three-dimensional objects on the basis of photos by means of a numerical triangulation of one and the same point from different directions. The methodical formulas and models are described in Agisoft LLC, 2021.

For scientific diving the photogrammetry has a lot of advantages. So it offers a better work plan and a better dive plan. With a first investigation dive it is possible to visualize an overview of large areas what can´t be seen by a diver at once. So, it is possible to show to all team members the points of interest, plan the dive depth and calculate your dive time. It is also possible to generate 2 or 3D grid for georeferenced maps. So locate sample points and points of interest can documented. Further, it is possible to compare and analyse large regions over a long period of time. It is also possible to calculate with the object and measure distances and volumes or use it for simulations. For the photogrammetry process the following steps of **Fig.4** are part of the calculation:

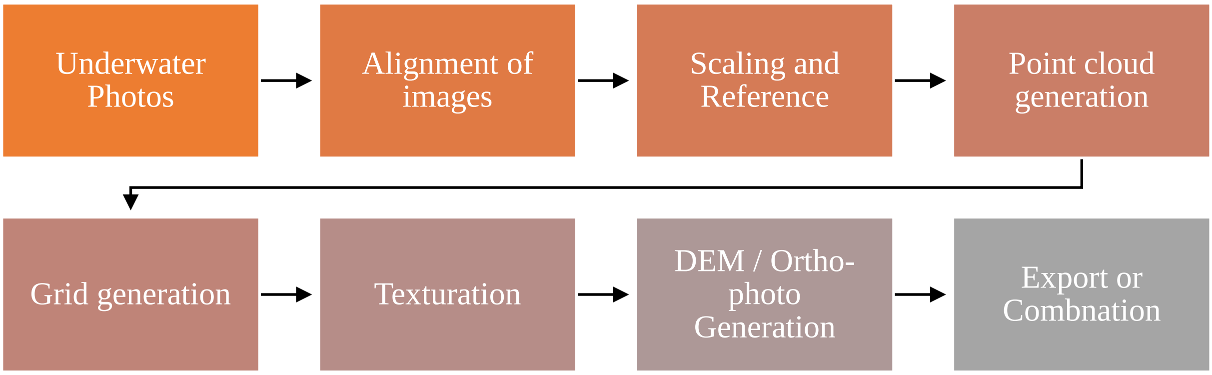

Fig.4. General process of the photogrammetry with an individual scaling process (Agisoft LLC, 2021)

For the start, the underwater photos are taken in a flodden quarry in Meissen, Saxony (51.16723°N, 13.49541°E). It is really essential to get qualitative good photos with light on the whole image to get a good result of the model. For the presented results a digital camera, Sony Alpha 6000, with an underwater case and two underwater lamps with 5.000 lm as video light are used. For the alignment of this object 145 photos with high accuracy were used. For the alignment more photos then theoretically necessary are used, to choose the proper photos and discard the before the the calculation. The result of the alignment is shown in **Fig.5** a).

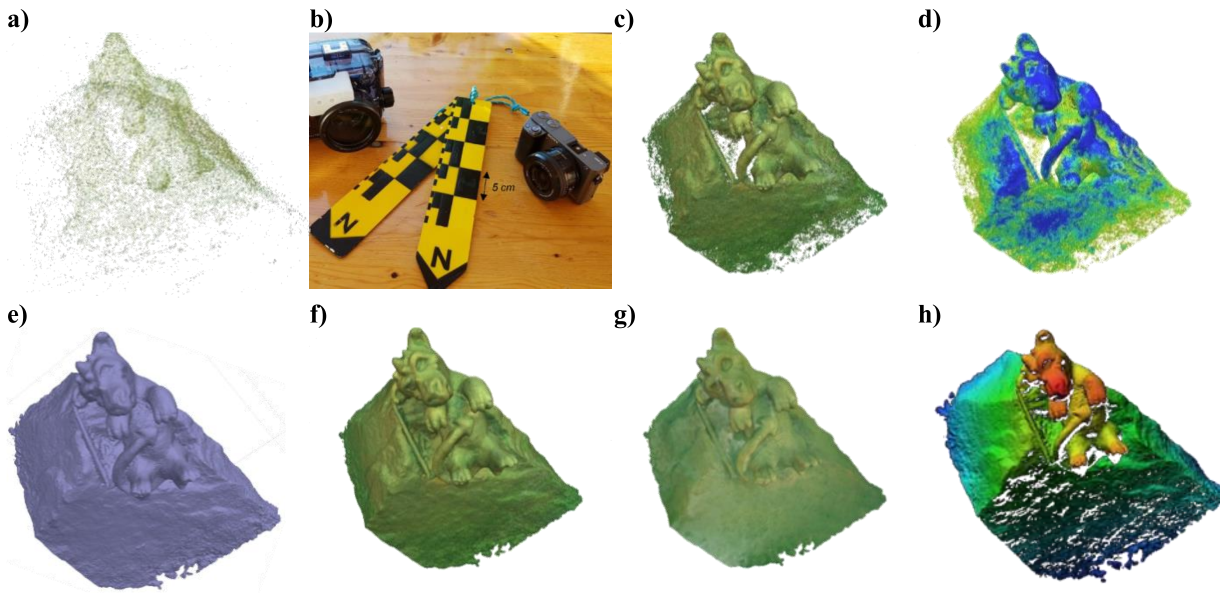

Fig.5. the photogrammetry process with the aligned images a), the scale and camera b), the coloured point cloud c), the confidence of the point cloud d), the reconstructed unstructured grid e), the coloured 3D-grid f), the textured model g) and the DEM-model h)

After that a scaling and reference process is necessary. For that every time of the photo process the scales, like **Fig.5** b) has to be part of the object. There you can measure at least 1 cm and rescale the object for a local reference system. With these markers it is also possible to use GPS coordinates.

With the result of the scaling process the depth maps und the point cloud are generated. These are shown in **Fig.5** c). For a better result the confidence index is calculated. It is an indicator for the number of depths maps at one point during the calculation process. For better results only points with a value of better than 3 are used. All other points are discarded and not part of the grid calculation.

The calculation is based on an unstructured triangle grid. With the reconstruct surface of the underwater object it is possible to measure and calculate distances, surface and volumes.

As mentioned in capture 2 the photogrammetry is used as trainings data for the artificial intelligence, the obstacle detection, object classification and separation. These is possible with the point clouds and the grid. For further investigations of the institute of computer science, use the generated point clouds. (Reitmann et al. 2021)

For a better visualisation, the texture of the object can be calculated. With that, the images are projected to the 3d-grid to get much more realistic objects. For further investigations a DEM-Models and orthoreflected photos can generated and used as 2D-Maps for bigger areas. There you can see the different levels of the object. In combination with an underwater bathymetry, you can get the orientation of the object on the ground. For the shown object, the whole reconstruction process takes 219 minutes on a numerical workstation. For the reconstruction process a full script based calculation on a high performance cluster system of the TU Bergakademie Freiberg is done.

The last step of the working process is to combine or export the models and point clouds to nearly every modern system you want. Objects can be shown as 3D-PDF, .obj, .stl, .ply or Image-File. Henceforth, you can share the models with all scientists. For the whole process the software Agisoft Metashape 1.7.0 is used. The parameters used for the reconstruction are shown in the **Table 1**.

Table 1. reconstruction parameter for the object 0,6 x 0,5 m dragon of the quarry in Meissen, Saxony

Photogrammetry Steps	**Reconstruction parameter**	**Results**	**Calculation time**
Alignment	High	145 of 145 photos 83.934 points	7 min 33 sec
Depths Map	High quality Mild filtering	145 depths maps	107 min 00sec
Point cloud	High quality Mild filtering	6.561.606 points	40 min 41 sec
Mesh	High faces	2.955.035 faces	4 min 03 sec
Texturation	Mosaic; Ghosting filter enable; hole filling enable	4,048 x 4,048 x 4, 4 channels,	15 min 39 sec
DEM	Source: Mesh	2802 x2554 pixel	06 sec
Orthophoto reconstruction	Source: Mesh	5292 x4120 pixel	6 min 14 sec
	Summary:	**Resolution:** 0.000869 m/pix **Point density:** 1.320.000. points/m²	181 min 16 sec

For the further investigations in the project RoBiMo a process for the combination of the photogrammetry object and the generated sonar point cloud will be developed and tested.

Conclusion

In the course of the investigation of the RoBiMo project, it has been shown that a complete combined investigation of the water bathymetry, the depth-resolved water parameters and the measurement of the respiration parameters is not possible. Therefore, 3 different measurement cases were developed, which can be carried out with a time delay as well as synchronously. This allowed the expected examination time to be shortened and a more flexible examination with coordinated measurement periods to take place.

The swimming robot intended for use, "Elisabeth", was prepared and tested by the Institute for computer science for the autonomous path planning. In the course of the project, however, it became apparent that the necessary flexibility and load capacity were not available. So, a new swimming platform "Ferdinand" was designed. This has the advantage of flexible loading and complete customized construction.

For the tasks of the SDC, an in-situ check and a comparison of the measured parameters with water samples were carried out. Furthermore, training data of the water structure are generated by means of photogrammetry. In this way, the algorithms for point classification can be tested on real objects. The photogrammetry process can be structured in the alignment, the depth map generation, point cloud calculation, meshing, texturation and evaluation. For that a numerical workstation or the high-performance cluster system of the TU Bergakademie Freiberg is used.

The photogrammetry process offers a big opportunity not only in scientific work. It is possible to transfer the unknown magic of the underwater world to all people, not only the divers. In addition, the data can be used for a better diving training, a better preparation for beginners and a new step of safety for the orientation in unknown areas. For science it offers the opportunity to investigate all details by specialists after the dive and with high resolution.

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Scientific case studies

Seascape value assessment of coastal and underwater diving spots

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Abstract. The Azores have a high potential for tourism differentiation, due to its distinctive and unique characteristics and natural beauty. However, there is a lack of interactions between known areas that can be used in innovation processes and international differentiation of the coastal and maritime tourism offer, since the value of seascapes remains underestimated. A seascape assessment methodology was developed based on data from databases, scientific publications, reports and existing promotional flyers/books, complemented by the empirical knowledge of local stakeholders, in order to access baseline seascape values (e.g., ecological, economic, cultural, social or aesthetic). In this context, underwater visual surveys play a vital role, allowing a detailed mapping in the underwater realm and complementing a detailed categorization of diving trails/spots, fulfilling characterization gaps that help to define standard evaluation criteria (e.g. biodiversity, habitats, substrate, geology, level of human impact, other uses, accessibility, cultural heritage, conservation status).

Introduction

Islands harbour a high number of endemic species and biodiversity considering their specific regional connectivity patterns and local ecological processes, often threatened by large-scale disturbances (Vitousek et al. 1995). At island scales, significant disturbances include anthropization, extreme environmental phenomena (major storms or hurricanes) and diverse human activities and impacts, among which tourism-related use (Jackson et al. 2014), especially when intensive tourism is rapidly developing, as in the Azores Archipelago.

The average income of the scuba diving tourists is potentially higher than the average income from regular tourists (Garrod and Gössling, 2008) however, as the number of scuba divers and snorkelers increases, concern about the deterioration of sites has also increased (Plathong et al. 2000; Flores-de la Hoya et al. 2018). Hence managers have become increasingly aware that successful protection of marine ecosystems depends not only upon an understanding of their biological and physical processes but also on their associated social and economic aspects, in a sustainable way. Additionally, the growing demand for recreational diving activities and the consequent specialization of users, demands a more detailed knowledge of the underwater environment, represented by biotic and abiotic elements intertwined together reflected in the overall seascape. Hence, the development of methodological approaches and definitions, suitable for use in different contexts and easily comparable with marine biotic heritage definitions and evaluations, is of primary importance (Rovere et al. 2010).

Seascapes have high biological diversity, ecological and economic connectivity, and aesthetic and cultural value (Atkinson et al. 2011). The value of the seascapes for tourism remains to be evaluated either in the Azores or elsewhere. Despite the importance of geosites for tourism and the geodiversity of the Azores, fully recognized by the establishment of the Azores Geopark in 2010 and its international recognition in 2013, or the more recent PaleoPark Santa Maria, in 2018, there is still a lack of data about underwater geodiversity, geological heritage and its valuation for recreational/touristic purposes.

This study aims to develop a seascape assessment methodology of coastal and underwater diving spots, based on Azorean natural resources towards local management and conservation needs, to meet the demands of an exigent and highly educated eco-tourist that visits the Azores (Bentz et al. 2016) which compel the development of new products.

Methods

Study area

The Azores are a small and dispersed island region, with nearly 250,000 inhabitants. The archipelago is composed of nine islands forming three groups (Western: Flores and Corvo Islands; Central: Faial, Pico, Graciosa, São Jorge and Terceira Islands; Eastern: São Miguel and Santa Maria Islands) and a maritime territory of about 1,000,000 km^2 with an average depth of 3000 m, located in the Mid-Atlantic region (36–39°N and 25–31°W – Fig. 1A,B). The archipelago is an emerging touristic destination for marine-related activities, including scuba diving (Bentz et al. 2016) (Fig. 1C).

The tourism sector has been considered as a strategic priority for the development of the regional economy, which has been thriving and has achieved a wide range of international distinctions and recommendations. Moreover, the Azores are internationally recognized by specialized publications, as an exotic destination and one of the best Nature tourism destinations in the world, where natural heritage and sustainability are a trademark (OTA 2011; IPDT 2016; Ressurreição et al. 2012). According to the Research and Innovation Strategy for Intelligent Specialization (RIS3 2014), in 2020, the Autonomous Region of the Azores was recognized as a destination of excellence for specific market segments, in which regional players, acting in a coordinated way and using innovative tools, can structure a qualified and sophisticated multidisciplinary but integrated science-based offer that promotes, in a sustainable way, the use of the differentiating elements of the Region. One of the priorities of the regional government (RIS3) is to benefit nature-based tourism that includes scuba diving, bird watching and geotourism (IPDT 2016).

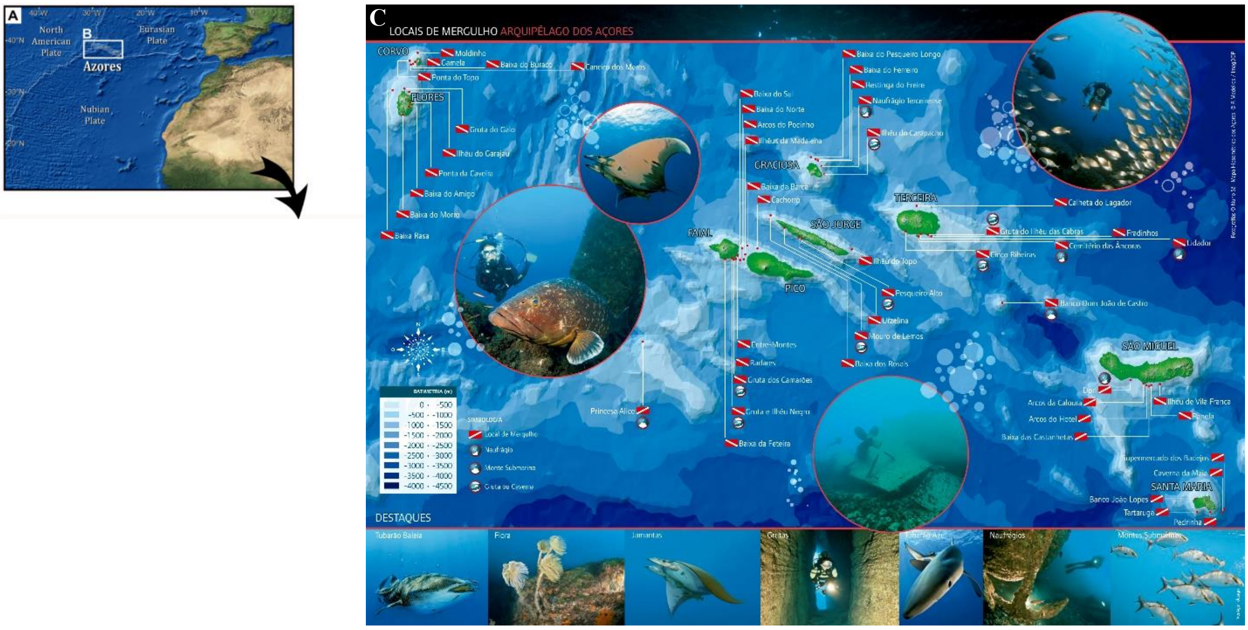

Fig. 6. A) Location of the Azores Archipelago; B) The Azores Region; C) Diving spots (red flags) and surrounding bathymetry. Source: www.artazores.com

Assessment methodology

A methodology was developed based on internationally accepted criteria, namely those related to naturalness, adapted to Azores regional context. An extensive literature survey was carried, compiling criteria for seascape valuation (e.g., biological and geological significance; pressures, including threats; stakeholder interest and level of support;

governance framework), elsewhere (Pedrini et al. 2016; Rhormens et al. 2017), together with the empirical knowledge of stakeholders and expert judgment to complement and help defining eligible criteria. This step-by-step process (Fig. 2) allowed identifying the amount of data required to be collected to fulfil the seascape evaluation. The criteria were selected within a multiplicity of options according to each criterion resilience, attractiveness and regional assets to be applied to the Azores archipelago seascape evaluation, including touristic trails/spots. Finally, a first underwater field assessment of the selected trails/spots at São Miguel, Santa Maria, Pico and Flores Islands, was conducted to allow seascapes prospection and fulfil gaps. Field surveys are mandatory to properly design, evaluate conditions and complete detailed characterization of trails/spots. Afterwards, this multicriteria process follows a pre-established scoring system for each criterion to assess the overall seascape value.

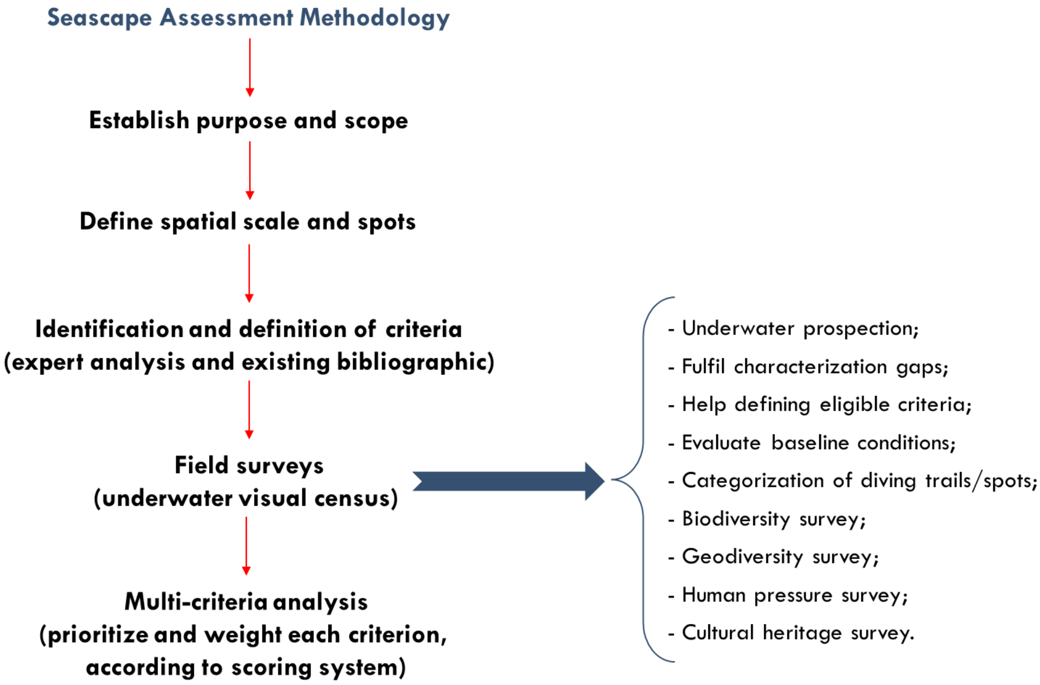

Fig. 7. Seascape assessment methodology, highlighting the importance of underwater field surveys.

Results and discussion

The evaluation of natural areas should include multidisciplinary aspects on both subjective and objective factors, including environmental and social aspects, often absent from many studies aiming at the conservation and management of marine environments (Rovere et al. 2011).

Selected criteria were clustered in nine different descriptors (Biodiversity; Geodiversity; Physical aspects; Cultural heritage; Accessibility; Human pressure; Legal protection; Knowledge of the area; Monitoring), of which six include underwater field surveys as specified in Table 1, with each criterion corresponding to a score between 0-5 (Fig. 3). Geodiversity plays an important role, especially considering the volcanic nature of the studied area which is usually underestimated in seascape assessment. Also, according to Aburto-Oropeza and Balart (2001), the spatial distribution of topographic characteristics like rock sizes, hollows and bottom types, provides the organisms with food, shelter and reproductive grounds. They found that the species richness increases in shallow habitats (boulders and walls), as well as where there is a high structural complexity through crevices, larger rocks and rugosity, suggesting that some species choose among the available habitats at a given depth according to several ecological processes such as resource competition and trophic considerations. Also, Cole-King (1994) states that topography in suitably clear water provides a degree of recreational and aesthetic interest which is different from wildlife observation. In fact, the topography descriptor has assumed growing importance in the last years, leading some authors to place biodiversity and geodiversity concepts side by side (Brilha 2002).

Table 2. Descriptors, criteria and information sources.

Descriptor	Criteria	Information sources
Biodiversity	Species diversity, abundance (DAFOR scale), conservation status, endemisms, protected species, key species, emblematic species, cryptic species	**Field surveys**, IUCN red list, local bibliography
Geodiversity	Slope, topographic complexity, dominant structures, specific geologic underwater formations (sedimentary structures, pillow lavas, submarine sheet flow, sub-aerial lava flow, arches, caves, giant´s kettles, dikes, prismatic junctions, cones, hydrothermal vents)	Expert knowledge, **field surveys**, local bibliography
Physical aspects	Visibility, currents, swell, degree of site shelter	Questionaries to companies, **field surveys**
Cultural heritage	Cultural/historical interest	Expert knowledge, **field surveys**, local bibliography
Accessibility	Difficulty, distance (affects the duration, comfort and cost of the trip)	Questionaries to companies, **field surveys**
Human pressure	Presence/intensity/consequences of human activities, litter, NIS	**Field surveys**, questionaries to companies and users

SCAPETOUR - CLASSES FOR CRITERIA

DESCRIPTOR	CRITERIA	INDICATOR	VALUE 0	1	2	3	4	5
BIODIVERSITY	Marine life richness	*Number of species of benthic fish*	0	1-5	6-10	11-15	16-20	>20
		Relative abundance of benthic fishes	Absent	Rare	Scarce	Common	Abundant	Dominant
		Nº species of pelagic fishes	0	1	2-4	5-7	8-10	>10
		Relative abundance of pelagic fishes	Absent	Rare	Scarce	Common	Abundant	Dominant
		Nº species of invertebrates	0	1-5	6-10	11-15	16-20	>20
		Relative abundance of invertebrates	Absent	Rare	Scarce	Common	Abundant	Dominant
		Nº species of macroalgae	0	1	2-4	5-7	8-10	>10
		Relative abundance of macroalgae	Absent	Rare	Scarce	Common	Abundant	Dominant
	Presence of protected species	*Number of protected species*	0	1	2-4	5-7	8-10	>10
	Presence of endemic species	*Number of endemic species*	0	1	2	3	4	≥5
GEODIVERSITY	Slope	*Slope*	Horizontal	Quasi horizontal	-	Sloped	-	Steep
	Topographic complexity	Topographic complexity/roughness	Flat	Quasi flat	-	Rough	-	Highly complex
	Visually dominant structures	*Size of visually dominant structures*	5-10m	10-20m	-	20-50m	-	>50m
	Geologic features	*Number of arches*	0	1	2	3	4	≥5

Fig. 8. Example of biodiversity and geodiversity score classes.

Field surveys

After a first prospection to calibrate assessment methodology, underwater visual census remains crucial to obtain information for several different key descriptors (biodiversity, geodiversity, human pressure, cultural heritage) and many specific criteria (Fig. 4). Environmental pressures, as marine litter and marine NIS (Non-indigenous species) should also be identified, contributing to the Marine Strategy Framework Directive (MSFD) monitoring.

Assessments of seascape should be done using high-definition aerial and underwater imagery (e.g., Nikon D-850+Ikelite water-proof case with macro lenses for detailed characterization, complemented by Go-PRO cameras) that enable qualitative and geo-referenced seascapes. Imagery gathered and in loco observations, by research team members, allow fulfilling the seascape evaluation criteria required and permit complete seascape characterization (e.g., allowing to identify habitats, biodiversity, and substrate type). The fieldwork also adds new data and descriptions to the coastal and underwater geosites, included in the analysed areas/spots/trails. This component involves an important amount of field assessments, to produce images/videos for further analyses and demand scientific expertise from different areas (e.g., Habitats/Invertebrates and fishes, Seaweeds, Geology, Ecology/Conservation, MPAs, human impacts). Therefore, before films team missions to the selected spots, in loco rapid assessment should be performed by team researchers on the selected trails/spots for methodological valuation. A minimum of three replicates (i.e., counts within plots within protection level) should be done on each spot.

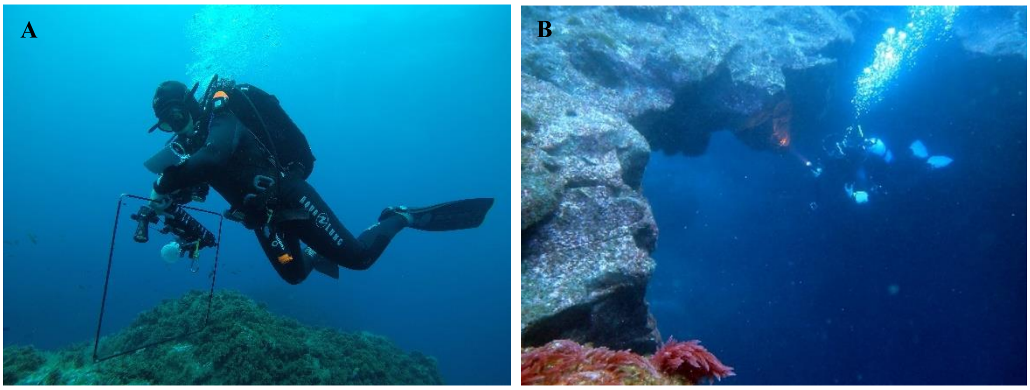

Fig. 9. Underwater field surveys. A) biodiversity survey; B) geodiversity survey.

Weighting criterion

According to Ramos et al. (2006), various factors define a "good experience" and influence people to prioritize between different criteria in the election of a site, some factors more relevant than others, depending on each perspective (conservation, education, tourism). For this reason, weighting factors should be calculated and used to increase the value of some variables in the score matrix, although based in a multidisciplinary team and stakeholders, by carrying out a short survey that consisted of criteria prioritization. Hence, a final average weighted score is given to each criterion to estimate the overall seascape score.

Conclusions

The Azores has a high potential for scuba diving activity (Queiroz et al. 2014) but sites are still underrated mainly due to a lack of marine biology and geology information. The use of the selected criteria allows highlighting the most important features of the diving sites.

The study area presents very acceptable features for recreational diving throughout the entire year, however, seasonal changes of the marine life (communities of fish and invertebrates), play an important role to define the attractiveness of the marine spots. In the context of a global approach to an area, the integration of geodiversity features complements the use of biodiversity to evaluate a seascape. The next step would be the establishment of a tourism and resource management plan for each area. However, first is necessary to estimate carrying capacities and limits of acceptable change.

This approach will allow the development of seascape value maps for tourism, including biological significance (species richness, important biological features and their status), socioeconomic factors (population, maritime tourism, enterprises, tourists), governance framework for the area and legal context of management and implementation level. This methodology can be exported and adapted for other geographic realities.

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Introduction of the technical diving method for scientific diving to investigate biocoenosis in the twilight zone of freshwater lakes

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Abstract. The existence of light-dependent (zooxanthellate) corals at depths between 40 to 150 meters (sometimes up to 300 meters) has been first reported back into the nineteenth century and they are specificyally called mesophotic coral reef (MCR) ecosystems. Their systematic study began about 50 years ago, but just in the last decade, mainly due to the development of new diving techniques, these deep coral reefs have been extensively studied.

At the same time from the Mediterranean Sea new communities in these depths - the twilight zone - are described consistently. For example, a veritable underwater forest of black corals (*Antipathella subpinnata*) was recently discovered from the Adriatic Sea (Tremiti Islands) between 52 and 80 meters of water depth.

A description of biotic communities in the twilight zone in freshwater systems, such as on steep walls, is searched in vain in the relevant literature. Detailed observations and characterization of mesophotic, almost lightless communities, e. g. of the steep walls in Lake Constance between 40 and 150 meters, are missing so far.

We present first dives into these area (40–100 meters) using the example of the steep walls of Lake Constance (Überlinger See), describe the necessary diving and sampling techniques and skills.

To our knowledge, these are the first scientific dives into these depth ranges in freshwater.

Introduction

Sylvia Earle, oceanographer and marine biologist, affectionately sometimes dubbed "Her Deepness", noted that our planets Moon and Mars are much better mapped than our oceans and marine biodiversity. Less than five per cent of the oceans have been observed and explored.

This is also true for the biotic communities of the twilight zone (mesophotic zone). The existence of light-dependent (zooxanthellate) corals at depths between 40 and 150 metres (sometimes up to 300 metres) has been known since the nineteenth century and they are specifically called mesophotic coral reef (MCR) ecosystems (for review see Turner et al. 2017). Their systematic study began about 50 years ago, but it is in the last decade that comprehensive and the most authoritative work on these deep coral reefs has been published. Corals together with sponges and algae form the basis for the formation of the biotic communities. In the meantime, these deep coral reefs are considered an extension of the shallow coral reefs we know well, since the same species occur in both depth zones. Thus, mesophotic coral reefs are thought to serve as a potential source of recolonisation for damaged shallow-water coral reefs. And they serve as spawning and nursery habitat for economically and ecologically important fish species.

New communities in these depths are also repeatedly described from the Mediterranean. For example, a veritable underwater forest of black corals (*Antipathella subpinnata*) was recently discovered in the Adriatic Sea (Tremiti Islands) between 52 and 80 meters of depth (Chimienti et al. 2020). Although closer research is still in its infancy, this "coral forest", the first in the Adriatic Sea, can be considered extremely important for the Mediterranean because of the fishes and other very conspicuous species it contains.

The Gombessa V Expedition by Laurent Ballesta (Blancpain Ocean Commitment Gombessa V 2019) aimed to study and to document so far unexplored areas in the Mediterranean Sea. As these biodiversity hotspots are found at great depths for scuba divers – between 60 and 120 meters – the Gombessa V team has developed a world-first diving method by a combination of saturation diving and deep recreational diving.

Region of Interest

A description of biotic communities in the twilight zone in freshwater systems, such as on steep walls in lakes, is searched in vain in the relevant literature. Detailed observations and characterization of mesophotic, almost lightless communities, e. g. of the steep walls in Lake Constance between 40 and 150 meters, are missing so far.

In connection with the alien and invasive quagga mussel *Dreissena rostriformis bugensis* (Bivalvia: Dreissendiae) (Brümmer et al. 2020), we are interested in its depth distribution, also. So far, unusual biocoenoses have been described in the upper part of the steep wall in Lake Constance (Brümmer and Müller 2015). However, studies in other areas e. g. deeper than 40 meters are lacking.

Methods

Traditionally, the depth range of recreational and scientific diving is limited by certain factors, amongst which the safety of the breathing gas air and its amount are of primary concern. Hence, the aforementioned divers have a widely accepted operational depth limit of 30-40 meters. In the 1990s of the last century, a method was developed for the autonomous diver to venture deeper and this in a safe manner (Remmers 2014).

Whilst involving mixed gases for different depth stages and using gas supply in a redundant way, this method proofed to be reasonable safe (Fock and Millar 2008). In the following decades, rebreathing diving apparatuses, so-called rebreathers, known from military and commercial diving, became available also for the technical divers, so that today the method of technical diving, involving helium-based mixed gas for the deeper part and oxygen-enriched gases for accelerated decompression in electronically controlled rebreathers (eCCR), is a safe way of exploring the underwater realm for depth in excess of 120 meters also from a scientific point of view (Sieber and Pyle 2010; Pollock et al. 2016).

Nonetheless, these diving procedures need very thorough and specific diver training, so the physical and mental challenges are well prepared for and the diver is capable of dealing with the involved dangers and needed awareness. Thus, only the specifically trained divers are well prepared and trained for scientific work at greater depth than the widely accepted limit of traditional recreational and scientific divers (Remmers 2014). The collection of samples, scientific work is therefore limited for reasons like restricted dive time and shortance of qualified dive staff.

For the collection of quagga mussels on the steep walls in Lake Constanze a combined method of photogrammetrie, videotaping, and sample collection was established and optimized.

In particular the diving procedures and protocols have to be tailored towards the demands for scientific work in this extended range of depths and low temperature.

Breathing gas:

Diving in the range to up to 80 meters is in theory possible with open circuit diving equipment. Nevertheless, usage of closed-circuit rebreathers (CCRs) has a number of advantages. Therefore, in a depth range of down to 140 meters rebreathers is considered to be the state-of-the-art equipment. CCRs provide warm and humid gas to breath. Electronically controlled CCRs such as the JJ-eJJR (JJ-CCR, Presto, Denmark) allow the optimum mix of breathing gas components for every depth. They allow for a high fraction of helium in the breathing gas without coursing extremely high costs for the gas and they are very efficient in terms of gas usage. In case of a malfunction of the eCCR system, divers carry axillary emergency breathing gases, so called bail-out gases (Wilhelm and Dederichs 2004).

For the given dive profils in the context of this research project (Fig.1), the device which was in use for the team was a JJ-eCCR in Global Underwater Exploration (GUE) configuration which allows for a high amount of bottom bailout gases as the system is attached with a twinset containing the diluent gas. In addition, the configuration of the system is similar to a “Doing it right” (DIR) style open circuit twinset with long hose and backup regulator configuration (Fock and Miller 2008).

Isolation:

Deep profile dives are always dives connected with massive decompression obligations and extended dive times. In most cases extending five hours of total dive time. Low temperature (Lake Constance 5°C) in combination with extended dive time requires a solid concept and equipment for isolation. The isolation has to ensure, that divers stay warm and comfortable for up to six hours in freezing cold water.

In addition, the concept has to ensure, that the compression of material in great depth has no negative impact on the isolation. Taking this into account only drysuits are suitable for this kind of dives. Modern drysuits made out of trilaminate, a telescope torso equipped with valves to pee, heating connectors and isolating suit inflation gases (argon) are first choice.

The electrical heating system consist of an external separate battery back, and either a heated shirt or a undergarment which is heated completely. The undergarment is of high importance because the material has to ensure that it allows for fundamental isolation even if the suit is flooded. In recent days, specialized suppliers guarantee isolation of wet undergarments due to the fact, that the material itself seals the air inside (Wilhelm and Dederichs 2004).

Lighting systems:

The deep regions of Lake Constance are completely isolated from natural light. Therefore, a reliable powerful diving light is essential for this kind of diving. Long burn times are considered crucial.

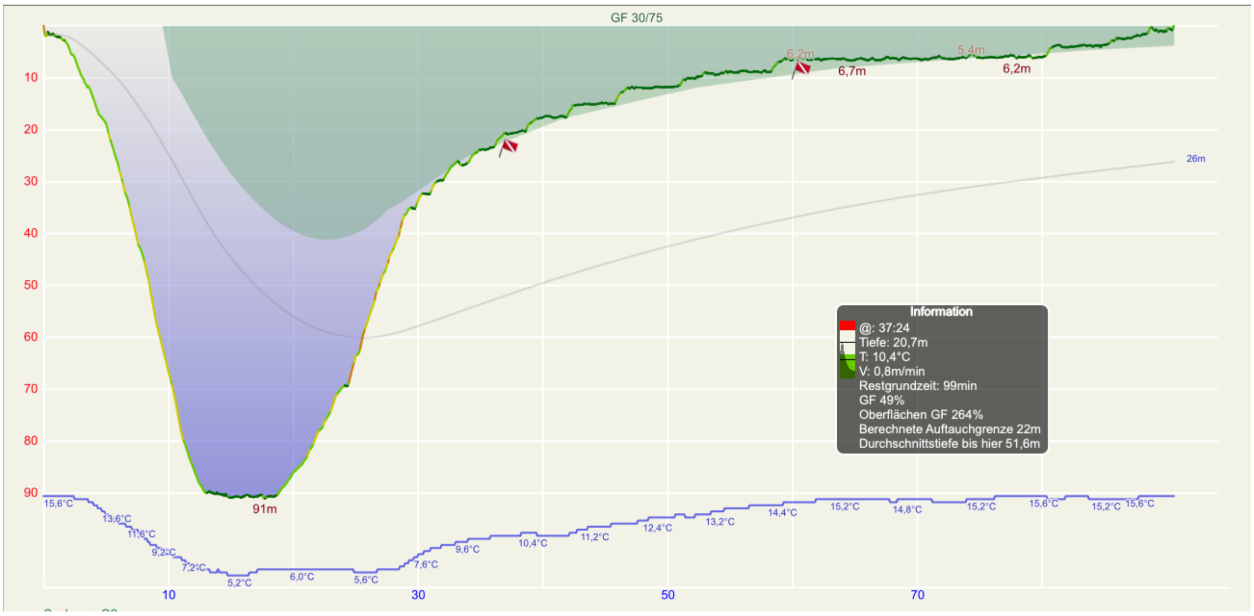
The primary light usually consists of a small light head including a Goodman handle and then a wired battery tank, which is mounted on the harness of the divers back plate. The lightning system is of high importance for visual inspection, illumination for photo and video tasks and in particular for communication during the dive. Therefore, a dedicated and specialized reflector system is required.

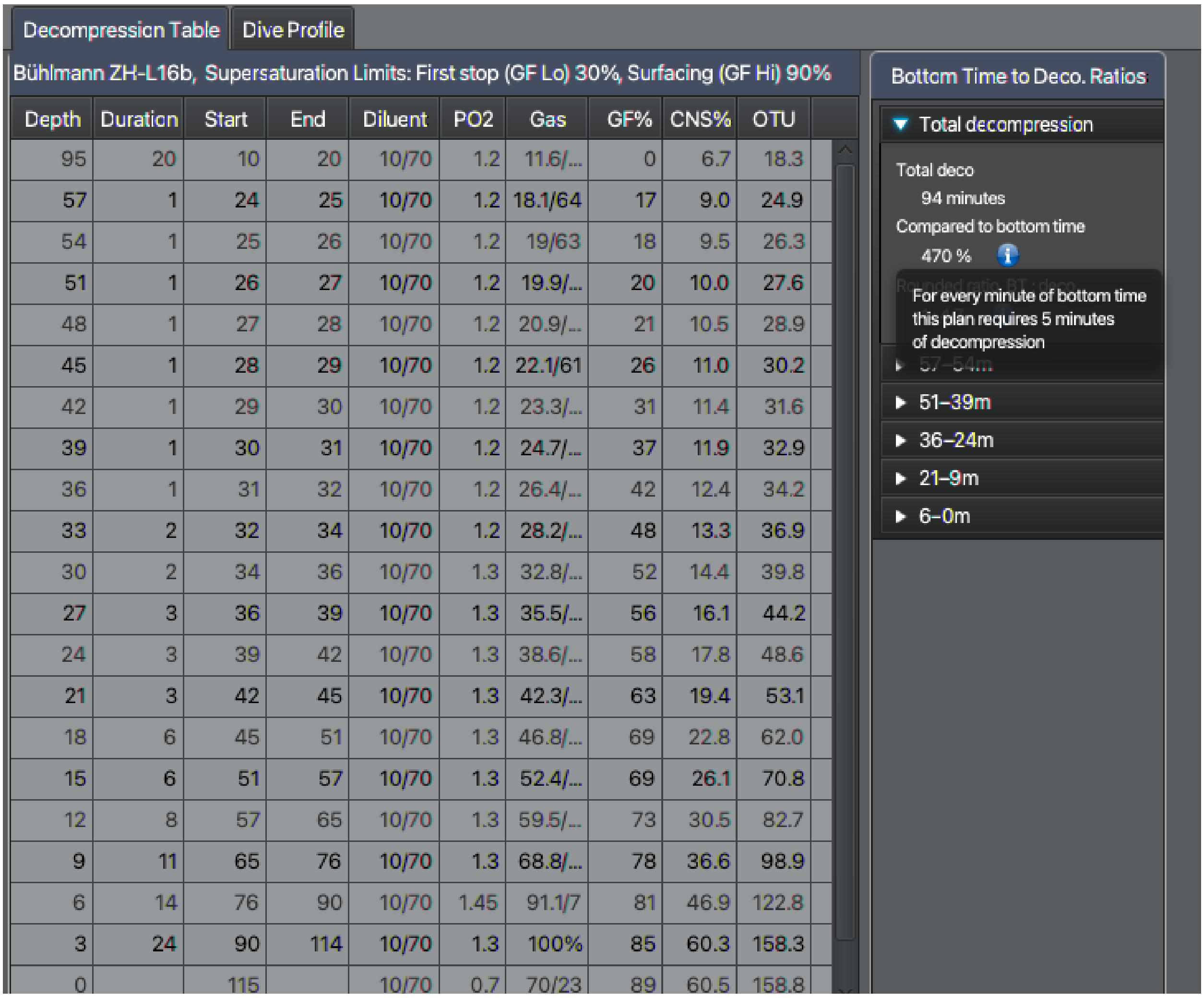
In case of failure of the primary lighting system two backup lights of smaller size are necessary. As rechargeable batteries, which are used typically in the primary light source, have the tendency for self-discharging, batteries are the choice for the backup lights.

Safety and spare equipment:

The safety equipment includes spare masks, a massive decompression obligation does not allow for immediate access to the surface, a safety buoy and a spool which allows communication with the surface if required and to arrange for surface support. Wetnotes, an underwater writing sheet, allows for complex communication under water if required and for taking notes regarding the sampling.

In addition, a set of underwater tools like a spanner, a multitool, etc. are very useful for basic repairs during the dive.





Depth	Duration	Start	End	Diluent	PO2	Gas	GF%	CNS%	OTU
95	20	10	20	10/70	1.2	11.6/...	0	6.7	18.3
57	1	24	25	10/70	1.2	18.1/64	17	9.0	24.9
54	1	25	26	10/70	1.2	19/63	18	9.5	26.3
51	1	26	27	10/70	1.2	19.9/...	20	10.0	27.6
48	1	27	28	10/70	1.2	20.9/...	21	10.5	28.9
45	1	28	29	10/70	1.2	22.1/61	26	11.0	30.2
42	1	29	30	10/70	1.2	23.3/...	31	11.4	31.6
39	1	30	31	10/70	1.2	24.7/...	37	11.9	32.9
36	1	31	32	10/70	1.2	26.4/...	42	12.4	34.2
33	2	32	34	10/70	1.2	28.2/...	48	13.3	36.9
30	2	34	36	10/70	1.3	32.8/...	52	14.4	39.8
27	3	36	39	10/70	1.3	35.5/...	56	16.1	44.2
24	3	39	42	10/70	1.3	38.6/...	58	17.8	48.6
21	3	42	45	10/70	1.3	42.3/...	63	19.4	53.1
18	6	45	51	10/70	1.3	46.8/...	69	22.8	62.0
15	6	51	57	10/70	1.3	52.4/...	69	26.1	70.8
12	8	57	65	10/70	1.3	59.5/...	73	30.5	82.7
9	11	65	76	10/70	1.3	68.8/...	78	36.6	98.9
6	14	76	90	10/70	1.45	91.1/7	81	46.9	122.8
3	24	90	114	10/70	1.3	100%	85	60.3	158.3
0		115		10/70	0.7	70/23	89	60.5	158.8

Fig.1. Depth profile and decompression information from a typical dive for sampling quagga mussels at the steep wall in Lake Constance, Überlingen.

Documentation and Sampling methodology

For scientific and documentation purposes the team usually carries a number of cameras e. g. action cams and camera/datalogger combinations. And on top, one professional high-end underwater camera systems with long lightning arms. All this equipment must be designed for depths of down to 150 meters which limits the number of suitable suppliers.

For documentation purposes during the transect dive (Fig.2 & 3) and collection of samples (Fig.5) three different methods for documentation have been utilized:

Diver 1 focusing on the collection of samples did use a helmet camera, which was mounted with the mask strap (Fig.4). This camera is providing video tape with overlay data in the image, such as: dive time, depth, temperature. Whenever a sample was collected, the dive computer was recorded together with the sample identification labeling.

Diver 2 did use a video camera for photogrammetry purposes. The 3D-model (Fig.3) illustrates the collection points of the samples. A sample was collected on the way up every 10 meters in depth. Secondly, Diver 2 did use a high-resolution photo camera with flashes to document the transect with high resolution images.

During the dives, samples have been collected into sample collection tubes (Falcon tubes 50 ml) (Fig.5) uniquely marked before the dives. In order to store and use or take the sample tubes, a special clipboard has been designed and utilized (Fig.5). As the work was conducted at the steep, in many sections of the transect vertical walls of the lake, the clipboard, connections and sampling tubes, were designed and manufactured to be neutrally buoyant. This in order to prohibit it from dropping down in any case.

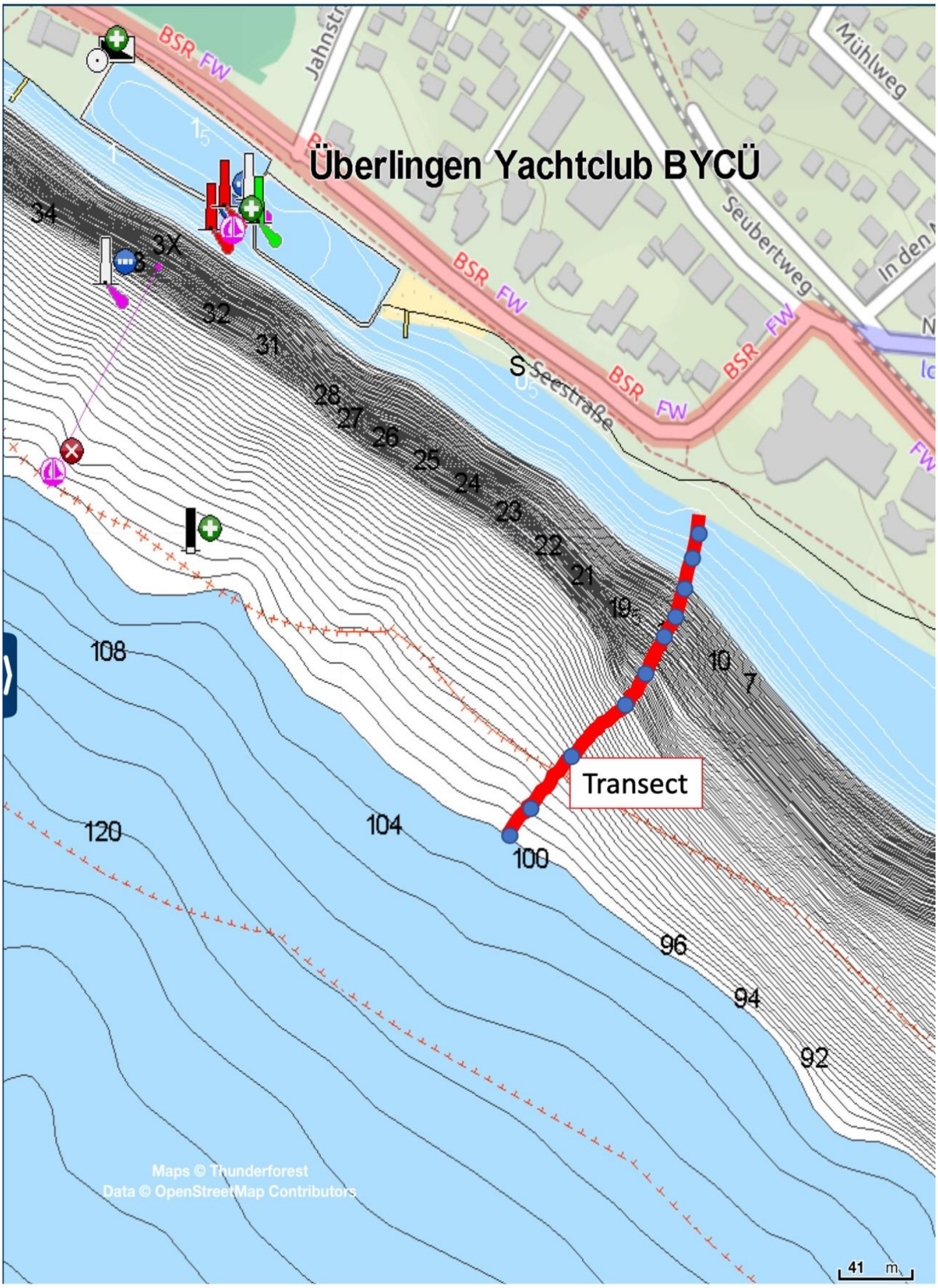


Fig.2. Map of the dive site in Überlingen, Lake Constance, with the depth contours and the dive transect (red line) and the sampling points (blue dots) along the wall.

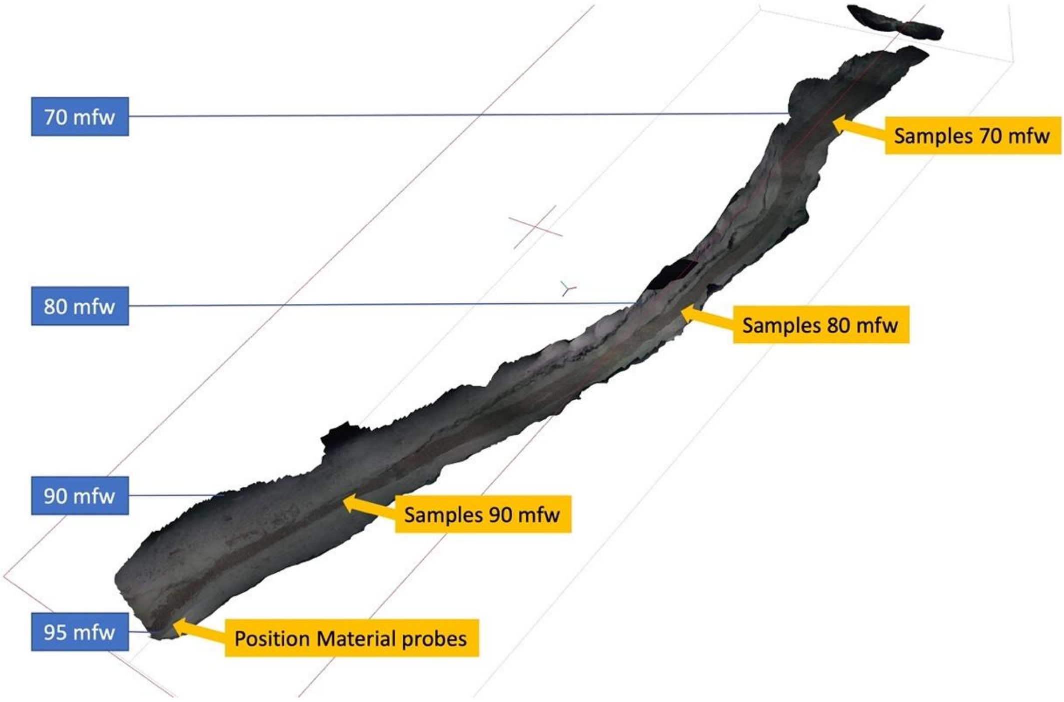


Fig.3 A 3D-reconstruction of the dive descent with the positions of the sampling sites from 70 to 95 metres (mfw = meters of freshwater).

