Work Package 4.1

Monitoring case studies in Italy

Paguro wreck

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Deliverables: D4.1.1, D4.1.2, D4.1.3, D4.1.4, D4.1.5, D4.1.6

Titles:

D4.1.1 Explorative survey with multibeam echosounder (MBES) and/or ROV/scuba
D4.1.2 Set up of an integrated monitoring system in situ
D4.1.3 Images and data transferred at land and visualized through different media
D4.1.4 Investigations through MBES carried out during the testing phase
D4.1.5 Extension of monitoring execution to other parameters (i.e. biological components)
D4.1.6 Collection and reporting of obtained data

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Dissemination level:

PU	Public (must be available on the website)	[]
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Specified group (if applicable):

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EXECUTIVE SUMMARY

This report describes the results of a survey carried out from June 2019 until July 2021 in the area of the Paguro wreck, offshore Ravenna (Adriatic Sea), Italy. Monitoring of reefs is essential for the continuous evaluation of their structural and ecological evolution, hence their capacity to sustain different economic activities, in line with the principles of the Blue Economy. This activity, funded by the EU through the Interreg Italy-Croatia CBC programme, was initiated in recognition of the underexploited potential for sustainable use of some natural and artificial reefs located in the Adriatic Sea and is part of ADRIREEF (Innovative exploitation of Adriatic Reefs in order to strengthen blue economy) project.

• Aim of the survey is a transborder investigation aimed at highlighting the unexploited potential of 7 selected reefs, natural or artificial, located offshore the Italian and Croatian coasts of the Adriatic Sea.

• During the survey, innovative technologies with low environmental impact were tested, based on the outcomes of ADRIREEF WP3.4 “Identification of technologies for underwater monitoring of reefs.”. However, a few modifications may have been introduced to reflect Case Studies specifics or to address unexpected situations that occurred during practical activities at sea.

• The scope of this work also includes an assessment of the potential reef vocation for the specific CS (e.g. tourism, farming, aquaculture, fishing, environmental safeguard,...).

• The Paguro wreck was studied from June 2019 to July 2021 with a multidisciplinary approach for investigating abiotic and biotic characteristics of the site. A preliminary bathymetric survey with the multibeam echosounder was carried out for planning the underwater sampling of scientific divers. Traditional (i.e. photographic sampling on standard surface, visual census) and new methods (i.e. underwater photogrammetry, stereo videos recording) were applied to characterize the benthic and fish communities. Physical and chemical water parameters were measured regularly as well as the water column currents.

• The main findings of this study were as follows:

1. A bathymetric survey with a multibeam echosounder was carried out at the “Paguro wreck” and it covered the whole area identified as SCI IT-4070026. It was useful in order to obtain bathymetric maps and 3D images of the site and for planning the underwater sampling of scientific divers.
2. An integrated monitoring system was set up, which included the deployment of a vertical acoustic current profiler (ADCP). Data on current speed and direction in each cell (1 m) of the water column were successfully monitored by the instrument over one year, from July 2020 to June 2021, thus providing information on daily / monthly averages, current intensity peaks at different depths and an overview of the most important meteo-marine phenomena, useful for divers / diving centers and which may have repercussions on the integrity of the submerged structures.

3. Vertical profiles of the main physico-chemical parameters were periodically collected during the study period and shared in real time using social media to guarantee a useful service for the end-users. The water temperature is particularly cold only during the winter months, while poor visibility is the major concern for scuba divers, especially at the deeper levels of the wreck. This hampered also monitoring activities. Nutrient, chlorophyll and dissolved oxygen concentrations confirm that the area of the "Paguro wreck" is generally in a good trophic state. However, despite the distance from the coast of about 11 nm, it is occasionally affected by the inputs from the Po river, which lead to temporary dystrophic conditions, especially in the autumn-winter period in correspondence with the Po discharge peaks.
4. During the study period, 72 structurally diverse pollutants (metals and organometals, organochlorine pesticides, PAHs, dioxins and dioxin-like compounds, PCBs) were monitored in two marine sediment samples collected at the study site. Observed concentrations are comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive and are generally below the EQSs set in Legislative Decree 172/15.
5. Investigations were extended to biological components. Concerning the benthic community settled on the reef, 60 taxa were identified in total, thus confirming the attractiveness of the site for scuba divers. In general, as previously observed by other authors, the benthic community is dominated by mussels, oysters, cnidarian and sponges that provide a suitable habitat for the settlement of other sessile filter-feeders and endobiotic species, as well as a refuge for crustaceans and brittle stars. Differences in community structure and biomass can be observed across depths.
6. Fish community at site is composed by demersal hard bottom fishes (i.e. *Chromis chromis, Diplodus annularis, Diplodus vulgaris, Oblada melanura, Serranus scriba, Spicara maena, Sciaena umbra, Scorpaena scrofa, Sparus aurata*) and pelagic species (i.e. *Boob boobs, Thunnus thynnus, Seriola dumerili, Sarda sarda*). Seasonal variation in body size of some species was observed (i.e. Chromis chromis), demonstrating that the wreck provides suitable ecological niches for the entire life cycle of some demersal species and doesn't limit it's ecological role at refuge to predation or food source. New methods of visual census have been tested and the resulting data demonstrated a large overlap between them. Traditional visual census observations provided greater diversity as human eyes are not affected by limiting video quality (i.e. resolution), which reduces the possibility to identify fishes far from the lens.
7. Underwater photogrammetry has been largely deployed at site and performed over different surfaces to map at different resolutions the rig and its benthic communities. Photogrammetry has been used to integrate traditional sampling methods (i.e. benthic community assessment) with new outputs (i.e. benthic community interactive 3D map), to develop innovative communication products (i.e. virtual reality scuba diving experience) and to involve local stakeholders and scuba diver volunteers to participative underwater mapping events.

1. INTRODUCTION

The “Paguro” drilling platform, owned by Agip Mineraria, was built by the company "Nuova Pignone" of Porto Corsini in 1962 and for three years was used in numerous perforations in the Adriatic Sea. It was a self elevating platform, with a drilling tower consisting of a floating triangular-shaped hull with three legs placed at the vertices. The hull housed powerful engines, pumps and machinery, while its surface was equipped with a lodging module consisting of 5 decks. The heliport was placed at the top of the bow leg, while the drilling tower of about 40 m was located at the stern, between the other two legs. On 29 September 1965, the platform was located 12 nautical miles offshore Ravenna and sank as a result of a fire caused by methane leaking from the well (Fig. 1.1). Currently it leans on the seabed with the starboard side buried several meters deep in the sediment (Ponti et al., 1998; Ponti et al., 2002).

In the years 1990-1991 and 1999-2000 additional steel structures, once used for off-shore activities, were deployed at the same site and now dominate several parts of the original wreck (Rinaldi et al., 2004; Fig. 1.2).

Figure 1.1 - The Paguro methane jack-up drilling rig. Images of the accident, September 1965.

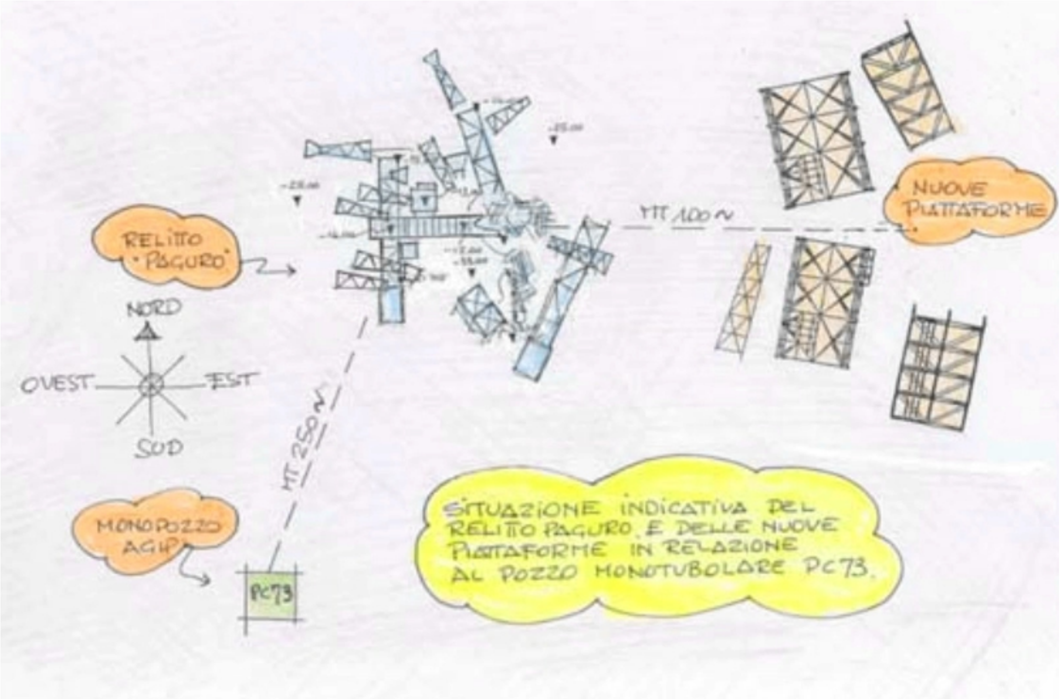


Figure 1.2 - Original drawing of the study area indicating the position of the Paguro wreck and the additional steel structures deriving from offshore activities with respect to the nearby mono-tubular platform PC 73 (drawing by Rambelli F.) .

The “Paguro” wreck, after its sinking in 1965, saw an explosion of marine flora and fauna, thus becoming a destination for divers and enriching the tourist offer of the territory.

In July 1995 it was declared a “Biological Protection Zone” by the Ministry of Agricultural Resources. This recognition, together with the establishment of the Paguro Association in 1996, contributed to the safeguard of marine life in the protected area. With Commission Decision 2012/14/EU, the “Paguro” wreck was also designated as Site of Community Importance (SCI code: IT4070026) and a management plan was redacted, delineating further conservation constraints. Finally, in 2019, the site was confirmed as Special Area of Conservation (SAC) by Ministry Decree 3 April 2019, thus assuring the conservation measures of the natural habitat. Consequently, recreational and professional fishing are not allowed activities across an area extended for 66 ha around the wreck. Conversely scientific research and recreational scuba diving are allowed for promoting the ecological relevance of the site. The Paguro Association, among its tasks, has the duty to manage all underwater visits in the wreck area, as defined by the Port Authority of Ravenna in 1997.

Existing information on the “Paguro” wreck derives from studies and monitoring programmes carried out by research institutes (e.g. University of Bologna, Centro Ricerche Marine – Cesenatico) since the mid 90s.

These activities were aimed at describing the evolution of biotic communities inhabiting the wreck, thus estimating their potential ecological and economic value and posing the basis for the SCI management plan. More recently, ARPAE Emilia-Romagna chose the "Paguro" area as a sampling site for the Marine Strategy Framework Directive (MSFD): in the period 2018-2020 annual samples of sediment and biota were taken to investigate the presence of environmental contaminants.