Fig.4. Diver 1 with the camera mounted at the mask picking up quagga mussel samples from the steep wall.

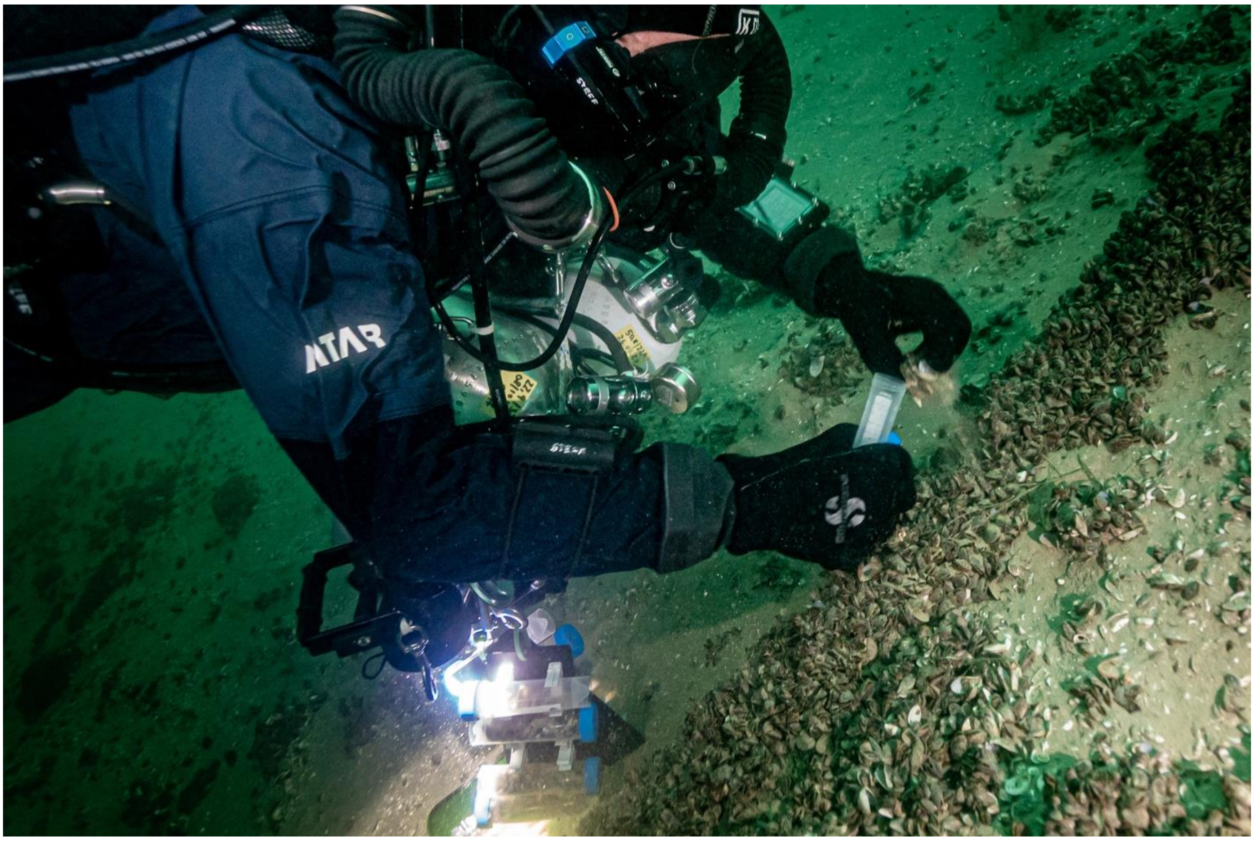


Fig.5. Samples of the mussels observed are put into the Falcon tubes, these are then sealed (blue cap) and stowed in the clipboard (lower edge of picture, centre).

Results and Discussion

The well-prepared CCR dives with sampling and documentation equipment adapted to the scientific research objectives have proven to be very suitable and safe. With this diving technology, it was possible to extend the depth range for scientific sampling and documentation of the invasive and alien quagga mussel in Lake Constance to almost 100 meters water depth (Fig.1).

Biological invasions by alien species (neobiota) are considered to be among the major factors threatening, endangering and displacing native species and communities.The zebra mussel *Dreissena polymorpha* (Pallas, 1771) and the quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897) are both invasive freshwater mussels that have spread into rivers and lakes e. g. Lake Constance.

In 2016, the quagga mussel (*Dreissena rostriformis bugensis*) was observed for the first time in Lake Constance (Güde and Straile 2016; Internationale Gewässerschutzkommission für den Bodensee 2019; Hesselschwerdt and Teiber-Sießegger). Since that time, the quagga mussel (*D. rostriformis bugensis*) in Lake Constance showed a very impressive and quick spread in the entire shallow water zone of Lake Constance.

Through scientific monitoring and the voluntary commitment of recreational divers as citizen scientists (Brümmer et al. 2021), we have obtained extensive data on the distribution of the quagga mussel and the simultaneous displacement of the zebra mussel. The quagga mussel was also observed at a water depth of about 40 meters, e. g. on the wreck of the paddle steamer JURA (Brümmer et al. 2020). However, due to the depth limit of 40 meters for recreational divers, there is no documentation and samples from e. g. the deeper areas of the steep walls. Here, however, we know the formation of novel biocenoses from the zebra mussel and freshwater sponges (Brümmer and Müller 2015).

Along the dive transect (Fig. 2 & 3) quagga mussels were observed and documented down to a depth of 96 meters. No live zebra mussels were found in any of the samples taken.

To our knowledge, this is the first documented observation of the quagga mussel in Lake Constance by divers and on the steep walls in this depth range.

Conclusion

Tech diving using CCR is safe to explore the twilight zone of freshwater lakes and to gain new insights into the biocoenoses deep down.

For the first time, living quagga mussels were documented and sampled at a steep wall in Lake Constance in this water depth of almost 100 meters using this diving technology.

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Monitoring the invasive quagga mussel by recreational divers in a citizen science project

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Abstract. Both mussel species, the zebra mussel *Dreissena polymorpha* and the quagga mussel *D. rostriformis bugensis* had become two of the most devastating aquatic alien species. These small freshwater mussels cause significant ecological and economic impacts attaching to hard surfaces via so-called byssus threads. In Lake Constance (Bodensee) – located on the northern edge of the Alps in the southwest part of Germany where Germany, Switzerland and Austria meet - a very strong increase of the Quagga mussel could be observed in the last four years.

In a Citizen Science project, interested recreational SCUBA divers obtained special information (underwater chart, training courses, easy to handle determination key, booklet) on both mussel species to document the distribution and abundance of the two mussel species during their dives. The quagga mussel is found in Lake Constance at all dive sites to the maximum depth for recreational divers of 40 meters and in a hardly imaginable abundance up to almost 40,000 specimens per square meter.

In some areas, the zebra mussel that used to be found there has been replaced by the quagga mussel due to its ability to colonize soft and very fine sediment as well as steep walls.

The frequent attachment of the quagga mussel to aquatic plants as well to snails and crayfishes is also striking. Furthermore, a previously unknown colour variation with orange siphons was frequently observed.

The quagga mussel was observed for the first time in quarry ponds on the Upper Rhine as well as in lakes in Lower Saxony, Mecklenburg-Western Pomerania, Saxony and Saxony-Anhalt.

This project was awarded as a citizen science project first prize for Sustainability and Sports in Baden-Württemberg (Nachhaltigkeit und Sport in Baden-Württemberg) and was thus also financially supported.

Introduction

Alien species (neobiota), which have reached areas outside their natural range due to human intervention, sometimes lead to major changes in indigenous floras and faunas. Worldwide, biological invasions are considered to be among the major factors threatening, endangering and displacing native species and communities.

In aquatic and terrestrial habitats, about 90 alien mollusc species have been detected in Germany so far. The zebra mussel *Dreissena polymorpha* (Pallas, 1771) and the quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897) are both invasive freshwater mussels that have spread into native waters and continue to do so successfully, sometimes almost unnoticed.

In Germany, the zebra mussel (*Dreissena polymorpha*) (Fig. 1) has also successfully spread and established itself in native waters (Tittizer 2001; VDST 2005). Since it attaches itself to other native mussels and crustaceans, for example, it is in direct food competition with them, which often results in reduced growth of native species. Water birds (Jacoby and Leuzinger 1972; Zintz 2014) and, among others, carp-like fish can use the zebra mussel as a food source, which means that it can have a growth-promoting effect on these species. However, economic damage is caused, for example, by the zebra mussel attaching itself to pipes in cooling water and drinking water systems. They also pose a problem for bathers, as they cause injuries to hands and feet (Brümmer et al. 2020). However, the formation of regular mussel carpets can also promote the development of certain new biocoenoses (Brümmer and Müller 2015).

The zebra mussel originates from the Caspian and Black Sea region (Pontocaspian region) and in 1824 it was found simultaneously in the Baltic Sea and in the London docks, and two years later (1826) in the mouth of the Rhine (Thienemann 1950). In the following decades, it colonised the entire Rhine and is today an integral part of the Rhine biocoenosis and has formed stable populations (Tittizer 2001).

D. polymorpha reached Lake Constance in the mid-1960s (Frank 1995; Güde and Straile 2016) and developed there into an important structure builder and the numerically most important macrobenthos taxon in the littoral by the beginning of this century (Güde and Straile 2016). As part of the project "Neobiota - Neue Arten in Tauchgewässern" (Neobiota - New Species in Diving Waters) of the German Underwater Federation (Verband Deutscher Sporttaucher; VDST), a detailed fact sheet on the biology and ecology of the zebra mussel was prepared (VDST 2005).

In 2016, the quagga mussel (*Dreissena rostriformis bugensis*) was observed for the first time in Lake Constance (Güde and Straile 2016; Internationale Gewässerschutzkommission für den Bodensee 2019; Hesselschwerdt and Teiber-Sießegger), which spreads rapidly and en masse throughout the shallow water area of Lake Constance in the past four years. It is assumed that the first entry into Lake Constance occurred before 2016 and possibly at several locations (Hesselschwerdt and Teiber-Sießegger).

The quagga mussel (*D. rostriformis bugensis*) (Fig. 2) also originates from tributaries of the Black Sea. In Germany, this species was recorded for the first time in the river Main in 2005 (Imo et al. 2010). In 2007, it was observed in the Rhine harbour of Karlsruhe (Martens et al. 2007). In the last ten years, it has spread extremely rapidly along watercourses such as the Rhine, Danube, Main and Weser (Glöer and Fuhrmann 2017), but also along shipping canals such as the Mittelland Kanal (Midland Canal) and Rhein-Herne-Kanal (Rhine-Herne Canal) (Schöll et al. 2012). In 2014, the quagga mussel reached the Müritz and the catchment area of the Baltic Sea (Meßner and Zettler 2015), then Lake Constance in 2016 (Hesselschwerdt and Teiber-Sießegger). It has also been detected in the new lakes of the post-mining landscape of Central Germany (Gilbert et al. 2019).

The quagga mussel is apparently displacing *D. polymorpha*, which was introduced more than 100 years ago and is found almost everywhere in the native inland waters (Schöll et al. 2012; Meßner and Zettler 2015; Hesselschwerdt and Teiber-Sießegger).

Both mussel species are very similar in their biology and share general ecological characteristics. For example, both species have a high reproductive potential, free-swimming larvae, an attached benthic adult phase with the help of the byssal apparatus and they are highly efficient suspension feeders. But there are some clear differences: they have different habitat requirements and differences in growth and population dynamics. Quagga mussels colonise greater depths up to 100 metres in lakes such as the Great Lakes (Mills et al. 1996) but also in Lake Constance (Brümmer et al. 2021). They also cope better with lower temperatures and colonise fine sediment habitats (soft bottoms) very successfully, where zebra mussels are rather rare. In addition, the quagga mussel develops better lentic ecosystems than in flow-through areas (Ackerman 1999). (On the biology and ecology of the two Dreissena mussel species reviewed here see e. g. (Nalepa and Schloesser 2014), (Brümmer et al. 2020).

But still only few data are available on the distribution of the invasive quagga mussel in the lakes of Germany. Therefore, a project was initiated to record the distribution of the quagga mussel within the citizen science project “Monitoring of the invasive quagga mussel by recreational divers”. For this purpose, it was also necessary to provide recreational divers with the relevant information on both mussel species, but also on their differentiation and determination.

Fig. 1. The zebra mussel *Dreissena polymorpha* (Brümmer, F.)

Fig. 2. The quagga mussel *Dreissena rostriformis bugensis* (Brümmer, F.)

Changes in ecosystems under water are often unnoticed since they are hardly to observe. Since divers are some of the few people that have the possibility to observe changes in theses habitats it is important to develop citizen science projects also for SCUBA divers, so that they can participate in this new form of citizen participation in research projects and programs and make a further contribution to the protection and preservation of our aquatic environment.

Successful projects are for instance the mapping and expansion of neobiota in local lakes e. g. the jellyfish monitoring in Germany (Fritz et al. 2007).

Another excellent example is the project "Diving for Nature Conservation" which aims to build a strategic alliance between nature conservation and recreational divers in Germany and beyond to achieve improved protection of (clear-water) lakes. NABU (Nature and Biodiversity Conservation Union) and VDST (German Underwater Federation) developed and established a training program in botanical and ecological surveys underwater. This collaboration gives recreational divers an opportunity to explore lakes from a new perspective and enables them to contribute to the lakes' conservation by regularly monitoring water conditions and macrophyte levels. The project was the winner of the German Nature Conservation Award 2013 of German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN). Within this project, an app for smartphones was developed ("Tauch-App Wasserpflanzen") and an identification book for macrophytes ("Pflanzen im Süßwasser") was published (Oldorff et al. 2017), which is now one of the most used reference and key for macrophyte identification. Due to those successful projects and the fact that only little is known about the distribution of the quagga mussel in lakes in Germany the citizen science project was initiated.

Successful applications of citizen science projects are providing quite a lot of information on ecology, biology and distribution of specific species as well as taxonomic training e. g. of macrophytes or the (two) mussel species.

Methods

As part of the Citizen Science project "Monitoring of the invasive quagga mussel by recreational divers", a writable underwater identification and protocol board for divers was developed. This contains important information about the zebra and the quagga mussel as well as for logging the dive (Fig. 3).

In addition, the most important information on the biology and ecology of the quagga mussel was distributed in the form of a booklet "Quagga Wissen (Quagga knowledge)". This booklet was distributed in printed form at events, for example, but it can also be read in digital form online (https://www.yumpu.com/de/document/read/63010416/quagga-wissen).

The monitoring of the mussels was done as part of the recreational dives and in compliance with the usual safety standards for recreational divers and the diving waters.

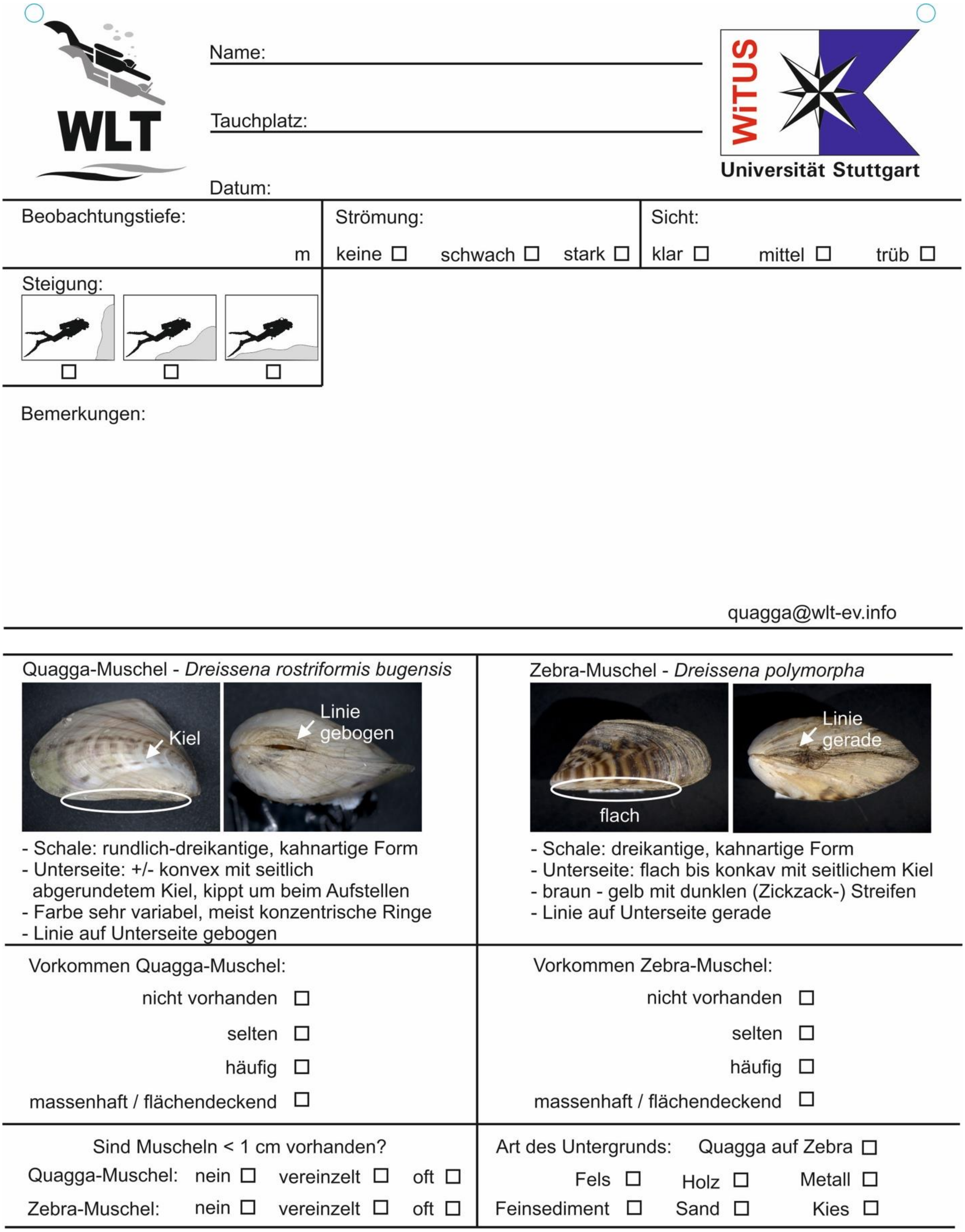

Fig. 3. The writable underwater identification and protocol board for recreational divers for monitoring the quagga and the zebra mussels: above: front; bottom: back side (Tersteegen, J.).

Fig. 4. The underwater protocol board in use: During the dive – here in Lake Cospuden - the recreational diver has the characteristics for distinguishing between the two Dreissena mussel species at hand on the board, finds a query of the most important parameters for the dive and can immediately record the observations directly underwater on the board. (Ramm, A.)

Results and Discussion

The Citizen Science Project by recreational divers to monitor two Dreissena mussel species resulted in many first observations of the quagga mussel in the diving lakes. Table 1 lists the divers' observations as well as the occurrences in lakes already described in the literature. However, this list does not claim to be complete.

Table 1. Current occurrences of the zebra mussel *Dreissena polymorpha* (Pallas, 1771) and the quagga mussel *Dreissena rostriformis bugensis* (Andrusov, 1897) in lakes in Germany as well as a few observations in the neighbouring countries Switzerland and France observed by recreational divers during the citizen science project or already described in the literature. (The table does not claim to be complete.)

Federal state or country	Location (original name in German)	Municipality	*D. polymorpha*	*D. rostriformis bugensis*	Date of Observation	Observed by divers/ (Described by)
Baden-Württemberg	Quarry Lake Giesen (Baggersee Giesen; Giesensee)	Dettenheim		occasional	27.05.2012	(Mrtens and Schiel 2012)
			occasional	frequent	27.11.2016	(Nesemann 2018)
Baden-Württemberg	Lake Constance Wallhausen	Wallhausen	frequent	widespread	27.05.2017	Vetter, W., Tersteegen, J. & F. Brümmer; WiTUS / Aldebaran
Baden-Württemberg	Lake Constance TGÜ Plätzle"	Überlingen	frequent	not observed	17.06.2017 02.09.2018	Vetter, W. & F. Brümmer; Vetter, W. & J. Tersteegen; WiTUS
Baden-Württemberg	Lake Constance Fischreiser ASV	Friedrichshafen	not observed	widespread	26.07.2018	Vetter, W. & F. Brümmer; WiTUS

Baden-Württem-berg	Lake Con-stance Argen estuary	Kressbronn	not ob-served	frequent	27.09.2018	Zintz, K., Univ. Hohen-heim & F. Brümmer, Univ. Stuttgart
Baden-Württem-berg	Lake Con-stance car park “Post”	Überlingen	frequent	widespread	06.01.2019	Rapp, L. & Tersteegen, J.
					14.08.2019	Genth, F. & F. Brümmer, WiTUS
Baden-Württem-berg	Lake Con-stance „Neuer Fischreiser“	Überlingen	not ob-served	frequent	20.07.2019	Vetter, W. & F. Brümmer; Wi-TUS
Baden-Württem-berg	Lake Con-stance	Nußdorf	occasional	widespread	30.05.2020	Genth, F. & A. Daul; WiTUS
Baden-Württem-berg	Quarry Lake Waidsee	Weinheim	occasional	not ob-served	25.06.2017	Tersteegen, J. & F. Brümmer; WiTUS
Baden-Württem-berg	Quarry Lake Giesen (Baggersee Giesen; Giesensee)	Dettenheim		occasional	27.05.2012	Martens & Schiel 2012
Baden-Württem-berg	Quarry Lake Matschelsee	Meißenheim	occasional	not ob-served	xx.06.2019	Andres-Brüm-mer, D., TC Uni Stuttgart Manatees
Baden-Württem-berg	Quarry Lake Deglersee	Plittersdorf	occasional	not ob-served	02.08.2019	Daul, A., Genth, F., Gräff, M. & C. Cornely; WiTUS
Baden-Württem-berg	Quarry Lake Giesen	Linkenheim-Hochstetten	occasional	occasional	15.08.2019	Daul, A. & F. Genth; WiTUS
Baden-Württem-berg	Quarry Lake Streitköpfle	Linkenheim-Hochstetten	occasional	occasional	15.08.2019	Tersteegen, J., Scholz, R., Gräff, M., Daul, A., Genth, F. & F. Brümmer; WiTUS
Baden-Württem-berg	Quarry Lake Burkheim	Burkheim	not ob-served	frequent	23.08.2019	Munzinger, P., Freiburg & F. Brümmer, WiTUS
Baden-Württem-berg	Quarry Lake Metzgerallmend	Untergrombach	occasional	frequent	09.2019	Hundshammer, R., Tersteegen, J. & S. Scholz
					01.2020	
Baden-Württem-berg	Quarry Lake Alte Allmend	Büchenau	not ob-served	not ob-served	11.2019	Trautmann, T., TC Amphiprion Sindelfingen
Baden-Württem-berg	Quarry Lake Apostel (Apostelsee)	Ettenheim	occasional	not ob-served	21.05.2020	Andres-Brüm-mer, D. & T. Plum; TC Uni Stuttgart Manatees
Baden-Württem-berg	Quarry Lake Bündwörth	Auenheim bei Kehl	occasional	not ob-served	30.05.2020	Duwe, S. & T. Huber; DUC Kehl
Baden-Württem-berg	Quarry Lake Schuttern	Friesenheim	not ob-served	frequent	01.06.2020	Bauder M. & H. Bauder; dufc Bietigheim-Bis-singen
Berlin	Lake Müggel (Müggelsee)	Treptow-Kö-penick	not men-tioned	observed	2011/2012	(Oldorff and Oldorff 2020)
Berlin	Lake Tegeler (Tegelersee)	Berlin-Tegel	not men-tioned	frequent	27.08.2013	(Müller et al. 2018)
Berlin	Lake Schlachten (Schlachten)	Steglitz-Zehlen-dorf	frequent	not men-tioned	2018	(Müller et al. 2018)
Berlin/Brandenburg	Lake Groß-Gli-enicker (Groß-Gli-enicker See)	Berlin-Kladow/Potsdam-Groß Glienicke	frequent	not men-tioned	2018	(Müller et al. 2018)

Brandenburg	Lake Werbellin (Werbellinsee)	Joachimstal	frequent	scattered to sporadic mass findings	2014 & 2015; 2017	(Müller et al. 2016) (Oldorff et al. 2018) (Oldorff and Oldorff 2020)
Brandenburg	Lake Werbellin (Werbellinsee)	Joachimstal	not mentioned	frequent	12.2019	Oldorff, S
Brandenburg	Lake Sechlin (Stechlinsee)	Neuglobsow	frequent	not observed	12.2019	Oldorff, S
Brandenburg	Lake Parstein (Parsteiner See)	Parstein	frequent	not observed	10.2017	(Oldorff et al. 2018)
Lower Saxony	Chalk-lake Hmmoor (Kreidesee Hemmoor)	Hemmoor	not observed	frequent	30.12.2019	Liebich, D.
Mecklenburg-Western Pomerania	Lake Drewitz (Drewitzer See)	Alt Schwerin	frequent	not mentioned	2016	(Zettler 2018)
Mecklenburg-Western Pomerania	Lake Schwerin (Schweriner See)	Schwerin	frequent	frequent	12.2019	Oldorff, S
Mecklenburg-Western Pomerania	Lake district Mecklenburg (Mecklenburgische Seenplatte Müritz, Kölpinsee, Schweriner See, Plauer See)	Waren, Klink, Appelburg a. o.	seldom	frequent	2014 & 2015	(Meßner and Zettler 2015)
Mecklenburg-Western Pomerania	Müritz	Waren	not mentioned	frequent	12.2019	Oldorff, S
Mecklenburg-Western Pomerania	Lake Boberow (Boberowsee)	Fürstenberg/Havel	observed	not observed	12.2019	Oldorff, S.
Saxony	Hasenbruch	Röcknitz	seldom	not observed	20.11.2020	Ramm, A.
Saxony	Lake Markkleeberg (Markkleeberger See)	Leipzig	seldom to frequent	not observed	24.03.2021	Ramm, A.
Saxony	Quarry Klein Ammelshain (Kleiner Ammelshainer Steinbruch)	Naunhof	seldom to frequent	not observed	26.03.2021	Ramm, A.
Saxony	Quarry West Brandis (Westbruch Brandis)	Waldsteinberg	seldom to frequent	not observed	28.03.2021	Ramm, A.
Saxony	Lake Cospuden (Cospudener See)	Leipzig	seldom to frequent	widespread	02.04.2021	Ramm, A. & Trassat, R
Saxony	Artificial post-mining lake Werben (Werbener See)	Pegau	seldom to frequent	not observed	27.04.2021	Ramm, A.
Saxony	Quarry Wildschüütz (Steinbruch Wildschütz)	Mockrehna	frequent	not observed	27.10.2019	Liebich, D.
Saxony	Quarry Sparmann (Steinbruch Sparmann)	Kamenz	seldom	not observed	09.11.2019	Liebich, D.
Saxony	Quarry Lake Förstergrube	Sandersdorf	frequent	not observed	10.06.2019	Tersteegen, J., Brümmer, F. & Genth, F.
Saxony	Quarry Haselberg	Naunhof	seldom	not observed	12.06.2019	Tersteegen, J., Brümmer, F. & Genth, F.
Saxony	Artificial post-mining lake Kulkwitz (Kulkwitzersee)	Leipzig	yes	frequent	13.06.2019	Weiß, J., Brümmer, F., Genth, F. & Tersteegen, J.
Saxony-Anhalt	Artificial post-mining lake Geiseltal (Geiseltalsee)	Mücheln	frequent	not observed	10.06.2019	Pinter, S., Genth, F. & Tersteegen, J.
Saxony-Anhalt	Artificial post-mining lake Frose (Froser See)	Aschersleben	widespread	not observed	11.04.2021	Ramm, A.
Saxony-Anhalt	Artificial post-mining lake	Gräfenhainichen	frequent	not observed	26.04.2021	Ramm, A.

	Gremmin (Gremminer See)					
Saxony-Anhalt	Quarry Löbejün (Löbejün Taucherkessel 1)	Wettin-Löbejün	seldom	widespread	14.06.2019	Tersteegen, J., Brümmer, F. & Genth, F.
Saxony-Anhalt	Quarry Löbejün (Löbjün Taucherkessel 3)	Wettin-Löbejün	widespread	not observed	06.08.2019	Brümmer, F.
France	Lake Gravière du Fort	Holtzheim, FRA	seldom	frequent	29.06.2019	Knapp, M.
Switzerland	Lake Constance Wreck of the paddle steamer JURA	Bottighofen, CH	not observed	occasional	02.2019	Weltz, K.-H., Tauch-Sport-Club Friedrichshafen; (Brümmer et al. 2020)

The spread of the quagga mussel with shipping traffic from the Danube via the Main-Danube Canal in the Main, Rhine and North German shipping canals to the Elbe and other river systems has already been impressively illustrated elsewhere (Schöll et al. 2012).

Usually, the Dreissena species can be distinguished by the colour by the siphons: The zebra mussel has white to transparent siphons, the quagga mussel has black siphons (see Fig. 1 & 2). In different lakes, such as Lake Constance or the quarry lake Metzgerallmend, during the citizen science project, an orange-coloured variation was observed (Fig.5.). And in contrast to the zebra mussel, two phenotypes are described for the quagga mussel, one of which (profunda form) has a clearly longer ingestion siphon (Fig. 6), which was also observed in different lakes by the recreational divers.

Fig.5. A bicycle completely overgrown with quagga mussels; Lake Cospuden, May 2021. (Ramm, A.)

Fig. 6. Observation of an orange-coloured variant of the quagga mussel; Lake Constance. (Brümmer, F.)

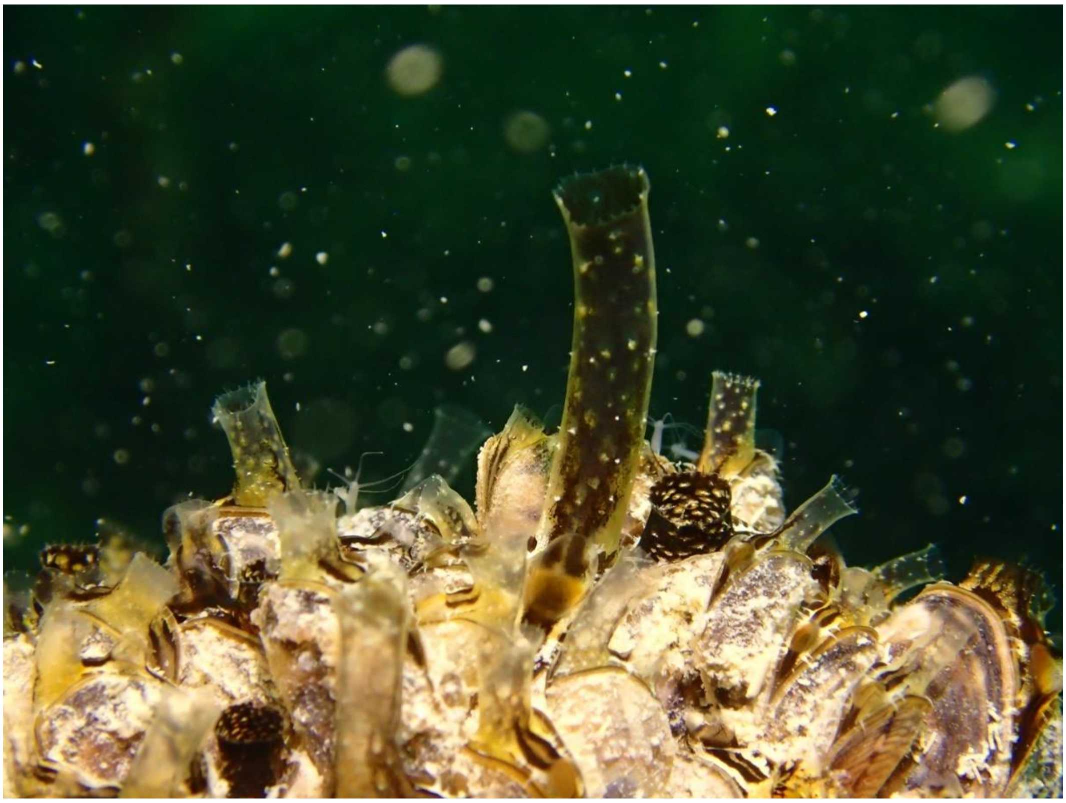

Fig. 7. In contrast to the zebra mussel, two phenotypes are described for the quagga mussel, one of which (profunda form) has a significantly longer ingestion siphon; Lake Constance (Brümmer, F.)

Conclusion

A writable underwater identification and protocol board for recreational divers was developed as part of the Citizen Science project "Monitoring of the invasive quagga mussel by recreational divers".

These boards turned out to be very helpful and easy to use. They can be conveniently stored in the outer pockets of the diving suits and are easy to write on with pencils. With the information on the underwater identification boards and further "quagga knowledge", the divers were able to recognise, observe more closely and distinguish between the Dreissena species during the dive. The knowledge that two very similar looking mussel species exist was missing until now and could be provided by the developed information media. Through the resulting reports, a first impression of the distribution of the quagga mussel in Germany could be gained in relation to the diving waters.

The quagga mussel (*D. rostriformis bugensis*) in Lake Constance shows very impressively how quickly it has spread since the first observation in 2016: In the meantime, it has conquered the entire shallow water zone of Lake Constance. At every dive site, the quagga mussel has been observed in large quantities and also frequently covering the entire area. And even on some shores and beaches, large quantities of mussel shells testify to the extreme reproduction.

Further data due to the engagement of the divers for a number of diving lakes in Germany also shows how quickly the quagga mussel has spread in recent years.

At this point it should be pointed out that we as divers should also be careful. It is important to contain the further spread of these invasive species. Every diver can contribute to this.

With the help of adhesive threads (byssus), the quagga mussel attaches itself everywhere, also to water pipes and filter systems, and thus also gets into other waters, e.g. stuck to ship hulls! But it also appears possible through diving equipment. So, if you use your diving equipment in different waters, you must clean it carefully and thoroughly, check it and let it dry. This is the only way to reduce the risk of invasive animal and plant species being carried off by us divers.

Acknowledgement

We would like to say a big thank you to all divers for their great commitment and the numerous feedbacks on the distribution of the two mussel species.

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ARPA PUGLIA Underwater Scientific Activities: ESDs Contribution in the ADRIREEF project (Interreg Italy-Croatia 2014-2020)

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Abstract. The ADRIREEF project, financed by the Interreg Italy-Croatia 2014-2020 Program, is aimed at the sustainable exploitation of natural and artificial reefs along the Italian and Croatian Adriatic coast according to the Blue Economy principles. The project partner ARPA Puglia, with its Scientific Divers team, has identified as study case the Torre Guaceto Marine Protected Area; in the zone "C" of the MPA was selected a bank-type coralligenous (biogenic) reef. Not destructive methodologies such as visual census of fish community and photographic surveys of benthic species were performed for a biological characterization of the reef, collecting an adequate number of videos and photos. The results of the surveys may contribute to improve the knowledge of biodiversity in the area and to promote the sustainable use for underwater tourism. The material collected will be useful for the creation of innovative promotional outputs.

Introduction

The ADRIREEF project, started in 2019, is financed by the Interreg Italy-Croatia 2014-2020 Program, with the aim to promote the sustainable exploitation of Adriatic reefs along the coast of the two Countries. In order to strengthen the Blue economy development through the attractiveness of the existing marine resources, both natural and artificial reef were considered. Reefs are attractive for the scientific community and for tourism because it is possible to practice and develop several activities such as scientific studies, fishing or nautical tourism, diving and sustainable aquaculture. In particular, the project aims to satisfy the specific need of a territorial development transferring the knowledge acquired from research to business. Through an in-depth analysis of the Adriatic reefs and a specific monitoring phase, testing also new environmental methods, it will be possible for the project partner to define Guidelines and Code of conduct for the Stakeholders and to produce innovative promotional outputs.

With the term "Artificial reef" are identified all the human-created underwater structure designed for a specific role and submerged for different scope, for example to restore and/or enhance fish and others organism communities of an area (i.e. concrete reef, shipwrecks), and at the same time to create new diving opportunities.

Natural reefs are all the relatively stable material resulting from natural, abiotic (i.e. ridge or shoal of rock) or biotic process (i.e. coral reef). In terms of biodiversity, Mediterranean Sea coralligenous bioconcrection could be compared with tropical coral reef because of the greater spatial complexity created by bioconstruction leads to the creation of numerous microhabitats that determine an increase in biodiversity. In fact, coralligenous habitat is considered the second most important subtidal "*hot spot*" of species diversity in the Mediterranean Sea after the *Posidonia oceanica* meadows (Boudouresque 2004). It is defined as a typical Mediterranean hard bottom of biogenic origin, mainly produced by the accumulation of calcareous encrusting algae, that can be colonized by other sciaphilic organisms, forming an intricate assemblage of species able to transform it in a multidimensional habitat with a high micro-spatial variability (Ballesteros 2006). For the numerous associated environmental and biological advantages provided by this habitat, it has been included in the Habitat Directive (EEC Reg. 1992/43, Annex I; Habitat code: 1170 Reefs) and more recently monitored as stated by the Marine Strategy Framework Directive (EC Reg. 2008/56). Coralligenous bioconstructions could build ups into two main different geo-morphologies: rims-structures on submarine vertical cliffs and banks-flat frameworks over horizontal substrata (Pérès and Picard 1964; Laborel 1987; Ballesteros 2006, Bracchi et al. 2014). The Apulia continental shelf are characterized mostly by the second morphologies that develops on a horizontal substratum, small coralligenous outcrops distributed between 30 and 100 m of depth on coarse detritic or muddy bottom (Piazzi et al. 2019). This kind of bioconstruction, correspond to the so-called bank-type coralligenous biogenic reefs. Chimienti et al. (2017) give a first economic value to the apulian's coralligenous habitat that attracts divers at national and international level, besides local customers, due to its high aesthetic value as a seascape. Considering SCUBA diving frequentation in the Apulia region and the generated revenue related to the existence of this habitat, a market impact of about €4.7 M in 2014 was estimated through a survey questionnaire distributed to diving centers across the region (Chimienti et al. 2017). Thus, in a project as ADRIREEF, where the emphasis would be given also to recreational diving activities, such as SCUBA diving, and the potential economic flow inside a region coming from natural reefs, coralligenous habitat is an important reef to focus.

To promote the sustainable use of an area, it is of primary importance to understand its carrying capacity in terms of different economic activities associated. To this aim, a continuous monitoring activity and assessment of the ecological status of the reef is essential.

Following the environmental monitoring goals of the project and taking into account the restrictions present inside an MPA, different non-destructive technologies and methods are preferable. Numerous non-destructive underwater methods are standardized by the scientific community, ARPA Puglia scientific divers (SD) team applicated several methods for the biological characterization of the reef, such as photographic samplings of standard areas frame and Stationary Point Count method.

Materials and methods

Study case

As a project partner, ARPA Puglia identified as study case the MPA (Marine Protected Area) of Torre Guaceto.

The Torre Guaceto MPA was formally established in 1991, but entered into force in 2001. The total surface of MPA is around 2227 ha and it is divided into three different protection degree zone according to the Italian law: two A zones (no-take/no-access zones, where any fishing is banned and access forbidden except for the MPA's staff, scientists and police forces e.g. coast guard); one B zone (the general reserve zone, where access is permitted, i.e. swimming, but fishing banned); one C zone (the partial reserve zone also called 'buffer zone' as it is the true buffer towards the exterior of the MPA, where access and regulated navigation are permitted) (Fig.1). The coast, mainly rocky with pocket beach, is characterized by a sloped rocky plateau, declining from the water surface to ~10–12m depth over coarse sand. Rocky bottoms alternate with sand and *Posidonia oceanica* meadows.

From about 25 to 35–40m depth, coralligenous outcrops formations alternate with sand and at deeper stands sandy–muddy bottoms widely dominate (Guidetti et al. 2010).

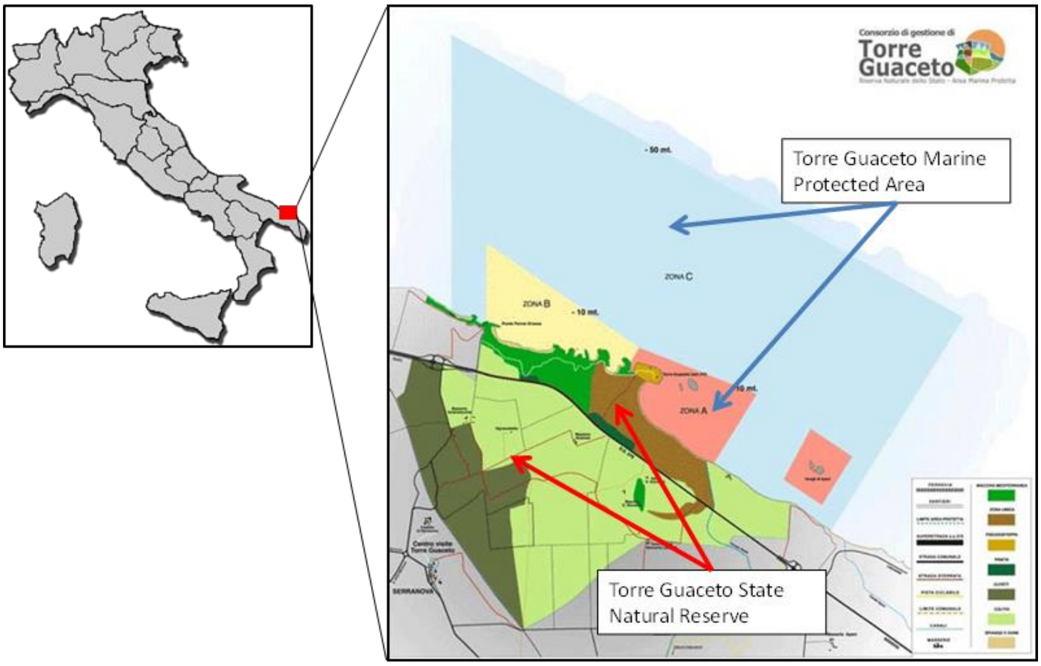

Fig.1. Marine Protected Area of Torre Guaceto and Torre Guaceto State Natural Reserve (http://www.parks.it/riserva.marina.torre.guaceto/mapl.php).

Most of the Apuglia Region coralligenous reefs were mapped and classified by the BIOMAP Project (BIOcostruzioni MArine in Puglia), promoted by Puglia Region, as a part of the program "PO FESR 2007/2013 – AXIS IV – line 4.4: intervention for the ecological network". In particular, for the specific area of the Case Study, the BIOMAP project identifies four subtypes of coralligenous habitat (Fig.2).

On the basis of the BIOMAP Project cartography, that allowed ARPA Puglia scientific divers (SD, team of the Regional Sea Center – CRM of the Agency) to understand where the coralligenous outcrops were located, the information achieved during the past year of ARPA Puglia's monitoring activities and the knowledge of the MPA's staff, three sites have been investigated during a pre-survey (Fig.2). Presence/absence of coralligenous assemblage exploratory assessment has been achieved in three days (28-29-30/08/2019) with the effort of four SD from ARPA Puglia - CRM and one diver from Torre Guaceto MPA. During these pre-surveys several photos and videos have been collected.

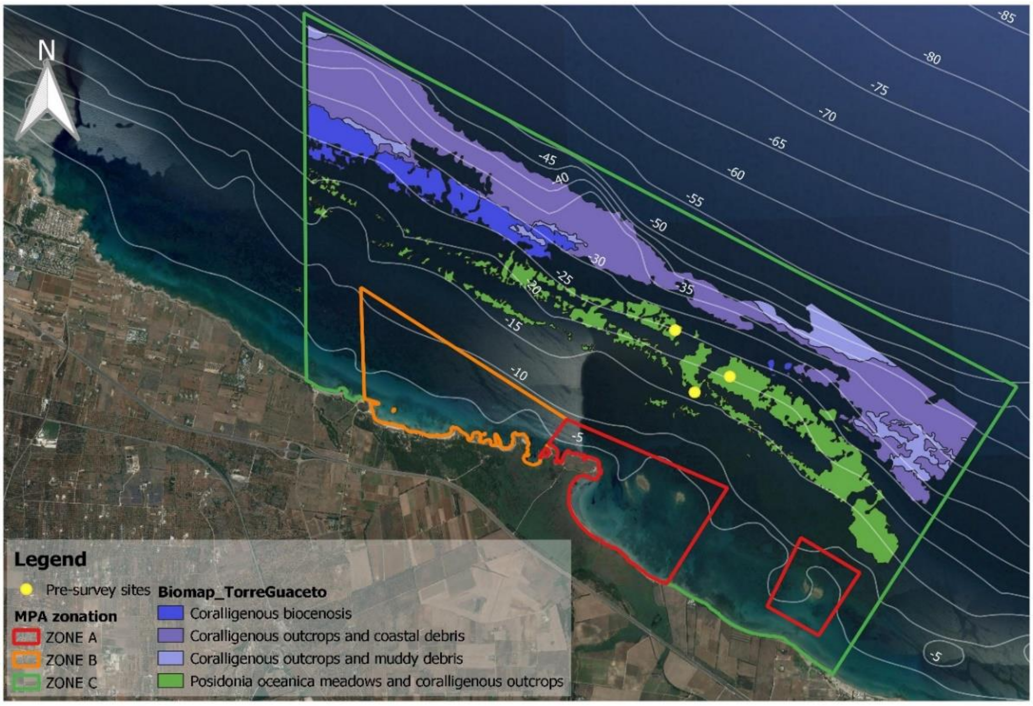

Fig.2. Marine Protected Area of Torre Guaceto, boundaries of protection regime, Coralligenous reefs classification from BIOMAP Project and Pre-survey sites.

After the preliminary phase, a bank-type coralligenous biogenic reef was identified (Fig.3). This reef is located 2 km far from the watchtower, following a route of 60 °. It is north-south oriented, it lay on a bathymetry of 27 m depth and its top is at 24 m depth, with a discontinues vertical wall of 3-4m on the east side. Three sampling sites have been identified at the north, central and south-side of the reef at a distance of 50 m from each other (A, B, C sampling sites).

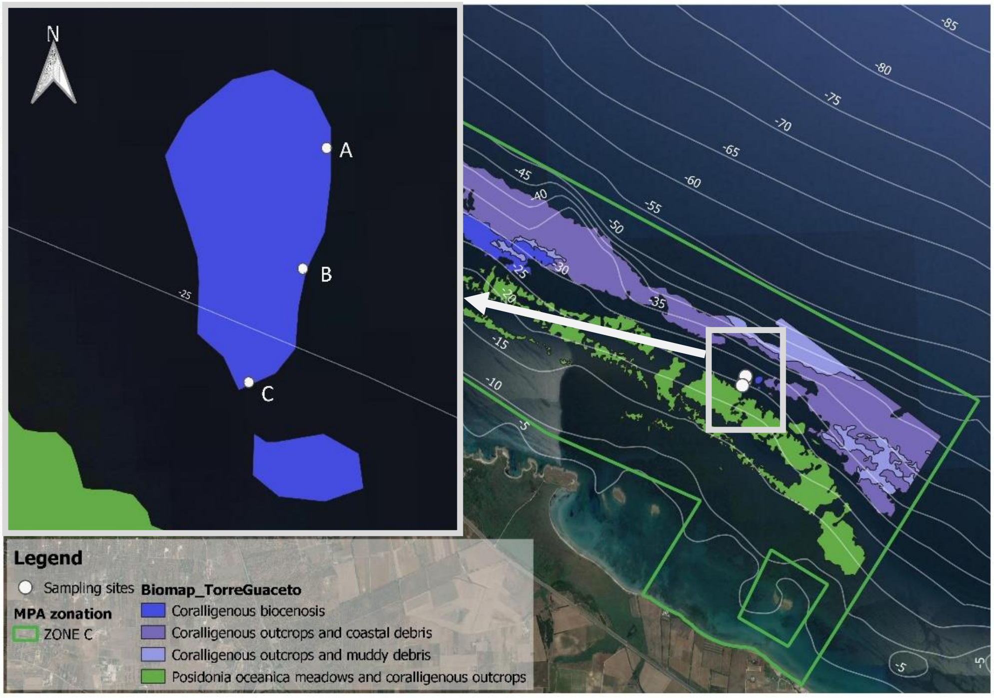

Fig.3. Marine Protected Area of Torre Guaceto, boundaries of protection regime, Coralligenous reefs classification from BIOMAP Project and Survey sites (A, B, C).

To deepen the morphological knowledge of the study area, a Digital Elevation Model (DTM) in raster format was developed. The attribute relating to the absolute quota has been associated with each pixel, the digital files have been provided by the Department of Earth Sciences and Geoenvironmental University of Bari. The DTM was subsequently managed with GIS software (Q-GIS ver. 3.16.0-Hannover) through which it was possible to extract the isobaths with an interval of 1 meter (Fig.4). The reef shape is elliptical and oriented to north-south gradient. The estimated total surface of the reef is about 6.700 m², its perimeter is about 350 m and the longest axis is about 140 m.

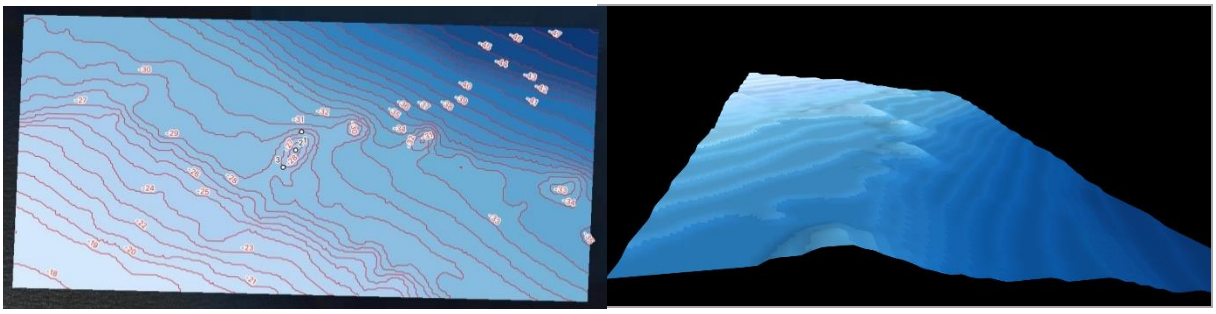

Fig.4. JPG file elaborated with Q-GIS software, the DTM and the isobaths. File source: DTM Cartography – Dip. Sc. della Terra e Geoamb. -UniBA.