Within ADRIREEF project, ARPAE Emilia-Romagna aims at testing innovative monitoring techniques with low environmental impact, thus diversifying the data available for the SCI site and increasing its attractiveness for scuba divers.

From June 2019 to July 2021, the Paguro wreck was studied with a multidisciplinary approach for investigating abiotic and biotic characteristics of the site.

A description of the geomorphological features of the reef was obtained through a one-time multibeam echo sounder (MBES) survey, covering both the "Paguro wreck" and the additional steel structures sunk in 1990-1991 and 1999-2000.

Physical parameters (i.e. temperature, salinity, conductibility, pH, Optical Dissolved Oxygen, PAR, chl-a and turbidity) were sampled from the surface to the sea bottom by using a CTD multiprobe IDRONAUT 316 Plus. Water samples for nutrients were collected at the sea surface and bottom using a Niskin bottle. Multiprobe data were published on social media using interactive web-interfaces. An Acoustic Doppler Current Profiler (ADCP) was placed at the sea bottom for collecting data on intensity and current direction.

Photogrammetric surveys were performed on the study site at two different spatial scales (small and medium) according to local sea conditions and water quality:

- Small scale photogrammetric surveys covered areas less than 20 Sq m each and were performed with horizontal visibility between 1 m to 5 m. Additionally, traditional sampling was carried out on a standard area to be used as a reference for estimation of communities biomass and diversity by photogrammetry.
- Medium scale photogrammetric surveys covered areas between 20 Sq m and 50 Sq m each and were performed with more than 5 m of horizontal visibility. The resulting point clouds were classified to community facies and associations and used to generate 3D benthic maps.

Photogrammetric surveys were performed on the study site aiming at mapping the largest possible part of the wreck. According to the water visibility conditions and the scheduled underwater operations, the wreck was sectioned in several portions and scanned during multiple field campaigns.

Visual fish census was performed at fixed stations within the study areas for photogrammetric mapping. Data on fish abundance and diversity for the most representative species were added to the 3D model of the area.

Visual census on fish communities was also performed with digital video cameras mounted on a stereo configuration. The cameras recorded videos at full HD over about 30 min. Fixed stations were selected considering the best functioning of the stereo video software and the automatic fish tracking and identification. At the beginning of each survey, the stereo cameras were calibrated by the means of a calibration board.

Also, a 360 degree video camera was deployed at selected locations on the wreck. The recorded videos were analysed by marine biologists using virtual reality headset (Oculus Quest 2) and simulating observation performed at site over 2 minutes each direction.

Underwater Visual Census (UVC) were carried out by 2 scuba divers on the same date and at the same location of stereo cameras surveys. Data on fish abundances, diversity, and size were used to validate the stereo camera records.

Both traditional (i.e. photographic sampling on standard surface, visual census) and innovative methods (i.e. underwater photogrammetry, stereo videos recording and 360 degree videos) were thus applied to characterize the benthic and fish communities at the case study “Paguro wreck”.

Table 1: Summary of the surveys performed at the Paguro wreck with details on the technology used, metrics calculated and outcomes provided within the ADRIREEF project.

Performed survey	Technology	Metrics	Output
Bathymetric survey	Multibeam echosounder	Georeferenced point cloud	Bathymetric map and 3D views of the SCI IT-4070026 Interactive 3D map available online
Water column physico-chemical parameters	Multiparameter probe and laboratory analysis	Temperature, salinity, turbidity, chlorophyll-a, dissolved oxygen, pH, nutrients (nitrogen, phosphorus and silica compounds)	Monthly water column profiles published online; seasonal dataset for nutrient concentrations at sea surface and bottom
Water column current profile	ADCP probe	Current speed and direction profile over depth	Annual dataset on water currents from bottom to surface at 1 meter resolution and recorded with 10 seconds frequency
Benthos community characterization	Taxonomic identification Photographic sampling on standard surfaces	Organisms count, taxa count, taxa coverage on standard surface, organisms wet weight and dry weight, shells and biogenic debris weight	Biodiversity indices, species couverture, organisms abundance per taxa, dry weight per taxa, wet weight per taxa, shell weight per taxa, recolonization taxa diversity, recolonization taxa coverture

Performed survey	Technology	Metrics	Output
Fish census	Stereo videos Visual census at stationary point	Species diversity, species abundance, organisms size	Iconic species selection, data gathering, methods comparison
Photogrammetric survey	Structure from Motion photogrammetry	Local referred point cloud	Online interactive 3D point cloud on scanned wreck, 3D bionomic map, fouling community volume estimation Volunteer scuba divers training and involvement in scanning activities and serious virtual reality game for simulating a dive at site (Annex III)

2. GEOMORPHOLOGICAL MAPPING

2.1. Description of equipment and acquisition/processing techniques

The acoustic survey at the case study "Paguro wreck" was carried out in August 2020 with the aim to obtain a detailed bathymetric map of the whole marine area corresponding to the SCI site IT-4070026 and a 3D reconstruction of the submerged platform structures.

The intervention area is located about 11 nautical miles off the Emilia-Romagna coast, in correspondence with Lido Adriano/Lido di Savio and has an area of approx. 0.66 km^2 (Fig. 2.1).