Methods

To describe the benthic community status, a photographic samplings of standard areas frames was performed, to describe the fish community, a Stationary Point Count method was chosen.

To date, 3 scientific monitoring surveys were achieved and data from the benthic community and fish assemblage were collected: the first one was done in autumn 2019, the second in summer 2020, and the third in autumn 2020.

Benthic community settled on the reef: Photographic Samplings of Standard Areas Frames

To assess the benthic community status a stratified sampling design was performed with a photographic sampling of standard areas frames method.

The factors considered in the sampling design are:

- north-south gradient: A, B, C sampling sites;
- inclination: Horizontal (H) and Sloped (S) faces through the east side vertical wall.

A transect of 100 m was deployed in the east side of the reef, close to the lateral vertical wall, in order to allow the scientific operator to easily move between the two faces.

The photographic sampling was performed in each site recording 3 photos by each level of factor, meaning a total of 18 (3 sampling sites * 2 inclination factor * 3 replicates) replicates collected on each survey.

To date, during the 3-sampling survey performed, a total of 54 photos sampling were collected.

The photos were recorded with a Sony RX-100 VI camera equipped with underwater housing (FantaSea) and underwater lighting systems (a SEA AND SEA YS-01SOLIS flash and a SUPE PV32-T Light mounted on Flex-Arm).

A Dive buoy was equipped with a GPS Garmin Oregon 600 and it was carried out by the diver during the sampling activity in order to georeferenced the photos with Geosetter software (Fig.5).

The sampling surface area was defined thanks to a square of 21*29 cm.

photoQuad v1.4 is the Image Analysis Software chosen (Fig.6) and the grid cell counts methods was followed (V. Trygonis & M. Sini, 2012).

Moving through the A, B, C sampling sites a visual census of ASPIM species were carried out by divers along a belt-transect of 100m of length x 2m wide, at the same time several videos were collected. To follow the aim of the project, data of the presence/absence of species of underwater interest were also collected. All the information collected from the operators and from the videos were reported in an excel file (Fig.6).

Fig.5. An ARPA Puglia - CRM SD during the photographic sampling survey.

Fig.6. GPS Garmin Oregon 600 tracks with the georeferenced photos (https://geosetter.de/en/main-en/).

Fish assemblage: Underwater visual census

In order to describe the fish community in terms of species composition and abundance, different methodologies based on different sampling techniques are enforced. These can be distinguished into trapping methods, mixed methods and non-trapping methods.

For this study, in an MPA, ARPA Puglia - CRM SD chose to use one of the non-trapping study methods: the visual census. Specifically, the sampling technique applied was the "fixed station" and therefore the Stationary Point Count method, applied during diving operations. The SCUBA activity involved the diving of 3 underwater scientific operators contemporary on the three fixed monitoring stations identified (A, B, C sampling sites), selected at a constant distance between them, as previously reported (Fig.7). They have been chosen not only for biological characteristics (presence of species, abundance, biodiversity, etc.) but also in compliance with geo-morphological ones (presence of canyons, height and particular conformation of the reef) and hypothetically attractive features for recreational scuba divers. Furthermore, these stations fully satisfy the provisions of the monitoring method: geographical exposure (north-south gradient) and aggregation effect of the natural reef (different levels of irregularity and morphology of the coralligenous habitat).

Data collection consists in gathering all the recognized fish species and their relative size class (0-10; 10-20; 20-30; 30-40; 40-50 cm), within a visual radius of at least 5 meters, on physical or digital support (in this case pvc tablet and pencil). The total time dedicated to the census is 5 minutes for each direction of the four cardinal points, for a total of 20 minutes. As a consequence of the presence of 3 divers operating at the same time, the total amount dedicated to the UVC is 60 minutes. The observation time of 20 minutes per station has been evaluated based on the operating depths and in compliance with no-stop dives, even if it does not exclude that more lasting observations can be carried out through special programming.

Innovative integrated monitoring systems of abiotic and biotic descriptors through the use of technologies with low environmental impact is one of the project goals. In this regard, the underwater visual census was also conducted by a ROV (Remote Operative Vehicle) equipped with digital video and cameras mounted in stereo configuration. The purpose of a combine use of SD and ROV is to test new environmental monitoring methods as required by the project. In this way it will be possible to verify the effectiveness of the method and to compare and eventually to validate the data collected by the divers and by the ROV.

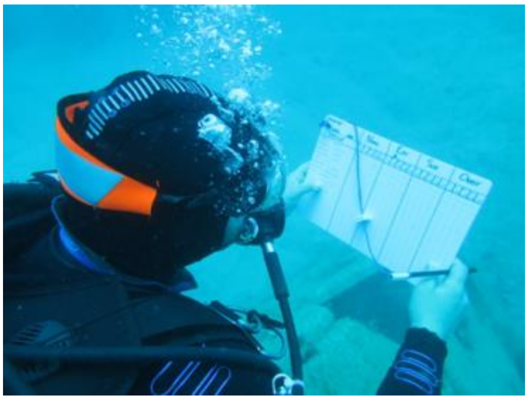

Fig.7. An ARPA Puglia SD during the underwater visual census survey.

Results and Conclusion

The data collection and the whole project is still in progress, therefore the data collected during the first operational phases can be illustrated and discussed.

At first, fundamental was the analysis of the maps and the cartography of the seabed, so graphical rendering of reliefs with multibeam and side scan sonar were very useful for identified the number of hypothetical stations with a relevant bank-type coralligenous bioconstructions. The reef, that falls into the “C” zone of the MPA so under relatively low level of protection, could be used both as a reference point to enlarge the knowledge of this kind of coralligenous formation but also as an example of how potentially implement some activities, such as diving, in an environmentally sustainable way.

The preliminary study has therefore made possible to reduce the number of dives in the pre-survey phase and therefore carry out a very targeted action, always considering the objectives of the whole project. Once the relevant bioconstruction was identified, the DTM cartography allowed the ARPA Puglia-CRM SD team to plan with accuracy the subsequent diving surveys for the monitoring phases.

The analysis of the 54 photos sampling collected on the benthic community revealed a total of 57 different taxon identified. The most representative phylum is the Rhodophyta represented mostly by Peyssonnelia and Mesophyllum genus, the two Corallinaceae algae considered the principal builders of the coralligenous reef. Filamentous Algae (AF), the so-called Turf, are wide recognized in the area. Porifera is the third most frequent phylum in the reef represented by 22 different taxa. Mostly of them are erected species, as *Axinella cannabina*, *A. damicornis* or *A. polypoides,* that could attract the diver curiosity. Different erected briozoa have been identified also, such as *Myriapora truncata* and *Pentapora fascialis*. Into the cnidaria phylum, the most interesting recognized species for divers are *Parazoanhus axinellae* and *Leptopsammia pruvoti* (Fig.8).

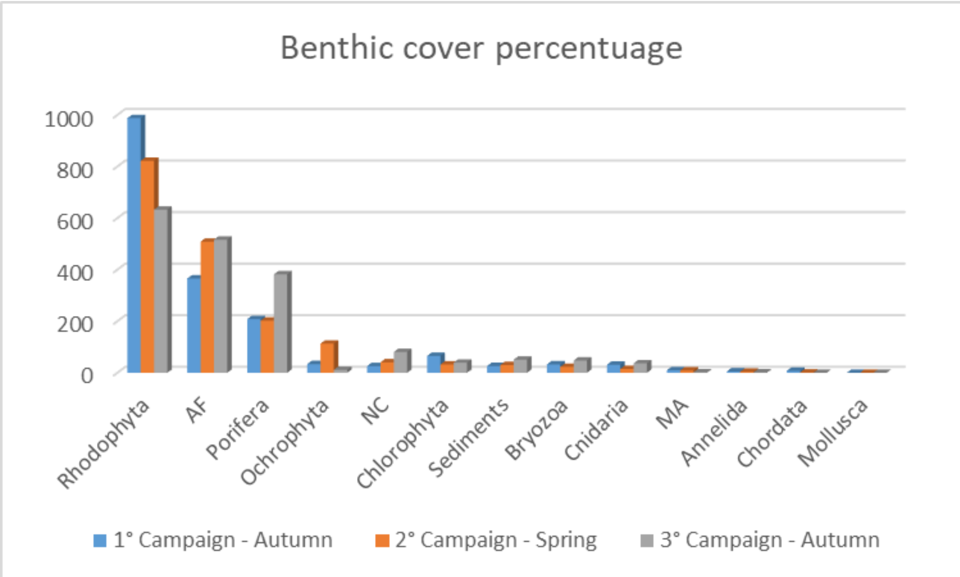

Fig.8. Benthic cover percentage of coralligenus reef over the 3 sampling campaigns. AF= Filamentous algae; NC=Not classified, MA=Mucilaginous algae

The number of taxa identified between the three stations does not differ significantly suggesting that the North-south gradient could not affect the difference in species, but is still missing the data of the last campaign. Some differences were identified between the slope gradient with a major number of taxa on the vertical face. The only alien species recognized was the green algae *Caulerpa cylindracea*. Moreover, 17 ASPIM species were identified: *Axinella cannabina, Axinella polypoides, Cladocora caespitosa, Hippospongia communis, Paracentrotus lividus, Sarcotragus foetida, Spongia agaricina, Spongia officinalis, Caryophyllia (Caryophyllia) smithii, Eunicella singularis, Eunicella cavolini, Leptopsammia pruvoti, Myriapora truncate, Muraena helena, Phorbas tenacior, Reteporella grimaldii, Sabella spallanzanii.*

Regarding the visual census about the ichthyofauna, the results obtained confirm the stability of the environment; in fact, both sedentary and seasonal species have been found as them expected (see at the Fig.9). For all the species found, different size classes were recognized, thus also highlighting a "like-normal" length distribution curve for the investigated fish populations, indicating a not (or poorly) disturbed biological community.

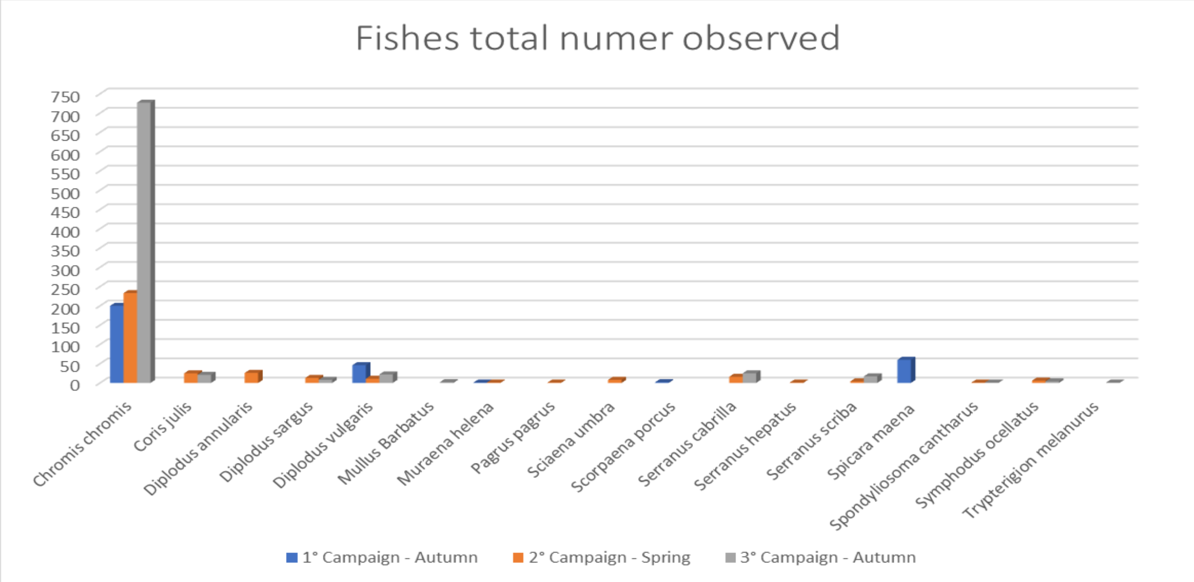

Fig.9. Numbers of fish identified during the campaigns.

During the visual census surveys any alien fish species was identified.

Regarding the use of ROV during the fish community visual census, at least in these first surveys some critical issues have been highlighted, for example the disturbance by both the electric engines (noise) and the lights of the ROV; in fact, using ROV the fishes get scared and have the tendency to move away or keep away. Therefore, in the case of scarce visibility, the risk of underestimation or losing some information on fish species presence is very high.

The same disturb take place also when a scuba diver descend in the water column, but only until the stabilization of diver position on the bottom; in any case, the impact of the diver with his bubbles appears to be lower with respect to the ROV. Probably, some forethought such as the camouflage of the ROV, as well as its painting with neutral colors, could be effective to improve data collection.

Anyway, the definition of the most appropriate monitoring methodologies could provide insights useful for the best management and study of these important marine habitats.

Acknowledgements

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Assessment of marine biodiversity in a protected bay: the importance of integrated methods for a better result

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Abstract. Like other Mediterranean Marine Protected Areas, Punta Campanella MPA (Italy) is undergoing some significant changes in biodiversity. To properly understand the situation and to depict a valid baseline, several monitoring campaigns have occurred to assess biodiversity in Ieranto Bay, a special zone B of the MPA that allows the sustainable interaction between humans and nature. This work aims to analyze the different monitoring methods used and how each of them has contributed to the assessment of more than 250 species in the bay, from algae to vertebrates. The results represent a substantial biodiversity baseline of data to assess eventual changes in the future, and a valid tool to inspire and suggest management plans. The census of underwater life in this protected bay is an ongoing and constant activity and is an experience of collaborative research involving experts and volunteers supervised by the MPA staff.

Introduction

The Mediterranean Sea is a marine biodiversity hotspot, contributing to more than 7% of the world's marine biodiversity (Coll et al. 2010). In the last years, worldwide biodiversity has been decreasing at an unprecedented and alarming rate due to several human impacts (United Nations 2019). To preserve nature, many Protected Areas (PA) have been created. A PA is defined as a geographically limited area, which is designated, regulated, and managed to achieve specific conservation objectives (Dudley and Stolton 2008). It has a fundamental role in protecting species and habitats from extinction and in supporting the natural ecological processes (Naughton-Treves et al. 2005), controlling the impacts, and trying to slow down the extinction process.

More recently, Mediterranean marine habitats and their managers have had to adapt to changing environmental conditions, requiring practical efforts to keep a climate-conscious design operational and management in the global network to ensure long-term effectiveness for safeguarding biodiversity and ecosystems (Tittensor et al. 2019; Azzurro et al. 2020). Due to the importance of monitoring wildlife and ecosystems in the last few decades, a big effort is being done to assess the environmental status (Molnar et al. 2008; Meola and Webster 2019; Azzurro et al. 2019).

Ieranto Bay

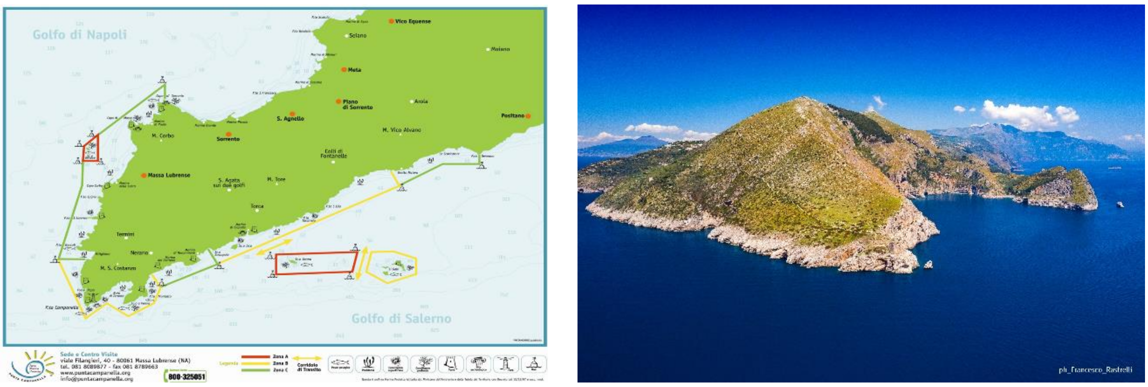

Fig.1. Punta Campanella MPA map with Ieranto Bay area signalized by the black shape (left) and view of Ieranto Bay (right – photo by Francesco Rastrelli).

The Marine Protected Area (MPA) of Punta Campanella (Fig.1 – left) is located between two important gulfs, the Gulf of Naples and the Gulf of Salerno. It was established in 1997, spanning an extension of 31 km with a total area of 1539 ha. The MPA is divided into the following 8 areas with descending levels of protection: 2 red areas (zone A) just for nature with no human presence; 3 yellow areas (zone B) where regulated human presence is allowed; and 3 green areas (zone C) with a larger human presence. In the middle of this MPA, in a zone B, lies Ieranto Bay, the heart of the Punta Campanella MPA (Fig.1 – right).

Ieranto Bay is located on an internationally popular tourist route between Sorrento, Capri, and the Amalfi coast and it is a renowned diving spot, as it presents high marine biodiversity. Until the foundation of the park in 1997, it was considered the perfect place for boat tourism due to its sheltered position, with hundreds of vessels anchored every day on the seagrass meadow (*Posidonia oceanica*) (pers. obs.). Today, the bay has two special measures of conservation: 1 – professional fishing is allowed only for 8 months per year – not allowed during summertime; 2 – the entrance of motorboats is not allowed, except for authorities and authorized guided tours.

To gather information about the bay and to protect it from boating, anchoring, and illegal fishing, the Punta Campanella MPA has developed a pilot management model (Fig.2) that is composed of 3 interconnected key actions: Monitoring, Conservation, and Communication (Sgambati et al. 2020). Despite their connection with each other, monitoring is the most important action. As reported by Vierros (2004), the correct application of adaptive management strongly depends on monitoring.

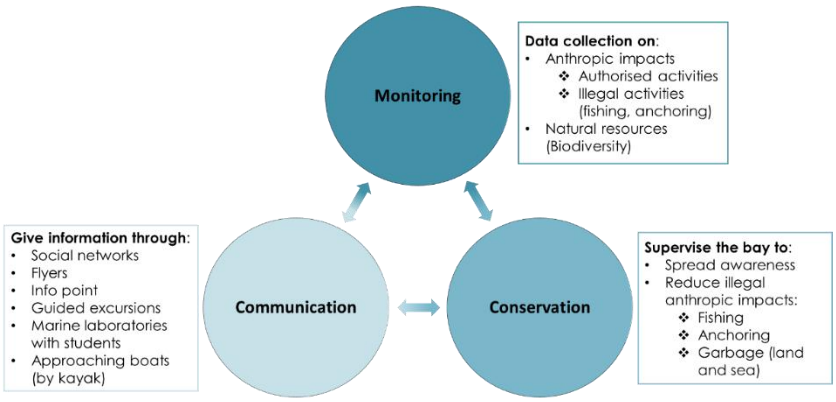

Fig.2. Punta Campanella MPA management model applied to Ieranto Bay.

Following the application of this model, the volunteers of Project M.A.R.E. (https://www.marineadventures.org/en/), an European Voluntary Service project that is funded by the European Commission through the European Solidarity Corps program and coordinated by the Punta Campanella MPA, have been running an assessment of the biodiversity in Ieranto Bay since 2015. This underwater life census is an ongoing and continuous activity and is an experience of collaborative research, involving local experts and foreign volunteers supervised by the MPA staff to explore and discover the biodiversity in the bay. These data will support future conservation plans, taking into account the challenges that conservation poses in this stretch of sea with a high population density and tourist presence.

Marine Biodiversity Assessment

According to MMMPA Supervisory Board 2016, all monitoring activities have numerous variables to consider when an assessment is being planned. Monitoring is needed to ensure the goals and objectives of the MPAs, but the methods are highly variable depending on what they measure, who performs it, and where, when, and how it occurs. They must be personalized and include good baseline data, robust indicators, and control sites.

The techniques used to run a monitoring activity can be "traditional" (e.g. visual census, video/photo sampling, genetic tools, etc.) or can be from emerging interdisciplinary fields (e.g. georeferred biocartography, genetic connectivity, biogeochemistry, etc.) (MMMPA Supervisory Board 2016). More recently, scientists have been taking advantage of citizen involvement and collaboration of sea users to collect useful scientific data (Preece 2016; Azzurro et al. 2019).

Ieranto Bay extends for approximately 51 ha with the following specific natural characteristics that provide valuable, complex, and mixed habitats:

- The presence of strong upwelling currents (De Alteris; de Ruggiero et al. 2016) – bring inorganic nutrients into surface waters, which result in some of the most productive marine ecosystems worldwide. They are important for organisms that rely on abundant phytoplankton and zooplankton food resources (e.g. sardines, anchovies, and mackerel) (Anderson and Lucas 2008);
- N-S orientation – provides different shadow-light expositions in a small area;
- A vertical underwater cliff, close to the Southern coast of the Sorrento Peninsula, located at the edge of the continental shelf (Ferrigno et al. 2018) – the cliff gives substrate to sessile organisms and shelter to organisms depending on the rocky environment;
- The presence of canyons and caves accessible with snorkeling.

Due to these characteristics, the bay has a mixture of benthic organisms (which live along the jagged coast and on the seabed covered with *Posidonia oceanica*) and pelagic organisms that are transported within the bay, with resident and occasional species.

According to Edgar et al. 2014, "global conservation targets based on area alone will not optimize protection of marine biodiversity. More emphasis is needed on better MPA design, durable management, and compliance to ensure that MPAs achieve their desired conservation value".

This work aims to build a solid biodiversity baseline of data from Ieranto Bay. Different monitoring methods are considered and evaluated based on their contribution to the overall assessment of marine biodiversity. These results are important to set a standardized protocol and apply it in other MPAs. The data collected has the important role of being the reference for future assessments, analyzing the changes that are occurring through the next years.

Methods

The performed underwater monitoring campaigns are in the framework of a long-term monitoring program started in 2012 and are based on different and complementary methods putting together standardized protocols, random punctual observations, fishermen, and citizen science records. This section focuses on the 7 different methods used during the 8 underwater monitoring campaigns realized between 2015 and 2020 (Table 1) inside the approximately 5 ha that cover the two bays: the big (A) and the small (B) bay (Fig.3).

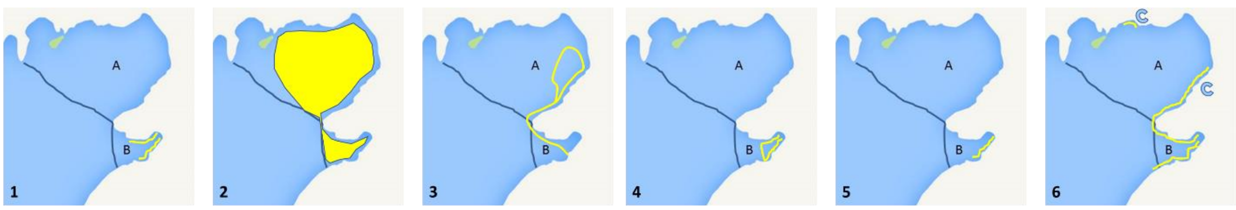

Fig.3. Maps with the transects (yellow line) performed each year for each method. A = Big bay; B = Small bay. 1 – 2015 and 2019 (Algae); 2 – 2015 (Fish) area where the 8 transects were performed; 3 – 2016 and 2017; 4 – 2018; 5 – 2019 (Animals); 6 – 2020 with the blue C representing the caves.

Table 1. Description of the 7 different methods used during the 8 underwater monitoring campaigns completed between 2015-2020. (all the methods using snorkeling took place from the surface down to a depth of 2-3 m and the ones using scuba diving down to 5 m) *the method used in 2016 is the same as in 2017. Total species (TS) = total censed species; Added species (AS) = species added to the species database in respect to the previous year and monitoring methods (new records for the study area). FVC = Fish Visual Census; BTA = BlueTeam in Action; SN = Snorkeling; SD = Scuba diving; DS = Destructive sampling; PS = Photographic sampling.

Year	*Focused group*	*Number of observers*	*Total transect (m)*	*Apparatus*	*Specifics*	*Species identification*	*Season*	*TS*	*AS*
2015	Algae	2	180	SN	-	DS	Summer	24	24
A total transect of 180 m was performed through the rocky walls of the small bay, by snorkeling, to collect samples of algae for a post-identification with microscope, id manuals, and experts.									
2015	Fish	1	100*8=800	SN	FVC	*in situ*	May + October	23	23
Eight transects of 100 m were made in 10 minutes, swimming at a constant velocity to observe the fish around the swimmer, covering a radius of 2.5 m (Azzurro et al. 2020). The fish were identified when they were observed.									
2016*	Animals	4	890	SN	BTA	*in situ*	Summer	90	71
2017	Animals	4	890	SN	BTA	*in situ*	Summer	95	30
Monitoring campaign carried out following the international activity BioBlitz (National Geographic). In the Punta Campanella MPA it has the name of BlueTeam in Action and it is done in all the area of the MPA including Ieranto Bay. The transect was performed using snorkeling and the identification of the species was done while they were observed.									
2018	Cnidaria & Porifera	1	235	SN + SD	-	PS	Summer	54	16
A total transect of 235 m was performed inside of the small bay to identify species from Cnidaria and Porifera phylum through *in situ* observations and photo identification when it was not possible to do the identification *in situ*. The photos were analyzed with id manuals and experts.									
2019	Algae	1	180	SN	-	*in situ* + DS	Summer	41	29
A total transect of 180 m was performed along the rocky walls of the small bay to identify *in situ* and collect samples for a post-identification with microscope, id manuals, and experts.									
2019	Rocky environment (Animals)	2	95	SN	12 h	*in situ* + PS	September – October	140	47
A total of 95 m was narrowly traversed through a rocky wall from the small bay in a total of 12 hours. The species identification was done *in situ* and with the analyses of photos. The photos were analyzed with id manuals and experts.									
2020	Rocky environment & Caves (Animals)	7	545	SN + SD	-	*in situ* + PS	October – February	92	9
A total of 545 m was performed in small and big bay, exploring the rocky walls and the caves. The identification was done *in situ* using specific underwater guides and the analyses of photos with id manuals and experts.									

Results and Discussion

In six years of monitoring the species in Ieranto Bay, we built a database with 271 species from 11 phyla (Plantae, Annelida, Arthropoda, Bryozoa, Cnidaria, Echinodermata, Entoprocta, Mollusca, Porifera, Protista, and Chordata) and the photosampling allowed the collection of more than 1000 photos. Overall data came from different sources, being the main one the underwater monitoring campaigns (91.9%) done by the volunteers from Project M.A.R.E. between 2015 and 2020. Nevertheless, a small percentage (8.1%), but highly significant from a biological point of view (since these species would hardly be identified by the monitoring campaigns), came from the following sources:

- The constant presence of the observers in the bay, which allows for the identification of species passing there or coming in specific moments with the currents, for example (e.g. *Planes minutus* and *Velella velella*);
- The presence of fishermen during the winter throughout many years, which allows for the understanding of changes through time and the identification of species from catches at a depth that we do not usually reach (e.g. *Coryphaena hippurus* and *Euthynnus alletteratus*);
- Random observations coming from the general public in the bay and also from scuba diving groups. This second type gives information from other places and depths in the bay that we usually do not cover in the monitoring campaigns (e.g. *Caretta caretta* and *Ichthyaetus audouinii*);
- Observations coming from other events of monitoring done in the bay, for example from the monitoring campaigns of *Pinna nobilis* (e.g. *Scyliorhinus stellaris* and *Caulerpa taxifolia*).

With all data collected in these years, the species found in the bay can be divided into 3 groups (Fig.4), with Invertebrates representing more than 50% of the species (55.7%) and Vertebrates and Plantae representing together the other 50% (24.0% and 20.3%, respectively).

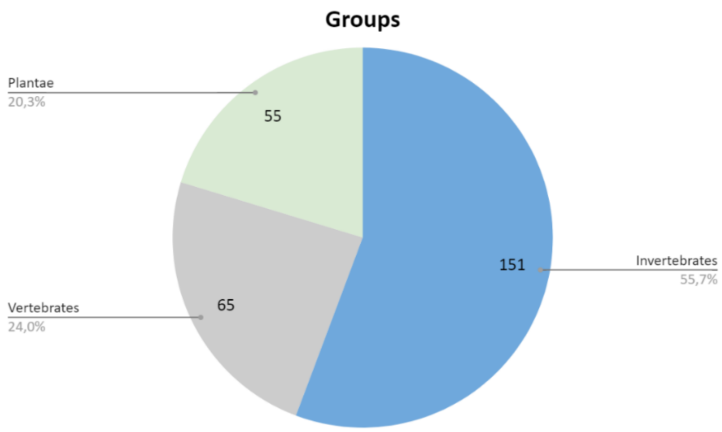

Fig.4. Group representativeness in Ieranto Bay.

These results are in line with the main characteristics of the bay, an extremely heterogeneous environment with mountains going into the sea (Ferrigno et al. 2018), and different shadow-light exposures that provide different conditions for various habitat types densely populated by invertebrates.

A close analysis of the data reveals that out of the 11 phyla (Fig.5 – left), the group Chordata (Fish) and the phyla Plantae and Mollusca represent more than 50% of the species in the bay (58%, 55%, and 41%, respectively). On the other hand, Annelida, Echinodermata, Chordata (others – birds, dolphins, and sea turtles), Chordata (Tunicata), Bryozoa, Protista, and Entoprocta represent less than 15 species each. In part, this distribution can be explained having into account some factors:

- Chordata (Fish) – the data for this group comes from one focused campaign in 2015, from fishermen and contains the most familiar species to the general public. It also is made up of species that are easier to find;
- Plantae – the data for this group comes from two focused campaigns (2015 and 2019);
- Mollusca – *per se* it is a big phylum and its common species are present within the rocky environment of Ieranto, which makes them easier to identify;
- Other groups (less than 15 species) – most unknown groups and with species that are morphologically smaller (< 5 cm), which adds the difficulty in finding them.

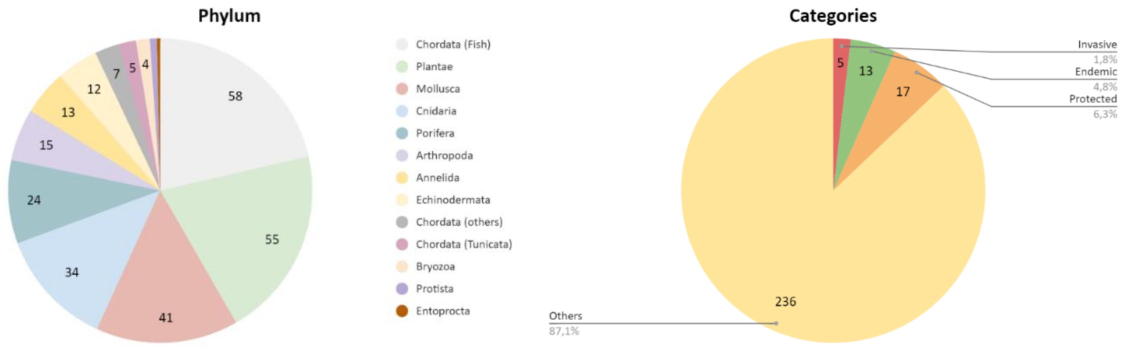

Fig.5. Distribution of Ieranto Bay species by phylum (left) and by categories (right).

From a conservation point of view, 5 invasive species (e.g. *Caulerpa taxifolia* and *Percnon gibbesi*), 13 endemic species (e.g. *Agelas oroides* and *Tripterygion melanurum*) and 17 protected species (e.g. *Luria lurida* and *Epinephelus marginatus*) were identified in the bay (see Fig.5 – right).

Focusing on the underwater monitoring campaigns, as shown in Fig.6, all new campaigns found some species not previously recorded in the database (identified as “New”), even when the same method was repeated (2016 and 2017). The method that identified the highest number of species (140) and had the second highest number of added species (47) was the one performed in 2019 – a small area (95 m) of rocky environment was explored, using snorkeling, to identify animals during September and October. The method performed in 2020 – exploration of rocky environment and caves, using snorkeling and scuba diving, to identify animals from October until February – also identified a high number of species (92) but added fewer species to the list (9).

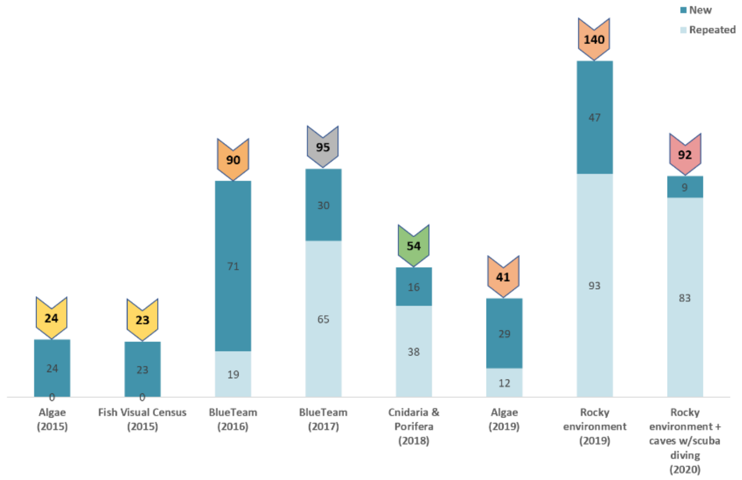

Fig.6. Contribution for the database given by each campaign. The number above the columns represents the total species identified in each campaign. “New” represents the species that appear for the first time in our database and “Repeated” the ones that were already identified in other campaigns.

The following details refer to the species found each year and the methods used to identify them (see Fig.6 and 7):

- 2015 was focused on two individual groups (Plantae and Chordata [Fish]), with the destructive sampling of algae identifying 24 species and the fish visual census identifying 23 species;
- in 2016 and 2017, using the *in situ* identification, species from 10 groups were identified (Chordata [Fish] – 43% [2016] and 32% [2017], Porifera – 6% [2016] and 9% [2017], Mollusca – 16% [2016] and 17% [2017], Echinodermata – 9% [2016] and 11% [2017], Cnidaria – 11% [2016] and 13% [2017], Bryozoa – 2% [2016] and 3% [2017], Arthropoda – 8% [2016] and 7% [2017], Annelida – 3% [2016] and 6% [2017], Plantae – 1% [2016] and 1% [2017] and Chordata [Tunicata] 2016 – 1% and Protista 2017 – 1%) with approximately the same proportions;
- in 2018, photosampling through snorkeling and scuba diving focused on Cnidaria (33%) and Porifera (26%), but other 8 groups with smaller representativeness were also identified (Chordata [Fish] – 17%, Chordata [Tunicata] – 2%, Porifera – 26%, Mollusca – 2%, Echinodermata – 6%, Cnidaria – 33%, Bryozoa – 2%, Arthropoda – 6%, Annelida – 4% and Plantae – 4%);
- in 2019, the campaign focused on Plantae using *in situ* identification and destructive sampling through which 41 species were identified. The photosampling in a rocky environment further identified 9 groups with

Chordata (Fish) (23%), Mollusca (21%), Cnidaria (16%), and Porifera (15%) having the higher percentages and the remaining groups (Chordata [Tunicata] – 2%, Echinodermata – 6%, Bryozoa – 3%, Arthropoda – 7% and Annelida – 7%) with lower percentages.

- in 2020, photosampling in rocky environment and caves, through snorkeling and scuba diving, identified 11 groups with Cnidaria (22%), Chordata (Fish) (20%), and Mollusca (15%) being the most representative and (Chordata [Tunicata] – 1%, Porifera – 10%, Entoprocta – 1%, Echinodermata – 11%, Bryozoa – 1%, Arthropoda – 8%, Annelida – 5% and Plantae – 7%) making up the other organisms found.

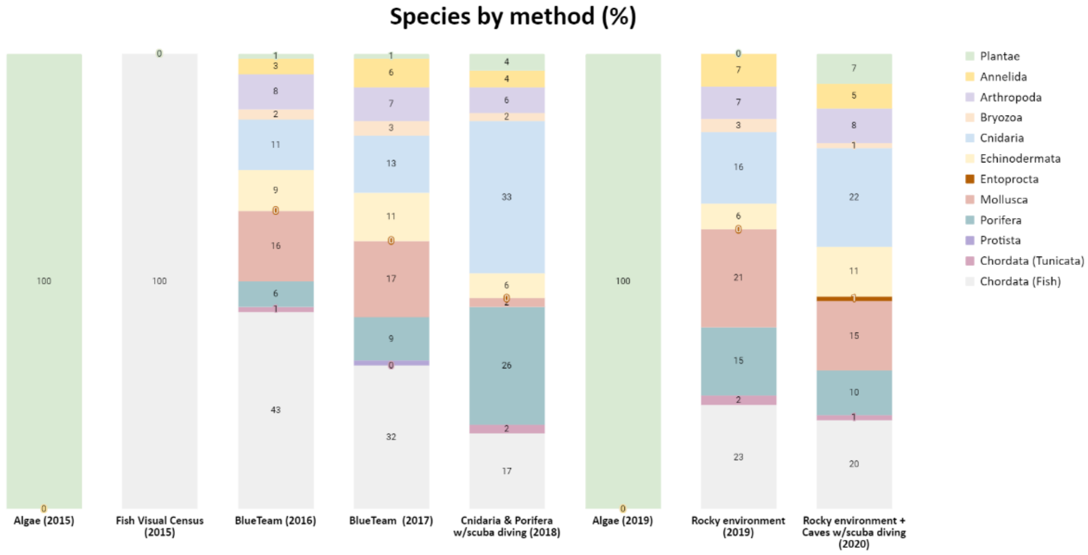

Fig.7. Distribution, in proportion, of species by each campaign completed.

It is important to highlight the different variables that are involved in these monitoring campaigns. Besides the different methods applied, there are also different observers with different experience and different focuses that change every year, and the campaigns were also done at different times of the year/seasons.

The particular and complex environment in Ieranto Bay, where we find an overlap of different organisms in the rocky ecosystems, requires the combination of different methods to have a more complete overview of all habitats and taxa.

Since this protected bay is part of the Mediterranean Sea, a complex region where ecological and human influences meet and strongly interact, there is a large and growing potential to impact marine biodiversity (Coll et al. 2010). Thus, it is highly important to know the present environmental status to understand and control the impacts.

With this work, we advocate for the application of the management model of the MPA because the monitoring information helps to provide a more comprehensive analysis of conservation and management initiatives to preserve biodiversity, as proposed by Coll et al. 2010.

All the work undertaken during the last 6 years also resulted in the creation of diversified disseminative and scientific materials (Fig.8, 9, 10 and 11) that help with the accurate identification of species and contribute to raising awareness of people attending the area about what can be found in the bay and how its extraordinary biodiversity can be preserved.

Fig.8. Algariums created in 2015 (A), 2019 (B) and 2020 (C).

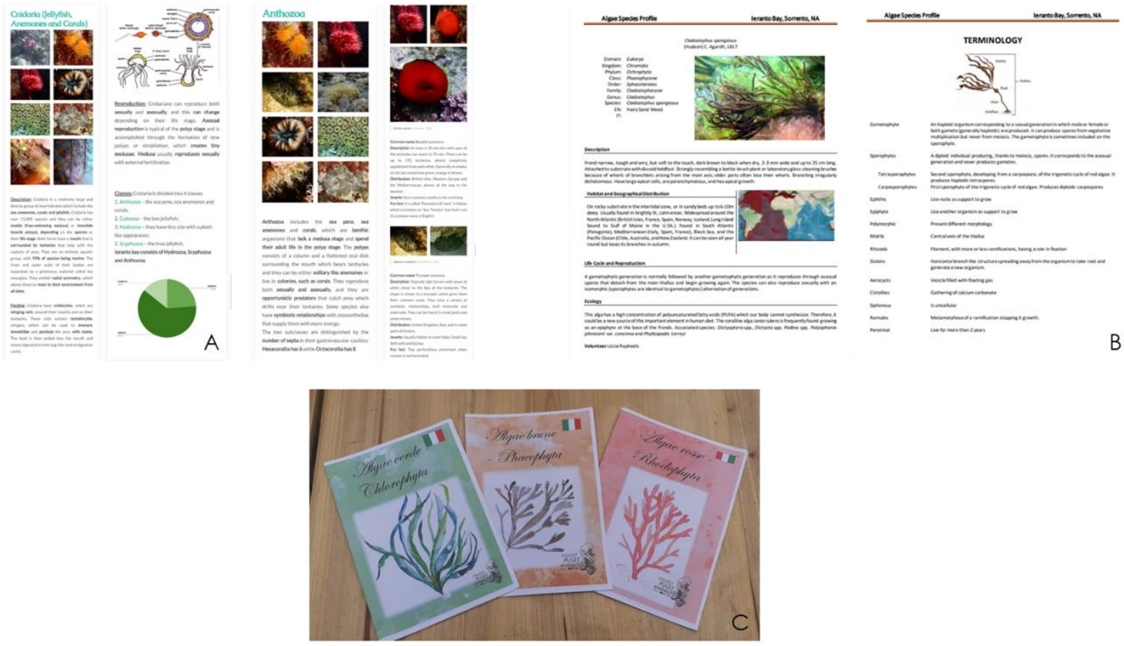

Fig.9. Species info sheets created in 2019 (A) and 2020 (B) and Algae info books (C) created in 2019.

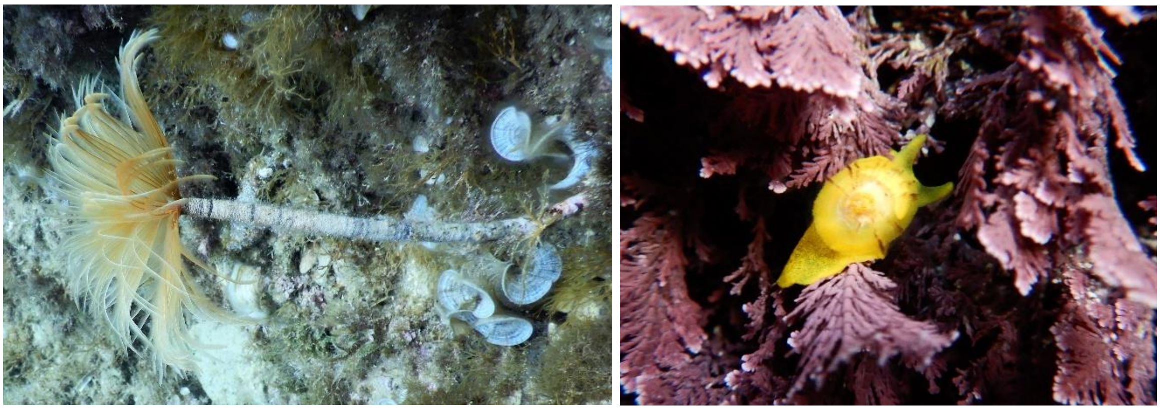

Fig.10. E.g. from photographic database: *Sabella spallanzanii* (photo by Domenico Sgambati in 2019 – left) and *Tylodina perversa* (photo by Érica Moura in 2019 – right).

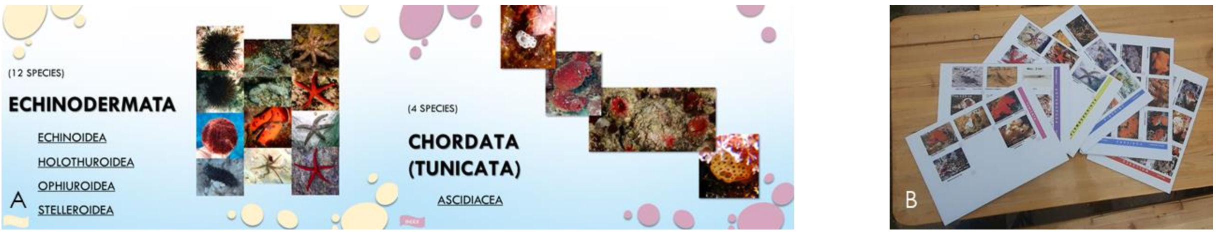

Fig.11. Species guides created in 2020: virtual and interactive guides (A) and forex underwater guides (B).

Conclusion

Similar to other MPAs (Bruno et al. 2018; D'Amen and Azzurro 2019), the Punta Campanella MPA is undergoing some significant changes in biodiversity, involving the presence of exotic species and native community shifts. To properly understand the current status of the area and to depict a valid baseline, several monitoring campaigns have been completed to assess biodiversity in Ieranto Bay, a special zone B of the MPA that allows the sustainable interaction between humans and nature.

According to Sgambati et al. 2020, the monitoring represents the central and most important action of the Punta Campanella MPA management model, as it allows for the evaluation of the different dimensions through which humans influence the sea resource, it examines the results of conservation and gives correct and updated information to the public.

Ieranto Bay allows the use of experimental tools and young volunteer involvement in marine conservation, from which efficient practices are developed and shared with other areas within the Punta Campanella MPA and with other MPAs. The results of this work represent an important biodiversity baseline of data to assess eventual changes in biodiversity in the future of the MPA, and a valid tool to suggest management plans. However, only recently was possible to put effort into the monitoring activities in this protected bay. The lack of old-time data, as the almost only old data available are the ones coming from fishermen, makes difficult the comparison between past and present data and for this reason we have the risk to incur in the shifting baseline syndrome (SBS) (Soga and Gaston 2018).

Nevertheless, the census of underwater life in this Ieranto bay is an ongoing open and constant activity, especially when looking to the future. It is an experience of collaborative research, involving experts and volunteers supervised by the MPA staff that is already planning its next steps: more data collection from citizens through the creation of a public group to share information/photos about species found in the bay, the exploration of new depths through the acquisition of an underwater drone (Barberá et al. 2012; Mallet and Pelletier 2014), and new collaborations with experts.

Monitoring is needed to ensure the goals and objectives of the MPAs are met, and it has to be individualized according to the area and its goals (MMMPA Supervisory Board 2016). It is necessary to know the status of biodiversity in a MPA to better understand the effects of future environmental pressures.

Acknowledgments

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Investigation of a karst sinkhole in a desert lake in southern Iraq

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Abstract. Iraq has a considerable number of lakes, but most of them are artificial reservoirs behind dams built during the last 70 years on Euphrates and Tigris and some tributaries. The natural lake Sawa provides several criteria to be a world natural Heritage site, but is so far not yet recognized neither by national or UNESCO level. For the first time ever, scientific divers investigated in the period 2014 to 2019 the only deep part of the lake and discovered a flooded karst sinkhole and proved subterranean discharge of karst groundwater as source for the existence of the Sawa lake. The lake water with total dissolved solids of 37 g/L in 2019 is in the range of seawater, but with totally different water chemistry. Stable isotopes give evidence that evaporation of the discharging karst groundwater is the responsible process. The radio-carbon age of 14.000 years of the discharging karst groundwater clearly indicate that fossil groundwater has fed the lake for thousands of years. Since two decades the decrease of the lake water level by several meters is getting evident and nowadays Sawa lake is close to vanishing. The most presumable cause for this fact is over-pumping of the karst aquifers.

Introduction

Sawa Lake is assumed to be a terminal lake in the desert of Southern Iraq. It is one of the very few natural lakes in Iraq with a size of just 4.5 x 1.9 km. It is a very shallow lake and has no surface inflow and no surface outflow with a water level at about 13 meter above sea level (masl). Sawa lake is about 200 km from the Saudi Arabian border and few km to the south-west from the Euphrates river and lies nowadays in a desert environment (Fig. 1). The Samawah province was blessed by hundreds of artesian wells discharging artesian groundwater from shallow Dammam (Neogen karst) underlain by Rus and Um Er Raduma aquifer along an area south-west of the Euphrates on a length of several tens of kilometers. The lake was probably lying on the edge to the desert for the last 10,000 years (Holocene) and offered a very special environment for birds and other animals and worth to be protected (Awadh 2016). Mean annual precipitation in the area of interest is 108 mm and the potential evaporation is about 3400 mm (Al Quraishi 2013).

By drilling wells since the 1970´s and pumping additional groundwater for irrigation and industrial purposes the groundwater level declined. Consequently, many natural artesian springs dried up and a decrease of the Sawa lake water level occurred. Consequently the total dissolved solids (TDS) increased from 19 g/L in 1975 (Jamal 1977) to 37 g/L in 2019 (own results). The BGR conducted a comprehensive study for Umm Er Radhuma and Dammam aquifer. The study showed that these two aquifers are shared between Iraq, Kuwait and Saudi Arabia and revealed that recharge is mainly through the Umm er Radhuma outcrops. According to the BGR report the general groundwater flow direction is from south-west towards the Euphrates Depression and the Gulf coast. The artesian springs scattered along the Euphrates river naturally discharge by means of artesian wells with slightly saline water into the uppermost local Euphrates aquifer. The three riparian countries exploit the aquifers primarily in the Dammam and the upper part of the Umm er Radhuma Formation. The study shows as well that Sawa lake is considered as a part from the artesian zone (NN 2013).

Major ions and some trace elements in the Sawa lake water were analyzed by (Awadh and Muslim 2014). The same authors investigated the gypsum precipitations, a kind of wall around the lake with a height between 3 and 6 m. By means of a numerical groundwater flow model (Khayyun and Minaty 2018) concluded that the water level in Sawa lake is not impacted by the surrounding groundwater, which is, however, at least very unlikely considering the general hydrogeological setup with many artesian wells in the region of interest.

In another project 8 surface water, 22 wells, 3 springs and 2 Sawa lake samples were taken in the area and investigated with respect to cations, anions and stable isotopes of water (Ali and Ajeena 2016). From the stable isotopes, the authors concluded that Sawa lake originates from groundwater.

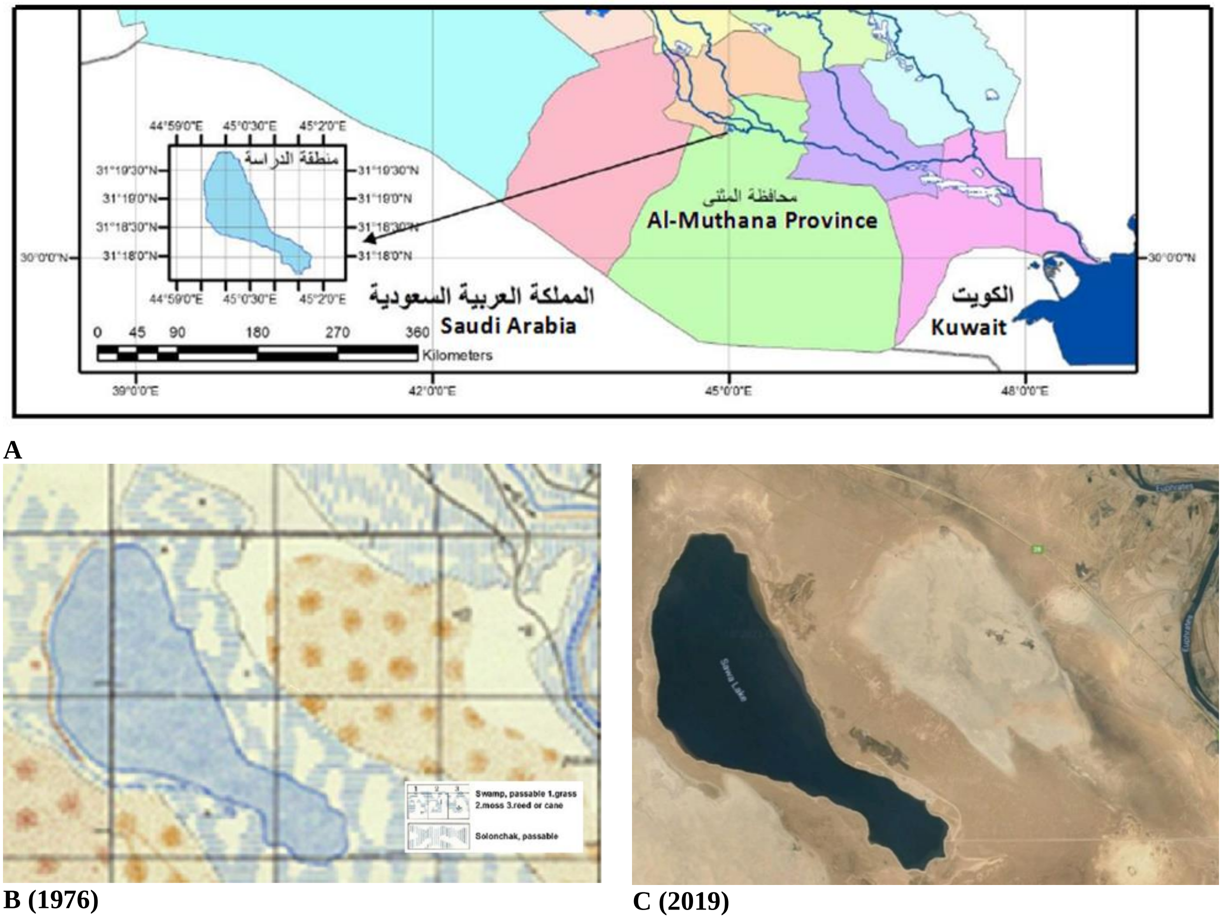

Fig.1. Topographic map of Southern Iraq (A), historical Czech map from 1976 (B) and a satellite image from 2019 (C). Within roughly 45 years the situation in the vicinity of the lake has changed significantly from a walkable but swampy area to a completely arid environment.

About 2 km south of the Sawa Lake is a well field with seven 80 m deep wells: Some of the wells are equipped with submersible pumps which are sporadically used to irrigate land and watering some animals. In a distance of 10 km to the south a cement fabric is pumping groundwater from unknown depth and unknown quantity. Approximately 10 km southeast of the lake a 34 km² large field with evaporation ponds and 18 productions wells (31°15’01’’N, 31°18’01’’ and N, 44°56’00’’E and 45°00’00’’E) is another large groundwater consumer (Pätzold 2016).

Materials and Methods

For the first time ever, the Scientific Diving Center of TU Freiberg investigated the karst sinkhole in the middle of the lake by means of scientific divers. In 2014 and 2015 dives were performed from a boat. In December 2015 a tiny island (Tahaider Island) appeared at the rim of the sinkhole. In 2019 Tahaider Island along the southern rim of the flooded karst hole had further grown because of the constantly declining lake water level. Therefor in 2019 the small island in the lake was reached by canoes and the dives were performed from the shoreline of Tahaider island (Fig. 2).

In 2014, 2015 and 2019 shape, depth, type of rocks and fish and plant were documented in the flooded karst sinkhole. Water temperatures, pH, ORP (oxidation-redox potential), O_2-content and EC were measured at different spots and depths. Furthermore, water samples were taken be means of syringes from karst discharge points and the lake water body. The water composition was investigated for in situ parameters temperature, pH, ORP (oxidation-redox potential), major cations and anions with ion chromatography (Metrohm 881 Compact IC Pro), trace elements by mean of IC-PMS (Thermo Scientific X Series) and isotopes (δ^2H, $\delta^{18}O$, ^{14}C, $\delta^{13}C$).

Fig.2. Photo documentation of Sawa lake (2014 and 2019)

Results

The lake had a water depth of about 1 to 2 meters in 2013 and about 0.5 m to 1 m in 2019. The only deeper point in the lake was the karst sinkhole. The submersible depth of the flooded sinkhole was 22 m in 2013; in 2019 the maximum depth was 16 m. The reasons for the difference of about 6 m are the declining lake level of about 2 m in this time period and the collapse of steep walls and overhanging rocks between 2016 and 2019, which might have been triggered by local earthquakes.

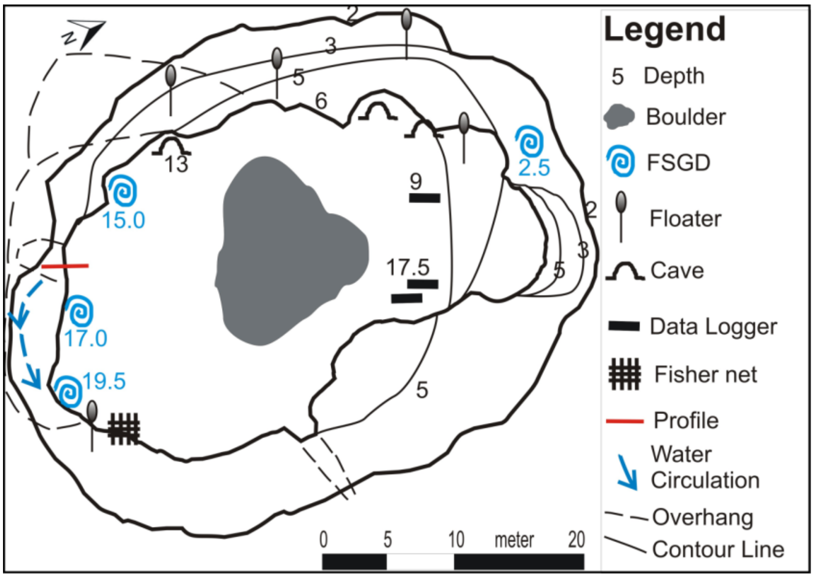

Fig.3. Sketch of the sinkhole (2014), FSGD stands for focus submarine groundwater discharge of karst water (Pätzold 2016)

A time-wise and location-wise change in the flow direction was observed: sometimes groundwater was flowing into the karst cave from adjacent smaller caves and fractures but sometimes the flow was in the opposite direction and water from the sinkhole flowed back in the karst aquifer. This is clear evidence either for two karst aquifers and/or a reaction on the pumping of groundwater in the vicinity. Because inversion of flow direction was observed during a single day the latter causation is very likely. In general, it can be stated that the shallow lake water stems from the karst groundwater and is enriched by strong evaporation (3400 mm per year). Measuring EC in the shallow lake revealed no spatial differences at particular time but over time a significant increase can be seen from Fig. 4.

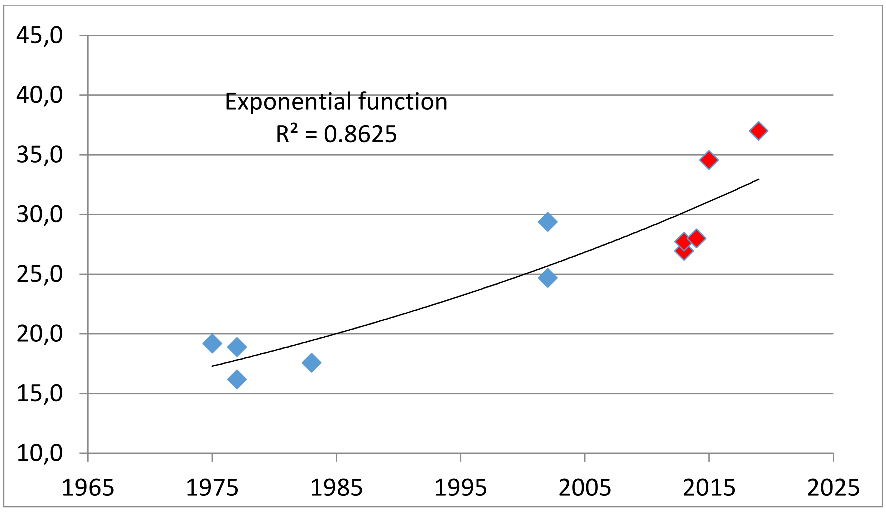

Fig.4. Increase of EC (25°C) in the shallow part of the lake over time. Red point are own data. Blue points are taken from (Jamal 1977), (Al- Naqash 1977), (Al-Muqdadi et al. 2002)

However, measuring EC in the sinkhole revealed much lower values and even lower values for the focused karst discharges in different depths (ca. 7 mS/cm). Therefore, sampling the focused discharge points by scientific divers and analyzing these samples revealed to be the key for understanding the hydraulic and geochemical regime of this lake. From all analyzed elements and species some are controlled by precipitation of minerals such as carbonate and gypsum; others are controlled by sorption. However, eight elements behave obviously as tracers. Na, K and Mg are obviously not impacted by cation exchange. B seems to be removed a bit from the water.

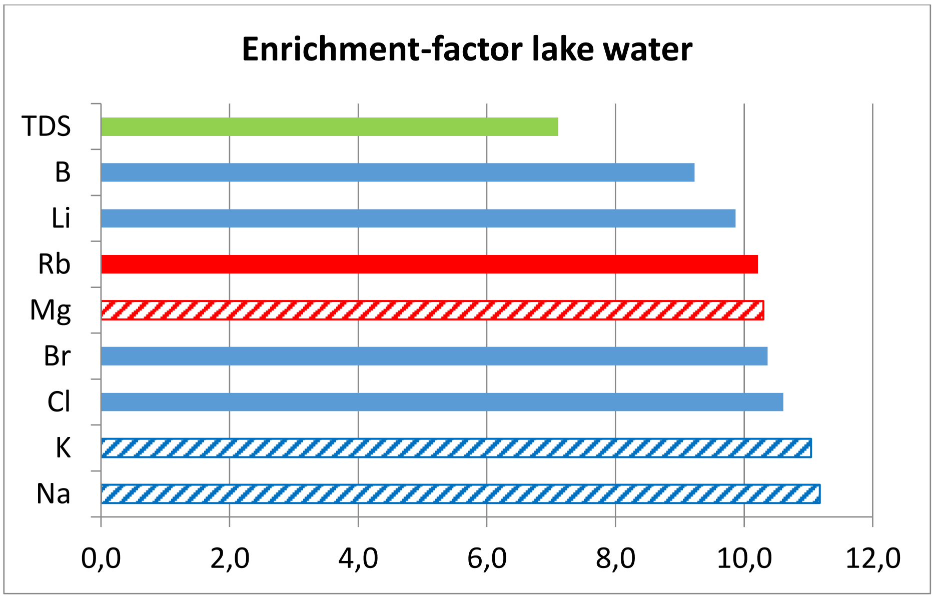

Fig.5. Enrichment factors for TDS (total dissolves solids) and eight elements that behaved as tracers in the Sawa Lake. The halogens Li, Br, and Cl behave as expected. A bit surprising is the behavior of Rb.

A sample taken 2014 from a focussed karst discharge in the sinkhole was analysed for ^{14}C and $\delta^{13}C$ by Leibniz Labor of Christian-Albrechts-Universität, Kiel, Germany. The $\delta^{13}C$ corrected value was 17.78 ± 0.11 which means a radiocarbon age of 13,875 years BP ± 50. The real mean residence is certainly younger. But such corrections are not easy in an aquifer dominated by carbonates and goes beyond the aim of this manuscript.

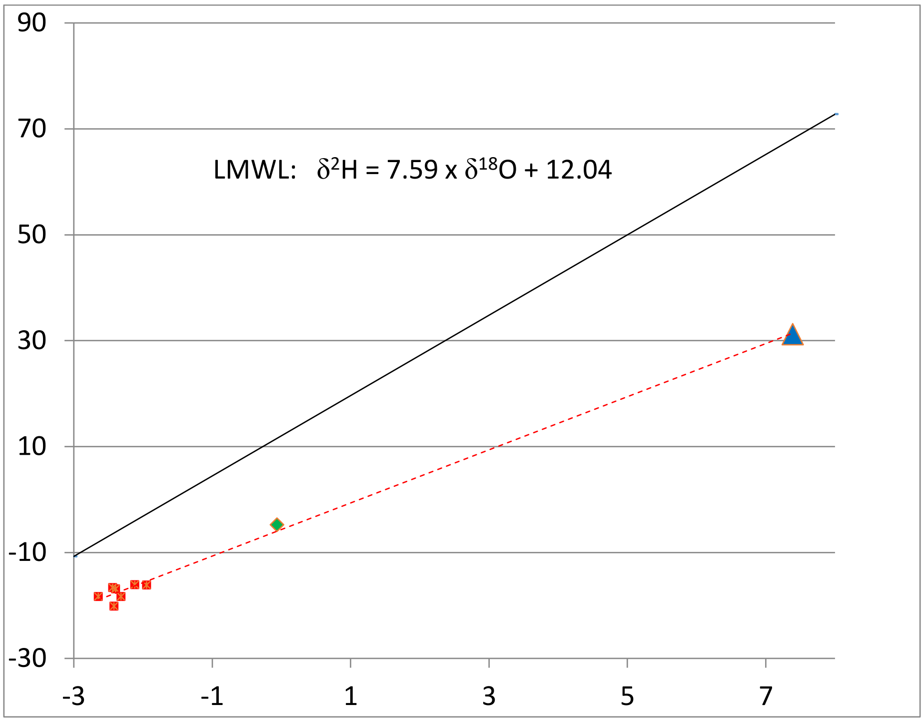

Fig.6. Stable isotopes values from sampling in 2019: lower left values are from under water discharge into the sinkhole and adjacent wells (about 40 to 80 m deep) and one artesian well at the shore of Sawa Lake. The blue triangle is lake water 200 m from the shore, the green diamond is a sample taken in 10 m depth in the sinkhole.

Discussion

As already mentioned in the introduction (Khayyun and Minaty 2018) concluded by means of a numerical GW flow model that the water level in Sawa lake is not impacted by the surrounding groundwater pressure. But this is very unlikely if one considers the general hydrogeological setup with many artesian wells in the region of interest. Furthermore, they assume unrealistic high inflow and outflow of groundwater, which is in contradiction with the 10-fold increased salinity in comparison to the groundwater. Additionally, sampling points around the lake revealed no clues for inflow and outflow of groundwater by means of temperature, EC or TDS. On the contrary, there is much evidence that Sawa lake is (was) fed by karst groundwater via a single sinkhole in the middle of the lake and the water in the shallow lake is result of evaporation in a terminal lake. However, the flow direction between the karst sinkhole and adjacent smaller caves changed sometimes within hours from inflowing to outflowing conditions due to response of the karst groundwater pressure head changes. It is very likely that this pressure head changes are caused by changes in the pumping rates of adjacent wells. It can be speculated that local earthquakes have triggered the collapses in the cave after 2016 and recognized in 2019. I cannot be excluded that these collapses blocked temporarily inflow from the bottom of the sinkhole. However, based on experience in karst caves such blocking is circumvented in very short times.

However, the game changing issue comes with looking at the lake water budget. Considering the lake area of 4.6 km^2 and a water depth of 2 m this is a volume of 9.2 million m^3. On contrary using 3400 mm potential evaporation and 100 m rainfall one ends up with 30 million m^3 evaporated water per year which equals 0.5 m^3/s on average. Thus, one can conclude that a minimum of 0.5 m^3/s of groundwater discharging towards the lake would be needed to compensate evaporation. But, looking at the fact that evaporation is 3 times the volume of the lake this would end up with a much steeper increase of TDS and EC than seen in Fig. 4. The only plausible explanation is that Sawa lake is (was) not a terminal lake, but a lake with subterranean outflow of water. But this is only possible with the inflow of karst water is well above the above stated 0.5 m^3/s. Only then a dynamic equilibrium and dilution of enriched lake water could establish over many centuries with certain fluctuations over the year (hot summer and moderate winter). It is hypothesized that the outflow occurred at the lake bottom via the local Euphrates aquifer.

Fig.7. Photo of Sawa lake from April 2021 (copyright Fadhil Mahmood). The lake dried up as long as anyone can remember and the flooded karst sinkhole is visible for the first time ever at the former lake bottom. Cement factories visible on the horizon in a distance of about 10 km.

Conclusion

The Samawah province was blessed by hundreds of artesian wells discharging fossil artesian groundwater from shallow Dammam (Neogene karst) underlain by Rus and Um Er Raduma aquifers along a line south-west of the Euphrates. By drilling wells since the 1970´s and pumping additional groundwater for irrigation, salt production and industry the groundwater level declined. Consequently, many natural artesian springs dried up and a decrease of the Sawa lake water level occurred since many years, but was not registered with a gauge since about 2015. Sawa lake is (was) feed predominantly by a single artesian spring in a karst sinkhole at the bottom of the lake discharging much more than 0.5 m^3/s of groundwater. Even nowadays no water management for the region of interest is in place, neither by means of water meters, licenses and water policy. Thus, there is an urgent need for sustainable concepts and one key issue is to learn from the failures.

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Large and small scale neotectonic structures in the submarine hydrothermal system of Panarea Island

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Abstract. Detailed structural mapping of small and large scaled neotectonic structures was conducted during scientific diving field campaigns at the submarine hydrothermal system of Panarea Island, Italy. Investigated structures are situated off the coastal line of La Calcara beach in the NE of the main island (coordinates: UTM 33S 506785/4277398). A sinistral shear structure of several decametres in length is assumed at this location showing general strike directions of 30° and 90°. Due to an up to 50 cm thick cover of medium to coarse grained sediment, tectonic structures in hard rock material cannot be identified directly. Hence, indicators were defined which can be connected to these structures. Assuming that mixed hydrothermal fluids are being discharged through channels and fractures of this tectonic structure, all indicators are linked to the emission of these fluids. Indicators can be fluid emissions themselves as well as bio mats, ore precipitations, and sedimentary structures such as cones and tubes (Stanulla et al., 2017). These indicating structures are much smaller in size yet distributed throughout the whole area of the assumed shear structure. The orientations of the indicators coincide with typical strike directions (main: 30°, minor: 60° and 90°) of the working area. Furthermore, temperature anomalies due to the discharged fluids (up to 134 °C) in the covering sediment give further hints to the structure underneath.

Introduction

The investigation of (neo-)tectonic structures is hindered by recent sediment covers in submarine environments in many cases. Waves and tidal movements often dominate the depositional system in shallow water systems. However, the tectonic system and the related geological features are crucial to understand highly dynamic systems and their geological and sedimentological processes. Therefore, intense research was carried out on scientific questions related to (neo-)tectonic structures in shallow marine hydrothermal systems, their appearance in such environments and general possibilities to assess them by means of scientific diving. The focus was set on the development of an inventory of applicable methods for underwater research as well as the identification of possible secondary indicators which are characterizing the tectonic structure in the underground. The shallow water hydrothermal system of Panarea, Italy, was chosen as a reference location, as it comprises different types of sediments, extremophile organisms as well as intense neotectonics activity at one spot.

As a result, the investigation of (neo-)tectonic structures being covered by recent sediments will be approached and advantages as well as challenges of these methods are analyzed and evaluated.

Region of interest and area of investigation

The area of investigation is located in the southern Thyrrenian Sea in the region north of Sicily. The isle of Panarea is part of the Eolian Islands which are aligned along a back arc system comprising recently active volcanic and hydrothermal activity. The back arc can be divided into three sectors: the western sector (Alicudi, Filicudi) which is classified *extinct*, the central sector including the islands of Salina, Lipari and Vulcano, showing moderate volcanic activity (mostly geothermal emissions) and the eastern sector, which is considered *active* and shows continuous volcanic and hydrothermal emanations (among others: Lucchi et al. 2013, Peccerillo 2017).

Fig.1. Overview sketch map of the submarine investigation site of La Calcara northeast of Panarea Island. The area comprises large sand plains bordered by Posidonia fields. Close to the shore surf-conglomerates crop out. The dashed rectangle marks the area of investigation being focused on. Modified after Adamek 2021.

The research was carried out at the north-eastern shore of Panarea Island, close to the bay of La Calcara. The water depth varies between 10 and 24 m. This location is characterized by a number of mixed fluid outlets and increased temperatures at the ocean-sea-bottom-interface (20–134 °C). Hydrothermal discharges always emit a mixture of both, hydrothermal waters and gases. At La Calcara, most emanations are gas-dominated (CO_2, SO_2, trace gases). Hydrothermal fluid discharge features are common. They appear in different facies, such as cones and tubes (Stanulla et al. 2017). Furthermore, hydrothermal mineral precipitation and cementation by sulfurous phases (Pyrite, Marcasite, and native sulfur) are typical but also iron(hydr-)oxides (e.g. Goethite) appear (Kürzinger et al. 2019).

The underwater portions of La Calcara are characterized by large sand plains (several decameters in extent), slightly dipping eastward. They prevail a recent, polymict sandy facies in the uppermost layer of about 10 to 40 cm. Underlying sandy facies appear mostly with a fine-grained matrix being made up of Alunites and Smectites (Stanulla et al. 2017). Fields of Posidonia border these sandy areas, which show prominent sedimentary structures due to tidal movement and waves (ripples). Near-shore, surf conglomerates crop out.

Methods

In order to examine the sediment structures as well as the secondary indicators being related to underlying tectonically induced structures the scientific divers conducted an expansive mapping campaign. The mapping included preparing sketch maps of the surrounding structures using sketch boards. Fix points were marked and their location determined with a GPS above water. Bio indicators, such as bacterial mats, were included into the mapping. The appearance and extent of precipitates and hydrothermal discharge features were assessed as well. Structural data was derived using common compasses or specifically prepared clinometers. At spots with a relatively thin sediment cover, a mobile airlift pump was used for the excavation of sedimentary structures (cf. Stanulla et al. 2016). Additionally, temperatures were measured at the emanation points of hydrothermal fluids as well as within the covering sediments. All findings were documented using cameras. Rock and sediment samples were taken.

Furthermore, the mapping campaign was extended to the above water areas of the bay of La Calcara. Here, mapping included sampling and documentation. The orientations of tectonic structures were measured with a geological compass. The derived data was plotted into rose diagrams and Schmidt nets.

Laboratory work contained of developing a geological map of the investigation area using ArcGIS (scale 1:10.000). A comparison of structures and secondary indicators from underwater and above water areas was carried out.

Results

Structural data of the investigation site of La Calcara could mainly be derived using secondary structures as the recent sediment covers the underlying tectonic structures. Secondary indicators can be for example bacterial mats and discharge features. Additionally, iron-bearing mineral precipitations can be traced in the vicinity of these structures.

In the southern portions of the investigation site, bacterial mats on top of the sediment are common which are arranged in line-like structures. The mats can extent of several meters. As these lines are not influenced by the ripple structures due to tidal movement it appears that these mats can be related to covered fractures and crevasses. As these fractures emanate (sulphurous) hydrothermal fluids, the bacterial mats (thiobacter) settle close by. The mats find beneficial conditions in the surroundings of these underlying structures as also temperatures of the sediment are higher than the surroundings. In some cases, the bacterial mats form honeycomb structures. Using this fact, strike directions of the covered structures can be measured. The most common directions are 000-180 ° and 030-210 ° but also 060-240 ° and 090-270 ° appear frequently.

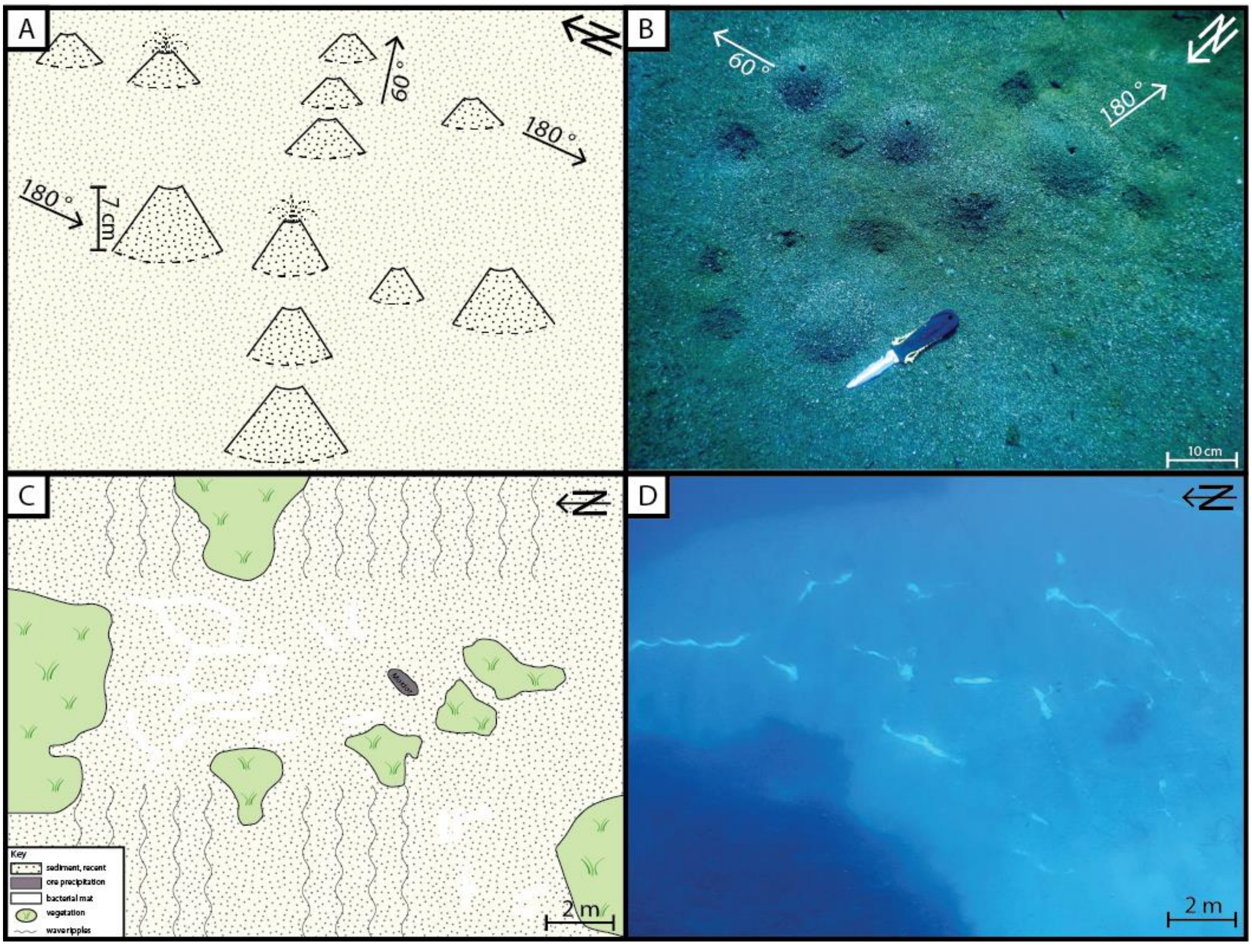

Fig.2. A – Sketch of aligned unconsolidated cones. B – Sand cones aligned along common strike directions. Hydrothermal fluids are emitted by these cones unfrequently. C – Sketch of bacterial mats forming line-like structures or honeycomb structures on top of the recent sediment cover. D – Bacterial mats highlight the shape and orientation of cracks and fractures that are covered with recent sediment. Modified after Adamek 2021.

At a number of spots, unconsolidated cones can be found, especially in the vicinity of *The Wall*. These features form concentrated fields of individual cones. Posidonia field can often be found close by. The majority of the cones are arranged along lines with typical strike directions of 000-180 ° and 060-240 °. Next to the cones, iron-bearing mineral precipitations form thin layers on top of the sediment.

In the area of La Calcara fluid temperatures can reach up to 134 °C, for example at the sub location *Mordor*. These temperatures correspond to the boiling point at these depths. The emanated fluids appear to be highly acidic.

Discharge features are spread widely across the investigation area. When removing the sediment cover, a single discharge point can turn out to be a spot of a number of vents in the underlying strata. Fluids are usually emitted at low flow rates (class A-B; Steinbrückner, 2009). Due to this unsteady emission, fluids are sometimes dispersed by the overlying sediment cover. Yet, there are also spots that show stronger fluid outlets in a concentrated area. Hydrothermal fluid exhalations which are arranged along lines are scarce in this area. A preferential orientation could hence not be identified.

These secondary indicators as well as their spatial extent hint on the existence of a several decametres large structure underneath the sediment cover. As the structure seems to prevail a sinistral shear sense it can be assumed that a rotational movement has affected the structure over time.

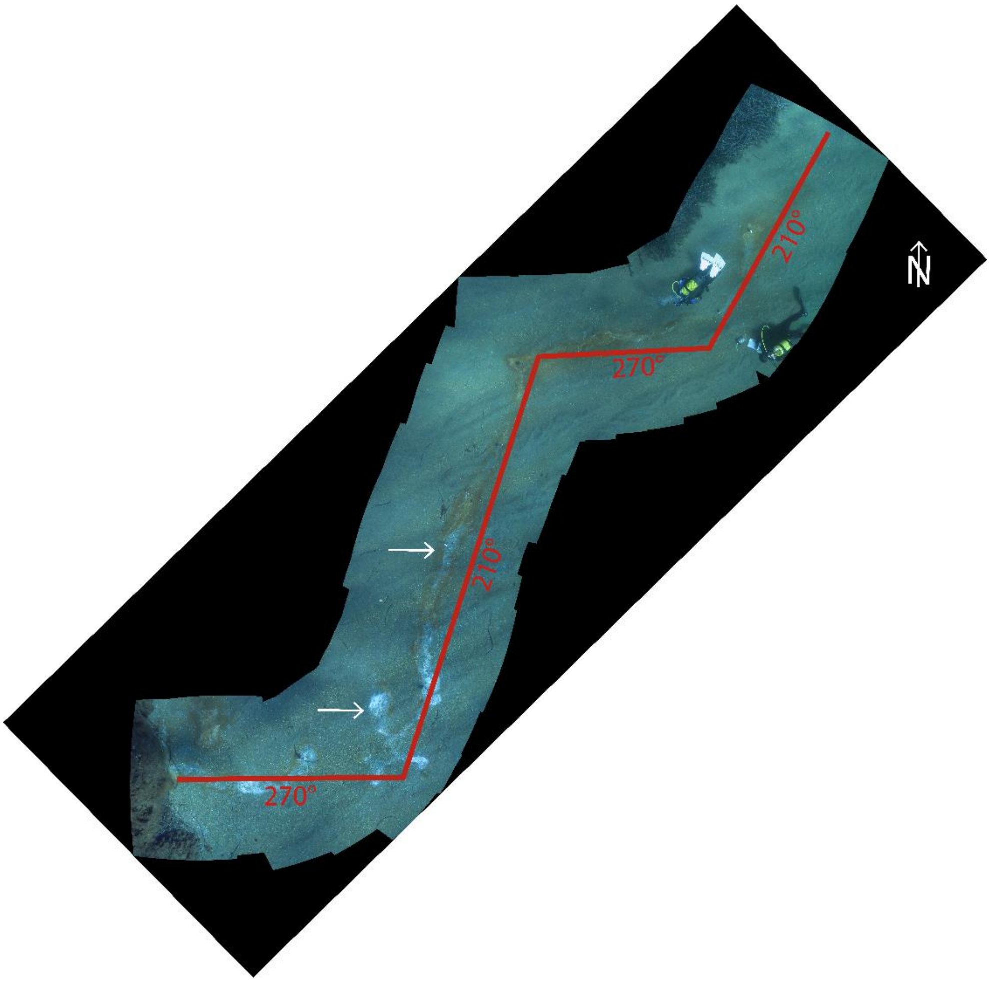

Fig.3. Overview image of the assessed structure at the investigation site of La Calcara which is covered with a decimeter thick layer of recent sediment. Bacterial mats as well as mineral precipitations can clearly be distinguished (arrows). Divers for scale, modified after Adamek 2021.

Discussion and conclusion

In order to evaluate the underwater findings, comparative studies were carried out in the subaerial portions of La Calcara bay as there are a number of features in the area that can be linked to both the hydrothermal and tectonic system of Panarea Island and its surroundings. Sulfurous precipitates, such as native sulfur or pyrite, can be found throughout the bay along uprightly rising structures. At active precipitation points temperatures are near boiling point. Columnar joints align in the southern bay and run into the sea with a general NE-SW trend. Preserved discharge features can also be found in the south of the bay to which bowls and lineament structures with a general 354/83 orientation (strike/dip) belong. Some structures were silicified. Hence, the initial fluid pathways have been preserved.

Taking the subaerial and the submarine observations into account, it becomes obvious that most of the observed features can be observed in both environments. Thus, there appears to be a natural relationship as the spatial extension is rather small. Although these secondary indicators might rise several elements of uncertainty, there seems to be a rather good correlation of both environments. Consequently, a genetic correlation of both outcrop situations can be assumed.

The combination of both submarine and subaerial investigations allows a better understanding of the environmental conditions and their effect on the preservation of neotectonics structures. Along with the investigation of secondary indicators, such as fluid discharges, mineral precipitations, bio indicators, or hydrothermal discharge features, this is a helpful tool to investigate neotectonics in shallow water hydrothermal systems.

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Underwater archaeological surveys in Salento waters: results and methods

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Abstract. This paper is related to the survey carried out in several coastal sites of Puglia in 2020, within the project UnderwaterMuse. The core of the activities took place at the Torre S. Sabina site, on the Adriatic Sea, where an integrated topographic and photogrammetric survey has been conducted on the late-imperial Roman shipwreck. Another activity, always on the Adriatic Sea, are been conducted in the "Le Cesine" Natural Reserve how led to the identification of a big pier from the Augustan period. On the Ionian Sea, furthermore, in Porto Cesareo Marine Protected Area, new evidence has been added to the numerous ones already known, such as some spectacular formations composed uniquely by cemented sherds of Tripolitanian amphorae (2nd cent. AD). This evidence seems to be significant markers of sea-level changes and the evolution of the seascape.

Introduction

This contribution concerns the archaeological survey carried out in September - October 2020 as part of the UnderwaterMuse Project (Italy-Croatia 2014-2020 Cooperation Programme)[1].

The activities were conducted at different levels of detail in various Apulian sites in the Adriatic and Ionian seas. The core of the activities took place at the Torre Santa Sabina site (Carovigno, Brindisi, Italy), in particular on the late-imperial era roman shipwreck, located in "Baia dei Camerini" on the Adriatic Sea (Fig. 1).

In the "Le Cesine" Nature Reserve, also on the Adriatic coast, and in the Marine Protected Area of Porto Cesareo, in the Ionian Sea, discoveries are reported, also obtained thanks to the use of new detection technologies (Fig. 1).

All these sites have shared characteristics that make it possible to highlight a series of aspects that are of interest for the reconstruction of the ancient environment and above all the variations in sea level since antiquity.

In methodological terms, the research conducted in the three areas followed a holistic, contextual, diachronic and transdisciplinary approach to the archaeology of landscapes, or rather seascapes, in this case, coastal and underwater. The primary objective of this systemic vision is to tell the story of social groups in changing landscapes, recording their discontinuities, formative processes and identity.

[1] www.italy-croatia.eu/web/underwatermuse.

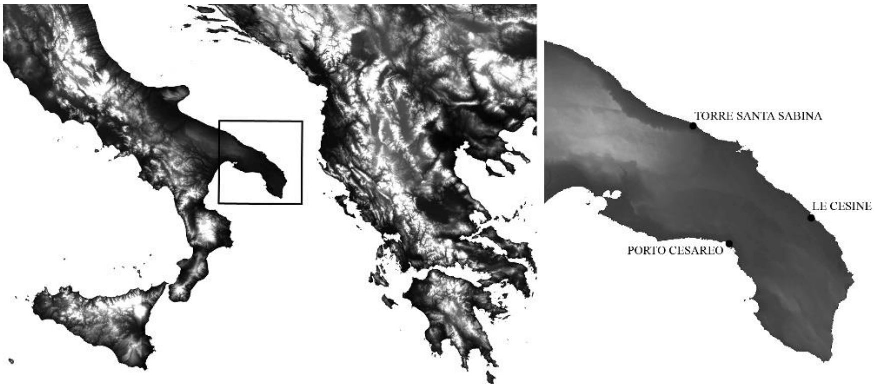

Fig. 1. Archaeological research areas of the UnderwaterMuse Project in Puglia.

Torre Santa Sabina

The choice of Torre S. Sabina as the setting for a pilot intervention within the UnderwaterMuse Project stems from the quality and variety of the archaeological sites in the bay (Fig. 2). The exceptional potential of this millenary landing place is an ideal scenario for a holistic approach to research, that is, that of the global archeology of landscapes, in this case coastal and maritime, or seascapes. It is a "super-site", with stratifications of events that are also significant indicators of the evolution of the coastal landscape: cargos and hulls, but also remains of quarries and settlements (Auriemma 2014).

The combination of data obtained through traditional and interdisciplinary survey methods and the use of new technologies, such as drones, remote sensing systems, underwater photogrammetry and the creation of a DEM of the seabed of Baia dei Camerini, obtained after the multi-beam survey (Fig. 3), allow us to argue our hypotheses of historical reconstruction on a solid documentary basis.

A general multiscale UAS survey of the Torre Santa Sabina settlement was carried out with the help of several drones, exploiting the possibility offered by the on-board GNSS that allows the direct georeferencing approach: using RTK (Real-Time Kinematik) or PPK (Post-Processing Kinematic) solutions (Fig. 2). Furthermore, a second activity was carried out concerning the underwater survey of the aft area of the Roman wreck using close-range photogrammetry (Fig. 4).

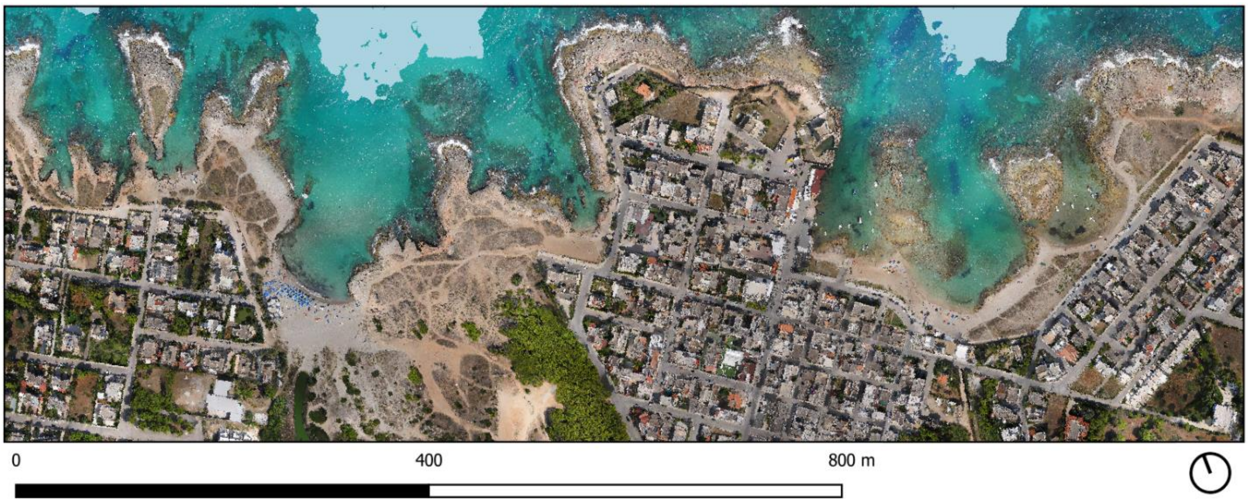

Fig. 2. UAS orthoimage of the shore of Torre Santa Sabina (eBee X).

The well-preserved shipwreck site found in the 1970s is related to a Roman ship dating from the late 3rd and early 4th centuries AD. The hull of the ship, which is still on the seabed, was over 20 meters long and of relatively heavy tonnage. There is no doubt that this wreck is one of the most interesting in the Mediterranean, due to its exceptional state of conservation which allows us to understand the details of the construction technique (Auriemma 2012).

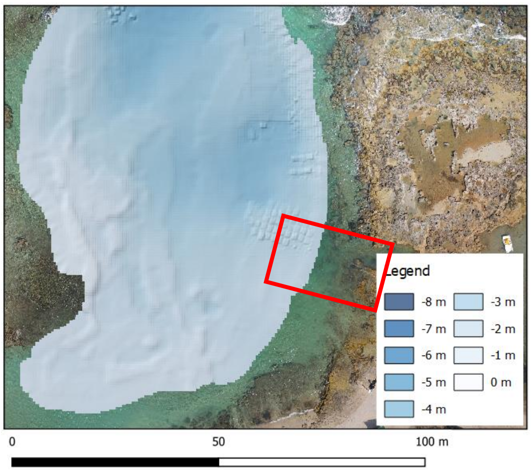

Fig. 3. DEM of the seabed of Baia dei Camerini obtained after the multi-beam survey; in red, the concrete blocks that protect the roman shipwreck's archaeological site area.

Fig. 4. Orthoimage of the aft part of the shipwreck.

The underwater photogrammetric acquisition of the aft part of the wreck was performed using an Olympus Tough TG-6 digital camera according to different acquisition schemes (nadir and oblique) useful for obtaining complete 3D and 2D documentation. The camera used can operate without underwater housing at a maximum depth of 15 m, reducing the residual systematic patterns of the image that are usually detected when the dome doors are used (Menna et al. 2020). The camera also integrates an underwater mode that performs radiometric adjustment on the fly. Also given the shallow depth over which the survey took place, this option was used without any further colour correction adjustments in pre-processing.

The measurement of the topographic points was carried out using TS (total station), with side shot acquisitions from the shore. Two divers manipulated the prism mounted on a 4 m rod to take the TS measurement points.

A previous survey campaign carried out in 2007 (Alfonso 2014) had produced a series of images acquired using a Nikon D50 (3008 x 2000 pixels) with underwater housing.

Since the images had suffered severe chromatic aberration (Agrafiotis et al. 2017), radiometric pre-processing was required, using the C-code adaptation of the ACE (Automatic Color Enhancement) image colour enhancement filter (Getreurer 2012), integrated into the image enhancement process tool of the i-MARECULTURE project.

The two sets of images of 2007 and 2020 made it possible to produce a complete orthomosaic and a DEM (Fig. 5) to facilitate the shape of the shipwreck and the understanding of the extension and plan future investigations and any recovery operations.

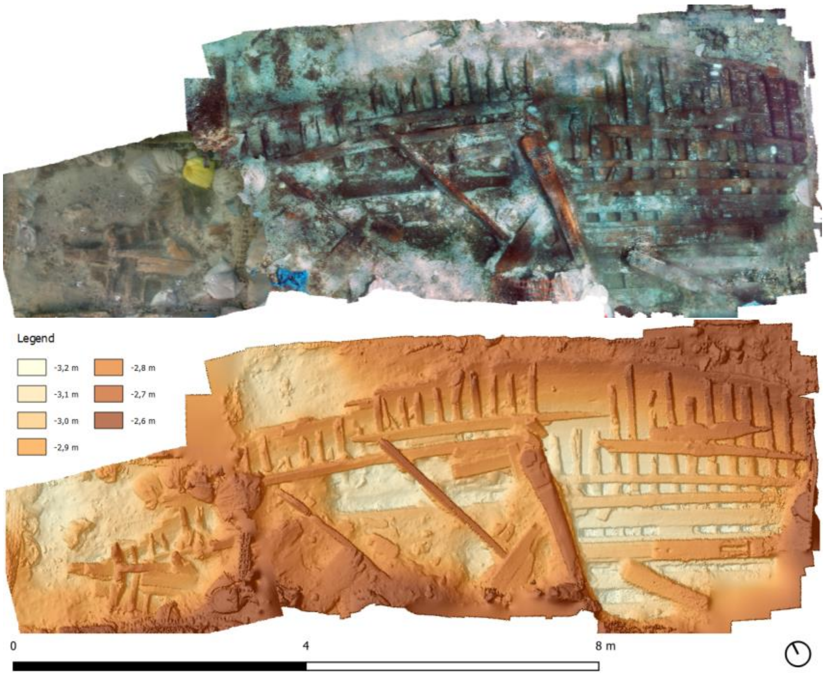

Fig. 5. On the top, RGB orthoimages of the two parts of the wreck surveyed in 2007 (right) and 2020 (left); on the bottom, DEMs of the same orthoimages of the two surveys.

"Le Cesine" Nature Reserve

Let's now pass to presentation of the results that emerged from the investigations in the coastal area coinciding with "Le Cesine" Nature Reserve, which constitutes one of the surviving fragments of the vast marshes that once extended along the coast of Puglia between Brindisi and Otranto. It is a wetland behind the dunes, the residue of an extensive ancient lagoon and marsh system, today greatly reduced due to large-scale reclamation and natural burial processes.

The shallow waters just off the Reserve have yielded much archaeological evidence consisting of particularly interesting submerged items that contribute to a more complete diachronic and contextual reading of the area.

A recent underwater and terrestrial survey has allowed the identification of further archaeological evidence, which enriches the previous knowledge of the area. In addition to the identification of a wall from the Bronze Age in Specchiuddhri, it is worth noting the discovery in 2020 of a submerged port structure of the Roman period, probably a pier, in the locality of San Giovanni, which offers a much more complex view of the ancient port of Lupiae.

Among the evidence already investigated and documented in the 1990s, some was also recognized in the latest photographs and video footage obtained by drone, while other items are no longer visible (Fig. 6).

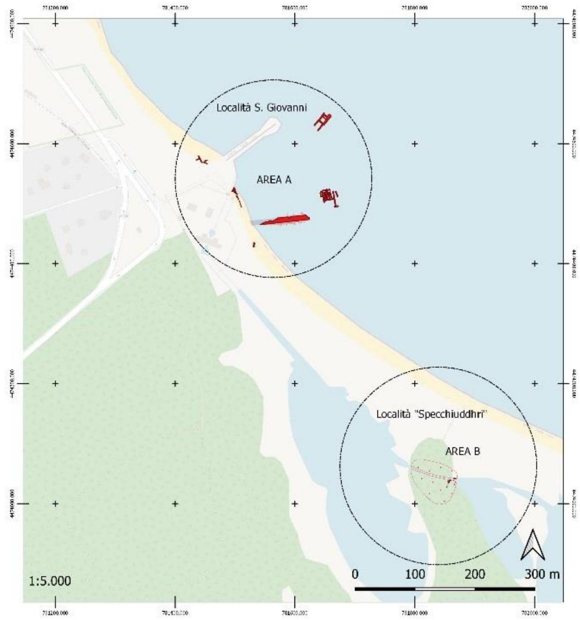

Fig. 6. Archaeological area in San Giovanni.

Also worthy of note here is the structure known as the "submerged church" located in the sea off the channel, 150 m from the shore, at a depth of about 4 m, measuring 33 x 15 m. Carved out of the rocky seabed to a further depth of 1-1.5 m are three large rectangular rooms. Only the layout is preserved, while the walls are believed to have been built of square blocks, judging from the material scattered in the immediate vicinity.

At about 100 m south of the channel and 125 m from the shore, at an average depth of 3 m, there is a rectangular structure composed of blocks of local calcarenite of varying size, arranged parallel and perpendicular to each other, occupying a rectangular area of 24 x 30 m; the complex may be even larger, as some rows of blocks seem to continue under the sand (Fig. 6).

In terms of both position and typological and technical characteristics, this structure seems to be connected to the imposing structure identified during the 2020 surveys. The latter is a pier built using the typical technique of landing stages in the Adriatic and other areas of the Mediterranean, especially eastern, with caissons: two parallel walls built with large parallelepiped blocks of local stone, the space between them filled with irregular stones, sometimes reinforced with internal partitions for the distribution of forces.

This structure begins about 15 m away from the shore (but the initial section may be covered by sand) and 65 m south-east of the outlet channel; it is bordered by two external curtains of large blocks and stretches east/north-east (84 ° N) for about one hundred meters (Fig. 7).

The initial section of the structure measures 43 m on the north side and about 50 m on the southern side. Furthermore, there are two rows of blocks side by side in the center of the pier in its outermost section, corresponding to the last 25 m, with an orientation substantially coinciding with the masonry of the outer walls.

The pier is about 8 m wide and the overall length, in this preliminary investigation phase, seems to be 100 m (83 m visible); the foundation rows of the two parallel alignments that make up the curtains are composed of large parallelepiped blocks (1.50 x 0.65 cm) which are laid end-to-end along the entire length of the pier (Fig. 8).

In some places, two or more overlapping rows are preserved, but on the outside of both faces, the collapsed blocks are scattered across a wide area.

Fig. 7. Aerial view of the submerged pier in San Giovanni.

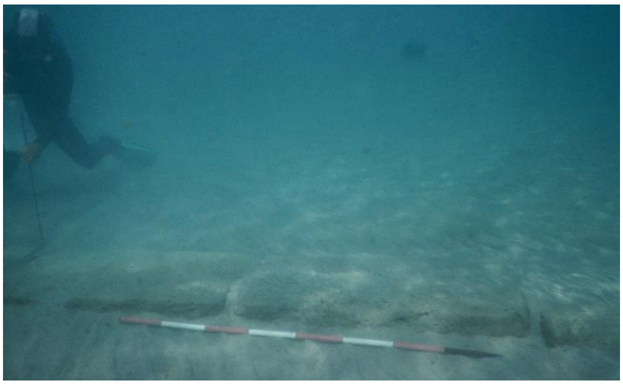

Fig. 8. Northern curtain of the pier seen from the south.

In the terminal stretch, in a secondary position, sections of a channel dug out of long blocks of limestone, sometimes overturned and no longer aligned, probably also removed by the force of the waves, can be seen. The depth of the blocks at the (assumed) start of the pier is less than one meter, while at the head it reaches 4.0 m. It is therefore an important marker of sea-level variation, considering a relative rise since the pier's construction of about 2 m, the draft of ancient ships being compatible with the remaining 2 meters.

This structure shows an affinity of type and construction technique with Hadrian's pier north of the wide bay of San Cataldo and the two structures are of similarly impressive dimensions and monumental character. The caisson technique recurs, as we said, all along the Adriatic coast, with local variations and adaptations. The same technique seems to occur in sections of the "new" pier of S. Giovanni, as well as in the submerged structure just to the north.

Together with the other structures mentioned above, the presence of the large pier of S. Giovanni indicates an important port complex, whose overall geometry has yet to be determined by means of a targeted study.

Certainly, a dating to the Augustan age of these port structures is a very appealing hypothesis. Sources mention Octavian's landing at the port of Lupiae on his journey from Apollonia to Rome[2]. Evidently, in the late republican and early imperial period, some infrastructures already existed in this area. Only later would the port be moved further north, with the construction of the new large pier wanted by the emperor Hadrian.