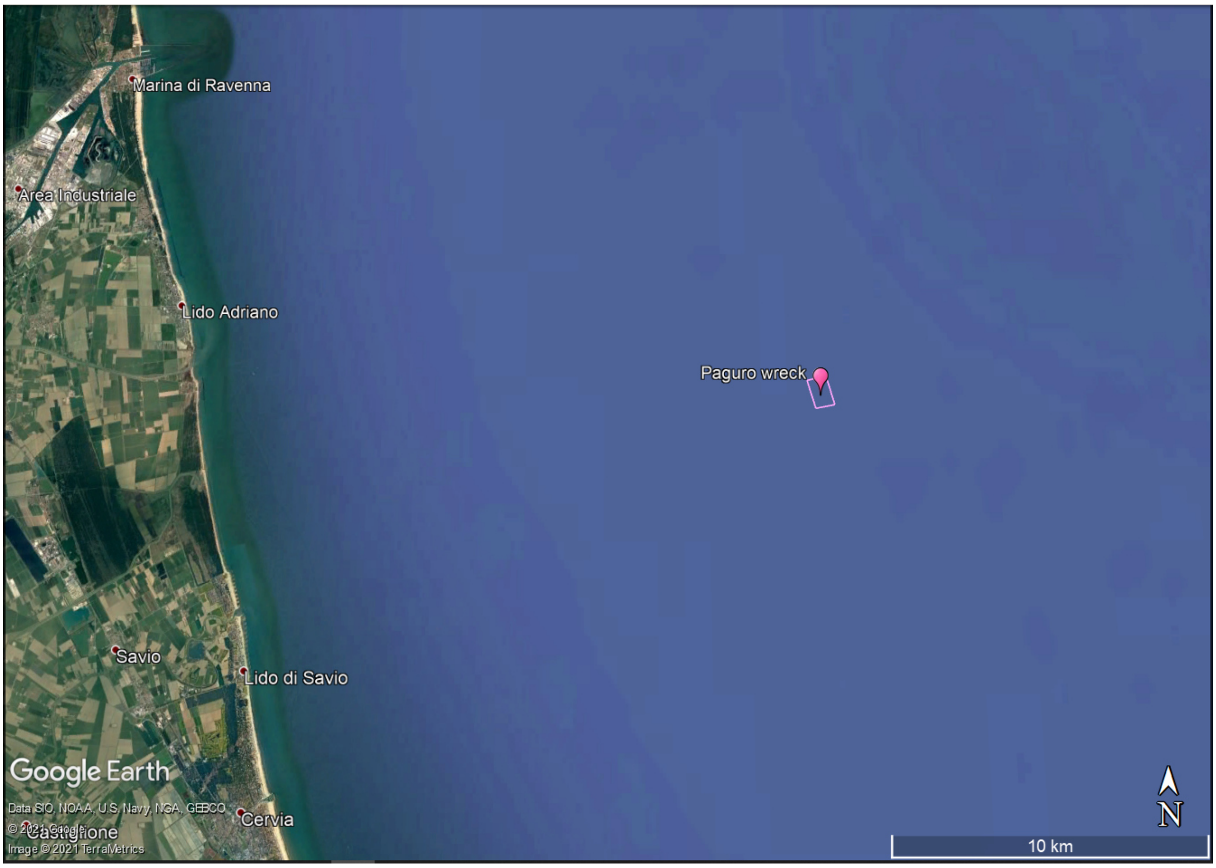


Figure 2.1 - Study area location showing the position of the Paguro wreck artificial reef (Google Earth images).

The bathymetric survey activities with the multibeam system were carried out using the vessel "TRER" owned by MarTech srl.

The following equipment and software were used:

- Positioning system: Trimble Marine SPS855 GNSS Receiver

The precision positioning system consisted of the Trimble Marine SPS855 GNSS Receiver which can receive GNSS satellites in differential or RTK mode in single or dual frequency L1, L2 and the new L5 frequency. It is used with the Trimble GA30 antenna specific for marine applications and can also track Glonass, Galileo, Compass and QZSS satellites and is compatible with Omnistar HP and MarineStar differential correction services for coastal and marine applications. It is equipped with an internal UHF radio modem and internet data connection through an external modem and can receive RTCM or RTK corrections from VRS geodetic networks. The system has the RTK Locator option that allows operating at sea with centimeter accuracy and real-time correction of the tide during coastal surveys. This positioning system is interfaced with the navigation software at the on-board workstation and the relative automatic positioning, navigation and acquisition softwares. The system was used in DGPS mode with MarineStar differential corrections.

- Reson SeaBat 8125 multibeam echosounder with operating frequency of 455 kHz, swath (cone opening) of 120°, number of acoustic beams 240, with beams opening angle (across track beam width) of 0.5°
- Integrated motion sensor and gyrocompass Ixsea Octans 1000
- Sound velocity probe mounted in a fixed position at the head of the Reson SVP-C transducer, thus allowing continuous control of the data
- Probe for the correction of the sound velocity on the water column model Valeport SWIFT Plus SVP
- Reson PDS2000 multibeam navigation, data acquisition and processing software package

The bathymetric survey activities with the multibeam system were performed to fully cover the entire SCI area of the "Paguro wreck", performing parallel transects at a speed of about 4 knots. In correspondence with the submerged wreck structures, transects were performed at very low speed, about 0.5 knots, in different directions, with an online acquisition grid of 0.5 m.

The following outputs were produced:

- a bathymetric map with isobaths every 0.25 m
- 3D views of the submerged structures with 0.1 m grid

2.2. Survey results

A complete bathymetric survey using a multibeam echosounder was carried out at the "Paguro wreck" and it was useful for planning the underwater sampling of scientific divers.

The area described as SCI IT-4070026 can be divided into two subareas: (a) the natural seabed surrounding the artificial reef and (b) the artificial reef area located in the central sector of the SCI site (Fig. 2.2).