Porto Cesareo Marine Protected Area

In the waters around Porto Cesareo, submerged and semi-submerged archaeological evidence has recently been uncovered by preliminary surveys carried out in close collaboration with the management of the local Marine Protected Area (Fig. 9). The surveys have added new evidence to the numerous discoveries already made (Alfonso et al. 2012).

[2] Nicolaus Damascenus, fr. 130, XVII-XVIII Jacoby (Life of Caesar); App., Civ., III 2, 10.

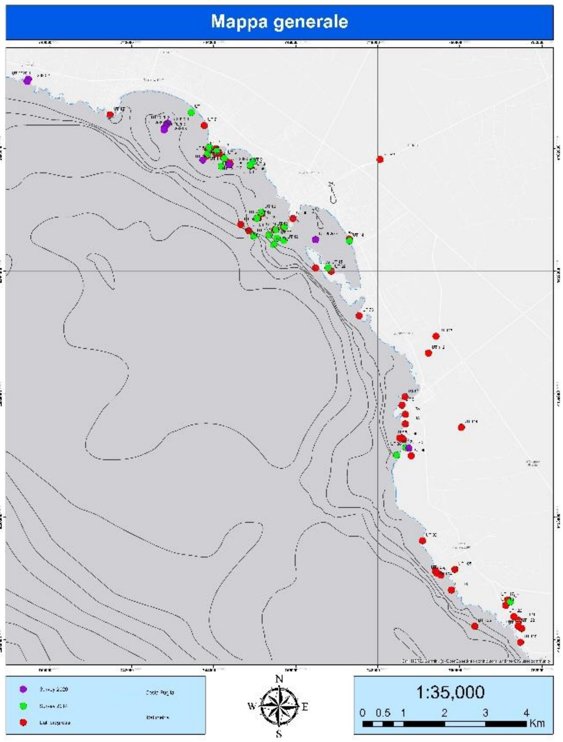

Fig. 9. Archaeological map of the findings. In red the presences already known, in green the data from survey 2014, in purple those of 2020

In the sea area called "La Pierta", which is the broad bay between Torre Chianca (to the south) and Torre Lapillo (to the north), at 600 to 800 m from the coast and at a depth of 3.5 to 4.5 m, on a rocky platform marked to the east – on the landward side – by a steep descent to a depth of 5.5 - 6 m, what was previously assumed to be rock formations have recently been revealed by Mino Buccolieri to be extensive concretions of fragments of amphorae - handles, bottoms, rims and walls. These are cemented both to each other and to rocky outcrops on the seabed, which, due to environmental erosion, in six cases have acquired a distinctive morphology, reminiscent of gigantic mushrooms, with a reduced base and elongated "hats" (Fig. 10).

Fig. 10. Tripolitanian amphoras' cargo remains.

The fragments are all of North African amphorae from the province of Tripolitania, classified as Tripolitan II (Fig. 11). Their homogeneity confirms that they belong to single ship's cargo. The Porto Cesareo specimens do not seem to have been dumped. They include no other types of amphora or vessel, whether common or valuable.

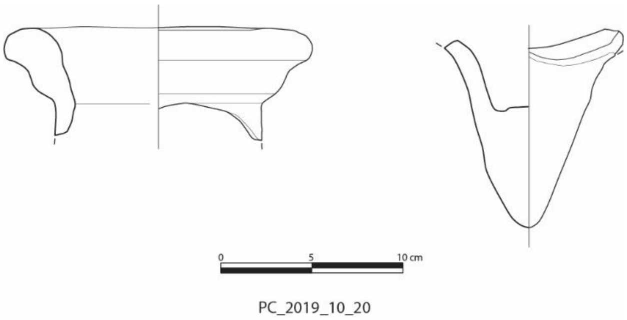

Fig. 11. Tripolitan II amphora fragments.

The remains are therefore attributable to a homogeneous cargo of considerable volume, given the number of fragments and the extent of the seabed affected. It therefore appears to have been a “direct” shipment from the place of production to the place of consumption: a “supertanker” travelling fully loaded with a “wholesale” shipment, probably headed east, towards the ports of the eastern Mediterranean, whose voyage was tragically cut short along the Ionian coastal route between Crotone and Capo Iapigio.

Regarding the dynamics of the formation of this field, the hypotheses are still being debated. The cargo was evidently fragmented by the impact on the bottom, and perhaps by the devastating environmental energy of the waves; the constant hydrodynamic movement subsequently grouped the fragments on the seabed, collecting both near rocky spurs and in depressions; in the sandbanks, the remains were captured and hidden by sediments. However, the erosion of exposed areas has helped to generate the spectacular formations that we see today, dispersed over an area of about 2-300 m².

In the last few years, further investigations have been also conducted at the Bronze Age site of Scalo di Furno, a protohistoric, long-term coastal settlement occupied almost without interruption from the early Middle Bronze Age (16th-17th centuries BC) to the Late Iron Age (5th-6th centuries BC). The underwater archaeological survey of the area between Scalo di Furno and the nearby islet made two important discoveries. First, a submerged wall (about 17 m long, 5 m wide and 1 m high) was found about 100 m southwest of the southern remains of the Bronze Age fortification wall. The second find concerns a large area (about 2000 m²) paved with stone slabs lying on the rocky substrate, which preserves the archaeological soil with hundreds of fragments of local handmade pottery and many fragments of animal bones. Both pieces of evidence lie about 3.5 m beneath the current sea level and demonstrate a substantial change in the coastal geography of this area that probably began during the first half of the 2nd millennium BC: all of the currently submerged area up to the islet was dry land during the Bronze Age and represented the lower terrace of the settlement.

In the same area the wreck of a Roman navis lapidaria, with a cargo of five monumental cipollino marble columns and 1 block from the quarries of Karystos in Evia, Greece, 8.5-8.8 metres long, with a total weight of 78 tons, lies 4.5 meters deep (Fig. 12).


Fig. 12. The wreck of a *navis lapidaria* during the survey phases

The latest investigations allowed us to complete the photogrammetric survey and the 3D model of the integrated ship (Balletti et al. 2016). Furthermore, the modelling and animation enabled us to understand the dynamics of the shipwreck; the ship ran aground due to its draft (3 metres) being greater than the depth at the site, considering that sea level was then approximatively 3 metres lower than today.

New discoveries, measurements and reports concern isolated or decontextualised finds, such as anchors, amphorae, lamps, table and kitchen ware, fishing equipment and ship components.

All these remains attest to the intense occupation of this area in ancient times, which was both a fishery and on a coastal trade route.

Finally, we must point out the presence of two beached wrecks. One is particularly relevant (Fig. 13), due to its chronology: it is dated by radiocarbon to 9th century AD, and seems to be a medium-sized cargo vessel, suitable for long-distance coastal navigation and similar to examples from the Levant or the Aegean (Alfonso et al. 2012; Auriemma 2012).

Particularly interesting is its vicinity to the place where was found a golden ring-seal of Basilios, the protospatharius and eparch of Byzantium, who took part to the legation sent by the emperor Basilios I to the Pope Nicola I in 867 AD, showing an intriguing coincidence.

Fig. 13. The medieval wreck of the "Bacino Grande".

Significant coastal seascapes' changes are testified also by the presence of archaeological material and anthropic deposits on the islets of the Porto Cesareo archipelago, dated from the Archaic to the Roman Age, and the structures partially under the sea level on the peninsula near Torre Chianca (Roman age) and on the "La Strea" peninsula (medieval age), the latter probably identifiable with the enigmatic settlement of Caesarea Augusta, founded by Federico II (Martin 1995); in the shallow water of "La Strea" a second beached wreck has been recently found, probably coeval to the settlement.

Also the quarry of Torre Castiglione, brought to the light by the powerful storms of 2019, is a precious testimony of a different ancient coastal landscape: in addition to the large deposit on the shore, squared blocks, of various dimensions, are currently under the sea level up to 2.10 m deep.

Discussion and conclusions

The main result of the activities presented in this article lies in the definition of a wide-ranging survey methodology that integrates and updates the previous documentation with the help of new documentation tools and technologies. An essential part of the activities carried out in the underwater environment was the photogrammetric acquisition of the aft part of the Roman wreck of Torre Santa Sabina, which allowed the experimentation of survey techniques to be used in the future campaign. It was also possible to integrate the new data with those of the survey conducted 14 years before this study.

The results presented show that modern photogrammetric algorithms can provide a valid alternative to direct investigations in the documentation of the excavation phases of archaeological sites.

The use of digital photogrammetry techniques applied to the archaeological survey of underwater sites can constantly speed up survey operations without neglecting the quality and reliability of the data collected. The implementation of these procedures also provides better conditions for the operators' involved thanks to the reduction of the total immersion time.

For some years now, marine photogrammetry has been an essential documentation tool and we have seen significant growth in applications. This methodology, in fact, allows to document, reconstruct and virtually restore the detected submarine assets (Bandiera et al. 2015) and make them accessible remotely (both to the public, but also specialists and scholars of the sector).

At the same time, the adoption of low-cost sensors offers the possibility of rapidly processing and obtaining photogrammetric point clouds, but often at the expense of adequate metric accuracy (Capra et al. 2015). Fortunately, geomatics allows us to overcome these problems by providing the tools to obtain reliable documentation suitable for the study, conservation and enhancement of cultural heritage (Capra et al. 2017).

The amount of data collected in the three sites will constitute the documentary basis on which to set future lines of research, allowing an organic vision of the problems and interpretative criticalities inherent in the historical reconstruction of this territory. It is an approach to documentation that wants to be global and contextually dynamic, that is, open to the revision and integration of data and the re-elaboration of the same.

The investigations in the coming months will further enrich our knowledge and contribute to the historical reconstruction of this region, but in general will provide fundamental data to understand the long process of interaction between man and the natural environment, in a landscape, i.e. the coastal landscape, constantly evolving.

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Polar night diving – lessons learned from the past four seasons

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Abstract. Due to its mission and working area, the Scientific Diving TEAM of the Institute of Oceanology Polish Academy of Sciences (IO PAN) has a long history of diving operations in polar regions, both Arctic and Antarctic. Until recently, due to logistic constrains, most of them took place during the short summer period. Noticing the lack of data from the winter season, since the beginning of the Mare Incognitum project in 2015, first Arctic polar night diving actions took place at Spitsbergen, Svalbard Archipelago (78°N). They were continued within the framework of LARVAE (2017) and FUND (2020) projects. At a first glance it might seem that these dives do not differ much from typical night diving under central-European winter conditions, but with total darkness for nearly four months (the sun is below the horizon), temperatures on the surface reaching -30°C and -1.5°C under water, the wind chill factor and drift ice, special preparations both of the gear and procedures are needed. Under such conditions the scientific work done underwater is usually the easiest part, as most of the effort is put into pre- and post-dive logistics. Here we report the most important aspects of polar night diving from our perspective. We describe the gear used (including lighting, heating and safety equipment), the most frequent malfunctions and failures as well as dive routines that make diving under such challenging conditions possible. Fortunately, the harsh environment has usually crystal-clear waters to offer which greatly compensates for all the inconveniences.

Introduction

For a long time, the Baltic location, and a large number of projects carried out in polar regions, made cold-water diving the main area of activity at the Institute of Oceanology Polish Academy of Sciences (IO PAN) (Balazy et al. 2014). Scientists from IO PAN have been present at Spitsbergen Island every year since 1997, have performed logistically difficult and challenging dive missions under the ice pack, as well as took part in longer Antarctic expeditions. Interestingly, until recently nearly all of this polar work was carried out only during more accessible summer months.

That has changed in 2014 when a large collaborative project led by Prof. Jorgen Berge called Mare Incognitum / Marine Night was initialized and IO PAN was invited to take part in it. The project involved two winter campaigns and lasted until 2015. Some of its findings are published in Berge et al. (2015) and Balazy et al. (2021). Apart from first studies of biological processes during the Polar Night that were done by Jan Marcin Węsławski and colleagues (1991) and project Cleopatra in 2006, the polar night received very little attention, most probably due to logistic constrains. No wonder that, for a long time it was assumed that the polar night period was almost completely devoid of life, where biological processes stop or slow down significantly and the most of the animals either travel south, or to the open sea, the ones that stay survive only on reserves stored during the short summer months when food is plentiful. This paradigm has been recently questioned (Berge et al. 2015). Mare Incognitum project apart from shedding new light for this little explored part of the year, was also the driving force for new projects run by IO PAN (2017 LARVA: Linking annual cycle of reproduction and recruitment, 2020 FUND: Filter Feeders Under Change). Within all of them diving was one of the main research tools. Most of the diving actions involved either sample collection (biological like meroplankton with diver operated under water pumps, diver towed nets; water) or instrument (time-lapse cameras, sediment traps, fluorometers, current metres and loggers, settlement panels) deployment, its recovery or maintenance. These tasks typically engaged two people being underwater for 45-60, very rarely 90 minutes, at shallow depth up to 20 m.

The conditions during the dives were challenging and quite changeable (Fig. 1).

Fig.1. Example of the conditions on the surface and underwater. A - snow in front of the cabin entrance, B – drifting sea ice on the dive spot, C – Base boat MS Farm in the snow blizzard, D – outboard engine covered with ice, E – MS Farm at dive site in search for ice fields, F – preparing for a dive, G – surface support, in the background MS Farm, H – diver recovering time-lapse camera. Photos: A – Maciej Chełchowski, E – Piotr Kukliński, B, C, D, F, G, H – Piotr Bałazy.

The polar night at Spitsbergen Island, Svalbard Archipelago (78°N) lasts for nearly four months (begins 24 October and ends 18 February). One may be surprised that: a) it is not always completely dark, and despite the sun is below the horizon the light conditions largely depend on weather, either there is a clear sky, full moon, northern lights or heavy cloud coverage and snow blizzard, and b) by the fact that since 2006 ice-cover is rare here. Monthly mean temperature in January at the surface is around minus 14 degrees Celsius, while underwater 1 degree. Both tides (the max. amplitude of tides is 1.8 m) and currents are not a problem but wind can be troublesome (mean wind speed 5 mps, strongest winds can reach up to 32 mps). While performing the dives in such natural settings one should consider several risk factors. First and most obvious ones is the complete darkness, the cold, sub-zero temperatures, wind chill factor and connected to this ice action, among which the drifting sea ice can be especially dangerous. You can imagine yourself in a situation when surfacing after hour-long dive you encounter a thick ice field that prevents free exit to the surface. Having experienced such an "adventure" in more controlled environment in Northern Norway we have treat this very seriously. Distance from civilization and decompression chamber is also of note. As well as the presence of potentially dangerous polar bears. Apart from all of that since all of diving activity, due to typically costly logistics, is packed into two-three week expedition standard diving hazards apply like repetitive, multi-day and sometimes heavy exercise diving.

Diving equipment and procedures

In the literature there are number of information on how to overcome and prepare to these difficulties (e.g. Jenkins 1976, Lang and Mitchell 1987, Lang and Stewart 1991, Jewett 2001, Lang and Sayer 2007, Marsh et al. 2013). It is a mix of knowledge derived from standard diving courses, like night and ice diving, with professional scientific and first-hand, mostly under ice diving operations experience. It is hard to find anything specific concerning polar night diving, as it is rather uncommon type of activity but surely worth recommending are for example the proceedings of the Polar Diving Workshop that was held in Ny-Alesund (Spitsbergen Island, Svalbard Archipelago) edited by Lang and Sayer (2007).

In this short summary there are presented subjective feelings and approach to certain safety issues applying only to: a) open circuit SCUBA gear (for those of interested in rebreather diving in polar conditions please see the article on the use of rebreathers in Antarctica by Heine and Bozanic (2017)), b) open water dives as it was assumed that fast ice should not be present in the study areas (Kongsfjorden, Isfjorden, Spitsbergen Island, 78°N) despite the polar night conditions, and c) non-decompression dives as at Spitsbergen there is only one decompression chamber located in Ny-Alesund, but without any staff employed, which means that in case of emergency one is expected to run it fully. Without proper earlier certification and training on this unit this is of course of little use, despite there is a manual lying next to it.

In polar night conditions proper thermal protection is of prime importance. Apart from hypothermia, chilling takes away not only the comfort of work, its precision, but increases also air consumption, and the risk of decompression sickness. Typically, to keep the thermal comfort high, thinsulate undersuits are used as they tend to behave much better when wet/flooded than standard materials. Shell tri-laminate dry suits are not protecting from the cold but dry faster, are lightweight thus easier to transport with a plane. We use wet hoods, but that of 11mm neoprene, which when well fitted, used with full face masks and neoprene neck seals sometimes event prevent water from flooding the head. Due to logistic problems with transporting the large tanks to remote locations argon was never used as our inflation gas. Instead we relied on efficient electric heating vests. Fully heated undersuits due to their limited power, and stiffness have not worked so well. To power the much warmer 60 W heated vests a spare battery pack is always stored on the diving boat. Electric gloves are used occasionally as having them underwater apart from increased temperature means also additional cables under the suit and less overall comfort. No heated socks though. Additional 1-2 kg of weight is beneficial as it enables for more air in the suit. Dry suit dump valves are always closed during the dive (apart from ascent phase) as the air has a better chance of heating as it is not replaced constantly. Prevention and behaviour underwater are important. One should remember to protect yourself against the cold much earlier before the dive, in the preceding days. Raising the hands while underwater from time to time makes a big difference as when hands are lowered or holding something almost all of the insulation is additionally compressed and squeezes the air out of the glove. We do not remove the wrist seals to enhance the flow of heated air as due to specificity of our work our gloves get punctured.

Small double 7 litre 300 bar tanks with isolator/shut off valve proved to provide enough air for our needs and are small enough to fit rubber boats. No problems were experienced despite the higher pressure (> 220 bar) and connected to this potential higher risk of freezing. Similarly, Apeks TX50 DS4 first stages were not freezing except one free flow incident, caused most probably by improper servicing. The tests performed in controlled and Antarctic conditions (e.g. Bozanic and Mastro 1992, Clarke 2007) did not list however this regulator as the one with the highest cold-water performance. Nearly minus 2 degrees Celsius seawater temperatures in Antarctica could be the possible cause except that we have also experienced such winter cooled water the last season (January 2020). Important safety precautions for preventing the free flow include opening the valves just before jumping into the water, taking the first breath only underwater where temperature is much warmer than in the air. A good practice is also having a stage bottle clipped at 1.5 m depth to assist that kind of submerging. At this depth a switch is made from the stage bottle to back gas without breathing the cool gas in the very cold air temperature. When inflating wing or dry suit short burst of air are the best method preventing freezing. We also try not to inflate the gear while taking a breath to decrease the flow of air. The use of full-face masks which add much safety in terms of loss of consciousness, and thermal protection is questionable with the described configuration as in the case of free flow the mask needs to be taken out of the head and replaced with spare one kept in the pocket. This is not as easy as the shutting the primary valve and switching to the back-up regulator suspended below the neck. If not using the full-face masks simple lip covers on the regulator mouthpiece provide more protection for the lips. I personally do not use the isolator valves on the intermediate pressure hose as I have seen situations when they have been accidentally closed by the diver.

Regarding the lighting equipment for the darkness which is also fundamental here, apart from the strong, reliable and long-lasting primary light on the Goodman handle, two small back-up lights, a powerful strobe and light sticks for each diver are used. To our knowledge the Trojan strobe is the most powerful strobe available on the market. Originally designed for wreck diving to be mounted on the shot line gives very bright light. Its big battery ensures constant work in cold water for at least 24 hrs which is a lot and fully covers our daily routines. These strobes were also used on the surface marking buoys and on the zodiac boat. You can easily give them different colours by putting them inside colourful mesh bags in order to differentiate between a diving buddy, buoy, or a boat. The base boat was fully enlightened and in constant search for possible ice fields dragged with wind or currents.

To eliminate most possible gear failures underwater all of the gear was kept as long as possible in a warm, dry place and not in the deck. Otherwise it froze. Regulators were pressurized just before the jump to the water. No earlier testing of their work / pre-breathing on the surface was performed. To assure a positive buoyancy before the jump wings were inflated orally. Proper maintenance between the dives / diving days included removing the water from the wing bladders as freshwater could freeze immediately when in contact with winter cooled seawater. Inflators, regulators with second stage diaphragms cover removed were always dried completely in warm place.

Safety equipment

Due to high Arctic location a polar bear walking down the main street in Longyearbyen was at least couple of times recorded in the recent years thus having a rifle on the diving boat is mandatory. A bear watch must be cautions as in the conditions of the polar night visibility is limited and with drifting ice present the curious bear can approach from any side. Apart from that the boat should be fitted with standard safety gear (oxygen unit, VHF Marine grade radio, GPS with spare batteries, additional fuel, engine oil, flares, etc.). In remote areas like Svalbard satellite phone, emergency beacons, InReach Explorer+ is frequently used.

Biggest surprises and things for consideration

The weather conditions encountered in January 2020 were quite special. Spitsbergen fjords were almost five degrees colder in 2020 than it was at the same time in 2017, and the fjords were freezing. Since the beginning of long-term measurements at Svalbard in 2002, only one year had temperatures that were about as cold as in 2020. Minus 27 degrees Celsius on the surface and nearly minus 2 underwater were a huge difference between the ordinary, mean minus 14. In such diving conditions small things started to matter like for example the material the rubber boat is made of: easily tearable in such frost PVC versus much stronger and resistant hypalon. The presence of the drifting sea ice, typically absent in the previous years, was responsible of loosing of couple of ship days which highlighted the amount of time needed for such operations, the pressure on the project and dive leader, and the importance of knowledge and experience of the local skipper. More than usually harsh conditions have though us to expect and prepare for the worst.

Once done that being underwater was in fact the easiest part. Diving in Arctic polar night conditions in calm weather is greatly rewarding as it offers crystal clear waters and great visibility limited only by the power of the light source, and a chance to encounter the organisms which are typically living on greater depths.

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Neptune Project: New Sea Sites to Promote Diving Outside the Ligurian Marine Protected Areas

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Abstract One of the objectives of the Neptune project is to improve the management of recreational diving, making it sustainable and integrated with the cross-border territory. In order to reduce the pressure of diving activities on MPAs and to promote the seabed of the Ligurian Sea, the Liguria Region, in co-operation with ARPAL, carried out a survey of natural elements in lesser-known diving sites along the Ligurian coast. More than 50 census dives were carried out and about 170 species of naturalistic interest were monitored, including about 15 protected species. These results have contributed to the implementation of the regional biodiversity database, confirming the richness in terms of species and variety of Ligurian habitats. Characterising the natural heritage in lesser-known areas is a good strategy to be shared across borders, with the dual objective of environmental protection and territorial promotion

Introduction

Neptune is a Maritime Interreg project with Italian and French partners, which aims to protect and promote the underwater environment. Amongst the Neptune partners, the Liguria Region, has carried out a survey of natural elements in lesser-known diving sites along the Ligurian coast, in co-operation with ARPAL.

Divers can affect the marine environment and organisms, either intentionally or accidentally, through physical contact with their hands, body, equipment, fins, the release of air bubbles trapped in sea caves and the resuspension of sediments (Milazzo et al. 2002; Di Franco et al. 2009; Luna et al. 2009).

The impacts of divers are generally caused by their inexperience, lack of technical expertise (though impacts are not necessarily associated with the type of certification) and behaviour than by the number of divers frequenting the site. In fact, if the damage produced by a single diver is not serious, the cumulative effect due to many divers diving in the same spot, as in Marine Protected Areas (MPAs), can cause a lot of severe damages. According to studies conducted over the years in the Portofino MPA (Betti et al 2019), the most frequently damaged species by human contacts are *Eunicella singularis* and *Astroides calycularis.* The identification of new dive sites is aimed at promoting the seabed of the Ligurian Sea, offering viable alternatives to recreational divers and reducing pressure and impact within MPAs.

Study area

Starting from the detailed regional cartography of marine habitats (Diviacco and Coppo 2020) and from consultations with local users, ARPAL has identified several areas of possible interest for divers (Fig.1). Following, we list the main sites where the most detailed survey activities were carried out (west to eastwards): Tuvi near Bordighera (Imperia), Secche di Santo Stefano al mare (Imperia); Secca di Marassi near Finale Ligure (Savona), Secca dello scalino near Savona, Secca dei Bianchi e Neri near Varazze (Savona); la Crena near Genova Nervi (Genova), Punta Manara near Sestri Levante (Genova) and Scoglio del Ferale near La Spezia.

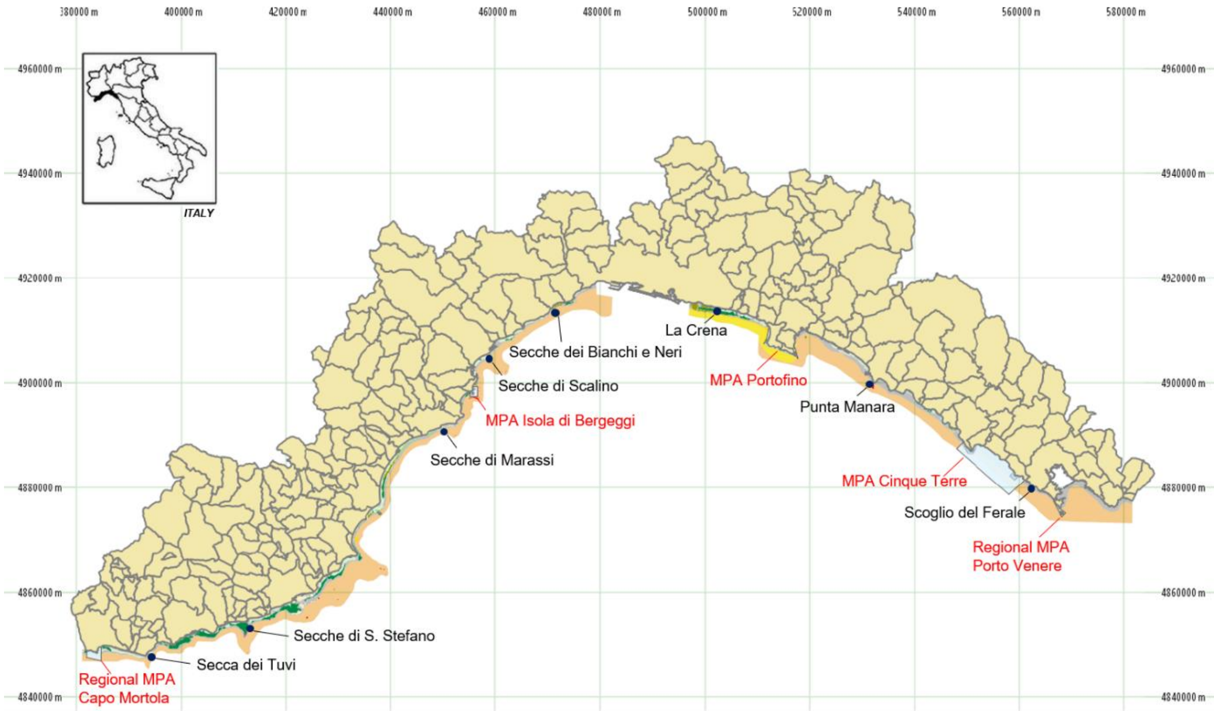

Fig.1. Map of Liguria, coordinate reference system WGS84. In black the dive sites under study, in red the Ligurian MPAs.

Methods

The regional detailed mapping of marine habitats (Divacco and Coppo 2020) was an important starting point for identifying areas of environmental value. In order to verify and complete the environmental information, two or more census dives by scientific diving operators were necessary.

The activities included the characterisation of the seabed (i.e. all information to define a diving route such as depth, direction, slope, etc.,) and the species present. An initial census of species and habitats was carried out directly by the scientific diving operators using an underwater blackboard. This activity was supplemented by video recordings (HD) and detailed photos of the route. Particular attention was paid to the species within the SPAMI (Specially Protected Areas of Mediterranean Importance) protocols (UNEP, 2005). based on the information gathered, Neptune site cards called "blue paths" were compiled. These site cards include the following fields:

- Location: Geographical location, Name of conservation area (or protected area), Degree of environmental protection, Dive site name, Geographical coordinates (reference system).

- Information: Type of access to the dive site, Site characteristics, maximum depth, difficulty, whether the site is of natural or cultural interest, Estimated number of dives made on the site per year and diving centres operating in the area.

- Route map: information on route, presence of SPAMI species and fragile species to watch out for.

- Description of the site from a natural point of view: description and list of the main species, surface of the main habitats, photos of the environmental heritage.

- Description of the site from a cultural/archaeological point of view (if of interest): description with photos of the cultural heritage.

Results and Discussion

Over 50 census dives were carried out and about 170 species of naturalistic interest were recorded including about 15 protected species. In addition, photos and films of the new sites have been archived, enriching the Liguria Region repertory. All the site cards presented an extensive description of the environmental context in order to better characterise each site. Amongst the most commonly recorded species of interest to divers are many benthic species such as: *Parazoanthus axinellae*, *Cladocora caespitosa*, *Leptogorgia sarmentosa*. Rarer is the presence of other gorgonians, such as *Eunicella singularis* and *E. verrucosa*. The coralligenous environment is present at some surveyed sites and encrusting red algae such as: *Lithophyllum strictaeformae*, *Mesophyllum alternans*, *Peyssonnelia rubra* and *P.*

squamaria. Amongst the species included in the SPAMI list, molluscs such as *Erosaria spurca* and *Lithophaga lithophaga*, the echinoderm *Paracentrotus lividus*, as well as many colonies of the madrepora *Cladocora caespitosa* were often monitore recorded. *Posidonia oceanica* is very present along the whole Ligurian arch. Amongst the fishes of the SPAMI list, we found *Epinephelus marginatus* and *Sciaena umbra*, highlighting how it is possible to find valuable species and habitats all along the Ligurian coast.

The cards called "blue paths" will be uploaded on the Neptune portal (in press) making it accessible to all the visualisation of the data. Below we present an example of part of the blue route developed for the "Scoglio del Ferale" (Fig.2 and Fig.3).

Fig.2. NEPTUNE blue paths. Information and location site

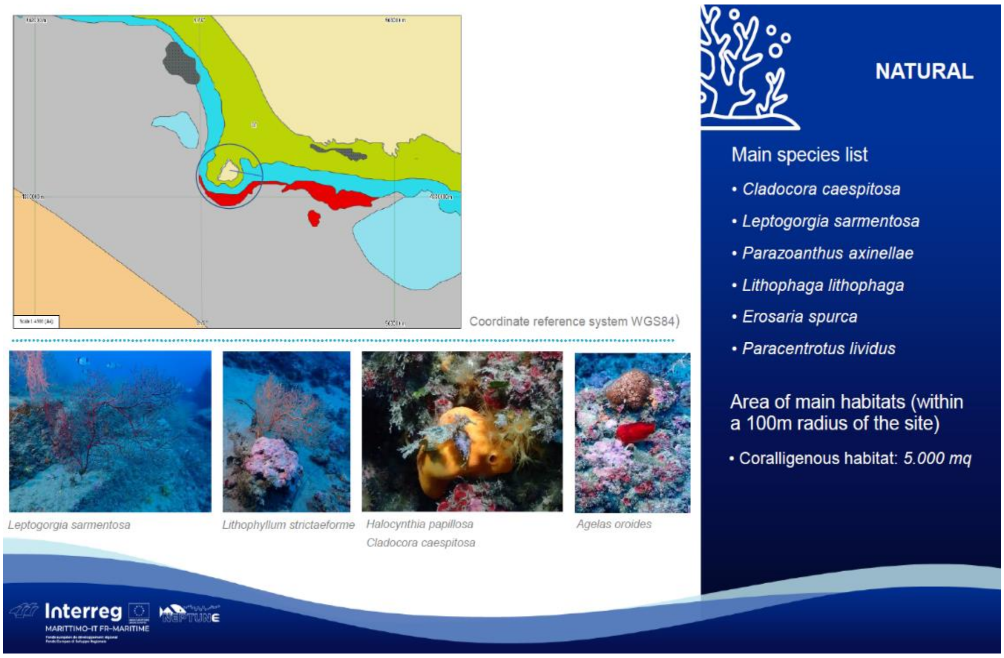

Fig.3. NEPTUNE blue paths. Characterisation of natural heritage: habitat map and photos

Conclusion

One of the objectives of the Neptune project is to improve the management of recreational diving, making it sustainable and integrated with the cross-border area.

This work will make it possible to promote the heritage of biodiversity that characterises the Ligurian seabed even in lesser-known destinations. Moreover, these results have contributed to the implementation of the Ligurian regional biodiversity database, confirming once again the richness in terms of species and habitat variety.

Characterising the Ligurian seabed in lesser-known areas is therefore a good strategy to be shared at cross-border level, which will promote regional diving by providing a valid alternative to the most popular destinations, combining environmental protection to territorial enjoyment.

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New scientific methods in breath-hold diving research

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Abstract. Physiological field research on breath-hold divers (freedivers) is challenging as divers are exposed to hyperbaric environments hostile to classical physiological measurement methods. Two main challenges are; I) The need of developing methods allowing measurements of physiological variables underwater at depth, II) To accompany the studied freediver in the water. The rapid vertical descent and ascent makes it impossible for researchers to use SCUBA to follow the participants to depth. We present new approaches in scientific diving to meet these demands. Our methods development of underwater technology has included water- and pressure-proof dataloggers to record and store data from a 12 lead ECG (250Hz) and photoplethysmograms from two SpO_2 probes using red- and infrared signals (30Hz), combined with ambient pressure and temperature loggers. We previously used SCUBA to enable real-time blood pressure and ECG measurements on freedivers, by waiting for them at the bottom of their pre-determined depth. A breath-hold diving approach for the researcher was found to be superior due to enhanced flexibility in contrast to a heavy, static SCUBA setup. A method was developed in order to perform such scientific freediving safely, the basis being diving in e.g., the professional Japanese Ama divers. Combining the use of novel wearable water- and pressure-proof physiological measurement methods with "scientific freediving", seems to provide optimal work flexibility for both our study participants and the researcher, and may be the preferred approach for our future research.

The challenges of freediving

Breath-hold diving is a natural way of engaging in different submerged aquatic activities, such as competitive freediving (Schagatay 2009, 2010, 2011), recreational freediving (Lippmann 2019), or as a way of sea harvesting and spearfishing (Rahn and Yokoyama 1965; Schagatay and Abrahamsson 2014).

In competitive freediving, "Apnea" the athletes strive to achieve a maximum time, distance or depth in several categories (Schagatay 2009, 2010, 2011). The International Association for the Development of Apnea (AIDA), the main organization for international competitions, has for nearly three decades arranged competitions in six main disciplines. In static apnea (STA) athletes aim to hold their breath underwater for as long as possible during rest; in dynamic apnea athletes try to cover the longest distance swimming underwater using fins (DYN) or without fins (DNF). Depth disciplines include constant weight freediving, where athletes aim to reach a pre-determined maximal depth with fins (CWT) or without fins (CNF) and free immersion (FIM), where freedivers use arms only to pull themselves down to a certain depth along a vertical line. In all disciplines the diver must surface in time to be able to perform a specific *surface protocol* to ensure that the hypoxia is not severe. The competing freediver is accompanied during the last part of ascent by a safety-diver, who is also freediving. Over the years elite freedivers have substantially pushed the known boundaries of human physiology (Schagatay 2011). Currently the AIDA world record for STA is 11:35 min, for DYN it is 300 m and for CWT it is 130 m (AIDA 2019a). Other organizations, including CMAS, are emerging on the international freediving scene, and arrange their own competitions in various disciplines.

A unique aspect of freediving, compared to most sports, is the abstinence of breathing. Therefore, even though freediving is very common, it can be dangerous to practice without supervision and proper education and training (Schagatay 2011). The body needs to cope with a limited amount of oxygen (O_2) during the dive. As oxidative metabolism is limited to the available O_2 brought down in the body stores – lungs, blood and tissues – O_2 needs to be conserved, and the ultimate limit of apneic duration is determined by the tolerance to asphyxia (Schagatay 2009). For the freediver it is essential to provide the most O_2 demanding organ, the brain, with sufficient O_2 to sustain consciousness, while in the swimming freediver propulsive muscle work must also continue based on available aerobic- or anaerobic resources (Schagatay 2010). While O_2 is being consumed, carbon dioxide (CO_2) is produced, and during under water activity, the freediver needs to balance propulsive work with progressive systemic hypercapnia and hypoxia. In long dives the resulting arterial desaturation may lead to loss of consciousness; "hypoxic syncope", also called "blackout" (BO), when freedivers attempt to maximize their dive (Craig 1961). Thus, a submerged freediver must resurface prior to reaching a level of hypoxia that may lead to BO (Lindholm and Lundgren 2009), for which the outcome may be lethal without immediate assistance. But how does the freediver know when to turn around in order to reach the surface before BO occurs? This is a central challenge in freediving research.

About 6.5% of dives in freediving competitions result in BO (AIDA-international 2019b), a result of athletes trying too hard to push their limits. While safety divers can assist and rescue the competitor, the deeper dives become more challenging, and athletes risk getting closer to their physiological limits due to the pressure effects and a long distance to return to the surface. Such situations are impossible to mimic in laboratory settings, where most freediving physiology research has been done to date. Present knowledge on freediving physiology gained by laboratory-based breath-holding (Dujic and Breskovic 2012; Heusser et al. 2009; Bain et al. 2018) must therefore be re-evaluated and expanded by studies at depth during actual freediving in the sea.

The basis of established knowledge

Since the laboratory is more suitable for advanced physiological measurements than the sea, a vast majority of studies focused on investigating the physiological responses to simulated diving. Studies have often been done by facial immersion and apnea (Lin 1982; Gooden 1994; Foster and Sheel 2005; Schagatay 2009), a setting known to evoke similar protective responses as in an immersed diver at the surface (deBruijn et al. 2009). Studies on breath-hold divers in a pressure chamber have been used to better mimic diving situation (Ferrigno et al. 1997), and yet others have recorded data before and after dives on the surface (Linér and Andersson 2008; Fernandez et al. 2019; Barak et al. 2020; Patrician et al. 2021).

A few studies succeeded in performing measurements on divers working at depth. Variables studied included diving depth and duration (Rahn and Yokoyama 1965; Schagatay et al. 2011), continuous electrocardiogram (ECG; Kiviniemi et al. 2012; Lemaitre et al. 2013), heart anatomy and function by echocardiography (Marabotti et al. 2009), stroke volume, heart rate and cardiac output by impedance cardiography (Marongiu et al. 2015), blood pressure by sphygmomanometer (Sieber et al. 2009; Breskovic et al. 2011) and heart rate and arterial oxygen saturation by pulse oximetry (SpO_2; Kuch et al. 2010; Stanek et al. 1993). Blood samples have also been collected at 40 and 60 meters in depth with the help of a researcher using a SCUBA set-up (Bosco et al. 2018; Scott et al. 2021). While some of these studies have confirmed the knowledge established in prior laboratory experiments, new insights have also been gained, sometimes unexpected, warranting continued research. Given the situation that competitive freedivers continue to reach more extreme depths, it also seems important to expand the established knowledge on deep freediving physiology.

A new approach

The need to forward knowledge on freediving physiology requires development and testing of new underwater physiological measurement devices, as well as conducting studies using these devices.

A main challenge is constructing a device which is small enough to wear and not assigned to measuring only at a predetermined depth, but capable of continuous monitoring during actual diving. Such a setting could optimize workflow for researchers by allowing multiple measurements during one session, as opposed to collecting individual datapoints from a boat during short periods. In order to efficiently study underwater physiology, the scientist also has to be able to follow the freediver at depth without hindrance of heavy equipment, thus there is a need for developing a flexible system allowing both work at the surface and rapid vertical movement.

There are practical challenges, other than issues that deal with making the technical devices pressure- and water resistant. Firstly, the measurement device needs to be adapted for underwater use during actual freediving in open water. A non-invasive method is preferred, since invasive methods entail a more complicated approach when submerged, and also do not offer the possibility to monitor physiological changes continuously (Stanek et al. 1993; Bosco et al. 2018; Scott et al 2021). Furthermore, using non-invasive methods would likely affect recruitment of research participants due to the infection risk. Secondly, a small streamlined device without external cables facilitates the use during freediving. External cables may jeopardize the safety of the freediver due to increased risk of getting entangled and stuck at depth during a dive. It is therefore considered important to insert the device inside the wetsuit of the diver, which is only possible when the device itself is small and flat enough.

To enable collection of data regarding physiological changes during entire dives, i.e., including pre-dive baseline values, descent, ascent and recovery, data must be collected continuously from before, until sometime into recovery after the dive. Previous studies using SCUBA gear measured selected physiological variables at pre-determined depths (Marabotti et al. 2009; Sieber et al. 2009), however, this only reflects changes a depth and does not account for the continuously changing demands of an actual freedive. The workflow of the researcher needs to be optimized to enable measurements of multiple freedivers consecutively, including placement and switching devices on and off, check-ups of sensor location and data quality. In this case, it seems more relevant for the researcher to employ freediving as a way of moving around at- and below the water surface rather than using SCUBA. A challenge with this approach is making freediving safe for the scientist.

Our aims of this paper were twofold:

I) To present recently developed specialized underwater instrumentation

II) To present a freediving method suitable for performing underwater studies

Specialized underwater instrumentation

Dive computers and depth loggers (Sensus Ultra logger, Reefnet Inc.) have been used previously in scientific studies related to diving physiology (Schagatay et al. 2011; Abrahamsson and Schagatay 2014), however there are only few devices which also record physiological parameters. Some Scubapro (Johnson Outdoors) dive computers can derive the workload from the diver by assessing breathing as well as heart rate. The breathing rate is derived from the pressure reading from the tank pressure sensor, and heart rate is acquired with a heart rate belt. While some Polar heart rate monitors, using 5.2 kHz transmission, also work underwater, newer generation heart rate belts, which use the 2.5 GHz ANT or Bluetooth protocol, cannot transmit underwater to a recording device, as 2.5 GHz data transmission will work underwater only for a distance of a few centimeters. Another commercially available device which is able to record heart rate of a diver, is the Descent Dive Computer from Garmin, which derives heart rate from a plethysmogram acquired at the wrist. It is also able to measure arterial oxygen saturation at the same location, however this measurement typically takes around one minute under motionless conditions, which is not practical for monitoring freediving. Furthermore, the location of arterial oxygen sensor on the wrist is not the best site for this measurement due to peripheral sympathetically-mediated vasocontriction.

Apart from the devices mentioned above, there are no other instruments commercially available off the shelf which can be used to acquire physiological parameters of freedivers. The reason for this may be that the market for such instrumentation is rather small, and development costs can be considerably high. This is especially the case as such devices, if commercially available, fall under the directive for medical devices, which require extensive and costly validation and certification. As a consequence, most research groups working in freediving physiology research rely on ad hoc and custom-built devices.

One straight forward way to design such instruments is to water and pressure proof commercially available physiological data recorders. Schuster et al. (2017) designed a system for the French Navy to allow recording of physiological parameters of military divers. In that study, a wireless core temperature datalogger (Vitalsense, Philips Respironics) was housed in a drybox (DryCase200, Otterbox), which was then water and pressure proofed up to 30 m in depth. Recently, our research group has been involved in the development of an underwater continuous wave near-infrared spectroscopy (NIRS) system, using a similar approach, whereby a PortaLite mini (Artinis) sensor body was housed in an aluminum case with a removable O-ring sealed lid, while the sensor head needed much custom work to finally be inserted in a silicone mould.

In addition, larger laboratory instruments were equipped with protective housings to make them suitable for underwater usage. One example is described in Marabotti et al. (2008), where an echograph ultrasonic imager is placed inside a housing, which is held at ambient pressure, allowing the device to be operated with integrated gloves. Another frequently used method to waterproof instruments is housing them in acrylic tubes. Our team has used this approach for ECG, temperature, blood pressure and SpO_2 recorders (Sieber et al., 2010). One major disadvantage of using such acrylic tubes or a housing like the Otterbox is the size of the device. Especially for competitive freedivers, where streamlining is essential to reduce drag and thereby oxygen cost, such large and bulky instrumentation can be cumbersome.

An alternative is to design underwater physiological data loggers similar to technical dive computers, where housings are frequently CNC machined from POM or Aluminum. This allows very compact designs, however the development effort is considerable, as this requires in depth expertise of mechanical design of water and pressure proof housings. Moreover, CNC machining of a single part is costly and typically only makes sense when a larger number of devices are produced.

Modern additive manufacturing methods enable a new method for designing water and pressure proof instruments. Typically, parts from cheap 3D printers are not water and pressure proof. Moreover, such parts usually have tolerances >0.1 mm and the roughness of such parts is high, which makes sealings with O-rings difficult. An alternative way to waterproof devices is to place them in 3D printed enclosures and then potting them in silicone gel, making the device insensitive to ambient pressure. Similar to CNC machined housings, very compact designs can be achieved. However, there are some electronic components which cannot tolerate higher ambient pressures, and should thus not be used in such designs. For instance, passive matrix OLED displays, which have a vacuum cavity, should be avoided in such designs, as the cavity may implode under increasing pressure.

Development of a universal datalogger for physiological parameters

In order to advance our research on freediving physiology, we have developed a universal datalogger in a 3D printed housing filled with silicone gel (Fig. 1). The requirements for this datalogger include:

- Readout of 1-2 SpO_2 plethysmogram channels
- Wireles receiver for a 5.2 kHz heart rate belt
- 12 lead ECG
- Digital ambient pressure sensor
- USB Port (download and charging)
- Display
- Possibility to monitor the signals in real-time (laptop or display)
- Marker switch
- Relatively small size to avoid discomfort for the diver

Core component of the datalogger is the STM32L452 low power ARM Cortex M$ microcontroller from ST Microelectronics Platform. The integrated floating-point unit allows fast calculation of algorithms in real-time. Moreover, the device features various interfaces including USB port, several I2C interface, one SPI interface, and SDIO interface for efficient data storage on an SD card, as well as direct memory access for most peripherals.

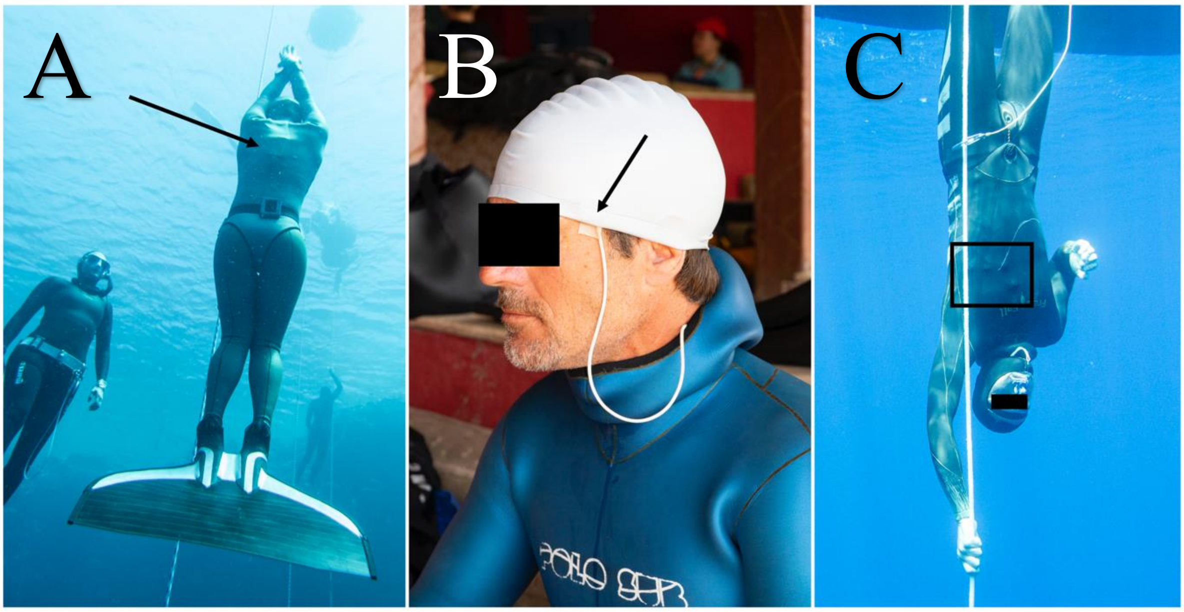

Fig.10. Freediver resurfacing from a dive, accompanied by a safety diver, black arrow indicates the placement of universal datalogger on the back of the diver, inside the wetsuit (A); freediver equipped with SpO_2 sensor (indicated by black arrow), held in place with tape and swim cap, and while diving also by the hood of the wetsuit (B); freediver engaging in a free immersion dive, black rectangle indicates ECG sensors placed on the torso (C).

The MAX30102 integrated plethysmogram sensos (Maxim IC) incorporates 2 LEDs, photodiode, LED drivers as well as photodiode amplifier and a 24-bit ADC in one single device. It is designed primarily for reflective pulse oximeters integrated in smartphones.

While it is simple to waterproof the device by encapsulating it in a suitable resin, it is unfortunately not pressure proof, as it has an internal air-filled cavity which is protected only by a 0.2 mm thin glass cover. To make the device pressure proof, the glass cover was removed and the cavity was filled with optically clear polyurethane resin. However, care has to be taken to not damage the components and dust has to be avoided, thus ideally this process is done in a clean room.

For ECG acquisition the ADS1298 from Texas instruments was chosen. It features eight differential input channels a 24-bit ADC, and can be configured for acquisition of 12 lead ECG. Correct sealing of the ECG electrodes needs extra attention. While in fresh water it is possible to acquire ECG even without any isolation of the electrodes against the surrounding water, the low conductivity of sea water practically short cuts the electrode, thus making it impossible to acquire meaningful ECG data. The disadvantage of applying ECG measurements is that correct sealing and placement of electrodes is time consuming. Therefore, an additional 5.2 kHz receiver for reception of signals from a heart rate belt was included, which allows a simpler way of collecting heart rate and heart rate variability data without the complications associated with ECG measurements.

Data is currently stored on a 32-GB SD card in *.csv file format, but storage in additional file formats are being developed. While data can be downloaded via USB port, a fiber optic transmitter is integrated in the device as well, which allows connecting the device with an up to 30 m long fiber optic cable to a laptop, enabling real-time visualization of the data.

As described above, the housing was fabricated with a 3D printer and the electronics were encapsulated in silicone gel, allowing a very compact design.

The biological equipment needed for freediving

Freediving is diving without using a breathing apparatus or any other external gas supply, thus while breath-holding. The ever-present risks of hypoxia potentially leading to BO must therefore be taken into account when using freediving as a method to perform under water studies. All resources needed for performing the dive must be present in the diver´s body, both sufficient oxygen stores and storage capacity for the metabolic waste products. There should also be means to recover rapidly between dives, should such activities be efficient. This “biological diving equipment” luckily seems to be present in our bodies, and freediving has most likely been used for obtaining food from the sea since the emergence of humans (Hardy 1960). Even our cousins, the Neanterthals, have been found to dive for collecting shellfish (Villa et al. 2020) and our earliest H. sapiens ancestors were leaving shell middens along the African coast, showing they were eating large amounts of mussles (Jerardino and Marean 2010). Shell middens and mounds are among the most widespread arcaeoholical deposits in the world (Villagran 2019). The long-term global distribution of human deposits of shells, likely collected at least in part during freediving, suggests that our bodies have for long periods been under evolutionary pressure to develop adaptations to frediving, which could explain why we share several protective responses with seals (Eftedal et al. 2016). While deep diving species of seals and whales have specific adaptations to extend dive durations and depths, the human ability to freedive is in fact typical of a large group of shallow divers among diving mammals (Fahlman and Schagatay 2014).