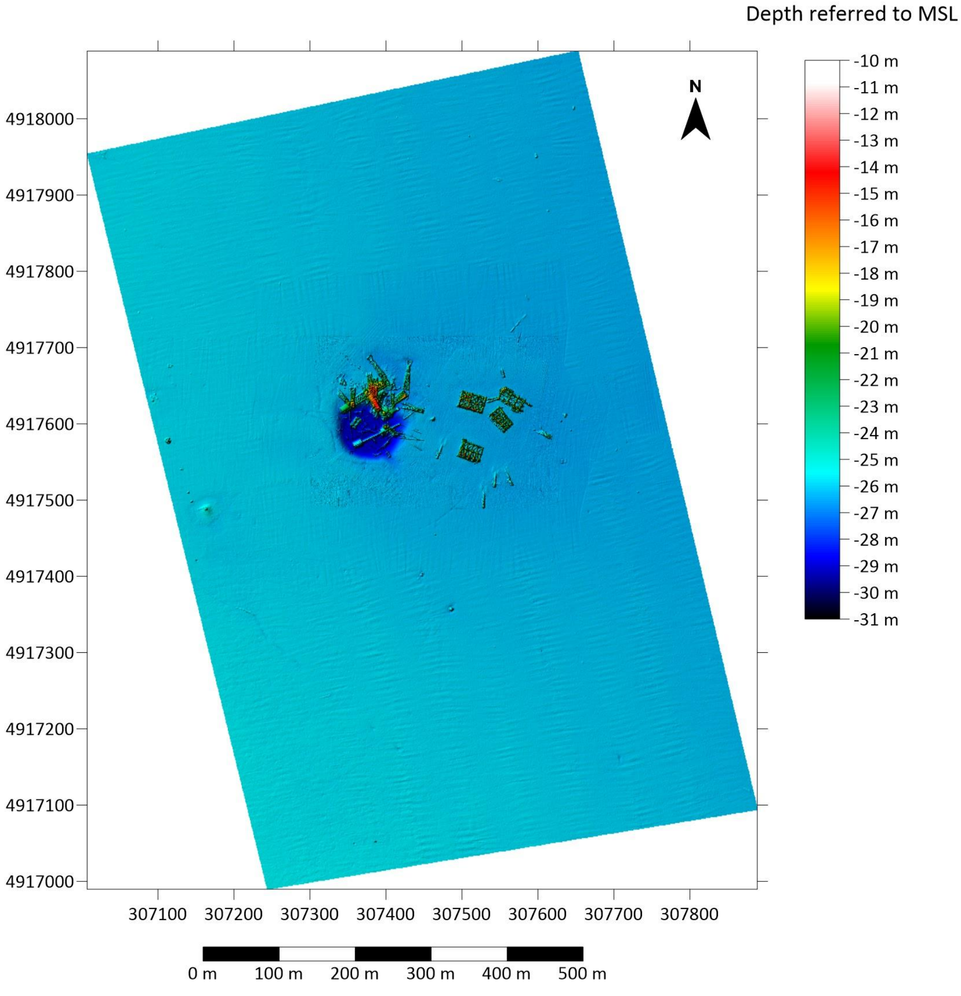


Figure 2.2 - Colour relief of the whole area of the SCI IT-4070026 mapped with multibeam echosounder Reson SeaBat 8125. Coordinates in WGS84/UTM zone 33N. Depths are referred to Mean Sea Level (MSL).

The average water depth of the natural seabed in the investigation area is about 26.0 m (maximum observed value is 26.9 m). The seabed is flat and generally smooth (Fig. 2.2), with few probable man-made features and anchor scars.

The artificial reef area shows an almost flat seabed of about 26 m of water depth. Close to the "Paguro wreck", a subcircular crater excavated by the gas eruption can be observed. It is of about 90 m diameter and up to 3 m deep from the surrounding seafloor (Fig. 2.3). In the crater area, the maximum depth of about -30.8 m was recorded near the southernmost footing of the original jack-up rig (white arrow in Fig. 2.4). The shallowest point is on top of one of the additional steel structures deployed in 1990-1991, where it lays above the Paguro hull (red arrow in Fig. 2.4). The following elements of the Paguro jack-up rig are identifiable (Fig. 2.5):

- the partially buried platform hull, NW-SE aligned and with a deep angle of about 90°;
- the accommodation modules;
- the three legs, SO-NE oriented. Of these three legs, the northernmost one is half exposed and still attached to the hull. The footing and the remains of the helideck are visible. The southern leg is almost completely buried apart from the footing. Between the end of the hull and the top of the southernmost leg, once joined, there is now about 15 m distance. The third leg is only partially visible in the NE area of the wreck.

All the other artificial structures present around the crater were added in the years 1990-1991.

Four more structures were added in the years 1999-2000 as a second fish restocking area (Rinaldi and Rambelli, 2004). They are located at a minimum distance of 65 m from the Paguro wreck and are WNW-ESE oriented. They show an elevation of about 5-6 m above the surrounding seabed and generally deep towards NNE (Fig. 2.4).