Our physiology is well suited for shallow diving due to several specific responses providing the necessary tool kit for coping with a limited oxygen supply. The “diving response“, initially identified in marine mammals (Irving 1938) occurs as soon as the human diver breath-holds and immerses the face (Schuitema and Holm 1988), and efficiently conserves oxygen by concentrating blood flow to the brain (Andersson and Schagatay 1998; Palada et al. 2007; Willie et al. 2015). This response is enhanced in non-divers by only 2 weeks of breath-hold training (Engan et al. 2013) and the long-term activity in underwater foragers and training in elite freedivers has improved this response to refinement, which allows them to perform longer apneas (Schagatay and Andersson 1998). Another human response shared with seals is spleen contraction, which elevates hematocrit during diving - an elevation which does not happen in splenectomized individuals (Schagatay et al. 2001; Bakovic et al. 2003). This response is triggered by the hypoxia in itself, with some additional effect from hypercapnia (Lodin-Sundström and Schagatay 2010; Richardson et al. 2012) so it needs to be “kick started“ by a warm up dive (Schagatay et al. 2005). Splenic contraction is mediated with sympatho-excitation (Bakovic et al. 2013) as a part of the non-specific peripheral vasocontriction that affects most peripheral organs including the heart (Kyhl et al. 2016). Beside brain perfusion, that is doubled during maximal dry apneas (Palada et al. 2007; Willie at al. 2015), liver perfusion is also maintained (Kyhl et al 2016). The circulating extra red cells will increase blood oxygen stores and can also help with gas transport during recovery. A difference between these responses is that, while the diving response turns on and off each dive as the diver breath-holds, the spleen response develops across a few dives and stays turned on between serial dives, allowing the red cells to transport new oxygen to the cells and waste products to the lungs (Schagatay et al. 2007). These two separate physiological responses thus work together to enhance oxygen stores and minimize their use, to enable the freediver to minimize the anaerobic metabolism. A factor important to extend dive time further is to increase the brain´s tolerance to hypoxia, which is also achieved with dive training (Lindholm and Lundgren 2006).

Repeated freediving as an efficcient method for gathering food

By using these two responses, several groups of professional freedivers work efficiently for many hours a day underwater using repeated diving with short recovery intervals. A relatively well known and studied group is the Ama-divers of Japan, that were already during the 1960-ies the target of much interest from physiologists (Rahn and Yokoyama 1965). (Part of this interest could have arisen from the vivid illustrations by photographer and anthropologist Fosco Maraini in a book published in English 1962, showing nearly naked women diving in the deep sea for shells and pearls).

While it was predicted in the 60-ies that these divers would no longer exist in a few decades, as their hard work would not be chosen by young girls, the profession still exists and recruits young divers in the 21st century. Early studies of their physiology revealed key features in their diving strategies (Rahn and Yokoyama 1965), and our more recent research visits have shown that using this very efficient repeated diving strategy, they can spend 50% of the working time underwater (Schagatay et al. 2011), a work that may be continued with undiminished efficiency until the 8th decade (Schagatay et al. 2014). The Ama divers nowadays use fins, masks, wetsuits and weights (albeit no snorkels; Fig. 2), but the older Ama report that in their early careers they dove with only simple masks (ES personal communication 2013). The Ama of Japan have been active for at least 2000 years, and are considered to have originated from the Cheju Island in Korea (Rahn and Yokoyama 1965), where the Haenyo, a Korean counterpart to the Japanese Ama, still work as freedivers (Hurford et al. 1990).

Fig.2. A pair of Ama divers using a buoy and buddy safety system during deep freediving for shells.

Another Asian group whose physiology has more recently been described is the Sama-Bajau of Indonesia, Philippines and Malaysia (Schagatay et al. 2011, 2014). They still dive using very limited external equipment, usually only wooden goggles, but have developed their biological equipment to dive to the extreme; they display a very pronounced diving response (Schagatay 2014), increased spleen size (Illardo et al. 2018) and even have the capacity to see well underwater without goggles (Gislén et al. 2003). Using only their internal equipment they are able to spend 60% of the working time diving underwater while breath-holding (Schagatay et al. 2011). Doing so for up to 9 h in a day, they may thus spend 5 h working submerged, which is sufficient to collect a large catch (Schagatay et al. 2011; Schagatay and Abrahamsson 2014 – a living based on BH diving).

While the human diving response was first described by Scholander (1940) spleen contraction was first observed in the diving Hae Nyo of Korea (Hurford et al. 1990). Bajau divers have been found to have larger spleens compared to non-diving populations (Illardo et al. 2018) a trait that the authors concluded could be result of long-term evolutionary changes. However, there is an enhancement of both spleen size and contraction with frequent exposure to hypoxia (Engan et al. 2014; Bouten et al. 2019) showing that it is not entirely genetically fixed but plastic, similar to the diving response. Both responses are thus present in these active professional freedivers, enabling them to fully benefit from the resulting enhancement in diving performance. Compared to SCUBA divers, who are limited in dive time by the size of their air supply, and even more so by the maximum exposure time and depth, and the necessary surface intervals to avoid decompression disease (DCS; Boycott et al. 1908) the freediver may thus sustain repeated diving for many hours across a day. A common misconception about freediving skills is that very long breath-hold duration must be achieved for productive diving. In competition diving this is given, when a single maximal effort dive is the goal and the athlete can thereafter spend long periods to fully recover. The contrary is true for the food diver, in which the daily total bottom time is the primary goal, and recovery time must be kept to a minimum. Their great knowledge allows them to time the dives to stay within the aerobic dive limit, which enables them to keep recovery pauses short, as no anaerobic waste products are accumulated (Schagatay et al. 2011). Interviews with 9 professional Ama revealed that they very rarely had incidences of BO; only two divers knew of such occasions (ES, personal communication 2013). They thus seem to avoid the risk of BO, but their means to sense their limits so well are unknown, and they use no external equipment to aid in detecting the developing asphyxia (ES, personal observations 2010-2013). An awareness of the risk still exists, as when deep diving, the Ama always dive in pairs on a shared buoy, alternating as a safety for each other (Fig 2).

Developing an efficient and safe freediving based working method

Inspired by these efficient food divers, we set out to develop a similar method to enable professional scientific and other work underwater, using only using human biological resources. The development was based on the observed diving patterns used by the Ama and the Bajau, and done in collaboration with the freediving club High Coast Apnea in Sweden during two subsequent summers. We identified some key features to be essential for efficient and safe freediving:

Efficiency:

1) Serial shorter dives within the aerobic dive limit will be more productive than making long single dives (as this would lead to anaerobic metabolism requiring long surface recovery)
2) The effective use of the limited aerobic resources requires special equipment, and proper weighting, (dependent on depth – enough to reduce buoyancy – but allowing rapid ascent)
3) Not overfilling the lungs
4) Use mask and snorkel – enabling breathing with vision while planning the next dive
5) Insulation (if water below 28 ºC) to reduce risk of shivering metabolism, by using a wetsuit (using a drysuit is not recommended)

Safety:

6) Diving in pairs, taking turns in diving and acting safety 1:1 dives
7) Keep dive time short while allowing longer surface intervals
8) Avoid hyperventilation (would delay IBM)
9) Use a buoy to rest between dives
10) Use a line to orient to the target and to enable efficient and safe ascent

Participating freedivers were told to always return to the surface at sensing the first involuntary breathing movement (IBM). Diving using this method could be achieved with 50% of the time spent underwater in trained freediving instructors, but only if diving duration was kept at less than 50 s in low intensity work, and below 40 s in high intensity work. (Note that longer surface intervals are recommended to increase safety margins). The next task was to develop a method to rescue subjects trapped in cars underwater, in collaboration with the Swedish rescue services (Schagatay and Åman 2019).

Evaluating freediving for underwater rescuing

Our main aims were a) to evaluate the dive times and total rescue times needed using repeated freediving to find and retrieve dummies from cars at 5 and 8 m depth. b) to determine if there was a risk of hypoxic blackout in these rescue attempts by measuring the resulting SpO_2.

The efficacy of the method was first evaluated, as the rescue services doubted that the diving performance by freedivers would be sufficiently effective to perform such work. The available methods to reach and rescue trapped potential drowning victims was by SCUBA diving done by specific diving firemen trained to be rescue SCUBA divers. There was a larger part of the firemen trained to do in-water surface rescue. The surface rescue team often reached the site of accident after an alarm, were neither allowed nor able to dive down to the victims underwater, due to their wearing dry suits and no weights. If a person remained submerged, SCUBA divers had to be called. When SCUBA-rescue divers arrived at the scene after 30-45 min, and another 10-15 min was spent getting in the water, the victim had almost certainly drowned. When using freediving to reach weighted submerged dummied inside cars, we hypothesized the time would be shorter. Additional key features identified for using the repeated freediving method for this purpose were:

Diving in pairs with one diver always at the surface was adopted, while recovery time was extended allowing sufficient time both for recovery and information on what had been done. To keep dives short, the divers were further allowed to accomplish ***only one*** tasks per dive, then inform the other diver what had been done: **1)** Find the car; **2)** Mark car with buoy; **3)** Opening door/crushing window. **4)** Cutting belt; **5)** Retrieve dummy to surface; **6)** Transport dummy to shore. Divers were equipped with mask, snorkel, fins, weight belt, wetsuit and a buoy with a belt-cutter and glass-breaker. Results showed that the time needed to accomplish all steps from finding the cars to transporting dummies to the shore, was 4 min 16 s from 5 m depth, and 6 min 22 s from 8 m depth, with a mean dive duration of 28 s (range 14 – 46 s; Schagatay and Åman 2019). We concluded that the new "repeated freediving" provided a realistic method to rescue victims within the possible survival time in submerged cars. Comparison of the efficacy of repeated freediving with SCUBA was clearly in favour of the freediving method, when the handling of equipment was included. Considering also the longer time needed for SCUBA divers to arrive at the site, it was concluded that freediving was likely more effective for rescuing people within their possible survival times.

Another critical point for using the method in the rescue services was their concern with hypoxia, and the next task was therefore to study if this method put rescue divers at danger of hypoxic BO. Freedivers arterial oxygen saturation was therefore measured in several dives of 30, 35, 40 and 45 s using pulse oximetry. Mean(SD) nadir SpO_2 after surfacing was 89% for the longest dives, which gives a good safety margin to the 50% level imposing risk of BO (Schagatay 2009). Full recovery occurred within 50 s after the longest dives. We concluded that it was central for safety to follow our method´s regulations and short dive durations. The participants in our study were, however, recreational freediving instructors, and we concluded that this method would be acceptable for working rescue personnel, only if the firemen were provided sufficient education and some training (Schagatay and Åman 2019).

Evaluation of the repeated freediving method for scientific work

Next was to determine if the repeated freediving method could be used by the scientist, e.g., when studying freedivers. Our group has a long history of field research in freediving physiology, and visiting remote areas we often used mini SCUBA-equipment, constructed from pony bottles. While such equipment was fairly easy to carry, a problem was that there was no mini-compressor that could fit in the rucksack, and the dive duration was therefore very limited by the available compressed air. It was considered necessary to develop a safe freediving-based method to replace SCUBA as a work tool in the shallower range of diving. We did an evaluation of freediving as a practical and safe way to perform under water studies. Studying the physiology of professional diving populations, including Ama and Bajau, this method provided means to both measure and observe these food divers, including documenting their work on video. The range of efficient use of repeated freediving was down to a depth of approximately 10 m for the freediving educated but moderately trained scientists, leaving sufficient bottom time when much time was needed for descent and ascent. Dive duration was kept within 40 s with 60 – 80 s recovery. Safety was arranged via line and a buoy, where equipment was stored, and pairs of divers alternated in diving and providing safety.

For studies of deep freedives training or competing in the sea, the researchers need to accompany the participant to a buoy, serving as the base for their dives, where a number of routine practices have to be performed by the freediver before diving down. The scientist must also position devices, turn them on or off, check signal quality and often reposition sensors while in the water. Additional challenges involve observations of the freediver underwater during the first and last part of the dive, while there is no way to follow the deep diver across the whole performance. The repeated breath-hold diving approach was found to be superior due to the enhanced flexibility for the researcher in contrast to a heavy, static SCUBA setup. The first prototype of the underwater pulse oximeter was evaluated using repeated freediving, by holding the pulse oximeter against the diver´s forehead to read the saturation during a stop at 10 m depth.

This method of repeated freediving was considered very useful for scientific diving and we recommend it for depths to approximately 10 m. In order to perform such scientific freediving safely, it is however essential that the developed safety system is used, that freedivers are provided with adequate equipment and that divers receive the necessary education and training. Using a wetsuit and proper weighting is essential to be able to perform this work without too much strain. We have adopted a model where all members of the research team take a beginner and an advanced course in freediving by one of the global organizations (e.g. AIDA, SSI, CMAS, PADI), and before periods of field work they have to spend some time training freediving to develop physiological responses and skills. Repeated freediving in this shallow range can be a useful tool e.g., in physiological studies of other divers, marine biology or archaeological investigations in coastal waters.

Conclusions and future perspectives

Combining the use of relatively small, novel physiological measurement methods with “scientific breath-hold diving”, seems to provide optimal work flexibility for both our study participants and the researcher, and may be the preferred approach for our future research. The technical advancements described here are still in development to enhance signal quality and awaits further validation. Further development of underwater monitors of essential variables is crucial, and developing training programs specialized for professional scientific freediving. Different diving organizations such as AIDA, SSI, CMAS and PADI, are specialized in providing education and training to freedivers, and an advanced course in any of these would provide the basic safety knowledge for freedivers. However as far as we know no organization today teach the safe use of repeated diving, which could be developed based on the provided knowledge. Another necessary step is the production of the essential diving equipment, including a buoy with pockets to safely store the technical devices for in-water transport to the dive site. A short (10 m) weighted line would enable the researcher to safely descend and ascend from the underwater workplace, and for the colleague to provide safety. Having used such a system for many of our physiology studies, we are confident this freediving method could benefit other researchers.

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Aspects of training scientists to work under water

ScienceDIVER: Capacity Building and Harmonization of Scientific Diving in Europe. Professional Acknowledgement of Scientific Divers

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Abstract. The ScienceDIVER project team presents the results of a survey concerning professional acknowledgment of scientific diving (SD) across Europe and worldwide, as well as the outcomes of a workshop focused on the criteria applying for identification of the required skills in becoming professionally acknowledged scientific diver. The report reveals the different standpoints, shared by experts and audience on SD key issues such as certification, legislation, remuneration, insurance and other features. It is reaffirmed that the scientific diving is a complex matter with extremely different rules and systems across the countries and is difficult to harmonize, especially with regards to insurance and other sensitive topics. A common European framework for SD is foreseen to mitigate existing asymmetries in acknowledgment of scientific divers and find suitable approaches toward relevant harmonization.

Introduction

Objective

A common European framework for scientific diving is foreseen to meet the Blue economy increasing need of skilled and qualified scientists to perform underwater dive-based research and to attract young students to pursue a valuable scientific diving career. This framework is the possible way to mitigate existing asymmetries in acknowledgment of scientific divers and find suitable approaches toward harmonization to overcome the gaps and allowing easier mobility of scientific divers. A common mutual professional recognition is one of the pillars for the harmonization of scientific diving in Europe.

While diving technics usage for underwater research has been widely employed since SCUBA diving emerged, the science diving itself is rarely recognised as a profession. The main goal of the study is the assessment of the current state of the professional acknowledgement of scientific divers by identification of the required skills in becoming professionally acknowledged scientific diver and the working benefits at a comparative study like minimum salary, insurance benefits and other criteria.

Definition

UNESCO provides definition of the term "professional recognition". It refers to the right of a holder of a qualification to practice the corresponding profession and to the formal acknowledgement of the claimed professional status. Besides the definitions in various regulations for the recognition of degrees or titles, two principal groups must be outlined: de Jure and de Facto professional Recognition.

De Jure Professional Recognition applies to the right to work in a specific country in a legally regulated profession. In the European Union, for instance, those regulations exist in both home and host countries and are subject to various European Union Specific Directives. De Facto Professional Recognition refers to situations of unregulated professional recognition applied by employers where no national legal authorization exists or is required (Fig.1) (Vlãsceanu et al. 2004).

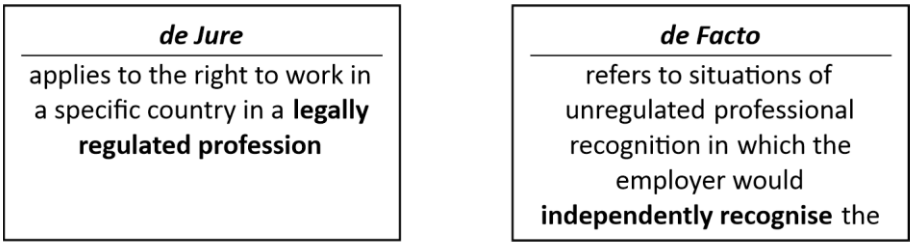

Fig.1. Definition of the term "professional acknowledgement" by UNESCO.

In general, the professional recognition is the formal acknowledgement of an individual's professional status and right to practice the profession in accordance with professional standards and is subject to professional or regulatory controls (https://www.qualityresearchinternational.com/glossary/professionalrecognition.htm). In many areas, professional recognition is not possible without having completed the professional programme of study.

Professional recognition may also extend across national borders. Many countries have procedures in place for the checking, verification and recognition of professional qualifications from another jurisdiction. The European Community issued a specific directive that describes the process of recognition of professional qualifications across borders (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32005L0036).

Material and methods

A survey, concerning the professional acknowledgment of SD in EU and at global level were performed in order to obtain relevant information. The principal approach consists of collecting publicly accessible/on-line facts, defining related terminology and/or assessment criteria and ratings, developing reliable system of questionnaires, on-line forms and interviewing mechanisms, performing stakeholder interviews and expert consultations and systematization, analyses and assessment of the collected data.

Assessment criteria and ratings selection

In order to provide consistent analyses and proper assessment it was essential to select relevant criteria.

Four groups of criteria are implemented in the assessment. First group is derived by the terminology, second are substantial and are connected to the skills required by legislation and to the working benefits, concerning the remuneration, and forth are bound to cross-country recognition practices.

Criteria derived by the terminology

1) The dive is a part of a scientific research with non-proprietary results;
2) The research is officially recognised;
3) A scientist is in charge of the activity;
4) The diver understands and is capable of implementing scientific technics;
5) The scientific diver instructor is relevantly certified;
6) Intra-organisational regulations are developed;
7) SD is an occupational activity;
8) SD is considered professional if the diver is compensated specifically for the current diving.

Substantial criteria

1) Requirement to appliance to national regulations;
2) Exemption from commercial diving regulations option;
3) Scientific Diver certification requirements;
4) General diving certification requirements;
5) First aid and/or CPR certification requirements;
6) Scientific expertise of divers requirements;

7) Organisational internal regulations requirements;
8) Medical examinations requirements;
9) Maximum depth requirements;
10) Insurance requirements;
11) Early retirement benefit.

Remuneration related criteria

1) Existing national rules to compensate financially scientific divers
2) employer practice to compensate financially scientific divers

Cross-country recognition practices

The cross-country recognition practices are related to visitor scientific divers' cross-country requirements.

Data collection

At the initial phase of the research publicly accessible sources were used to define the fundamental parameters of the methodology: the terminology and the assessment criteria. The inherent information was collected through reliable system of questionnaires, on-line forms and interviewing mechanisms, performing stakeholder interviews and expert consultations. Correspondents represented either national institutions or corporative structures. The findings were openly presented to the stakeholders and supplementary material was collected through interaction with the audience.

Results

The survey succeeded in obtaining data form 18 countries: 10 EU-countries and 8 non-EU countries. Following results are obtained through systematisation of the collected data (Table 1):

Table 1. Matrix of the obtained data. Legend: N – on national level (officially recognised/enforced by a certain legislation act); O – on organisational level (de facto recognised/enforced/applied by employer, but not regulated in national legislation); P – in progress (regulation is being currently developed or in process of appliance); D – outdated (regulation is existent but is either not implemented anymore or in process of revoking); Empty cell – N/A (there are no data about the topic in the country)

Criteria	EU Countries										Non-EU contries							
	Bulgaria	Croatia	Germany	Greece	France	Italy	Latvia	Poland	Romania	Spain	Albania	Australia – New Zealand	Canada	Singapore	South Africa	UK	Ukraine	USA
the dive is a part of a scientific research with non-proprietary results													**N**		**N**			**N**
the research is officially recognised													**N**		**N**			**N**
a scientist is in charge of the activity												**N**						
the diver understands and is capable of implementing scientific technics																		**N**
the scientific diver instructor is relevantly certified																		**N**
intra-organisational regulations are developed																		**N**
scientific diving is an occupational activity																		**N**
scientific diving is considered professional if the diver is compensated specifically for the current diving																		
existence of national regulations	**P**		**N**			**N**		**N**			**N**	**N**	**N**	**N**	**N**	**N**		**N**
requirement to appliance to general regulations						**N**		**D**			**N**	**N**			**N**	**N**		
exemption from commercial diving regulations option						**P**		**N**				**P**	**N**					**N**
Scientific Diver certification requirements											**N**				**N**	**N**		
general diving certification requirements	**O**	**N**		**N**			**N**				**N**		**N**			**N**	**O**	
first aid and/or CPR certification requirements													**N**					
scientific expertise of divers requirements											**O**							
organisational internal regulations requirements								**O**			**O**							
medical examinations requirements		**N**		**N**		**N**	**N**						**N**			**N**		
maximum depth requirements		**O**				**N**	**O**											
insurance requirements				**N**		**N**		**O**			**O**	**N**				**N**		

early retirement benefit																		
existing national rules to compensate financially scientific divers				N														
employer practice to compensate financially scientific divers	O																	
visitor scientific divers cross-country requirements (denial, permission, equalisation, affiliation)					N							N						

According to the collected data one third of the surveyed countries reported general diving skill requirements on national level and 11 % – on organisational level. There are only few countries requiring specific scientific diver certificate – 17 %. Most of the countries require recreational certificates corresponding to the diving conditions.
The information about scientific divers' remuneration is scarce. In most cases the remuneration practice is not clear; either depends on separate projects capabilities, either on the practice in the specific organisation, or is not applied at all. Significant deviations appear by countries and vary in the range of 50 – 100 EUR/per diving day in cases of non-decompression occasional dives. Young scientists, implementing regular diving activity in their work, would be compensated with monthly salary of 1000 – 2000 EUR in EU countries, while in USA were detected rates of 30 000 to 90 000 USD per year according to qualification. There is no sustainable information concerning the compensations obtained by divers working on larger scale projects. We may conclude that there is no consistent general policy in EU countries concerning SD remuneration. (Fig.2)

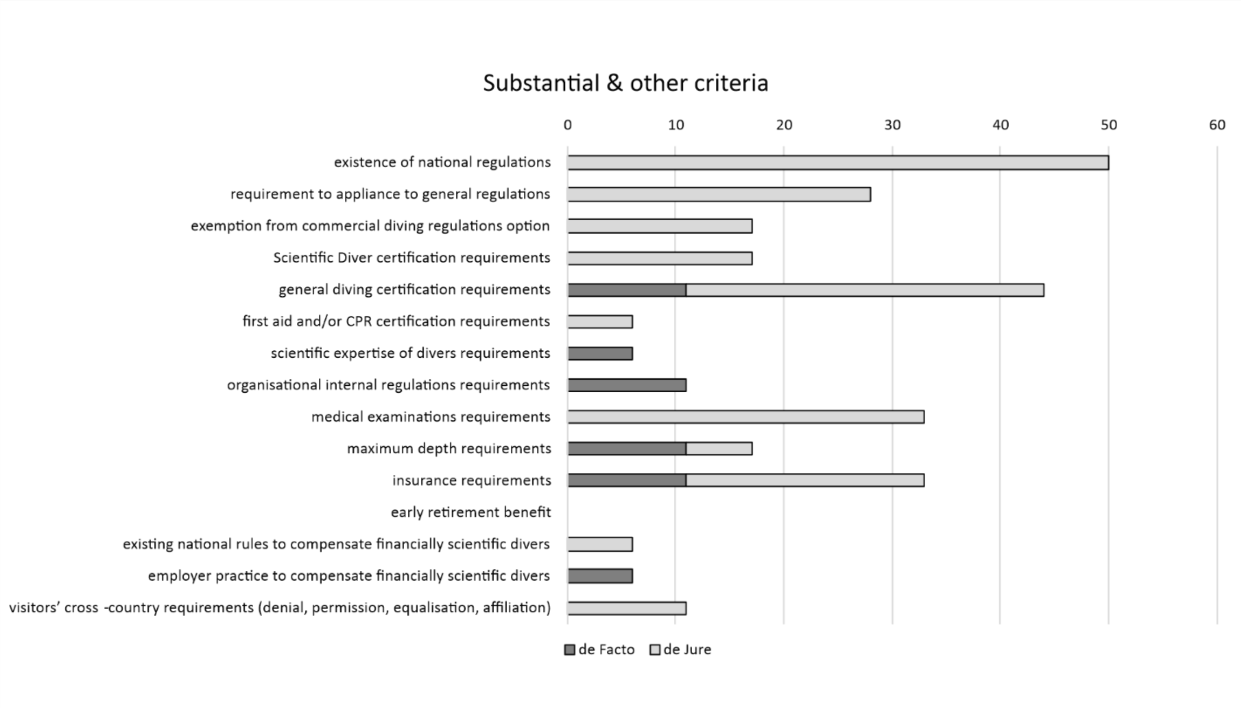

Fig.2. Substantial criteria shares amongst surveyed contries.

In the course of the data assessment we also found that:

- only four countries are reported to have distinct definition of the term "scientific diving". They are non-EU.
- in the legislation of the half of the reported countries exists the term "scientific diver"
- in most countries which apply their national rules to scientific diving is observed process of implementing exemption option from commercial diving regulations
- only one fifth of the reported countries require specific scientific diving certificate. Two of them are European Union countries. This certification is generally required for archaeological purposes only
- no proper data about scientific expertise of diver's requirements are available, neither on national, nor on organisational level
- medical examination is commonly applied
- few of the reported countries limit the SD to a certain depth
- insurance policy is commonly required where diving certification is required, predominantly on national level
- visiting foreign scientific divers are generally not treated in the host country legislation but France and Australia reported relevant regulations.

Based on the feedback of the presented Project outcomes, the expressed points of view and the interaction with the audience, it is reaffirmed that the scientific diving is a complex matter with extremely different rules and systems across the countries and is difficult to harmonize, especially with regards to insurance and other sensitive topics. It is obvious that despite the long-lasting efforts, the progress made so far and the achievements of the SD community, there are open issues expecting to be solved.

Conclusions

On the basis of all material gathered from free sources, personal conversations, interviews and questionnaires several important issues could be defined:

- Predominantly, there are not available legislative/official documents concerning the professional acknowledgment at national level. Scientific diving is not regulated in a clear manner, even in countries where it has been considered as well developed.
- The institutions set with the aim to promulgate scientific diving are still not nationally recognized by any state administrative act as organization responsible for the professional acknowledgment of scientific divers. In practice, they don't provide training courses and don't issue certificates. Usually they adopt minimum standards for the certification of scientific divers and their members further develop own manuals meeting the minimum requirements and the safety at work regulations applying for underwater work in the relevant country.
- The recognition of divers varies according national rules, but often companies employing divers for scientific research have own rules (at organizational level). The difference between EU countries is significant. Some of them recognize European Scientific Diver certification, others require commercial diving certificates, and some prefer recreational diving certificates. Requirements could depend also on the sea conditions and specifics – low visibility, currents or diving below sea ice, and others.
- A lot of countries recognize Divers Alert Network insurance, as well as some others accept national occupational accident insurance. Usually companies pay the insurance for the divers employed, otherwise diver has personal insurance.
- The topic of remuneration seems very sensitive – there is not reliable information obtained. The options vary from additional payment to the basic salary of the scientist for their diving activities – certain amount per diving day, or to be based on the time spent underwater and the depth of performed work. Some countries define salaries for scientists, implementing regular diving activity in their work, either on monthly or on yearly basis. The salaries depend on the organizations hiring the scientific divers, the place, the research site, and other specifics. Additionally, there are scientists practicing diving supporting their researches, without any additional payment. It is remarkable that salary rates are not significantly bound to the minimum or average wages of countries. The scarcity of the information does not allow statistical analysis, but it can be concluded that, first, Scientific diver's labour remuneration is formed considering the ability of divers to migrate in regional or global scale; and, next, in countries with "mature" diving legislation scientists, occupied in positions, requiring diving in their work, would be compensated on yearly basis, while in the rest of the countries rates would be lower and remuneration would be delivered as an addition to the salary.

The conclusions demonstrate the necessity of establishment of common framework. The professional recognition is essential to divers involved in scientific researches. It is important to understand that SD is a particular underwater activity and restricting it within the frame of commercial diving is an obstacle to proper implementation of the tasks and may lead to withdrawal of skilled specialists. In some countries (exmpl. USA) this issue is solved by conditional removal of SD from the general safety legislation and applying appropriate rules developed and controlled by specific agencies.
If you are intending to insert figures and tables please put references inside the text clearly linking each figure (Fig.1) or table (Table 1) to your text. Links on figures or tables have to be inserted manually. Figure thereby is abbreviated as "Fig.", table is NOT abbreviated ("Table").

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The ScienceDIVER project. Training framework online workshop

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Abstract. Within the framework of the ScienceDIVER project an online workshop was organized in December, 2020 concerning Scientific Diving Training Framework. The main objective of this endeavor was to bring various stakeholders together and discuss the current situation, as well as the opportunities for the creation of a common framework, that will bring together the various approaches that have been developed hitherto. The major topics that have been brought up during the workshop derived from the preliminary survey that was conducted by the ScienceDIVER project team. The topics addressed within the workshop included issues of harmonization, connections between training and professional acknowledgment, stakeholders, main features that define SD along with how they are expressed in SD training, the learning objectives of SD training courses, the necessary prerequisites, the structure of the courses, etc. In addition to the discussion among panelists, questions and remarks were submitted to the webinar platform and a questionnaire concerning the aforementioned topics was shared to all attendees.

Introduction

The "Scientific Diving Training Framework online workshop" was organized in December 2020 in the framework of the ScienceDIVER project. The project "ScienceDIVER: Cross-sectoral skills for the blue economy market" started in November 2019 and comprises the joint effort of three universities (Aristotle University of Thessaloniki, Greece - University of Calabria, Italy - University of Stuttgart, Germany), a research institution (DAN Europe) and three companies representing the advisory maritime industry (Atlantis Consulting, Greece – Envirocom, Germany – Marine Cluster Bulgaria). It is fully funded by the European Maritime and Fisheries Fund. The foremost objective of the ScienceDIVER project is to support the development of effective cross-sectoral skills in order to meet the evolving needs in the labor market of Blue Economy. Through the straightening of collaborations and structures between academia and industry, it aims to offer standardized training and clear career pathways to diving scientists within the European Union over the course of three structured phases. The first stage comprises the mapping of the relevant landscape and an assessment of needs. Subsequently the consortium will develop tools for the promotion of the project's principal objectives. Lastly there is the testing phase and the provision of viable solutions with the final results.

Region of Interest

One of the major objectives of the ScienceDIVER project is to map the current state of the Scientific Diving (SD) landscape in order to analyze the data and provide a better understanding of the hitherto choices in the organization of SD. This procedure will yield a solid base on which one can postulate proposals on the development of harmonization practices and the promotion of SD at various levels. In order to approach the subject, the work was divided into separate tasks which includes the conduction of three separate studies concerning 1. Professional acknowledgment, 2. Legal matters and 3. Training Framework. The study of the training framework was designated to be of paramount interest since it is the backbone of every diving scheme. It entails all the theoretical and methodological information of each diving framework and has been designed to transmit this information from one person to another in a comprehensible and coherent manner. A primary feature of these studies was the implementation of three reciprocal online workshops that would investigate these topics in a more inclusive manner. More specifically, the interest of the currently presented workshop lies in the way that training is formed within the existing schema in several places of the world, i.e. their structure, their content, the people involved, their impact and the ways in which they interact with each other.

Method

In combination with the study conducted by the ScienceDIVER workgroup that was appointed with the task of collecting data from official bibliography (Kur & Mioduchowska 2018; Ponti 2012; Sayer 2005,2007; Sayer *et al.* 2008), online sources (AAUS 2020; ADAS 2020; CMAS 2020a; HSE 2020; GUE 2020), manuals (NOAA 2017), code of practices (Flemming & Max 1997; UNESCO 2013), standards (AAUS 2019; CMAS 2020b; ESDP 2017) and other kinds of educational material and correspondence with training organizations and individuals related to the subject, the online workshop was organized in order to (a) provide information on the project's aims, methodology, participants and preliminary results and (b) promote a platform of interaction among all stakeholders, in order to commence an open discussion.

The online workshop concerning the Scientific Diving Training Framework took place on December 16th, 2020. The online platform that was used was WebEx and run under the supervision of DAN Europe, who also supported the necessary digital logistics.

The main objective of the workshop was to bring various stakeholders together and discuss the present situation, as well as the opportunities for the creation of a common framework that will unify the various approaches that have been developed hitherto. The major topics that have been brought up during the workshop derived from the survey that was conducted by the ScienceDIVER project team and comprise issues of harmonization, connections between training and professional acknowledgment, stakeholders, the main features that define SD and how they are expressed in SD training, the learning objectives of SD training courses, the necessary prerequisites, the structure of the courses and other aspects (Tourtas *et al.* 2020).

In the beginning of the workshop, there was a short presentation of the study's preliminary results by the ScienceDIVER project team. The scope of this study was to provide an overview of the scientific diving training landscape and through comparative and analytical tools to offer some insight on the various approaches that are taken spotting either common ground or indisputable differences. The objectives set in order to provide this result were firstly to make a list of all the official diving courses related directly or indirectly to SD, to study them and produce some analytical / comparative interpretations and discuss them, in order to come up with relevant conclusions. For methodological purposes, the sequence "Training standards > Training course > Certification > Qualification / recognition" was adopted in order to be able to synthesize the data (training courses, organizations, learning objectives, material, prerequisites etc.). From analyzing the gathered information that comprises a variety of training courses, the study has concluded to six (6) recognizable qualification systems, which are directly related to scientific diving: (a) American Academy of Underwater Science (AAUS) / Canadian Association of Underwater Science (CAUS), (b) Australian Diver Accreditation Scheme (ADAS), (c) Confédération Mondiale des Activités Subaquatiques (CMAS), (d) European Scientific Diving Panel (ESDP), (e) Global Underwater Explorers (GUE), (f) Health and Safety Executive (HSE). An evaluative comparison of these courses was conducted on three separate levels. The first level was to analyze the prerequisite requirements requested for entering to the course. Each entity examined has a requirement of a recreational diving status (whether basic e.g. Open Water Diver or novice e.g. CMAS **, Rescue Diver or equivalent) in combination with Basic Life Support capabilities (e.g. CPR, First-Aid, defibrillation, oxygen provision). Most of them require medical examination and again all of them require a number of logged dives to prove some kind of experience, although the number and type of dives fluctuates from a minimum of twenty-five dives of any type to more specific demands such as dive planning, participation to science projects, etc. Furthermore, in various cases there are additional prerequisites which specify a current professional status, age limits, nationality issues, medical requirements, swimming proficiency and aquatic-skill standards, etc. The second level of analysis focused on learning objectives. An in-depth analysis of the various courses and analyzing the basic themes on which they are based resulted in a comparative list containing the following recognizable features: (a) dive safety, (b) project management, (c) scientific method, (d) data recording & handling (methodology, mapping, data management, u/w imaging), (e) legal aspects, (f) dive theory, (g) dive modes (e.g. SCUBA, CCR, SSD), (h) seamanship, (i) special conditions (e.g. chamber, night, decompression dives), (j) specialized equipment (e.g. full face mask, dry suit, communications, DPV, lift bags, line reels, compressors), (k) other topics (e.g. u/w navigation, search methods, video systems). Through that process it became obvious that there are certain topics that are common to all training schemes such as dive safety, project management, legal aspects and dive theory. Moreover, it is evident that the majority of the systems (five out of six) provide training on scientific methods, data recording and handling, dive modes, and specialized equipment. Although there are differences with regards to the mode and extent of each topic being approached, the aforementioned learning objectives appear to define the content of the term scientific diving as far as training is concerned. The final level of analysis referred to the output of the process as a whole, specifically the certification provided and its acknowledgment. An important feature was the title granted upon completion of the training, due to the fact that it is absolutely related to its training systems' approach. Thus, along with the obvious Scientific Diver title, one comes across the terms *professional diver* and *occupational diver*. The fragmentation of the SD landscape also results in student certifications not being globally recognized, although reciprocity arrangements are becoming more and more common between organizations, at least in terms of training. Apart from this issue of recognition, there were other notable points of concern that were raised during the study. For example, the fact that GUE and CMAS, the two systems that are also training organizations, are preferable for individual training, since the rest require either a connection with a scientific institution or a professional status. These limitations also result in a tendency for gaps in the existing qualification systems to be covered by courses provided by training organizations (e.g. recreational diving agencies and universities) that do not refer to SD directly or are not connected to the aforementioned schemes. This is quite common in many countries that have either an insufficient or a total lack of SD framework. In such cases, recreational diving courses with learning objectives related to SD or short seminars organized by universities or relevant to the subject organizations seem to compensate for the lack of officially recognized certification. Lastly, an ongoing topic of discussion of burgeoning interest refers to volunteers, amateurs and citizen scientists in research projects and their role ion SD.

The presentation of the study was followed by the presentation of the workshop's key features. A list of main questions that derived from the study, were posed to the panelists and the rest of the attendees in order to serve as guidelines in the discussion. These were:

1) What's your POV on the current situation?
   a. about the fragmented landscape of the SD training framework and the need for harmonization. How close are we to harmonization and is harmonization indeed necessary?
   b. about the connection of the training framework with the legal framework and professional acknowledgment. Can there be a training framework independently?
   c. about the stakeholders that should be involved in a commonly accepted SD training framework. Who are currently and who should carry out SD training, (academic institutions, individuals, diving organizations etc.)?
2) What are the main features that define SD and how are these expressed in SD training?
   a. What are the main categories of learning objectives that a SD training course should include (scientific procedures, dive safety, administration and project management etc.)?
   b. What are the prerequisites for attending SD training (academic status, professional status, previous training level, insurance etc.)?
   c. Can there be a Credit Transfer System (like ECTS is used in university courses)?
   d. How should SD training be structured (levels, entry-advanced, thresholds etc.)?
3) Considering the creation of a unified framework, on what scale should harmonization occur and how?
   a. Can there be a reciprocity chart, like the one used in recreational diving? If this could happen for training reasons, what would the implications be in legal matters and professional acknowledgment?
   b. Can we decide on thresholds (on various levels)? Would that be enough to work on reciprocity and collaboration for future joint training courses?
   c. What other ways do you propose for achieving harmonization through the SD training framework?

Subsequently, the two guest panelists provided their presentations. The first panelist, Dr. Keiron Fraser, Academic Diving Manager at the University of Plymouth and member of the Scientific Diving Sub-Committee of the Health and Safety Executive Board presented the main features of the university's SD training program along with other aspects of SD performed in this context. As the university's Diving Officer and Academic Diving Manager, Dr. Fraser is responsible for managing diving that is carried out by staff and students at the University of Plymouth, which means diving carried out on the HSE SCUBA courses run by the university, diving on student placements and student dissertations and diving by staff to collect samples or gather data for their research. His responsibilities extend to diving both in the UK and overseas. He has worked as a marine biologist in both the Antarctic and Arctic (BAS) and managed their diving operations and he is also a member of the Scientific Diving Sub-Committee (SDSC) of the Health and Safety Executive, which means that beyond his experience within the University of Plymouth he has extensive knowledge of the wider national framework concerning SD. In his presentation, Dr. Fraser noted that the SD training program in the University of Plymouth is the only one remaining in the UK that offers in-house, professional SD qualification (HSE SCUBA). The university provides a Scientific Diving module (OS207 - 48 places a year), as well as opportunities for BSc, MSc & PhD diving projects, research diving - typically around 1,900 dives per year - and an employed dive team of 7 staff members. The presentation included also the key features of the SD training program, such as prerequisites, structure, learning objectives, follow up opportunities, as well its connection to the wider HSE diving framework that coordinates SD in the UK.

The second panelist, Ralph Walter Müller is the Managing Director of the Faculty of Energy, Process and Biotechnology of the University of Stuttgart and co-director of the university's SD group "WiTUS". Mr. Müller made an introduction about the University's SD activities and their placement within the national and international framework. A key feature about Mr. Müller is that he is also responsible on behalf of the University of Stuttgart for the Bologna Process, the series of ministerial meetings and agreements between European countries to ensure comparability in the standards and quality of higher-education qualifications. In this framework, Mr. Müller hones his professional experience on the coordination and organization of inter-faculty and cross-faculty courses and has valuable experience in collaborative endeavors, such as the 1st European Conference on Scientific Diving that was held in Stuttgart in 2015. Returning to the University's SD training program, the panelist provided a short presentation of its major features, i.e. prerequisites, modules, learning objectives, theoretical knowledge and practical skills, examination, etc. Mr. Müller highlighted the explicit need for collaboration and mutual acknowledgment among different SD training programs in order to achieve a more sufficient SD framework.

Both panelists have extensive experience in matters of scientific diving training and provided insights on several aspects of this procedure. A discussion followed with the participation of attendees through questions and remarks that were submitted to the webinar platform. The nature of the questions ranged from high specificity, such as details on the presented training programs and the way they operate, to more generic ones addressing the European SD landscape as a whole, the implications of Citizen Science in SD, the connections between Commercial Diving and SD, issues of reciprocity, etc.

Furthermore, an online questionnaire concerning Scientific Diving topics was shared to all attendees. The questionnaire focuses on the content and structure of SD training as well as issues of harmonization.

Results - Conclusion

The online workshop was attended by a total of 95 people from various fields of research such as biology, ecology, archaeology, geology, engineering, cultural heritage management and conservation, media, etc. One of the most valuable outcomes of this online workshop was the fact that it engaged a significant amount of people who had previously known of the project and the already formed discussion channels, along with the diversity of backgrounds and fields that participants represented. Moreover, there was a noticeable increase in interaction with the general public and individuals interested in the development of SD with regards to training framework and choose to contact the consortium afterwards and offer their relevant contributions to the study. Educators, SD experts and representatives of the existing SD training schemes have been reviewing the preliminary results of the study and a number of online chats has been conducted or scheduled in the period following the workshop. The results of these meetings along with the reviews are extremely valuable, corroborating or amending the gathered results, since the landscape is extremely wide and complicated. This form of collaboration is what the project was aiming for, all along, so it wouldn't be false to say that the online workshop achieved its main objective.

For those who want to learn more, please visit the project 's website at sciencediver.eu/ and find a complete recording of the webinar under the title *Presentations from Webinar 03 "Training Framework"* in the news-events tab or follow the link https://www.sciencediver.eu/news-events/presentations-from-webinar-03-training-framework/. Additionally, if you would like to express thoughts on the matter please contacts us at sciencediver@auth.gr or take part in the research by filling the relevant questionnaire at sciencediver.eu/training-framework-questionnaire.

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ScienceDIVER: Capacity Building and Harmonization of Scientific Diving in Europe. Reviewing the Legal Framework

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Abstract. ScienceDIVER project team organized a virtual workshop entitled “Capacity building and harmonization of scientific diving in Europe”. The workshop aimed at raising awareness on the project goals and activities towards the creation of a common framework for scientific diving in Europe. The outcomes of this endeavor will be presented focusing on the legal framework of a majority of the European countries, as well as some overseas ones, in order to define any gaps, address possible issues or limitations related to scientific diving. Research findings of this study showed that although certain important steps have been made towards improvement of the legal frame-work, there are persistent issues that need solutions adopted by legal authorities. This paper discusses also the possibility of harmonization and the creation of a proposal to the European Union for a new directive covering the field of Scientific Diving, an aspect that will help scientific divers, especially the younger ones, to have a legal identity, professional rights and potentially a career in the field.

Introduction

Scientific Diving (hereafter SD) is a field that has significantly contributed in many fields of science and brought to light knowledge that promotes and extends humanity’s progress. At the moment, important challenges are documented by way of Scientific Divers (SDs) in areas concerning environmental protection, the effects of climate change, marine litter, overfishing, the protection of underwater monuments and shipwrecks, among others. Still, the legal framework that is related to SD is not so clear and in the majority of cases, it does not exist at all. This lack of legal framework and the respective professional acknowledgment results in a rather opaque condition for SDs, especially the younger ones that find many problems in engaging in this crucial and innovative field within science. During recent decades, attempts were made in the countries that have a rather mature legal framework and significant progress has been recorded. There is however a list of cases where the SD in terms of legislation is covered by laws and regulations intended for commercial and/or professional diving. The latter burdens SDs with the obligation to train and certify in conditions that are more technical and in some cases irrelevant compared to the actual ones they operate in the field. This resulted in unnecessary and costly training for the SDs and in certain cases posed an important issue that lead to the decrease of the number of young SDs. In other cases, it was recorded that SDs face problems of recognition for existing diving certifications and diplomas, creating further obstacles for the development of the field. Another important issue is the respective insurance policies that might vary from country to country as well as when working for a public or a private organization. All the aforementioned issues affect the scope of work that can be conducted by SDs in the EU who use diving as part of their work and in certain occasions render the endeavor an impossibility. SD is regulated only in very few countries in the world. Though the body of research is limited, there was a study that recorded the framework of SD in the 1980's which described in detail a list of very important data with the precious contribution of experts from all over the world (Flemming and Max, 1988). Although the authors emphasize Codes of Practice, they recorded important issues related to the legal framework of that time. An ambitious attempt to record, categorize, evaluate the progress/updates, communicate and discuss these issues at present was made from the research team, aiming to support a just and progressive harmonization and hopefully new clearer legislation for SDs initially in EU and then in the rest of the world as well.

Objectives of this study

The main objective of the present study was to examine the legal framework for SD in EU in order to clarify certain important aspects affecting the community of SDs and to examine the possibility of potential harmonization. In parallel, the legal framework for SD internationally was also examined, with emphasis in countries that have rather mature legal framework in order to identify the potential progress from the regulation point of view as well as the good practices and the lessons learned. The overall scope of this study is to identify the "grey zones" for SD regarding the respective legal framework and bring to light the problems SDs face when underwater research is included as part of their work in order to contribute to the potential solution and progress beyond.

Time framework

It must be underlined that the present research is ongoing and it will conclude approximately 2 years from the present time. It began in June 2020 and the first phase ended at the end of July. Dissemination activities and discussions continued and the organization of 3 Webinars open to the public were decided. The respective webinar for the Legal Framework was held on December 9th and it is available on-line (https://www.sciencediver.eu/news-events/presentations-from-webinar-02-legal-framework/). The webinar was welcomed by colleagues from all over the world and additional feedback was also provided, enriching in this way the research team's database. At the moment, publications and further dissemination activities are expected to provide more feedback and comments on the team's research findings, contributing in this way to the improvement of SD legal framework in EU and internationally.

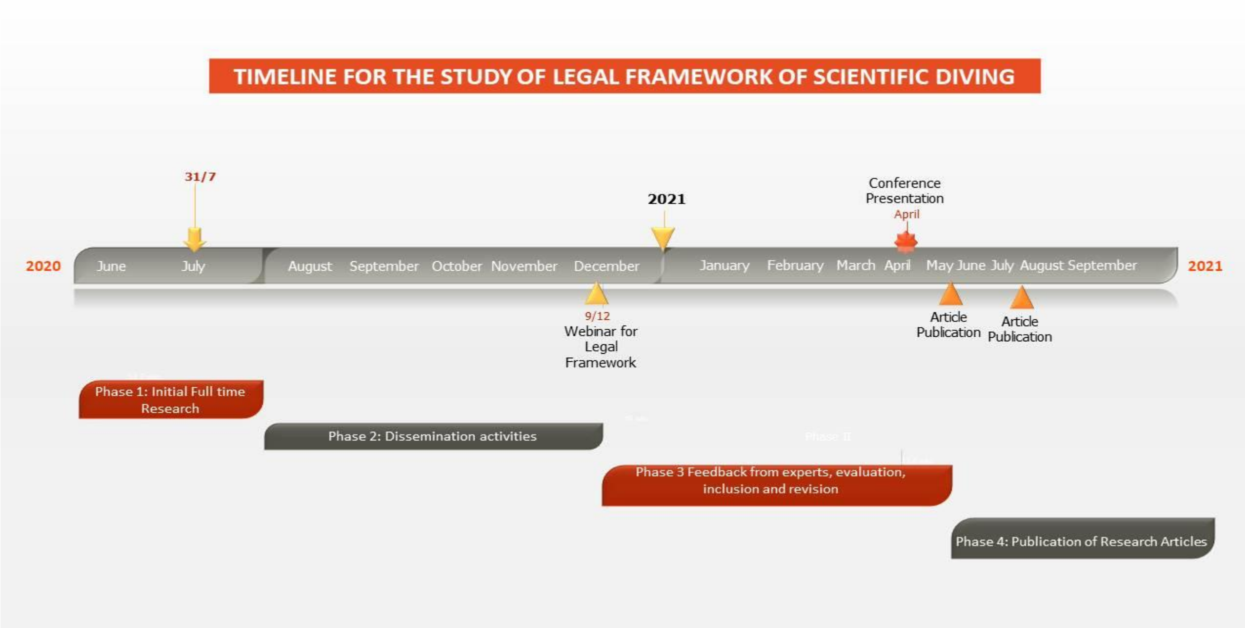

Fig.1 Time framework regarding research and dissemination for the Legal Framework of Scientific Diving.

Research Methodology

In order to identify, collect and categorize the research data, appropriate task allocation inside the extended research team was set. Different groups of researchers searched different part of Europe and other non-European countries as well. The SD legal framework in selected EU countries (hereafter focus countries) was studied in a more detailed manner.

The main research tools included:

- Desk research and Internet sources using all the direct and indirect key words and their derivatives that were translated occasionally to increase the possibilities of successful results in terms of the appropriate legal documents.
- Interviews with experts, where a list of questions that were decided from the research team to be the most central and less time consuming for the interviewed experts was sent. In some cases an actual interview took place in parallel.
- Personal communications, with colleagues and other professionals in order to examine the level of legal framework implementation and the examination of legal framework existence for the cases of countries that do not have mature legal framework.

Results and Discussion

The collected information and feedback were extremely pertinent in terms of quantity and quality. For the convenience of discussion, a brief summary for most of the sub-chapters is presented here and more details will be published in the near future, noting that the research is on-going and new data, evaluations and assessments come to light. Also, for the convenience of reading and potential future comments/corrections/improvements/revisions, the references concerning legislation are presented in the form of links within the text.

Definitions. One of the major problems regarding the legal documents is the definitions. During the research team's study, a list of definitions of various kinds of diving was recorded. The most important definitions that include diving that can be found are:

- Professional Diving
- Occupational Diving
- Commercial Diving
- Scientific Diving
- Recreational Diving
- Off shore Diving
- Technical Diving
- Military Diving
- Police Diving
- Free Diving

In certain cases, especially the term Professional Diving overlaps the other, a fact that can pose certain problems for the SD community. Most of them though, are not included in national legislation but they appear in codes of practices, training and professional certificates.

European Union (EU). EU countries were searched in a more detailed manner. National legislation is higher in legal hierarchy and as a result the respective research was rather difficult. Initially, the research team decided to focus on five representative countries to examine and evaluate the situation and draw safe conclusions that can be compared with other EU countries and the rest of the world as well. From the five countries, three were selected on the basis that the consortium partners were their citizens (i.e. Germany, Greece and Italy) and as a result the outcome was expected to be more reliable. France was selected because it is known to have a rich SD history as well as mature legislation. Croatia was selected to examine the level of maturity regarding legislation as it is a rather new member for the respective issues. Furthermore, consortium partners cooperated with colleagues from Croatia in previous projects that included SD. Eventually, with the progression of the team's research as well as the support from colleagues; all EU countries were examined for their national legal framework for SD. As the feedback continues, information is updated regularly. The initial five representative countries in alphabetical order were:

- Croatia
- France
- Germany
- Greece
- Italy

Croatia. In Croatia SD is not regulated but there are certain regulations followed by the institutions as well as the diver's diploma that relate with the maximum depth for example. The medical check-up and the insurance framework are unclear and there is no adaptation of any particular safety procedure. Regulations regarding Archaeological Research was found and is available online (https://narodne-novine.nn.hr/clanci/sluzbeni/2010_08_102_2798.html).

France. SD in France is regulated by many laws. SDs should possess certification and specific licenses from public or other authorities/organizations in order to work in the field and it includes very strict discrimination levels depending on depth. There are limitations of SD in terms of tasks that depend on the certification level. National health System covers the emergencies as well as additional insurances. Certain medical and annual checks apply that are partially or fully covered by the public health system or the private sector depending on the contract. France defines very clearly the underwater scientific activities**,** including procedure, workers, health and safety and related aspects; even the decompression methods, but creates problems with free movement of workers to and from France. The respective laws and regulations are presented below.

A/ Décret n° 2011-45 du 11 janvier 2011 relatif à la protection des travailleurs intervenant en milieu hyperbare**.**

This is a regulation for the protection of workers that intervene at hyperbaric conditions and it is issued as on the following code of practices, laws and regulations:

Directive 2006/123/CE

Conseil du 12 décembre 2006 relative aux services dans le marché intérieur, ensemble la lettre de notification du 28 décembre 2009 à la Commission européenne ;

le code général des collectivités territoriales, notamment son article L. 1424-2 ;

le code des transports ; (Tranpostation code of practice)

le code du travail ; (Work code of practice)

le code du sport ; (Sport code of practice)

la loi n° 78-17 du 6 janvier 1978 modifiée relative à l'informatique, aux fichiers et aux libertés ;

la loi n° 2000-321 du 12 avril 2000, notamment son article 24 ;

le décret n° 85-755 du 19 juillet 1985 relatif à l'hygiène, à la sécurité du travail et à la prévention au ministère de la défense ;

le décret n° 90-277 du 28 mars 1990 relatif à la protection des travailleurs intervenant en milieu hyperbare;

B/ Arrêté du 30 octobre 2012 et publié le 15 novembre 2012

Définissant les procédures d'accès, de séjour, de sortie et d'organisation du travail pour les interventions en milieu hyperbare exécutées avec immersion dans le cadre de la mention B « techniques, sciences et autres interventions. This regulation defines the methods and procedures related to diving for science, technology and other interventions.

C/ 14 mai 2019 et publié le 24 mai 2019, Relatif aux travaux hyperbares effectués en milieu subaquatique (mention A). This is issues as an extension to specify the hyperbaric work that takes place in aquatic environments and defines the particular aspects related to diving (Available online https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000038501752&categorieLien=id)

Germany. SD in Germany is not legislated. Certification and specific licenses: CMAS: CMAS SD Commission for Research Diving in Germany: Research Diver. Certain rules define scientific diving operation while the depth limits are defined by the diver's diploma and risk assessment. However, exemptions can apply depending on diving in hazardous conditions that can expose the diver in risky situations. Specific insurance policies are accepted and therefore recognized by Germany. Medical requirements are obligatory in order for a diver to perform a scientific related diving job. SD operations must comply with the laws and regulations in Germany. In waters where diving is prohibited, it is imperative to obtain an official permit. There are also special regulations for diving e.g. at night and with scooters. These have to be fulfilled in any case.

Greece. There are no laws in Greece that regulate SD, but several laws have tried over the years to incorporate the SD community of Greece into the law systems in terms of definition, payment, insurance and operation of scientific work underwater (this mainly applies with archaeologists). Certification and specific licenses: In most of the cases, the certificate should be such that can be recognized by the Port Authorities as an equal or of higher demand of a 2* diving diploma. At this point it must be noted that although according to the Standards of a 2* of CMAS/EOYΔA is demanded which is equivalent to the Rescue Diver) in many cases this is downgraded to the equivalent of Advanced Open Water. Maximum depth with AIR is set to 40m. More than 40m it is considered as Technical Diving. Types of insurance policies that are recognized for SD: DAN or private insurance companies for projects that are not administrated by the State. For state research it is covered by a public insurance.

Medical requirements involve annual checkups depending on the contractor. Diving regulations for the Diving plan, Gear, behavior underwater and after the dive can be found. Permissions refer mainly to cultural heritage-related SD job therefore the permissions are authorized by the Ephorate of Underwater Antiquities. No safety procedures unless it is part of the national law or the international diving regulation (decompression stops, safety stops etc.). The respective laws and regulations are presented below.

Law 3409/2005 - ΦΕΚ 273/Α/4-11-2005 «Καταδύσεις αναψυχής και άλλες διατάξεις» ("Recreational Diving and other legal provisions") which technically "releases", in general, SCUBA diving in Greece (available online https://www.e-nomothesia.gr/kat-naytilia-nausiploia/kataduseis-anapsukhes/n-3409-2005.html).

Law 7 of N. 2557/1997-ΦΕΚ 271/Α/24-12-1997- «Θέματα οργάνωσης και διοίκησης των υπηρεσιών και των φορέων του Υπουργείου Πολιτισμού» (Matters of organization and administration of the services and bodies of the Ministry of Culture) -Definition of the Diving personnel of the Ministry of Culture (status, diving diploma and skill requirements), Available online https://www.e-nomothesia.gr/kat-arxaiotites/n-2557-1997.html

Law 66 of N. 4481/2017 «Ασφάλιση καταδυόμενου προσωπικού του Υπουργείου Πολιτισμού και Αθλητισμού» (Insurance policy of the diving personnel of the Ministry of Culture). Available online https://www.kodiko.gr/nomologia/document_navigation/272968/nomos-4481-2017.

Regulations: ΥΠΠΟ/ΔΟΕΠΥ/63/ΤΟΠΥΝΣ/63/46324 (ΦΕΚ 1212/26.08.2003) «Κανονισμός λειτουργίας και οργάνωσης υποβρυχίων αρχαιολογικών ερευνών της Εφορείας Εναλίων Αρχαιοτήτων και των Εφορειών Παλαιοανθρωπολογίας – Σπηλαιολογίας του Υπουργείου Πολιτισμού» (Regulation of the operation and organization of underwater archaeological research of the Ephorate of Underwater Activities and the Ephorates of Paleoanthropology-Speleology of the Ministry of Culture). Available online https://www.mydocman.gr/ippo-doepi-63-topins-63-46324-2003.

ΚΥΑ ΥΠΠΟΑ/ΓΔΔΥΗΔ/ΔΔΥΟΝΕ/ΤΝΕ/46493/3993/122/10/7-2-2018 (ΦΕΚ 357/Β/7-2-2018) «Καθορισμός ημερήσιας αποζημίωσης του καταδυόμενου προσωπικού του ΥΠΠΟΑ» (Determination of the daily compensation of the diving personnel of the Ministry of Culture (Available online https://www.e-nomothesia.gr/kat-periballon/anti-seismikos-kanonismos/upourgike-apophase-dnsg34033-pephn-275-2016.html)

Italy. SD in Italy is not regulated. There are laws that regulate commercial diving “Safety and Protection of health during the underwater professional hyperbaric activities for industry services – Operational Procedures”. No specific certificate is needed by law and every public institute has its approach. Some require a commercial diving certification, some refer to the ESDP standards, and some others allow the dive in the limit of the recreational diving license. There are limitations of SD in terms of tasks that can be performed and depth. They depend on the institutions and the tasks that the divers need to perform. The tasks are always in the framework of low physical work without the use of heavy tools.

Other EU countries. For the rest of the EU countries, the team collected information, interviews and variations that were very important. Only Sweden and Spain had laws and regulations that include SD whereas for the case of Portugal as we were recently informed SD is mentioned in the legislation of recreational diving law (https://dre.pt/home/-/dre/259882/details/maximized). A list of other have laws and regulations related to health and safety standards, some other have mature legislation for professional/commercial diving and SD is covered under these laws. For certain cases, no data were found at all. It must be noted that legislation changes and the team was informed that come countries (i.e. Portugal and Cyprus) are about to change and update their legislation. In some other countries, discussions for this issue have already begun. An important problem that was recorded during this particular research for EU was that all national legislations were different.

Other European Countries. From the other European countries, in geographical terms, none included SD in its legislation. In certain other cases, like for example in Norway and Switzerland, SD is covered from laws and regulations related to commercial diving and as a result, SDs are obliged to take costly courses that demand much higher skills. For the majority of the countries, laws and regulations concerning diving in general were not found. In general, codes of practice and diplomas from well-established organizations are followed and accepted.

English-Speaking Countries. In English-speaking countries (namely, USA, UK, Canada, Australia/New Zealand and South Africa) legislation for SD is more mature. A few years ago an informative research article was published where the legal framework for most of these countries is described (Benjamin and MacKintosh, 2015). In brief, the legal hierarchy includes the following:

- **Statutes (laws)**. Statutes are at the top of the legal hierarchy and are created by a legal body.
- **Regulations.** A regulation is the second step in hierarchy of law. Regulations have the force of law which is made by an executive authority under powers delegated by primary legislation.
- **Codes of Practice.** Codes of Practice do not have the force of the law. They provide guidance from the regulator on how to comply with requirements and obligations under work health and safety laws and regulations. They are used mainly in UK and Australia and they can influence court proceedings under the health and safety laws and regulations.
- **Standards.** They don’t have legal force, but can similarly be used to establish norms for certain classes of diving. These are voluntary consensus documents, which, although not automatically a legal document, may be incorporated into legislation by reference or used in private contracts as a set of specifications and procedures. They are distinct from the American regulatory standards.

In the USA, an exemption has been included in the respective legislation. A list of questions describes if a dive can be considered as SD or not. SD can be found as a term in its legislation. For most of the cases the information can be found on-line, a fact that it is a plus, especially for the young SDs that are trying to build a career in this field. Further clarifications were obtained by an extensive interview with a highly skilled SD that holds an important position in USA's administration for the respective issues.

Asia, Africa, Central and South America. In Asia, research of the existing literature and personal communications revealed that laws and regulations for SD do not exist and the team at the moment examines ways to verify these findings and build upon the dissemination activities that were proved fruitful so far. Singapore has a Code of Practice for SD part of which is available online. Other than that, nothing else similar was found. At the same time, diving centers that operate in some of these countries provide courses and certificates for SDs. For the cases of Central and South America, Internet research was also performed in Spanish with the respective key words and derivatives; the research team had no feedback. After the webinar, an Argentinian colleague saw the problem and offered help by sending an interview and the respective legislation. Similarly, after the participation and presentation in the 6th European Scientific Diving Conference which was held on 21 & 22 April, Freiburg, Germany, 2021, a Peruvian colleague provided also information for the legislation in Peru and Chile as well. As a result, the research team expects to purchase similar information from other countries as well in the future.

European Scientific Diving Panel (ESDP). The last decades ESDP has made important efforts to help in standardization of SD. The research team invited, as panelists, two of its most prominent members and their presentations and comments can be found in the link mentioned earlier in the time framework chapter. They described ESDP's efforts for the last decades and provided very important information which is in line with the current research's objectives. There are two different levels of recognition, both of which are professional: (a) the European Scientific Diver (ESD) and (b) the Advanced European Scientific Diver (AESD). Both of the Standards are available on-line. It must be underlined, that ESDP is not a legislative body and mainly suggests, consults and provides standards for SD that at the moment are gradually integrated in several national legislation in EU, especially for the health and safety issues.

United Nations Educational, Scientific and Cultural Organization (UNESCO). UNESCO has actively supported underwater studies and is responsible for important contributions for SD, especially for the Codes of Practice that although not mandatory, are followed from all the experienced SDs, with emphasis to underwater archaeologists. Other than the literature cited earlier in this paper, UNESCO has published lengthy reports with updated information (Flemming and Max, 1996; Maarleveld et al. 2001; Benjamin et al, 2019). In general, Codes of Practice from UNESCO are respected, but they do not have any legal force, and as the authors of the reports mention in all cases, national legislation should be followed, being at higher level in regulatory hierarchy.

The role of webinar and the impact of dissemination. As previously stated, the research team has organized 3 workshops related to SD. The 2nd one on December 9th (2020) was dedicated to the Legal Framework of SD. The webinar proved to be a strong, positive turning point for the research team and the global SD community in general. Moreover, it provided the opportunity and gave a voice to colleagues from all over the world confirming that they are having the same problems more or less with the ones presented in this study among others. Additionally, important feedback was obtained for countries where information concerning national legislation was not found. Other colleagues provided information for relative legal cases and a list of others offered help and support.

Brief summary of the collected information. The results proved that the team and the project in general are aligned with the needs, professional rights and reasonable expectations of the SD community. Indeed, the legislative part of SD proved to be a very difficult and complicated task in most of countries. In EU, where the effort of research was higher and more difficult compared to other countries, such as the USA for example, only 3 countries include SD in their legislation, France, Sweden and more recently (Summer 2020) Spain. France however, has too many laws regarding SD making the free movement of colleagues rather hard. All the previous will be published more extensively with more details in the near future.

Capitalization of the results

As it was stated previously, the present research is on-going and the feedback from colleagues and experts of SD is perpetually updated, with new entries and new knowledge gained in parallel from all over the world. The research team of this study will continue the dissemination activities as at the moment leads the research for this very important aspect for the SDs and it is open to comments, suggestions and co-operations. Information from colleagues as well as publication of the problems they all have to deal with is of critical importance in order to improve the existing legal framework. Data concerning important issues, such as the medical insurance of SDs, need further clarifications in a list of cases. Other information includes the mutual recognition for medical examinations of SDs among certain countries and at the same time, in other countries there is no legal need to have a health certificate from a specialized doctor. Other issues include the differences found in the field from the geographical point of view. Different training and as a result different regulatory framework, being reflected in national legislation may be required for the low visibility cold seas of the Northern countries compared to the warm and clear waters of the Mediterranean Sea. All these aspects require a further insight in order to create a solid and reliable document that can be used as a guide for improving the legal framework of SD in EU which would facilitate even the development of an EU directive.

Conclusions

The experience gained from the team's research at the moment verified that there is an apparent need for clarifications and further improvements of the SD Legal Framework. Although important steps have been made, in most of the countries SD is not exempted from commercial or professional diving which makes the working conditions for SDs harder and more expensive. In many cases, general legal framework for diving was not found at all. Since research for this task was greatly time-intensive, it can be understood that actively working within SD could be complicated further. In countries that have more mature legal framework situation is better, but other kinds of problems can be found as well. Especially for the case of EU, national legal frameworks are different and hard to follow making the free movement of scientists that use diving as part of their work problematic. Since this study is on-going, the research team expects to gather more qualitative and quantitative information in order to contribute to a realistic solution. At the moment, harmonization of legal framework seems to be feasible through a brand-new directive in which clearer definitions and reasonable claims could be included. In order to achieve that, active participation and support of the SD community would be required, a fact that was verified so far from the research team of the ScienceDIVER project. The details of this study are updated and evaluated and there would be a relevant publication in the near future.

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Assessment of the training, legal and professional state-of-the-art in scientific diving in combination with stakeholder perspectives in Greece

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Abstract. This study aims to highlight Scientific Diving (SD) training, legal and professional, state-of-the-art, aspects in combination with Greek stakeholder perspectives on scuba diving performed for scientific purposes. A questionnaire-based survey was carried out online, in order to collect data from various scuba divers concerning four thematic areas: general questions, questions regarding diving activities, questions regarding diving research and suggestions on facilitating underwater research. The conclusions of the survey were combined with the findings of three technical studies implemented in the framework of ScienceDIVER project for Greece. These studies conclude to summarize all the currently valid training, legal and professional aspects of the SD topic in Greece, Europe and worldwide. This combinative assessment aims to bridge the gap between theory and practice and to shed light into both convergences and deviations.

Introduction

Diving has broadly been used in the past decades as a research tool, supporting a variety of cutting-edge underwater sciences worldwide, both in marine and freshwater environments (for a review of relevant literature see Sayer, 2007 and Sayer & Barrington, 2005). Scientific Diving (SD) as a research tool and/ or professional activity is approached differently in many of the European countries (Sayer *et al*., 2008). SD as an activity may range amongst different countries from highly organised, integrated fully into the national health and safety legislation, to an activity undertaken without any, or barely under an organisational framework. The latter applies to Greece, with the only exception of the legal frameworks for underwater scientific activities of the Ephorate of Underwater Antiquities (Ministry of Culture) and the Hellenic Centre for Marine Research (HCMR). In addition, some countries fail to recognize certification and/ or standards regarding SD activities from other countries (Sayer *et al*., 2008), something that also applies for Greece.

The work presented herein has been carried out within the framework of ScienceDIVER (Cross-sectoral skills for the blue economy market) project (funded by the European Maritime and Fisheries Fund, EU, CINEA), which aims to support the development of blue and smart cross-sectoral skills to meet the evolving needs in the labor market of the Blue Economy by facing the challenges of Scientific Diving in Europe. The project's primary aim is to drive policy making towards the recognition of diving performed in the framework of the occupational activities of scientists and thus towards a relevant unified regulation among EU countries. Moreover, this endeavor promotes the development of a relevant official national framework in those countries that currently do not have one in place. In favor of this aim, three Technical Studies were implemented (Tourtas *et al*., 2020), summarizing the currently valid training, legal and professional aspects of Scientific Diving. This mapping exercise was implemented in countries with and without an official framework in place (in Europe and worldwide). The main conclusions of these studies describe the current landscape of Scientific Diving on several spatial scales and levels, i.e. regional, national, European, international, global.

As far as the legal status is concerned, the corresponding study concluded that there are no laws in place that regulate SD in Greece. There are, however, many laws regarding safety and standards for diving and laws concerning the protection of Underwater Natural and Cultural Heritage. According to the study on the professional status, SD is not recognized as a professional activity in Greece. Finally, the study focuses on the SD training concluded that there is currently no official training framework in Greece and these issues were until recently not addressed on a national level. Conclusively, the lack of a relevant national legal framework and professional acknowledgement in Greece is accompanied by a total lack of a training framework, as well, with the exception of the training provided by the HCMR to its employees, being the sole official representative of the European Scientific Diving Panel (ESDP) in Greece. It should be noted, however, that Greece is a candidate country in the ESDP and evidently there is a movement by either individuals or institutions belonging to the Greek (unofficial) SD community that strives towards the creation of a holistic SD framework in Greece.

It should be noted, that the lack of an official SD framework in Greece does not mean that there is not any SD activities performed in Greek territorial waters and that that there is no existing SD community. It just proves that the SD activities are being performed in alternative frameworks. Thus, it is extremely important to understand the current situation in order to move towards the integration of these activities and the corresponding stakeholders into an official framework.

In the preliminary work presented in this study, we focus on Greece as a case study of a country lacking an official SD framework. In order to outline the main components of such a potential framework in Greece, we combine the conclusions of the three Technical Studies of ScienceDIVER project, regarding Greece, with the results of a questionnaire-based survey that has been carried out online and addressed to the various types of citizen scuba divers (scientists, recreational divers, non-specialized citizens) involved in SD activities in Greece, voluntarily. Essentially, we assess the results of the survey in the context of the basic findings resulted from the three technical studies, to reach meaningful conclusions about the current status and the potential of SD in Greece.

Material & Methods

The one-day event about "Scuba Diving and Citizen Science in Greece" held in Piraeus, Athens (Greece) on the 7th of March 2020 was used as an opportunity to promote a national online and in-vivo survey. The purpose of the event and the corresponding survey was to investigate, at a national level, the perspectives resulting from the interaction between Scuba Diving and Citizen Science.

For the purpose of the survey, a questionnaire was designed and developed in order to collect information concerning four (4) balanced thematic areas: i.e. (1) general questions (demographic and personal background), (2) questions regarding diving activities, (3) questions regarding diving research and (4) suggestions on facilitating underwater research. This survey is part of the ongoing research taking place in the framework of the ScienceDIVER project and can been reached at the following link: https://www.sciencediver.eu/research-questionnaire/.

The data collected by this questionnaire-based survey are analyzed in this study. A statistical analysis was performed in order to produce some initial conclusions. The statistical analysis reveals useful information regarding the relationship between individual scuba divers and citizen science including underwater research in Greece. Moreover, on a wider view the results give useful insight into existing or potential SD target groups, current practices, end-user needs and expectations, and the demographic imprint of the interested parts. In other words, they reveal the relevant stakeholders and their interaction with SD. At the last stage of this analysis, in order to reach the final conclusions, the questionnaire-based survey results are combined with the main results of the three ScienceDIVER project's Technical Studies (mentioned in the Introduction).

Results

Herewith the results of the survey are presented in brief. The questionnaire was answered by a total number of 167 individuals from Greece.

General Questions

Regarding general information, the majority of the respondents belongs to ages from 35 up to 50+, and most of them are male. Their educational level varies, with most of the respondents having received a higher education. Most of them interact with the marine environment as part of recreation activities, followed by awareness and educational activities. Their interests referring to Scuba Diving and Citizen Science are closer to topics concerning the environment. Regarding personal goals referring to Scuba Diving and Citizen Science most of the respondents pointed at "access to information about the sea", followed by "participation to underwater diving research" and "vocational scientific diving". The answers regarding propositions about Ocean Science citizen support were divided, with a small majority pointing at "information about scientific research procedures and results". The survey sample had approximately by 74% experience of diving, and by 26% not.

Scuba Diving Experience

As far as the sample's diving activities are concerned, most of the participants based on their certification belong to the recreational diving category, followed by diving instructors and scientists. Regarding their diving depth limit, the responses showed a wide dispersion, with the higher percentages associated to 30, 40, 50 and 65 meters. The same pattern continues to the next questions about the yearly number of dives, where the answers exhibit an impressive dispersion, from zero (0) dives to a thousand (1.000) dives; although the latter is a unique answer and probably either a typo or an exaggeration, while the actual range fluctuates between 0 and 400 dives, with an average of 100 dives. Most of the respondents have dived less than a month before taking the survey, followed by those who have dived at least once in the last six months. The vast majority of the sample performs yearly diving medical exams, while an equally large majority performs yearly technical maintenance checks of their diving equipment. Also, the majority has diving insurance, and has participated in underwater research projects.

Underwater Research

As far as the sample's information on underwater research, most of the respondents who had participated in underwater research activities denoted that these activities were organized by official agencies and most of them took place in Greece. Most of them are volunteers and professionals follow. We should note that an official definition of the terms "professional" and "volunteer" were not provided and each participant answered based on his/ her own perception of the terms. Also, the majority denoted that diving was their main contribution to these research projects followed by those who denoted that their contribution was surface support. Most of the respondents state that during these research diving projects, diving and scientific protocols were followed always and to the letter. However, we should once more clarify that the exact meaning of the terms "diving or scientific protocols" were not provided, hence the answers are based on individual/ arbitrary perceptions of their meaning. From those who denoted that diving protocols were not always followed, the majority spotted deviations at the research protocols, followed by those who spotted deviations during the collaboration with the official agencies involved.

Facilitation of Underwater Research – Suggestions

Finally, regarding the suggestions on facilitating underwater research, the majority assesses that the legal framework or the underwater research procedures should be constantly evolving. Moreover, the majority considers that the cooperation between official agencies and the diving community is of crucial importance. Most of the respondents believe that it is necessary to set and comply with certain standards in the employment of diving scientists, while the majority believe that systematic cooperation is necessary for the transfer of know-how between stakeholders. Also, the majority believe that the exchange of data amongst diving research projects is of extremely important as well.

Questionnaire-based survey and Technical Studies results combination

The combination of the questionnaire-based survey results with the basic findings of the three ScienceDIVER project's Technical Studies is presented in Figure 1. In most cases the picture formed by the participants' answers corroborates the one deriving from the three technical studies. The lack of an official SD framework as described in the technical study for the legal status is definitely something that stakeholders acknowledge, hence there are relevant answers in the "suggestions" section concerning its development. Moreover, both the technical study on the legal status and the questionnaire results show that even though there is no specified legislation, individuals participating in underwater scientific activity in Greece follow alternative or unofficial standards that are in most cases loans from existing SD frameworks in other countries or promoted by SD organizations such as AAUS (2019), ESDP, CMAS (2020) etc.

Concerning professional status, the absence of relevant legal framework results in a corresponding absence of professional acknowledgement. This is evident both in the technical study of ScienceDIVER project and the answers to the questionnaire, where the majority of individuals engaging in underwater scientific research are not recognized professional scientific divers. Mostly, they come from the recreational diving community along with various commercial divers who support specialized underwater tasks.

The same statement refers also to the training part of SD, since besides a noticeable minority who have received SD training in other countries, the vast majority of divers engaged in such activities have been trained through recreational diving training programs and are supported by few commercial divers. This result of the technical study referring to training status is also corroborated by the answers of the questionnaire, where the majority of participants have stated that they take part in underwater scientific surveys are either as recreational divers and diving instructors or as commercial divers.

Lastly, we should add that this preliminary study indicates that in Greece today there is an increasing keen interest from the diving community to have access to information about the sea and the underwater environment, as well as scientific research procedures and results, making this interest one of the major drives for all participants to engage with diving. This is in complete accordance with the basic concept of all Scientific Diving Frameworks, i.e., the direct pursuit of scientific knowledge.

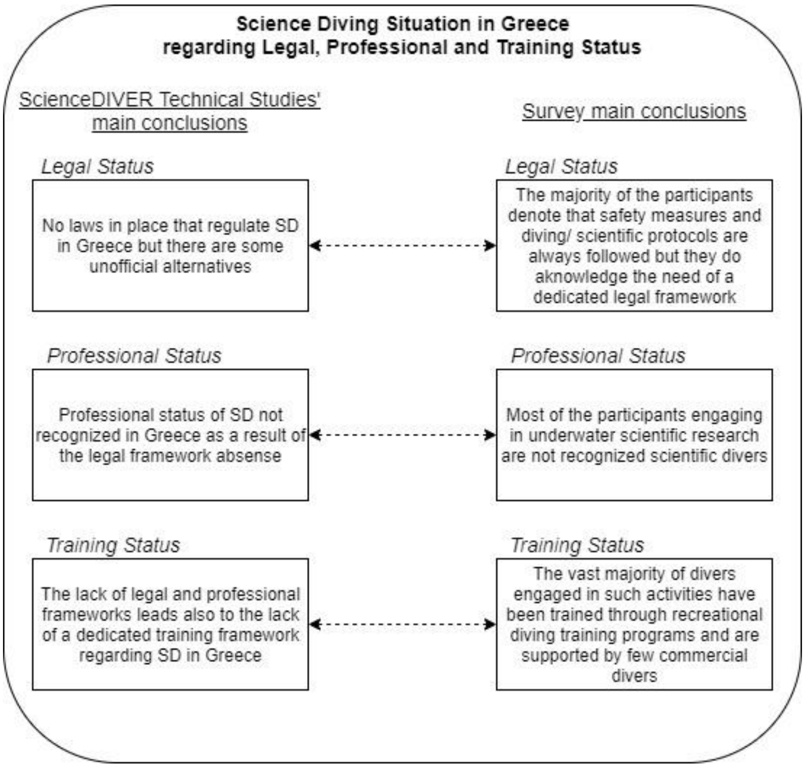

Fig.1. Combination of the main conclusions of the three ScienceDIVER Technical Studies and the survey results regarding Legal, Professional and Training status of Science Diving in Greece.

Conclusions

The lack of a professional SD framework combined with the lack of an official SD training framework, prevents the development of SD in Greece. There is an urgent need for collaboration between the official national authorities and the relevant stakeholders (e.g. educational and research institutions, diving scientists, diving community), towards a well-defined Scientific Diving legal framework that will work as the basis for the development of Science Diving training and professional acknowledgement, as well as the formation of safe and effective procedures for underwater scientific work. The opportunity that arises from the fact that Greece is a candidate country in the ESDP panel, should not be missed. Furthermore, there is a need to guaranty mobility and allow collaborations beyond the national level. For this to happen, a common basis is required between countries.

There is also a need for better collaboration between the various SD stakeholders themselves, individuals and institutions, of the SD community in the country. SD engages several stakeholders that need to work together and share knowledge and insights in order to provide an efficient SD framework.

Finally, a big discussion about the connection between Citizen Science and Science Diving needs to open in order to manage issues of professional acknowledgement, insurance and social engagement. Most of the participants of the herewith presented survey belong to the “recreational diving” category, followed by “diving instructors” and “diving scientists”. There is great interest in other categories beyond scientists for SD activities, which brings forward the discussion of Citizen Science (CS), as well (Cohn, 2008; Dickinson *et al*., 2012). So far CS is not clearly associated with SD, however there are approaches in various parts of the world towards the inclusion of CS in the larger SD scheme. Due to the lack of an official SD framework in Greece, traditionally, people outside the official scientific community have been engaged in Science Diving activities. For this reason, this issue needs to be addressed and the legal framework has to provide clarifications on the role of every participant in SD research programs.

The above conclusions provide some insight into the current situation of SD in Greece in order to promote the relevant discussion on a national level, as well as to serve as a case study for corresponding surveys in other countries developing their own national SD framework regarding legal, professional and training frameworks.

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Risk management of cold-water impact on divers

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Abstract. Cold-water diving exposes the divers to highly stressful conditions at physical and mental level. Scientific divers of the Woods Hole Oceanographic Institution are routinely exposed to low temperatures during the winter months. The main reported physical impact resulted to be loss of dexterity with reduction of manipulative capacity. The impact on mental functions was represented by a general slowing down of the elaborative capacity and reduction of situational awareness and short-term memory. Several key-points have been identified as viable defense against the cold-related risk including limited dive-time, adequate thermal protection, proper rest before the dive, strong team mutual support and training and rehearsal of the operations. Diving protocols have been developed allowing for safe and proficient operations in cold water.

Introduction

The human body is adapted to function within a very narrow range of core temperature around 37ºC. Thermoregulatory mechanisms have evolved over time to maintain such temperature independently from the external environment. Those mechanisms are most effective on land becoming less efficient in water (Mekjavic 1987). The thermal conductivity of water is about 24 times that of air (0.6 vs 0.025 W/(m·K)) and its specific heat is about 3,500 times higher. As a consequence, heat loss when submerged happens 4-5 times faster than in air. For these reasons, the thermoneutral temperature (at which the heat loss is perfectly balanced by the metabolic heat generation at rest) in water is 35ºC, compared with 26ºC in air. Moreover, for a diver breathing compressed, dense, dry, and cold air, the heat loss from the respiratory tract will also be increased (Tipton et. al. 2004). Once submerged, the thermoregulatory capacity of humans is severely tasked by these specific thermal characteristics of the aquatic environment that enhance heat loss.

If the immersion in water at temperature below 35ºC is prolonged enough the heat loss will overwhelm the heat-production capacity of the body causing progressive drop in core temperature until hypothermia develops.

Hypothermia is classified in function of the core temperature as (Epstein and Kiran 2006):

- Mild hypothermia: core temperature between 35ºC and 32.2ºC
- Moderate hypothermia: core temperature between 32.2ºC and 28ºC
- Severe hypothermia: core temperature below 28ºC

Divers in cold water are more likely to experience mild hypothermia (Sterba 1990). This is because the discomfort associated with generalized cooling will prompt the divers to terminate the dive before deeper hypothermia can develop. If the divers cannot leave the water, such as when long decompression stops are required, then the level of hypothermia may increase.

It is necessary to wait at least 24h and have proper food, hydration, rest, and rewarming to be totally restored after a dive that caused any degree of hypothermia (Tipton et al. 2004).

A properly insulated diver, using a drysuit with adequate thermal undergarments, is unlikely to become seriously hypothermic within the timeframe of a single scuba dive. But a more subtle danger may develop, mostly when multiple cold-water dives are performed, in the form of "silent hypothermia". This is a slow loss in core temperature which causes a feeling of cold, fatigue and general uneasiness and that may require long rewarming time and rest to be totally resolved (Somers 1987; Sterba 1990). Slow cooling, in the order of 4 – 6 hours seems to affect higher cognitive abilities even in well trained and experienced divers (Diving Medical Advisory Committee 1981).

Sudden exposure to cold water can set off "cold shock" with abrupt increase in breathing and pulse rate. The induced hyperventilation generates a drop in the blood partial pressure of CO_2, alkalosis and cerebral vasoconstriction causing dizziness and, in extreme cases, convulsions (Lloyd 1986; Wattmers and Savage 2002). For example, cold shock can follow the sudden flooding of a dry suit when diving in very cold waters leading to loss of control of the respiration with potential inhalation of water and increased risk of drowning, mostly if loss of consciousness occurs. Immersion in cold water has a strong physiological impact on the human body triggering a series of compensatory reactions aimed to maintain thermal homeostasis (Pozos and Danzl 2002).

During cold water immersion the heat flux from the skin can increase up to 1.000 W/m^2 (Mekjavic et al. 2003). Resulting changes in peripheral and core body temperatures are sensed by the hypothalamus, which activates a series of compensatory mechanisms. To avoid heat loss, strong peripheral vasoconstriction is induced so that the skin and the subcutaneous fat, deprived of blood circulation, will act as a thermal shield (Golden and Tipton 2002). This vasoconstriction affects the distal extremities first; the fingers and the joints of the hands will become stiff with loss of dexterity. When the skin temperature of the hands drops to around 13 ºC, dexterity impairment is observed and at 10 ºC pain develops; additional temperature drop will cause numbness and total loss of tactile function. In sub-freezing waters, non-insulated fingertip temperature can drop to 10 ºC in less than 30 minutes leading to potential non-freezing injuries with damage to the affected tissues (Sterba 1990). Cooling of the forearm muscles reduces the gripping strength further affecting the manipulative capacity (Hoffman 2002). These impacts should be carefully considered using conservative dive time planning for dives in very cold waters.

The initial vasoconstriction is followed by vasodilatation in cycles of 3 to 5 times per hour increasing the heat-loss but also improving the blood circulation in the hands. This effect is called the "hunting reflex" (Wattmers and Savage 2002). During the vasodilatation phase, divers can regain some dexterity, but due to the cyclical nature of the reflex, these few minutes will be followed by further vasoconstriction and loss of manipulative capacity.

In addition to vasoconstriction, the thermoregulatory mechanisms of the hypothalamus when diving in cold water can trigger shivering as a form of heat-production (Sterba 1990). Shivering begins once skin temperature drops to around 26 ºC and increases until the core temperature drops to 35 ºC; further drop in core temperature will reduce shivering that will terminate at 30 ºC (Wattmers and Savage 2002). The basal metabolic rate can be increased two to five times by shivering with potential doubling of the metabolic heat production (Danzel and Zafren 2017). Intense shivering may degrade motor performance interfering with voluntary muscle movement (Golden and Tipton 2002). A diver who shivers intensely can become unable to perform even the basic motor functions such as swimming or climbing a ladder to exit the water.

Another danger of excessive shivering is that it causes a strong increase in oxygen consumption, which adds to a general increase in oxygen demand for a given level of work when core temperature is below normal. For example, an increase of up to 50% in oxygen intake to perform work has been measured in individuals with a core temperature reduced by 0.5 – 1.0 ºC (Danzel and Zafren 2017; Wattmers and Savage 2002). Additionally, air consumption was measured to be 25 to 100% greater during dives at 5 oC when compared to those at 20oC (Davis et al. 1975). This increase in oxygen consumption, caused by increased metabolic rate and hyperventilation, can cause gas management problems for the divers mostly in deep dives, and when using some models of rebreathers that deliver oxygen at a constant value based on assumed metabolic demands (Bozanic 2010).

Diving in cold water affects the performance of divers in three main ways (Mekjavic 1987):

- Impaired dexterity and reduced motor skills due to peripheral tissues and muscles cooling.
- CNS and mental capacity are affected by drop in core temperature.
- The discomfort due to being cold has a "distracting" effect on the divers.

The impact of loss of dexterity on a diver is extremely debilitating, making even simple tasks a challenge: adjusting the diving gear, controlling the BC inflator, and activating the drysuit valve may become difficult, if not impossible. The use of tools is also severely impaired with increased likelihood of dropping items or being unable to perform the required manipulation. Writing notes on a pad is hampered by stiff hands and often notes are illegible even to the writer. All these effects impact not only the performance of the divers but also their safety making very difficult the correct and fast execution of emergency procedures. For scientific divers the impact on proficiency is even higher because the need for using often delicate instruments and the importance of data recording.

Cold can cause cognitive impairments by acting as "distraction" and making it more difficult to focus on the task at hand (Mekjavic 1987). Short-term working memory is weakened by being exposed to a cold environment with negative consequences on mental data-processing (Hoffman 2002; Lloyd 1986). The cooling of the skin activates the cold-receptors leading to cortical arousal that can interfere with mental processes. The more elaborate the process and the more continuous is the stream of information to be analyzed the higher is the detrimental impact of cold (Diving Medical Advisory Committee 1981).

Perception of elapsed time during the dive is often altered with the divers thinking that less time is elapsed than the actual one (Lloyd 1986.) This can have a serious impact on safety because unless a timing device is frequently checked, the divers could stay underwater longer than planned, with increased inert gas loading and extended decompression needs. Longer exposure to the cold water also causes further heat loss that in turn will further affect performance creating a vicious circle.

During their de-briefing, the divers may fail to recall important information and events that happened during the dive because of memory impairment by the cold (Davis et al. 1975). This is clearly a serious issue for scientific divers whose job is often to collect data and information during the dive.

Cold and immersion also causes a transient increase in blood pressure due to peripheral vasoconstriction and increased venous return to the heart. This will trigger renal blood-pressure receptors that will cause the kidneys to increase diuresis to reduce the blood pressure (Golden and Tipton 2002; Danzel and Zafren 2017). While this can cause discomfort, increased diuresis can lead to dehydration in the divers, especiallywhen the sensations of thirst are reduced by being in a cold environment (Roberts and Hamlet 2002). Blood plasma volume is reduced up to 18% during prolonged cold-water dives due to diuresis, and results in increased blood viscosity (Tipton et al. 2004; Wattmers and Savage 2002). This can affect the efficiency of inert gas exchange during the dive and enhances the risk of DCS.

When the diver exits the water, the sudden drop in environmental hydrostatic pressure causes an efflux of blood from the l core towards the periphery, and towards the legs under the pull of gravity. If this effect is further enhanced by fast rewarming, such as hot showers or entering in over-heated lock rooms, or the diver is dehydrated, a hypovolemic condition may develop causing fainting or temporary loss of consciousness (Golden and Tipton 2002). It is therefore important after a dive in cold water to progressively and slowly rewarming avoiding sudden increase of temperature. Drinking warm, non–caffeinated liquids also facilitate the rewarming, and it is a good hydration source.

Cold-induced vasoconstriction interferes with the normal inert gas exchange within the tissues causing an increase in the risk of DCS. If the diver is exposed to cold water during the decompression phase of the dive, the off-gassing of inert gas can be hampered, making the mathematical models used for decompression planning unreliable. A sudden rewarming can also trigger formation of inert gas bubbles in the tissues, mostly the skin, enhancing the risk of DCS (Makjavic et al. 2003; Tipton et al. 2004). Being warm during the bottom phase of the dive increases the uptake of inert gas, thus potentially increasing the risk of DCS; this can be an issue mostly when active warming is used such as hot-water diving suits (Toner and Ball 2004).

A degree of "cold acclimation" has been observed in persons routinely exposed to cold environments such as cold-water fishermen. The main impact is on the onset of cold vasodilatation in the hands that is anticipated in individuals used to work in the cold thus allowing for better manual dexterity (Hoffman 2002). The level of such acclimation is variable in different persons in function of physiological attributes such as: thickness of the subcutaneous fat, mass/surface body ratio, genetic heritage, age, and level of fitness (Brown et al. 1954; Sawka et al. 2001). Therefore, when a team of divers works in cold water, it is the less acclimated of the group who will dictate the exposure limits. Moreover, the real level of effective and proficient work that even an acclimated diver may sustain is questionable.

The best protection from the impact of cold-water is to use proper thermal insulation. In water around 10 ºC an insulated drysuit causes 0.3 ºC/hour of heat loss with 15h of survival time compared with about 10h using a 5 mm wetsuit (Tipton et al. 2004). The core of the trunk is the main source of metabolic heat generating up to 56% of the total heat (Somers 1987). Its thermal insulation is therefore of paramount importance when diving in cold water.

Bad planning of diving time, poor sheltering from the external environment between the dives, insufficient rewarming and fatigue are the main causes facilitating the onset of hypothermia during diving operations (Sterba1990).

Diving in cold water is often associated with other environmental stressors such as bad visibility and depth that can enhance the overall stress on the diver both at physical and mental levels.

Cold-water diving is also demanding for the diving gear with potential freezing problems for the regulators due to ice formation in the equilibrium chamber of the first stage or within the second stage due to the sharp fall in temperature caused by the "Joule-Thomson" effect associated with the expansion of the breathing gas following the pressure drop from the high value inside the cylinder to the ambient one (Ward 2004).

Cold also reduces the efficacy of the chemical absorbent used by rebreathers to remove CO_2 to regenerate the breathing medium; their effective duration should therefore be assessed when diving in cold waters (Bozanic 2010).

Diving environment and diving configuration

Most of the dives considered in this paper are conducted around the Iselin Pier of the Woods Hole Oceanographic Institution (WHOI) located in the homonymous village in Massachusetts (USA). The pier is part of a commercial harbor that includes a ferry service for the nearby island of Martha's Vineyard.

The area is characterized by a modest bay (Woods Hole Great Harbor) that connects the Vineyard Sound with Buzzards Bay through a narrow passage. Strong currents may develop and therefore the dives are planned during periods of slack water.

The maximum depth is around 20 meters, and the seafloor is covered by debris, seashells, and some silt. The visibility is very variable in function of the tides and weather; runoff from the surrounding area and/or periods of high winds with formation of waves able to stir the seafloor can strongly deteriorate the visibility.

Another common diving area is represented by an offshore tower, hosting an array of sensors both topside and underwater, about two miles from the southern shore of the island of Martha's Vineyard. The tower is part of the Martha's Vineyard Coastal Observatory (MVCO) managed by WHOI. The maximum depth is around 15 meters over a flat sandy seafloor. The area is strongly affected by southern winds with formation of swells and waves, and its movement may stir the relatively shallow seafloor reducing the visibility to almost zero. Currents are related to the tide cycle with main direction East-West reversing with the tide.

For seven months the water temperature in the diving areas is below 15 ºC, which is the definition of “cold water” provided by the US Coast Guard (CFR 4837, 1983)**.** During winter (January – March) the water is mostly below 5 ºC dropping often to 2 ºC during the coldest weeks in January and February (Fig. 1). Occasionally during the coldest winters, ice forms at the surface and the water temperature may fall below freezing temperatures for several days. The external temperature in winter can plunge down to -15 ºC or -20 ºC, with strong chilly-factor during windy days.

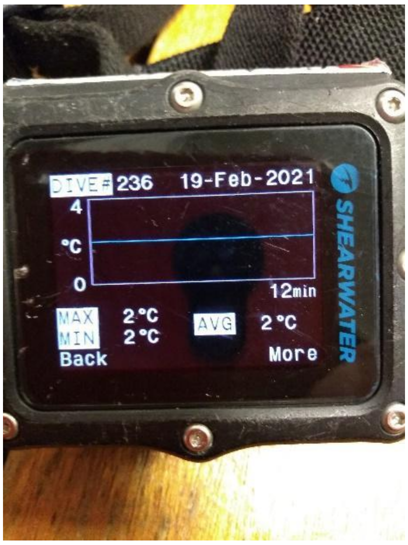

Fig. 1. water temperature as indicated by the computer

During the cold months in winter the use of drysuits is mandatory. The most common configuration includes multi-layered passive thermal undergarment, wet hood, and wet or dry gloves. The usual thermal undergarment is composed by three levels: a breathable base layer, an insulated vest and a full-body insulated garment. Insulated socks are also worn. Some divers use an electric-heated undergarment that also includes heated dry gloves. The most commonly used drysuit is a trilaminate-type shell. Neoprene drysuits, with lighter undergarment, are utilized for shorter dives in the 5 ºC to 10 ºC range allowing for better flexibility and easier swimming due to the reduced drag. For some specific applications, such as shallow-water (less than 5 meters) long (one and half hour) dives performed in aquaculture activity neoprene wetsuits are used showing a good degree of thermal insulation even in cold water and allowing for more flexibility and reduced complexity that a drysuit.

The scuba gear used by WHOI divers includes doubles and single cylinders depending on the habit of the divers and the tasks to be completed. When using doubles the “Hogartian” configuration is adopted (two independent regulators one with long-hose as primary and the other one as secondary); with single cylinder configuration an “octopus” (one first stage connected to two second stages) is used. A number of dives are performed by closed-circuit rebreather system. Surface-supply with helmet and umbilical is utilized mostly during routine survey, cleaning, and maintenance operations for the scientific vessels of the institution and for operations that fall under OSHA (Occupational Safety and Health Administration) standards. Other gear includes cave lights, reels and SMB that are carried by each diver as standard equipment.

The breathing gas is air or Nitrox with oxygen percent variable from 30% to 32%. A separate inflation system for the drysuits, charged with air, is also used by some divers.

The gear is donned in a heated locker that is also the store area for diving gear and cylinders. The compressor is hosted in its dedicated heated container just off the entrance of the divers’ locker area (Fig. 2).

Fig. 2. Compressor van with heating system top left.

The divers enter the water jumping from the dock. A ladder is available to climb back on the pier. For the offshore operation, a Coast Guard inspected boat (RV Tioga) is mostly used. The boat has a climatized below-deck space with galley and rest area. The divers enter and exit the water using a stern platform with a ladder.

In the period 2017 – 2019 WHOI divers performed 3.787 dives; the prevalent activity was linked to researcher tasks that represent the higher percent of dives, the close second number of dives include training and proficiency dives (Fig.3). WHOI arranges a scientific diving training for its employees each year starting in late spring and continuing through summer and often autumn. Once certified the divers are also required to maintain their active status by logging a minimum of 12 dives each year. For this reason, proficiency dives are organized at the Iselin pier through the year. The area is also utilized to rehearse procedures to be used for underwater projects in the field.

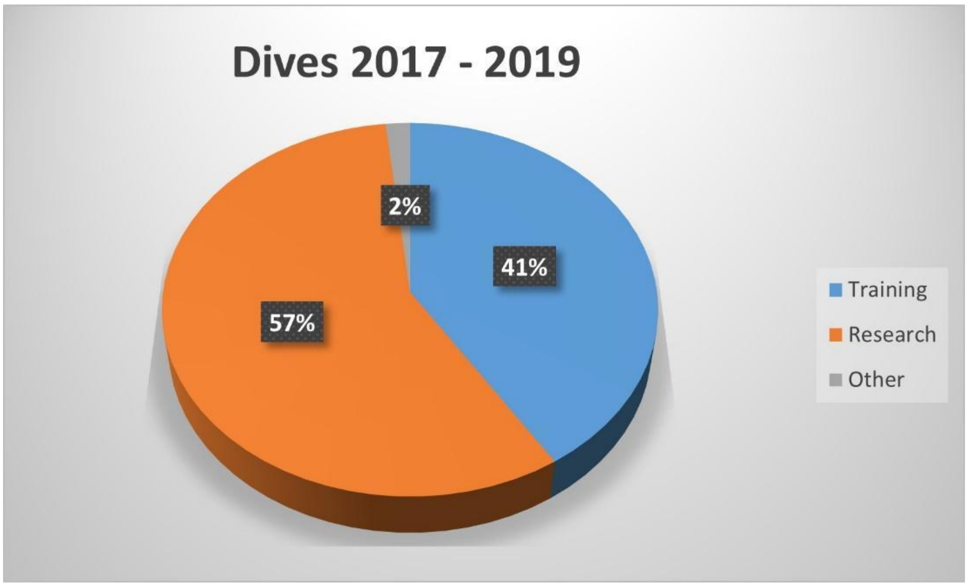

Fig. 3. Typology of dives performed by WHOI divers

The diving schedule is controlled by diving computers; diving tables are employed as back-up and for general planning purposes. Most of the dives follow a "squared profile" with the maximum depth reached quickly and maintained until the end of the dive; the dives are within the non-decompression limit and a safety stop of 3 minutes at a depth between 5 and 3 meters is performed at the end of each dive. The use of Nitrox and the relatively moderate maximum depth allow for a maximum non-decompression time around one hour. During ship maintenance longer dive times, in the order of two to three hours, are common; these dives are still within the non-decompression limits because are performed at very shallow depth (around 5 meters) just below the keel of the vessel.

Observed impact of cold water on divers and equipment

Even well insulated divers started cooling in longer dives with an identified threshold of 45 minutes before being very cold. Divers that were using an electrical-heated undergarment remained comfortable for longer times up to above one hour.

The divers indicated that being cold severely impaired their dexterity**.** The loss of dexterity was largely due to very cold hands with pain and loss of sensitivity. This made manual tasks very challenging requiring longer time (on average 30% more time) to be completed and causing more frequent drops of tools and parts. Using dry gloves helped in reducing the cold impact on the hands but, because of the characteristics of the gloves, dexterity is anyway reduced. Moreover, the dry gloves fabric is generally more exposed to potential puncturing and damage when harsh manual job, such as cleaning of fouled surfaces, is to be performed thus limiting their use.

The cold was mostly described as “distracting” affecting the reasoning and requiring more effort to remain focused on the job. It has been noted that in general during the cold dives the team leader who was in charge of planning the operations, did not have issues in remembering all the needed steps; on the contrary divers briefed just before the dive often forgot relevant key elements of the procedural actions.