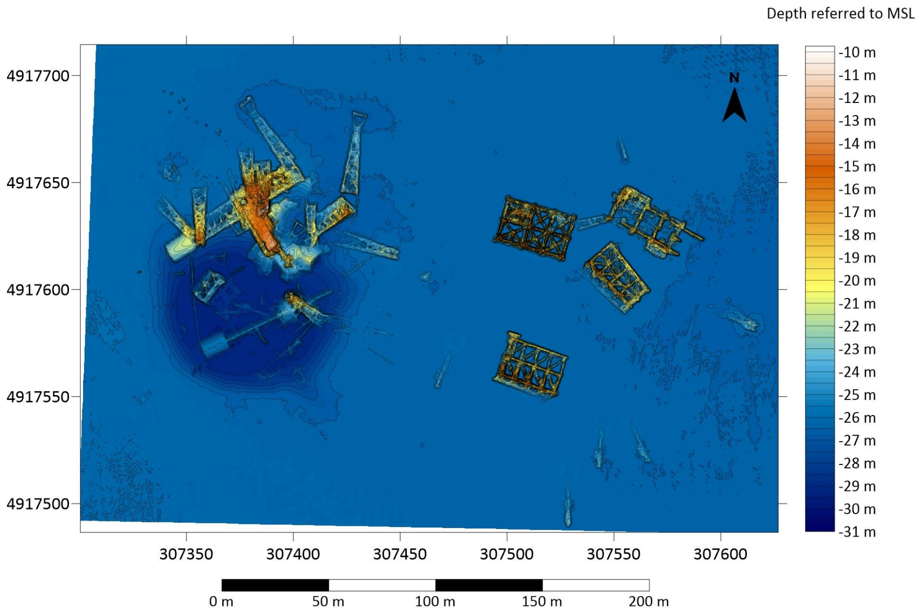


Figure 2.3 - Bathymetric map obtained with multibeam echosounder of the artificial reef "Paguro wreck". It is possible to see the remains of the sunken jack-up rig and the decommissioned structures added around and over the wreck. Coordinates in WGS84/UTM zone 33N. Depths are referred to Mean Sea Level (MSL).

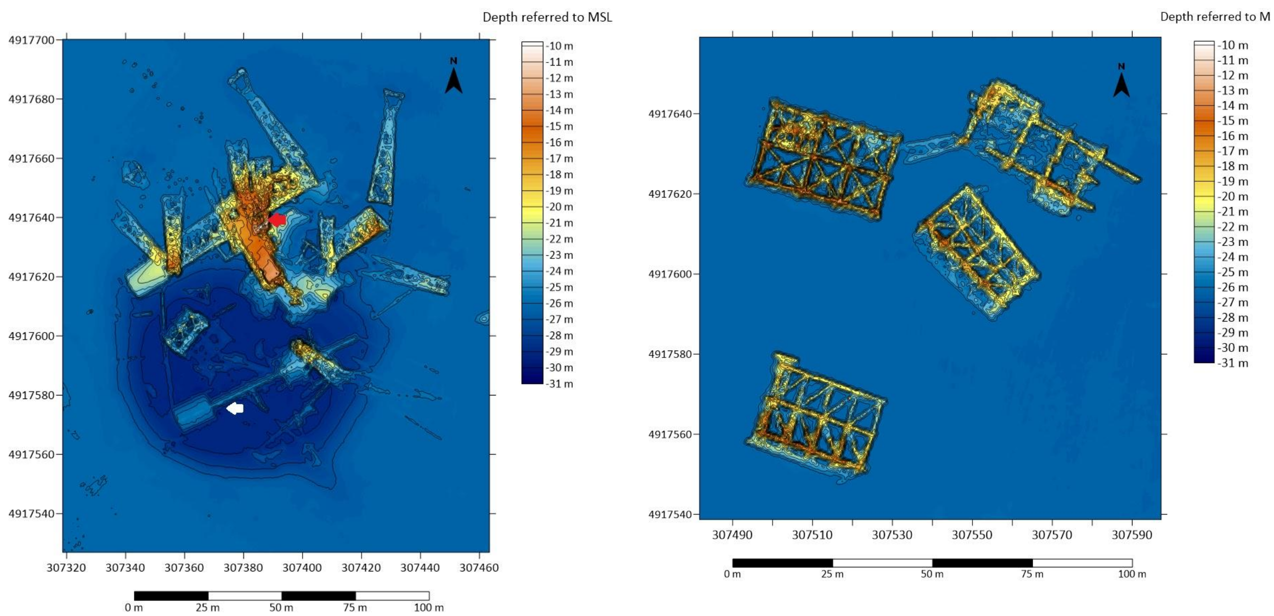


Figure 2.4 - Detailed bathymetric data from MBES Reson SeaBat 8125 of the case study "Paguro wreck".

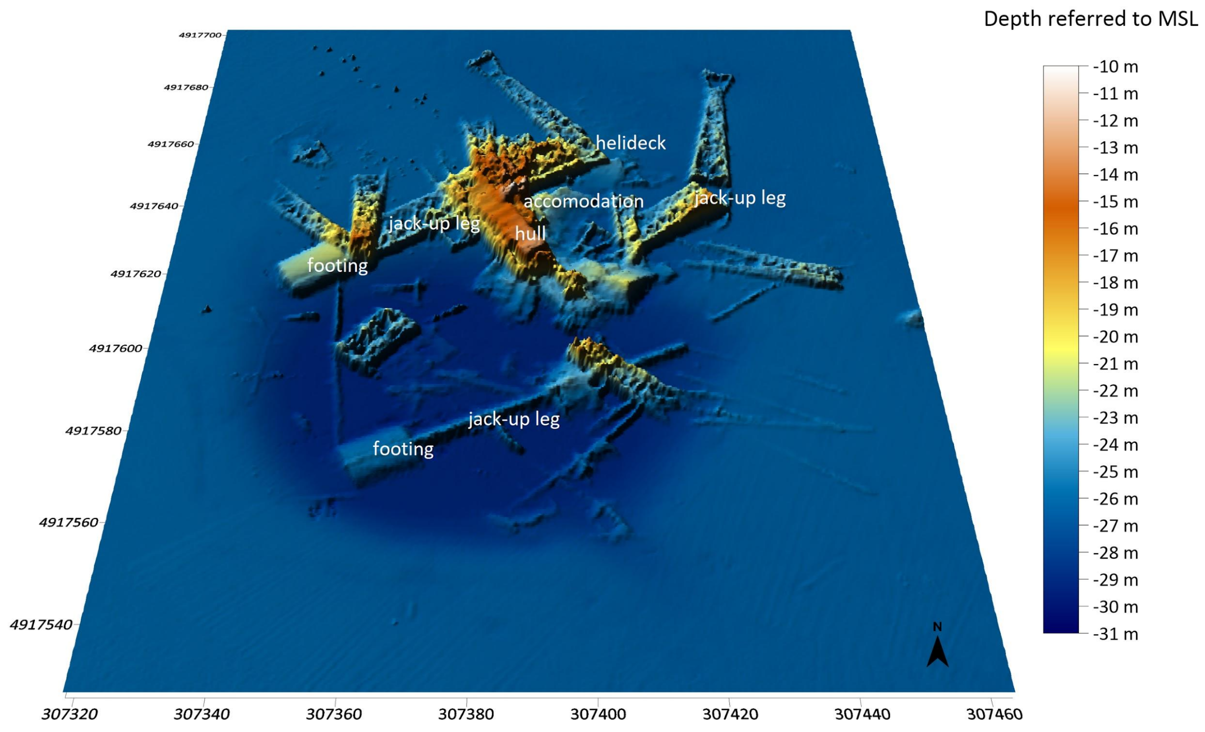


Figure 2.5 - 3D image of the case study "Paguro wreck".

The output of the multibeam echosounder was aligned with the point cloud of the areas of the wreck mapped using underwater photogrammetry. It will be uploaded to a dedicated online platform where users can view and interact with the scaled dataset.

3. SAMPLING TECHNIQUES AND METHODS OF ANALYSIS

The study area of the "Paguro wreck" is located 11 nautical miles offshore Ravenna and has a surface of about 0.66 km^2. The position of the sampling stations for collecting data on water currents (station ADCP), water column parameters, nutrients concentration and pollutants in sediments (station PG_01) are indicated in Table 3.1 and Figure 3.1. Details on the sampling stations used for the study of benthic and fish communities will be specified in paragraphs 3.4 and 3.5.

Table 3.1 - Geographic coordinates of the sampling stations (WGS84, latitude and longitude in decimal degrees).

Sampling station	Latitude [degrees_north]	Longitude [degrees_east]
ADCP	44.38514	12.57941
PG_01	44.38125	12.57958

Figure 3.1 - Map of the study area with geographical position of the sampling points. Platform PC 73 is also indicated.

3.1. Speed and direction of water currents

Current speed and direction were recorded along the water column in the area of the "Paguro wreck". To carry out this task a Teledyne Acoustic Doppler Current Profiler (ADCP) Sentinel V100 300 kHz was moored at a depth of about 26 m in a site at 200 m and 245° direction from the artificial reef (Fig. 3.2).

The ADCP was setted with the number of depth cells to 29 with a bin size of 1 m. The sampling interval was set to 60 pings per ensemble with a ping rate of about 1 ping every 10 sec. Recording started on 10th July 2020 and is still ongoing. Here we describe the data collected until 18th June 2021, with a suspension in the period 28th November - 18th December 2020 due to instrument maintenance.

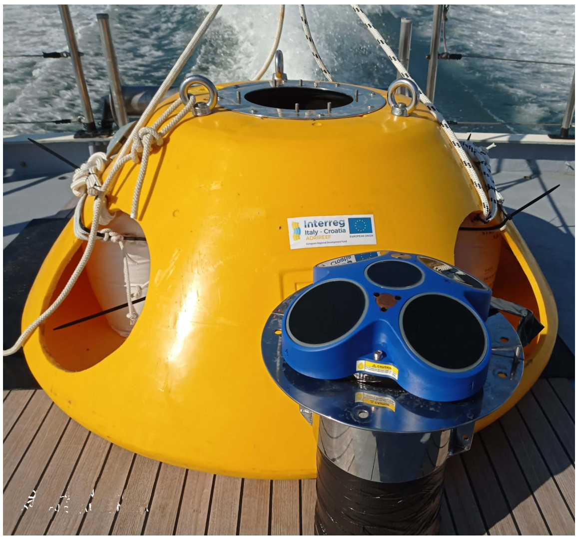


Figure 3.2 - Picture of the Teledyne RDI ADCP Sentinel V100 5 beams with the bottom-mount resinex barnacle used in this study.

3.2. Water column parameters

The sampling station was monitored periodically from June 2019 to March 2021. Temperature, salinity, dissolved oxygen and chlorophyll “a” data were monthly acquired (except during winter period when only one sampling was carried out) using CTD (Idronaut 316 Plus). Water samples for nutrient analyses (nitrogen, phosphorus and silica) were seasonally collected using a Niskin bottle respectively at surface and bottom level from July 2019 to March 2021. Nutrients concentrations were analyzed in the laboratory using QUAATRO analyzer (Tab. 3.2).

Figure 3.3 - Left: water sampling with Niskin bottle. Right: multi parameter probe during data collection along the water column.

Table 3.2 - Methods used in the laboratory for the analysis of nutrients in seawater.