It is known that when a degree of hypothermia develops the mental functions are affected with difficulties in remaining focused on the job and reduction of the working-memory. Divers more used to dive in cold conditions seem to be more resilient to the distracting effect of the cold.

The impact on the diving gear was limited. We anyway test all the regulators that are back from being serviced during specific test-dives before the gear is issued to the scientific divers for their operations.

Being exposed to a cold environment affected the performance of the batteries used by the dive computers. A sharp drop in the battery charge, highlighted by a specific icon on the computer screen, was often noted as soon as the computer became cold. This was more evident when the batteries were already not at their full charge. No appreciable loss in the battery performance of the underwater lights was observed. This is likely due to the fact that the lights used have very long burning-time if compared with the average dive time and are then recharged.

Risk mitigation procedures

A number of risks and potential consequences (Table 1) and associated mitigation strategies (Table 2) have been identified.

Table 1. Cold-related risks and potential impact

Risk	Potential consequences
Hypothermic diver/topside crew	Reduced mental capacity, unable to perform
Frozen regulators	Free-flow with loss of gas supply
Reduced CO_2 scrubber time	CO_2 building-up in the breathing loop
Loss of dexterity	Inability in performing the tasks including emergency procedures
Cold-enhanced decompression stress	DCS
Fatigue	Loss of proficiency

The risk of becoming hypothermic affects both the diving team and the topside personnel mostly during the coldest spells when wind chill-factor adds to the low ambient temperature. The consequence of developing even a mild hypothermia is a reduction in performance both because of the impact on mental capacity (distracting effect) and physical discomfort. This is often coupled with loss dexterity and inability in performing the tasks including emergency procedures.

Diving in cold water drains both mental and physical reserves easily leading to increased fatigue that in turn causes loss of proficiency.

DCS risk is enhanced by diving in cold water due to the induced changes in blood circulation and inert gas exchange rates. The situation is particularly adverse when the divers are exposed to cold temperatures during the decompression phase of the dive.

Freezing of the first or second stage of the regulators will start a free-flow with further cooling of the escaping gas (Joule effect) and quick depletion of the gas reserve.

When using CCRs, reduced efficacy in the CO_2-scrubbing reaction due to the cold environment may lead to potential build-up of CO_2 in the breathing loop.

Table 2. Cold-related risks and mitigation strategies

Risk	Mitigation strategies
Hypothermic diver/crew at surface	Exposure suits, use of heated undergarments, reduced dive time
Frozen regulators	Cold-water regulators, redundant air supply
Reduced CO_2 scrubber time	Reduced dive time
Loss of dexterity	More complex manipulation at the beginning of the dive
Cold-enhanced decompression stress	Use of Nitrox, conservative dive profiles
Loss of proficiency	Overlearning, rehearsal, team support
Fatigue	Adequate rest, reduced dive time

The first step we addressed was to assure that the divers started the dive as warm as possible; for this reason they got dressed in a heated locker and the diving gear was also set-up in a climatized area. For offshore operations, the gear was stored in the heated area of the boat and set-up relatively shortly before the dive so to reduce the exposure to the cold environment on the deck.

Another point was to assure the correct thermal insulation of the divers during the underwater activity. The use of drysuits is enforced during the coldest winter months.

The insulation of the torso is very important in limiting heat loss from the core and the following hypothermia and should be implemented using appropriate undergarment configurations. Adding an insulated vest to the undergarment configuration strongly reduced the heat loss form the torso with a reported increase of comfort and resilience to the cold.

The use of dry gloves reduced the cooling of the hands but also impaired some of the finer manipulation. The divers had somehow to "trade" between having warmer hands and being able to manipulate small parts. The more vulnerability of dry gloves to damage when manipulating sharp objects was also taken in consideration. In general the operations requiring more complex manipulation were done at the beginning of the dive so to avoid the impairing effects of the cold on the hands.

The diving time was limited to 45 minutes that avoided excessive heat-loss; for more complex operations this time-limit required to divide the overall project in multiple steps that could be carried out by multiple teams or by the same team during multiple dives. Adequate surface interval, allowing for rest and rewarming, was also allowed when planning multiple dives in the same day.

In order to mitigate the DCS risk the intake of inert gas was limited by breathing Nitrox (up to 33%) and by a conservative dive schedule that allowed for the divers to be well within non-decompression limits. A safety stop of 3 minutes at a depth from 5 to 3 meters was routinely performed at the end of the dives to further facilitate the offgassing. The safety stop was also used as a "rehearsal moment" during which the divers could practice some basic emergency skills such as deploying the SMB, access the cylinder valves to verify of being able to close the post in case of regulator free-flow, quickly disconnect the inflator hose from the drysuit in case of free-flow.

The impact on short-term memory was mitigated through early briefings, often the day before the dive, providing adequate time for the information to be well assimilated and memorized. The briefings followed a well-defined structure that ensured that all the key information was shared between the team. The over-learning of some tasks, mostly the ones related to the diver's safety, is another strategy that was adopted in order to reduce the detrimental effect of the cold on mental performances.

The diving gear used in very cold waters should be specifically designed with anti-freezing features. Of particular importance is the choice of the regulators; we mostly used environment-sealed first stages that prevent the direct contact between cold water and the regulator's mechanisms, strongly reducing the risk of freezing and free-flowing.

The management of cold-water issues was done at team level considering the less cold-resilient diver in the team as a limiting factor. This was particularly important when a team using different gear was in action. As an example, if there was a mix of divers using passive and active (electrically heated) insulated undergarments the time limit of the dive was based on the threshold (45 minutes) for the passive-insulated divers.

Conclusions

Diving in cold water has a strong impact both at physical and mental level, cold also affects the diving gear leading to increased risk of malfunction.

The risks associated with cold-water diving require an attentive assessment in order to identify their potential impact on divers' safety and overall proficiency.

The main mitigating strategy is to reduce the exposure to the environmental stressors through the use of thermal-insulated exposure garments both for the divers and any topside personnel who are also exposed to the impact of cold climate. Limiting the dive time is a valid system to further control the exposure of the divers to the cold environment.

Operating under cold stress inevitably causes a degree of loss in proficiency and this should be addressed when planning more complex operations. It is often needed to divide the task in multiple steps that can be accomplished without overloading the diving team and without exceeding the limited dive time.

The briefing is a key element in diving safety and for the good outcomes of the dive. Providing a detailed and consistent briefing well in advance of the planned operation strongly increased the memorization of the information offsetting most of the mental impact of cold.

Overlearning of procedures, mostly the ones associated with emergency situations, and rehearsal of more complex operations are both useful strategies for improving safety and proficiency when ding under stressful conditions such as the one caused by cold water.

The diving gear is also exposed to harsh conditions when diving in cold water. The main risk is represented by potential malfunction of the regulators due to freezing. The mitigation procedure adopted included the use of specifically-designed regulators for cold water and the use of redundant breathing-gas supply and bailout.

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Training the next generation: the scientific diver-training programme at the University of Plymouth

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Abstract. SCUBA-based scientific diving has been a vital factor in improving our understanding of the marine environment since the 1950s. Unfortunately, primarily due to cost, many scientific diving programmes have closed in the UK over the last few decades, including the National Facility for Scientific Diving in 2018. The University of Plymouth are now the sole facility in the UK providing University based in-house scientific diver training to a professional standard. Scientific diving in the UK is considered as 'diving at work' if divers are paid, or gain any significant benefit from the diving operation. In turn, UK scientific diving is regulated within the framework of the Health and Safety Executive, the body responsible for managing UK commercial diving, alongside civil engineering and offshore commercial diving. The framework UK scientific diving operates under is rigorous and quite inflexible. However, it has resulted in extremely high safety standards. This paper will introduce the scientific diving framework in the UK, the scientific diving training programme at the University of Plymouth and describe how scientific diving fits with the marine based degree programmes and harmonises with the European Scientific Diver accreditation programme.

Introduction

There is a long history of scientific diving in the region of Plymouth that started with some of the earliest scientific dives in the UK by Jack Kitching in 1931 at Wembury Bay (Kitching et al. 1934; Norton, 1998). These early dives were carried out using a crude hardhat diving system, but since the general availability of SCUBA in the 1950s and 60s the use of diving for scientific research has greatly increased in the region (eg. Hiscock, 2005; Saunders et al. 2003; Teagle & Smale, 2018). The University of Plymouth has offered the opportunity for students to gain Health and Safety Executive (HSE) professional diving qualifications, in both SCUBA and surface supply since the late 1970s. At this time the University was a Polytechnic, rather than a University and courses were initially offered to Civil Engineering students in a partnership with Fort Bovisand Underwater Centre, one of the UK's primary commercial diving schools. In the following years students from other degree options including Marine Biology and Marine Science were allowed to attend the HSE Part IV SCUBA courses that were subsequently renamed HSE SCUBA. In 1991/92 the University took a decision to bring all diver training in-house and an HSE diver training school was started at the University's Coxside Diving and Sailing Centre offering HSE SCUBA courses only.

In 2013 it was decided to significantly change how the HSE SCUBA programme was taught at the University and reduce the number of student places from around 150 to 56, this reduced the number of annual dives from over 5000 to around 2200 (Fig. 1a) and resulted in a large decrease in the number of staff and students carrying out scientific dives (Fig 1b) The large drop off in dives and number of staff and students diving in 2020, was due to the COVID-19 pandemic (Fig. 1). The reduction in the scale of the HSE SCUBA diver-training programme has allowed more time to be spent on teaching specific scientific diving skills and developing a diving supported research programme. With regard to dive depths, excluding 2020, which was heavily impacted by COVID-19, there is no really clear trend in the depths of dives undertaken at the University over the last decade although there is considerable inter-annual variability (Fig. 2).

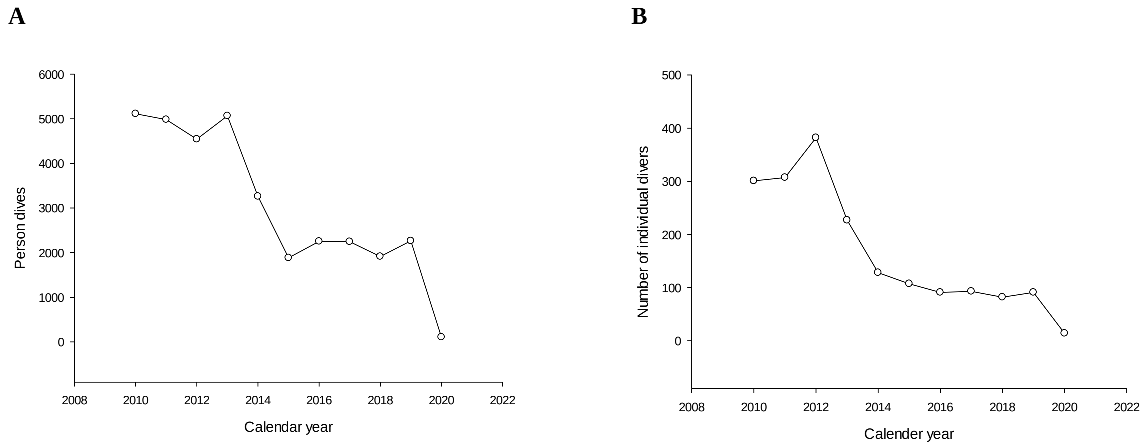

Fig.1. Number of scientific training and research person dives carried out per year (A) and number of individuals carrying out least one scientific dive per year (B), from 2010-2020 at the University of Plymouth.

Legislative background

The initial Scientific Diver training currently provided at the University of Plymouth is the HSE SCUBA qualification. This qualification is the first step of the commercial diver-training framework in the UK and is a pre-requisite (unless an equivalent professional qualification is held) for undertaking training as a surface supply diver and onwards training up to closed-bell diver. Diving in the UK is regulated by the Health and Safety Executive under the Diving at Work Regulations (1997) (DWR 97, HSE, 1997). These regulations are goal-setting rules and are implemented via the process of Risk Assessment and formal Dive Project Plans (Sayer, 2007). These regulations are recognised as industry best practice in the UK. The HSE publish a series of sector specific Approved Codes of Practice (ACOP) that provide guidance to industry sectors in implementing DWR 97. The ACOP that the scientific diving sector primarily work under is the Scientific and Archaeological ACOP (HSE, 2014).

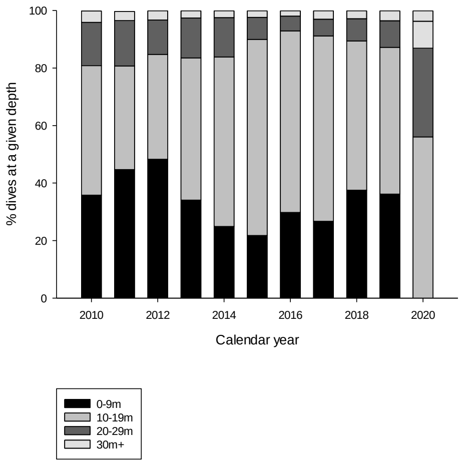

Fig.2. Depth ranges of dives carried out at the University of Plymouth 2010-20.

HSE SCUBA Program

The HSE SCUBA course at Plymouth is essentially a generic commercial SCUBA course that meets the competencies required by the HSE, who in turn audit the courses. The HSE SCUBA qualification is suitable for a range of sectors in the UK including civil engineering, commercial scallop diving, aquarium and media diving and is primarily focused at providing skills in commercial diving methods, including the use of full-face masks, hardwired and through-water communications systems, lifelines and lifeline communications, as well as UK legislation. HSE diving qualifications are well recognized and accepted internationally. There is no requirement to provide science specific training on the course, however, the HSE do expect training providers to provide students under training with in-water tasks on dives. In turn, this has generally resulted in training centers setting in-water tasks that reflect the training center's primary training interest, which in the majority of cases is civil engineering. At Plymouth, we focus on in-water tasks that are focused on scientific skills, such as the use of sampling transects, quadrats and species surveys. The HSE are not keen on task loading students during training, hence in-water tasks provided at this stage of training need to be simple.

The University of Plymouth HSE SCUBA diving programme is currently only available to students and staff based at the University. The courses are heavily oversubscribed, with only about 65% of students gaining a training place. Access to training is restricted to a limited range of degrees, Marine Biology, Marine Science, Environmental Biology and Environmental Management and Sustainability, due to the capacity limitations. To date we have very rarely taken non-University personnel on a course. All students who express an interest in the HSE SCUBA training are required to undertake a water aptitude test to check their ability to swim, general fitness and water confidence. Fifty-six students who pass the water aptitude are randomly selected for places on the HSE SCUBA programme.

Students attending the HSE SCUBA program are required to hold a range of pre-requisite qualifications and experience prior to the course commencing. These are:

- An entry level SCUBA qualification (PADI Open Water, BSAC Ocean diver, CMAS 1* or equivalent).
- Ten additional dives after gaining a SCUBA qualification at least 5 of these dives in a drysuit.
- An HSE Diving Medical (a specific UK commercial diving medical).
- First Aid at Work – (a UK specific 3-day first aid course designed for the workplace).
- Oxygen administration.
- A drysuit.

Four HSE SCUBA courses are run annually, between the start of June and end of September, with each course being 4 weeks in duration and having space for 14 students. The HSE SCUBA course is not part of the student's degree and costs an additional £2500 (correct 2021). Although the course costs are high, they are substantially cheaper than other HSE SCUBA course providers and the University of Plymouth HSE SCUBA course is specifically designed for diving scientists.

The students are initially assessed on their basic diving skills on joining the programme and provided with remedial instruction if required, to ensure they reach an adequate basic half-mask SCUBA standard. After which professional skills such as the use of lifelines, full-face masks, through water and hard-wired communication systems are taught progressively, with students given the opportunity to practice a new skill and then assessed. The training programme consists of the following components:

- 6 x In-water training sessions
- 4 x Dry training sessions
- 9 x Theory lectures
- 19 x Practical in-water assessments (some with in-water instructors)
- 3 x Non-diving assessments (supervising, compressor operations, cylinder filling)
- 6 x Written multiple choice exams – 80% pass rate
- 1 x 40m recompression chamber dive

The total teaching time for the HSE SCUBA course is around 160 hours and students will undertake around 25 dives. Typically, 6-8% of students fail the course. In addition, the following subjects are covered.

- UK legislation and paperwork
- Dive supervision
- Compressor operation and cylinder filling
- Recompression chamber familiarisation
- Diving in low vis and hazardous environments
- Basic underwater searches
- Equipment fault finding
- Use of hand tools
- Knots and splicing
- Basic chart work & tidal calculations

Scientific Diving degree module

Forty-eight students, who have gained the HSE SCUBA qualification at the end of their first year at the University, have the opportunity to undertake a 20-credit Scientific Diving module in their second year. The elective module provides the qualified divers with the opportunity to learn the core skills required by a scientific diving including the following:

- Use of quadrats and jackstays for biological surveying – survey design and theory
- Sediment coring and water sampling
- Underwater photography including use of strobes
- Advanced search techniques
- Use of lift bags
- Offset and trilateration surveying
- The opportunity in groups, to plan and undertake a baseline survey for an environmental impact assessment including presenting the findings and writing a client report.

The Scientific Diving module has 56h hours of face-to-face teaching and students will typically carry out 10 dives. Once the students have completed the HSE SCUBA programme and Scientific Diving module, they should be competent and will have undertaken around thirty-five dives with the University.

Scientific research diving

The qualified undergraduate students also have the opportunity to propose and undertake third year dissertation projects that involve the use of scientific diving and the diving support will be provided by the University dive team. In addition, extensive diving support is provided for Masters level, PhD and academic research projects as required. Many diving projects require significant numbers of divers and qualified students have the opportunity to volunteer on a range of diving projects.

The University additionally deliver a significant amount of diving on commercial contracts and funded research grants. Where possible students are involved with this diving and in some cases, the students are paid, thereby gaining valuable commercial experience.

Typically, by their third year undergraduates will have obtained enough scientific diving experience to gain a European Scientific Diver qualification increasing their ability to work within Europe.

Discussion and conclusions

The University of Plymouth runs one of the largest University based scientific diving training and research programs in Europe. The diving programme is well embedded within the marine-based degree programmes and although expensive to deliver, the diving programme is a significant specialist niche at the University that attracts students.

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ESD Operators: roles and duties for the environmental monitoring activities of ARPA Puglia

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Abstract. The professional figure of European Scientific Diver (ESD) is still poorly known and spread in the European Countries, despite the Scientific Scuba Community strongly works to reach this target. ARPA Puglia (Regional Agency for the Prevention and Protection of the Environment), adopting the guidelines "Good Practices for safe underwater scientific activities of ISPRA and the Regional Environmental Agencies" (ISPRA Manuali e linee guida 94/2013 ISBN: 978-88-448-0625-5), has recognized this professional figure, and through a tiring path, has created a specific team. In particular, this operative team works in the “Centro Regionale Mare” of the Agency and is involved in a large number of sampling and monitoring activities according to European Directives as well as other technical-scientific rules.

ARPA Puglia roles and aims

The Italian law n°132/2016 established the National System for the Protection of the Environment (SNPA), a network system on the national territory involving ISPRA (Higher Institute for Environmental Protection and Research), 19 ARPA (Regional Environmental Agencies) and 2 APPA (Provincial Environmental Agencies). SNPA, ARPA and APPA play a leading role in water monitoring, whose results are necessary for the classification of the quality status of water bodies as well as for the implementation of programs of measures to be applied for the achievement/maintenance of the good environmental status.

Specifically, one of the missions of the Regional Environmental Agencies is the protection of the marine and coastal environment, trough specific monitoring activities. For example, we can mention the monitoring of water bodies pursuant by the Water Framework Directive (WFD - Dir. 2000/60/EC), those provided for Bathing Water Directive (Dir. 2006/7/EC) and the ones required by the Marine Strategy Framework Directive (MSFD - Dir. 2008/56/EC). In addition to these, recently the Agencies have the task of carrying out some activities under the Habitat Directive (Dir. 1992/43/EEC).

The Apulia Regional Environmental Protection Agency was established with the Regional Law no. 6 of 22 January 1999, while the institutive Act was the Regional Law n. 27, of 4 October 2006. The head office of the Agency is located in Bari, the Puglia capital town, but other departments are located throughout the region.

The “Centro Regionale Mare” (CRM) of ARPA Puglia

With its 1,040 km of coastline, the Puglia alone represents 14% of the overall development of the Italian coasts. To ensure the implementation and coordination of all the sampling and monitoring activities relating to the marine and coastal environments ARPA Puglia planned the institution of the Regional Sea Center (CRM), that was established with the D.D.G. n. 179 of 29/03/2018. The CRM is placed in a building at old time a maritime railway station, located close - inside the port of Bari (Fig.1).

Among the various and different tasks in charge of the CRM, there are also activities to be carried out by scuba diving. For this reason, rooms dedicated to underwater activities have been planned during the building renovation works, special equipment were purchased and a warehouse too (Fig.2), and mostly an ESD specialized team was organized.

Fig.1. The CRM headquarters

Fig.2. Some equipment dedicated to underwater scientific research

The steps of ARPA Puglia for the recognition of the ESD profession

The route for the constitution of the ESD Team in the Agency began in 2015.

The first step was the implementation of safety protocols for the dives based on the provisions of the Italian Guide Lines "*Good Practices for the safe underwater scientific activities of ISPRA and the Regional Environmental Agencies*" (ISPRA Manuali e linee guida 94/2013 ISBN: 978-88-448-0625-5). The above-mentioned Guide Lines were officially adopted by ARPA Puglia in 2016 with a specific Act; thus, the underwater scientific activity assumed a well-defined role in the Regional Agency.

Diving equipment and specific training of employees were the priorities in the initial stage of team constitution; in the 2018 the Agency authorized an updating course for safety (BLS-D, OX-Provider, Scuba Rescue) and a Scientific Diving Course for the maintenance of the standards set as required by European Scientific Diving Panel. This specific course was directed by the International School for Scientific Diving (ISSD).

Together with the training, medical specialistic controls for underwater job duties start to be planned to ensure work safety during underwater scientific activity.

Later, in the 2019 ARPA Puglia opened a national call for the acquisition of new professional figures as the Underwater Scientific Operator, to enlarge the ESDs team in the CRM.

Finally, in the 2020 the diving equipment was included in the Agency's list of "Personal Protective Equipment" (PPE), in order to assure the highest safety level during underwater operations.

ESD's specific activities in ARPA Puglia

As already mentioned, the ESD Team of CRM is organized according to the Italian Guide ISPRA 94/2013, regulating operators functions and roles according to different level of responsibility for all the phases of the work. Therefore, the CRM diving organigram provides a Scientific Scuba Supervisor, a Scientific Scuba Chief, several Scientific Scuba Operators and a Surface Assistants.

Among the different activities carried out, according the Water Framework Directive (Dir. 2000/60/EC) the CRM ESDs are involved in the monitoring of Biological Quality Elements for the evaluation of the marine waters' ecological status, such as the seagrass *Posidonia oceanica* and the macrobenthos communities.

According to the Marine Strategy Directive (Dir. 2008/56/EC), the CRM ESDs are involved in the monitoring of the Descriptors 1 and 2, in particular: Not Indigenous Species (NIS), benthic habitats (i.e. coralligenous), *Posidonia oceanica* meadows (Dir. Habitat too), and the protected species *Pinna nobilis* (Dir. Habitat too). Moreover, CRM ESDs carry out other technical activities, for example visual census for the evaluation of habitat distribution and species populations, evaluation of anthropic impacts on the sea bottoms, sampling of species, sediments and water (Fig.3).

Fig.3. Some examples of scientific underwater activities

The ARPA Puglia ESD role in the monitoring of Posidonia Oceanica meadows

As a rule, for the monitoring of *Posidonia oceanica* meadows (under the WFD and MSFD Directives), the ISPRA protocol (Cicero and Di Girolamo 2001) is applied, locating two monitoring stations (one at -15m depth and the other at the meadows' lower limit depth) for each chosen site. In Puglia the sites monitored by the Agency are 17, where the meadows Lower Limit does not exceed 30 meters depth. Thus, Safety Diving Standards are always respected being the first dive on the deeper station (Lower Limit), so the NDL (no decompression limit) is never exceeded. During the dives, the scientific operators take information about some bioecological parameters: plant density, coverage, presence of Posidonia flowers, bottom type, anthropogenic disturbing factors, presence of other invasive species (es. *Caulerpa* spp and other), etc. Moreover, bottom sediments samples are collected for the chemical lab analysis as well as orthotropic plants in order to lab evaluation on lepidocronology and morphology.

In the-15 m station a hierarchical sampling strategy is applied, which consists in the survey and samples collection on the meadow in n. 3 separate areas of about 400 square meters each and spaced about 10 meters apart (Fig.4). Table 1 shows all the operations carried out by the underwater scientific operators during the sampling dive on this station.

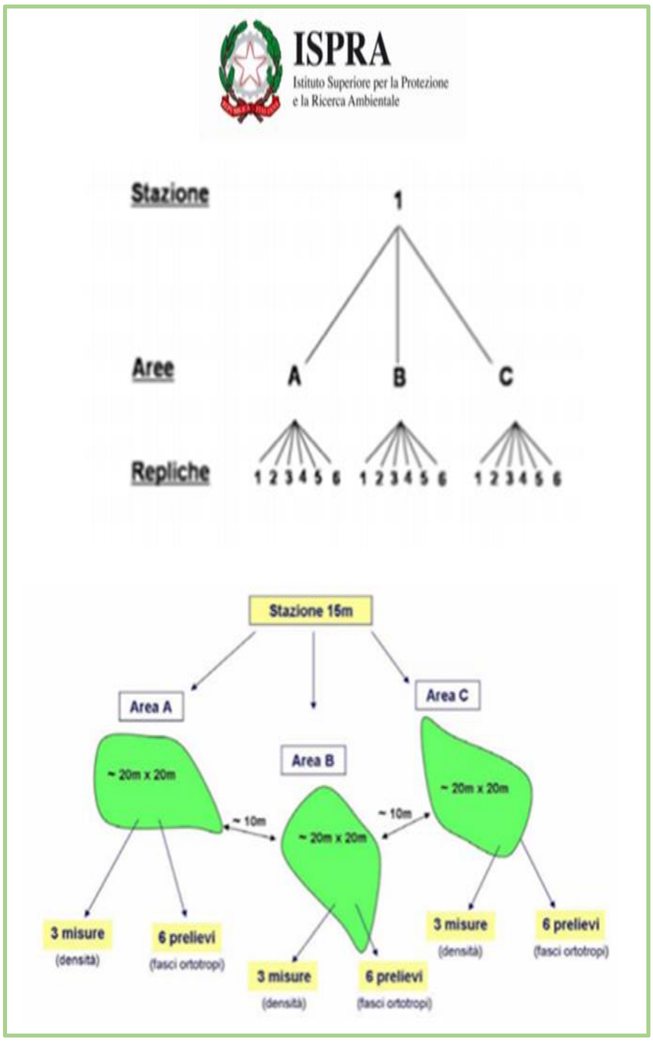

Fig.4. Hierarchical sampling strategy applied to the station closed to -15 m depth (from ISPRA"Scheda di campionamento delle praterie di *Posidonia oceanica*" rif Bertrandy et al, 1986).

Table 1. Parameters detected by ESDs during the dive at -15m on *Posidonia oceanica* meadows (Legislative Decree 152/06)

n. 3 zones x 3 measurements = 9 plant counts in square metal (40x40 cm) for density measurements (bundles / m2) and % of plagiotropic and dig out bundles
n. 3 zones x 6 bundles = removal n. 18 orthotropic bundles, (three-year frequency)
n. 3 zones x 1 = 3 estimates of the coverage of the Posidonia on the seabed;
visual detection of some bioecological parameters (blooms in progress, type of substrate, disturbing factors anthropic, presence of invasive / alien algal species, etc.)
n. 2 bottom samples taken for analysis grain size and T.O.C.
n. 1 data-logger positioned on the bottom with pole metal in the prairie for continuous recording of temperature and light, with autonomy of over 1 year.

At the lower limit station, monitoring consists of the examination of the limit on a 50-60-meter-long transect (Fig.5). Table 2 shows all the operations carried out by the underwater scientific operator during the dive on this station.

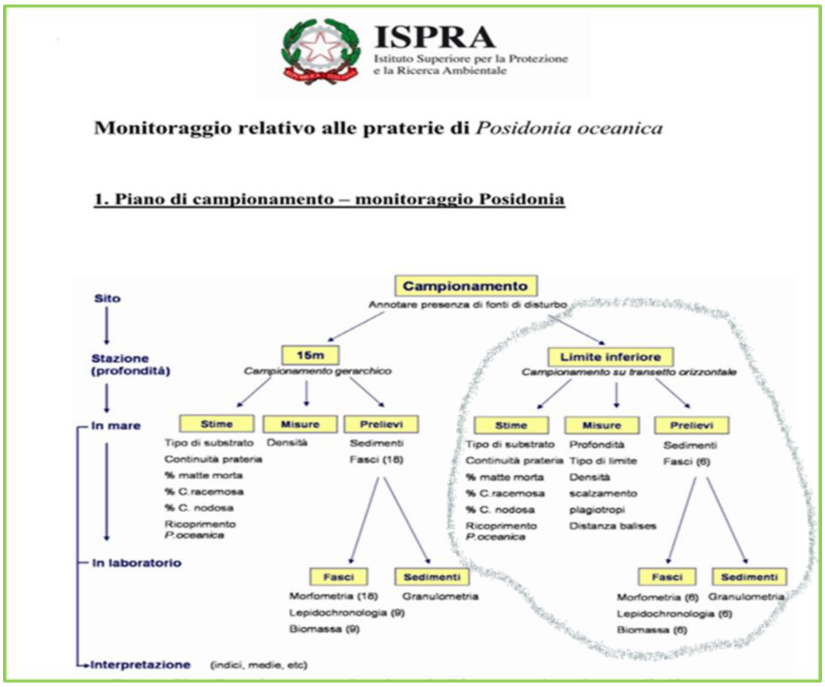

Fig.5. horizontal transect sampling applied on the lower limit (the circled part in the image) (from ISPRA"Scheda di campionamento delle praterie di *Posidonia oceanica*" rif. Bertrandy et al, 1986)

Table 2. Parameters detected by ESDs during the dive at L.L. on *Posidonia oceanica* meadows (Legislative Decree 152/06)

n. 3 zones x 3 measurements = 9 plant counts in square metal (40x40 cm) for density measurements (bundles / m2) and % of plagiotropic and dig out bundles
n. 3 zones x 6 bundles = removal n. 18 orthotropic bundles, (three-year frequency)
n. 3 zones x 1 = 3 estimates of the coverage of the Posidonia on the seabed;
visual detection of some bioecological parameters (blooms in progress, type of substrate, disturbing factors anthropic, presence of invasive / alien algal species, etc.)
n. 2 sediment samples taken for analysis grain size and T.O.C.
Survey of the type and depth of the Lower Limit part of the meadows with contextual video shooting underwater
survey of lower limit variation measurements (balisage)

All the operations described above are done by two different Scuba operators (Buia et all., 2003).
To carry out the activity the following tools are used (Fig.6):
- 40x40 cm plastic or metal squares;
- underwater camera;
- underwater video camera;
- sample holder net;
- illuminators;
- spatula and jars for sediment collection;
- steel poles;
- cable ties;
- irradiance sensor.

Fig.6. Some tools used from ESDs during the dives for *Posidonia oceanica* monitoring

The ARPA Puglia ESD role in the monitoring of Pinna Nobilis

The ARPA Puglia ESDs are involved in the visual census about the population of *Pinna Nobilis*. The purpose of this monitoring is to evaluate the distribution and density of the species as well as to verify the health state of the population in the surveyed area. The monitoring protocol is described in the methodologic schedule used in Italy for the application of the MSFD (Dir. 2008/56/CE).

In Puglia the Agency actually investigate 15 zones (5 square km each), from 10 to 20 meters deep, and in each of them 3 sub-areas 100m x100m have been identified (A, B, C); for each sub-area three transects (t1, t2, t3) are considered at a regular distance from each other (Fig.7). The three transects are covered by two scientific operators, that during the dive carry out the visual census considering a strip 6 meters wide (3 m for each visual side). In this way 600 square meters are investigated for each single transect.

To carry out this activity, the surface assistants lowered 100 meters of lead rope to the bottom using cartographic references for start and finish, positioning surface buoys. The pair of scuba operators approaching the signals and following the compass direction, proceeds to roll out a reel of 100 meters. The reel wire act as a physical reference on which carry out the visual census. Usually each transect corresponds to one dive, in the event that (for example shallow depths) the couple has sufficient air or nitrox breathing mix supply they proceed to another transect. During every single dive the presence of any waste or litter on the bottom is noted on a special marine blackboard together to data collected on the species presence (n. specimens, dimensions, status) (Fig.8).

Fig.7. Graphic arrangement of the survey areas and transects

Scheda di Campo – *Pinna nobilis*

Rilevatori SUB:	Data:
Operatori di superficie:	
Descrizione del sito di rilevamento	
Nome area di indagine: N. sito (cella): Coordinate centro cella (100*100m): Lat°N Long°E	Livello di protezione sito: Presenza criticità e/o impatti: N° Verbale: MM /AA

Dati sul popolamento		
N. transetto: 1-2-3 AB C	Direz. linea base: °N	Direz. transetti: °N
Densità (n. esemplari) per transetto:		

Tansetto ID	Individuo ID	Stato di salute	Profondità (m)	Tipo di substrato	Biometria UL (cm)	W (cm)	w (cm)	Note

Dati su residui plastici			
Tansetto ID	Tipo di Rifiuto	Abbondanza	Note

Note: ESEMPLARI MORTI ADAGIATI SUL FONDO IN MANIERA ORIZZONTALE, MISURA w STIMATA IN BASE ALLA DIVERSA COLORAZIONE DELLE PARTE DI VALVA PRESUNTA INTERRATA, SE NON RIPORTATA PERCHE' NON PRESENTE

Fig.8. Data sheet recorded by the ESDs during the dives for monitoring the population of *Pinna nobilis*

To carry out this activity the following tools are used (Fig.11):
- 100m of leaded rope;
- various cordage;
- surface buoys;
- safety buoys;
- reels with high visibility rope;
- sub slate;
- compass.

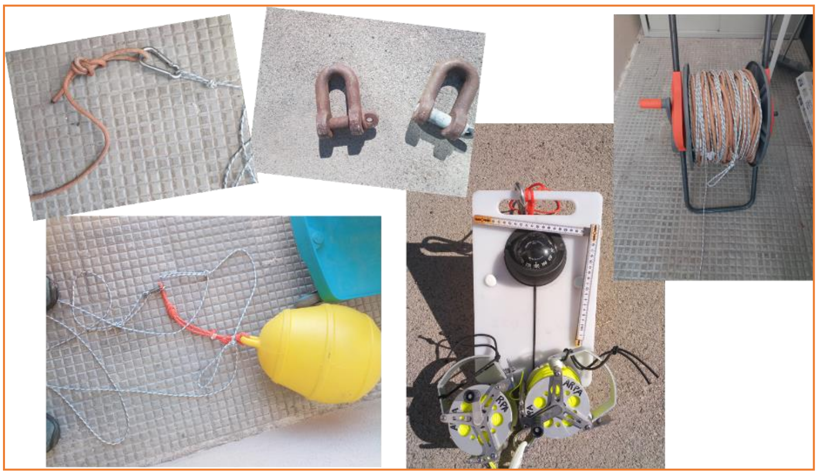

Fig.9. Some tools used from ESDs during the dives for *Pinna nobilis* monitoring

The ARPA Puglia ESD role in the monitoring of NIS (not indigenous species)

The ARPA Puglia ESDs carry out in coastal marine areas the monitoring of invasive alien species (IAS) also, according to the MSFD (Dir. 2008/56/CE) obligations.

Different approaches are used for the specific activity, through surveys that involve standard sampling methodologies such as scratching, bucket or box corer, fishing gear depending on the substrate or visual census.

ARPA Puglia carry out the monitoring of NIS in some harbor areas along the regional coast, where the sampling consists in the scraping of hard substrate (artificial jetty) (Fig.10); during a single dive in which 3 ESD operators are involved, a metal square 32x32cm is used with 3 replicas at different depths (3 and 9 meters) (Bouderesque et al., 1971) (Fig.11). Two divers work for samples recovering and storage (to be analyzed in lab), while a third one makes photos of the fixed surface to be scratched, in order to estimate the species coverage.

Fig.10. N.3 ESDs during the sampling phases of scraping on an artificial jetty

Fig.11. The metal square 32x32cm used by ESDs during the scientific diving

To carry out this activity the following tools are used (Fig.12):
- 32x32 cm metal squares;
- net with very fine mesh;
- underwater camera;
- illuminators;
- trowel or similar instrument to scratch.

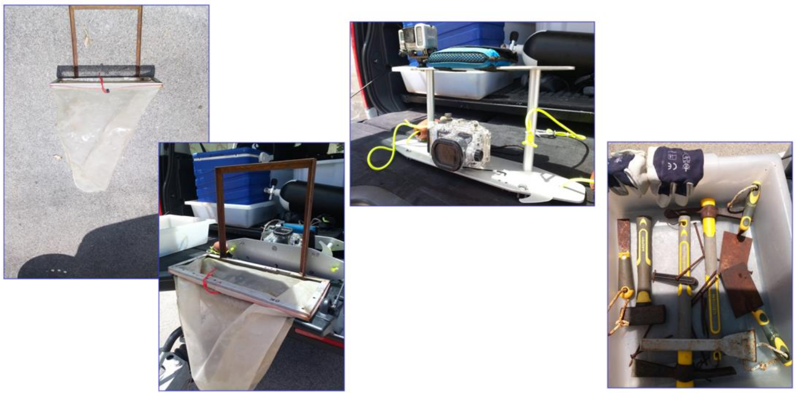

Fig.12. Some tools used from ESDs during the dives for *NIS* monitoring

Conclusion

According to the ARPA Puglia institutional mission, the different phases and timing for reaching the recognition of the ESD professional figure within the Agency were described.
Moreover, the main underwater activities carried out by the ARPA Puglia-CRM ESD Team have been detailed; currently, about 200 dives are carried out annually by the ESDs team of the Agency. The underwater environmental activities are constantly evolving in Puglia as well as in Italy, so the ESDs can be considered as a resource to expand the range of institutional services from Environmental Protection Agencies.

Although much was done in ARPA Puglia, there are still some steps to finalize. In particular, there is the need for recognition of indemnities linked to the specific risks, as well as have to be formalized the physical health maintenance protocol (specific training program), as a form of prevention from diving accidents (DCS, etc.).

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Underwater Cultural Heritage Hand Signals

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Abstract. Underwater Cultural Heritage is fascinating because of the mystery of its location underwater, its historical context, and the wealth of information in can provide us. The discovery of an underwater object, a wreck or a ruin makes it possible to dive into the past. It is the memory of a time long before us and sometimes of human tragedy such as shipwrecks and wars. As soon as underwater cultural heritage emerges from the water and is exhibited on land, for example, objects from underwater archaeological sites are deprived of their context and lose some of their meaning. Therefore, in recent years, there have been many efforts to preserve underwater cultural heritage *in-situ*, and let visitors experience the sites in their original location underwater. This is done through different means, including dive trails, underwater tours for non-divers and underwater museums. For a better communication, the Underwater Cultural Heritage Commission of the World Underwater Federation (Confédération Mondiale des Activités Subaquatiques, CMAS) and three universities of the UNITWIN Network for Underwater Archaeology, which complements the work of the UNESCO Secretariat of the 2001 Convention on the Protection of the Underwater Cultural Heritage, developed, for the first time, underwater hand signals for Underwater Cultural Heritage objects.

Safeguarding cultural treasures

The World Underwater Federation (CMAS) developed international Underwater Cultural Heritage hand sigals for a better understanding and safeguarding of our cultural treasures. Underwater cultural heritage is fascinating because of the mystery of its location underwater and the its unique historical context. As soon as underwater cultural heritage emerges from the water and is exhibited on land, for example, objects from underwater archaeological sites are deprived of their context and lose some of their meaning. Therefore, in recent years, there have been many efforts to let visitors experience the cultural heritage underwater in its original location. The aim of this study is to make everyone aware of the importance of the underwater cultural heritage and the need to protect and safeguard it.

Visitors underwater

Diving allows recreational divers to experience underwater cultural heritage in the splendour and authenticity of its original environment. However, diver access initiatives must go hand in hand with site protection. Various countries have found creative solutions to this problem, including the establishment of official dive trails, the protection of sites in metal cages and the awarding of site stewardship to certified local dive clubs. Successful examples now exist around the world: Dive sites of the Cape Peninsula, South Africa; The wreck of the SS Yongala, Australia; The Florida Keys National Marine Sanctuary, USA; Underwater Archaeological Park of Cesarea, Israel; The Thunder Bay National Marine Sanctuary, USA; Guide to underwater archeological sites, Sicily, Italy; The Bou Ferrer Roman wreck, Spain; Shipwrecks protected by metal cages, Croatia; Underwater Archaeological Park of Baia, Italy; WWII Maritime Heritage Trail, Saipan, USA; Prehistoric Pile Dwellings Trail, Austria (UNESCO).

Communication underwater

Communication between divers is important to exchange information underwater especially when they see an archaeological object. This communication is necessary not only for underwater archaeologists, but also for all divers who have a potential to see these historical and archaeological objects. A group of experts on Underwater Cultural Heritage in CMAS have developed hand signals after a long study and several meetings. Scientists from the Centre for Maritime Archaeology & Underwater Cultural Heritage, Alexandria University, Egypt; the Department of Restoration and Conservation of Cultural Heritage, Faculty of Art, Akdeniz University; the Faculty of Archaeology, University of Warsaw, Poland; the University of Buenos Aires and Curatorship Pile Dwellings, Austria have actively worked on this subject with the support of other members of the CMAS Underwater Cultural Heritage Commission. The implementation was carried out by a team from Akdeniz University too. These Universities are full members of UNESCO UNITWIN Underwater Archaeology Network.

20 signals

Selected 20 hand signals have been developed for the most common objects that could be found underwater. These are cannons (Fig.1.1) of the war ships or trade ships (Irion 1980; Tripathi 2004); Ancient bridges (Page 2001; Arıkan 2016), which were usually burned and sunk during war (Fig.1.2); Amphorae from the shipwrecks (Parker 1973) which were common on ships from Bronze Age to the Medieval Period (Fig.1.3); Ballast stones (Boycea et. Al 2009) of sunken ships (Fig.1.4); Column Drums (Galili et al. 2002; Carlson 2016) from the ancient constructions that were submerged as a result of earthquakes, or sea level rise. Also they were carried as cargo on board ships (Fig.1.5); Grapnel anchors which were common from since the Medieval Period (Fig.1.6); Harbour structures (Oniz 2018) which could be submerged due to earthquakes or sea level rise (Fig.1.7); Ingots mainly made of copper (Oniz 2019), iron or tin usually from Bronze, Iron or Roman Ages (Fig.1.8); Lead parts of wooden anchors which were common from the 5th to the 3rd century BC (Fig.1.9); Pottery, mainly from the shipwrecks as cargo or kitchen ware of the ship or submerged sites (Landau et al. 2020; Ricca et al. 2021) (Fig.1.10), Rigging materials of the ships (Fig.1.11), Statues from submerged ancient constructions e or from a cargo of a shipwreck (Fig.1.12); Wooden posts from ancient dwellings, bridges or quays (Fig.1.13); Stone anchors (Oniz 2014) from Bronze Age to Medieval Periods (Fig.1.14), Stoppers which were made of clay and use to close amphorae (Fig.1.15); Wrecks of all periods (Oniz 2020) (Fig.1.16); Engines of the steam ships or modern ships (Fig.1.17); Settlements which were hit and sunk by earthquakes (Oniz 2016) or sea level rise (Fig.1.18); Roof tiles which were from the cargo of the shipwreck or from the roofs of ships (Fig.1.19); Plates which were from the cargo of the shipwreck or kitchen ware of the ship. There are many archaeological objects and submerged remains that could be seen underwater, however, these are most common of them from the Mediterranean to the Baltic Sea, from the Indian Ocean to Atlantic Ocean.

Fig.1. The developed underwater signs for underwater cultural heritage objects (1-20).

Better communication under water is only possible if people understand each other and if all divers are aware of the cultural heritage under water. These hand signals have serious potential for safeguarding cultural treasures. These new signals will contribute to that.

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Citizen Science underwater

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Abstract. Citizen Science is a possibility of participation in scientific projects of people who are not tied to institutions in that field of science. Science is more and more recognizing the potential and the manifold possibilities offered by Citizen Science for example surveys where extensive data has to be collected. This also applies to marine and fresh-water research and to the exploration of our native waters. The CMAS Citizen Science Specialty Course is designed to enable interested and volunteer recreational divers to participate in scientific projects and at the same time to anchor this new form of citizen participation in a goal-oriented manner and make a further contribution to the protection and preservation of our environment. After successful completion of the course, the Citizen Science Diver is able to support a scientist under and above water in his or her work. He/she can competently support scientific projects on the basis of scientific guidance. The Citizen Science Diver is part of the CMAS's diver training system. It offers an international framework for diver and instructor qualifications in scuba diving. As a non-profit organization our aim is to deliver quality education for divers at all levels.

Region of Interest

Aquatic ecosystems – both freshwater and marine – provide habitat for numerous species of plants and animals as well as microorganisms and fungi. However, microplastic pollution, ocean acidification, decrease aquatic biodiversity, overexploitation of natural resources - to name just a few challenges- affect not only the aquatic ecosystems itself, but these challenges also necessitate new forms of science as participatory science supporting the involvement of interested citizens as Citizen Scientists (Cerrano et al. 2017; Lucrezi et al. 2018). Therefore, it is important to develop a Citizen Science specialty course for recreational divers, too, so that they can also participate in this new form of citizen participation in a goal-oriented manner to collect data as well as to create new research procedures and programs and make a further contribution to the protection and preservation of our aquatic environment.

Participation and involvement

Citizen Science is an opportunity for participation and involvement in scientific projects by actors who are not in scientific projects by actors who do not work full-time in science. This is nothing new for various associations and professional societies, as e. g. decades of bird watching show. But science is increasingly recognizing the potential and the manifold possibilities offered by Citizen Science, be it, for example, surveys of extensive data collection. Marine Citizen Science" stands at the interface between ocean science and ocean literacy. It is a means by which science and society can work together for mutual benefit, through a partnership between marine scientists and the general public (Garcia-Soto et al. 2019). And this is also true for research of our local freshwater eco-systems.

Successful projects are for instance the mapping and expansion of neobiota in local lakes (Fritz et al. 2008) as well as the jellyfish monitoring in Germany (Fritz et al. 2007, 2009). Another excellent example is the project "Diving for Nature Conservation" which aims to build a strategic alliance between nature conservation and recreational divers in

Germany and beyond to achieve improved protection of freshwater lakes (Arendt et al. 2011; Stoodt et al. 2020). Many lakes, even in Natura 2000 sites, have gone from oligotrophic (i.e. nutrient poor and oxygen rich) to meso- or even eutrophic waters, which has not only affected their fauna but also significantly changed their characteristic floral composition. The original habitat type is now in an unfavorable conservation status across most of the EU. NABU (Nature and Biodiversity Conservation Union) and German Underwater Federation (VDST) developed and established a training program in botanical and ecological surveys underwater. This collaboration gives recreational divers an opportunity to explore lakes from a new perspective and enables them to contribute to the lakes' conservation by regularly monitoring water conditions and macrophyte levels. Conservationists, administrations and private land owners benefit as well, since they can use this data as an early-warning system to indicate changes in a lake's condition and, so, adapt their management measures accordingly. The project was the winner of the German Nature Conservation Award 2013 of German Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN). The "Diving for Nature Conservation" project was one of the 27 finalists under the 2020 edition of the Natura 2000 Award of European Commission. The Natura 2000 Award of is designed to reward excellence in the management of Natura 2000 sites and showcase the added value of the network for local economies.

Diving clubs are often interested in the ecological status of their local lakes. Thus, basic practices in sampling, mapping and documentation are an expedient introduction to understand and monitor waterbodies. One of the most popular marine Citizen Science projects is certainly the well-known "Reef Check" with the ambitious aim to get a general overview and furthermore to help preserve the oceans and reefs, which are critical to our survival, yet are being destroyed (Freiwald and Beahrs 2020).

Citizen Science projects under water are a constructive possibility to receive wide information for further evaluation of the biodiversity and ecology. The projects are interdisciplinary ranging from biology, geology, hydrogeology to archeology. Dedicated and well-instructed sport divers, which have the ability to collect substantial data, are the basis for citizen science projects. Collecting large date sets on habitat properties as well as on biodiversity could never be managed by a small number of scientific divers. Thereby educated scientific divers adopt the supervising function and the evaluation of the produced data.

Ten principles of Citizen Science

The "sharing best practice and building capacity" working group of the European Citizen Science Association, led by the Natural History Museum London and other organizations, formulated the following ten points, which are important as key principles within the framework of good practice in Citizen Science (ECSA 2015):

- Projects actively involve participants in scientific endeavor that generates new knowledge or understanding.
- Projects have a genuine science outcome.
- Both the professional scientists and the participants benefit from taking part.
- Participants may, if they wish, participate in multiple stages of the scientific process.
- Participants receive feedback from the project.
- It is considered a research approach like any other, with limitations and biases that should be considered and controlled for.
- Project data and meta-data are made publicly available and where possible, results are published in an open access format.
- Participants are acknowledged in project results and publications.
- Programs are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
- The leaders of projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

CMAS Citizen Science Diver

The Citizen Science Diver course is a specialised course designed for recreational divers interested in science. It is intended for recreational divers 18 years of age and older who have CMAS** or equivalent certification. Participation requires 40 open water dives after reaching the training level CMAS** and a valid diving medical certificate.

Instructors must have a CMAS Scientific Diving Instructor qualification. These are recreational diving instructors having wide experience in scientific diving matters and are employed at scientific institutions such as Universities, Technical Colleges, Government research Laboratories, National and Regional Museums, Charitable or non-profit research foundations etc. (Parts of the theory may be taught by instructors authorised by the CMAS Scientific Commission). Parts of the theory may also be taught by other instructors duly authorised by the Scientific Committee. The course should be conducted over five days or can also be conducted in two weekend courses (2 ½ days) or five days in one weekly course. The training units consist of a theoretical part with 12 learning units (LU á 45 min.), a practical part with a minimum of 6 dives and a further practical part with two thematic dives or project-related dives.

In summary, there is an ever-growing need to further knowledge and understanding of global ocean systems, and hence to gain insight into the impacts that climate change and other natural and anthropogenic influences have had, and will have. Given the sheer geographic scale of the ocean and coastal areas, and the wealth of information they hold, it would be impossible for marine scientists to gather all these data alone. Involving citizens in marine science research can offer formidable means of overcoming these issues, while at the same time furthering education and Ocean Literacy amongst the general public.

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