Parameter	Analytical method
Total nitrogen and phosphorus	Methods of Seawater Analysis, Grasshoff K, M. Ehrhardt, K. Kremling Eds, Verlag Chemie, Weinheim, 1983. Valderrama J.C., 1981. Mar.Chem.,10 SEAL Analytical Q-031-04 Rev.2 (multitest MT3A) SEAL Analytical Q-035-04 Rev.7 (Multitest MT3B, 3C)
Phosphate	SEAL Analytical Q-031-04 Rev.2 (Multitest MT3A)
Ammonia	SEAL Analytical Q-080-06 Rev. 2
Nitrite	SEAL Analytical Q-030-04 Rev 3 (Multitest MT3A)
Nitrate	SEAL Analytical Q-035-04 Rev.7 (Multitest MT3B, 3C)
Silicate	Bran+Luebbe N° G-177-96 Rev.1 (Multitest MT19)

3.3. Contaminants in sediment

Sampling of sediments was conducted in June 2019 and June 2020 at the study site Paguro wreck (monitoring station PG_01) in stable weather and sea conditions, paying attention to cause the least possible disturbance to the matrix to be sampled. Surficial sediments were collected in triplicate using a Van Veen grab sampler (0.112 m^2 of sampling surface and 22 liter capacity) (Fig. 3.4). From each grab, the top 5 cm of the sediment was taken and thoroughly mixed into a site composite sample in the field. The site composite sample was then divided into aliquots and each aliquot was identified with the code of the sampling station and the type of survey for which the sample was intended (grain size, heavy metals, organic contaminants).

Figure 3.4 - Sampling of sediment using the Van Veen grab.

Sediment physical parameters and chemical analyses for the determination of inorganic and organic contaminants were performed following procedures routinely used at ARPAE Emilia-Romagna.

Metals (Hg, Cd, Ni, Pb, As, Cr):

- UNI EN ISO 13657:2004
- EPA 6020b 2014 Inductively Coupled Plasma - Mass Spectrometry
- G.U. N 116 del 21/05/2003 D.L. 08/05/2003 (Chromium VI)

Tributyltin compounds (TBT):

- Internal method - Extraction with methylene chloride, digestion in nitric acid and determination in ICP-MS

Pesticides (Aldrin, Dieldrin, Hexachlorobenzene, ortho and para forms of DDT, DDD, DDE, Alpha-Hexachlorocyclohexane, Beta-Hexachlorocyclohexane, Gamma-Hexachlorocyclohexane):

- Internal method - Method for the determination of organochlorine compounds in sand and sediment samples by Quechers extraction and GC-MS/MS analysis
- Pesticidi Organoclorurati. Quad. Ist. Ric. Acque, 64. Metodi analitici fanghi Vol.3. Gennaio 1988
- EPA 8081a Organochlorine pesticides by gas chromatography
- EPA 8270c Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS)

PAHs (Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo[a]anthracene, Chrysene, Benzo[b]+[j]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Indeno[1,2,3-c,d]pyrene, Dibenzo[a,h]anthracene, Benzo(ghi)perylene):

- EPA 3545a 2007 Pressurized Fluid Extraction (PFE)
- EPA 3630c 1996 Silica gel cleanup
- EPA 8270d 2014 Semivolatile Organic Compounds by GC-MS

Dioxins and furans (2.3.7.8-T4CDD, 1.2.3.7.8-P5CDD, 1.2.3.4.7.8-H6CDD, 1.2.3.6.7.8-H6CDD, 1.2.3.7.8.9-H6CDD, 1.2.3.4.6.7.8-H7CDD, O8CDD, 2.3.7.8-T4CDF, 1.2.3.7.8-P5CDF, 2.3.4.7.8-P5CDF, 1.2.3.4.7.8-H6CDF, 1.2.3.6.7.8-H6CDF, 2.3.4.6.7.8-H6CDF, 1.2.3.7.8.9-H6CDF, 1.2.3.4.6.7.8-H7CDF, 1.2.3.4.7.8.9-H7CDF, O8CDF):

- EPA 1613B 1994 Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution HRGC/HRMS

PCBs (PCB 31+28, PCB 52, PCB 101, PCB 81, PCB 77, PCB 123, PCB 118, PCB 114, PCB 153+168, PCB 105, PCB 138, PCB 126, PCB 128+167, PCB 156, PCB 157, PCB 180+193, PCB 169, PCB 170, PCB 189):

- Internal method - GC-MS/MS

Grain size characterization:

- Metodologie analitiche di riferimento - Programma di monitoraggio per il controllo dell’ambiente marino-costiero (triennio 2001-2003), Ministero dell’Ambiente e della Tutela del Territorio Servizio Difesa Mare e ICRAM, p. 84
- ASTM E11 - 09e1 Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves
- ISO 3310-1:2000 Test sieves - Technical requirements and testing - Part 1: Test sieves of metal wire cloth
- ISO 13317-3:2001 Determination of particle size distribution by gravitational liquid sedimentation methods - Part 3: X-ray gravitational technique

3.4. Benthic community settled on the reef

Samples for the study of the benthic community were collected by scuba divers by scraping off the substrate (Fig. 3.5). This technique, albeit destructive, was carried out on small representative portions, in order to be able to sample non-visible macrozoobenthos organisms through photographic sampling. Quadrats of 20x20 cm were scraped around the wreck at the depth ranges of -10 to -14 m, -15 m to -18 m, -19 m to -23 m and inside the wreck at the depth of -20 m. At each depth range, three surface portions were chosen to represent the different orientations of the wreck (Fig. 3.6). Each portion was scraped twice: at the beginning of the survey and after a certain period of time as indicated in Table 3.3. This allowed the study of the recolonization of the wreck by benthic organisms.

Further photographic samples were collected before and after the scraping to estimate the coverage of colonial organisms. Sampling areas inside the wreck were not resampled and they were used as a survey of the aphotic biocenosis.

Figure 3.5 - Sampling benthic community by scraping standard surfaces.

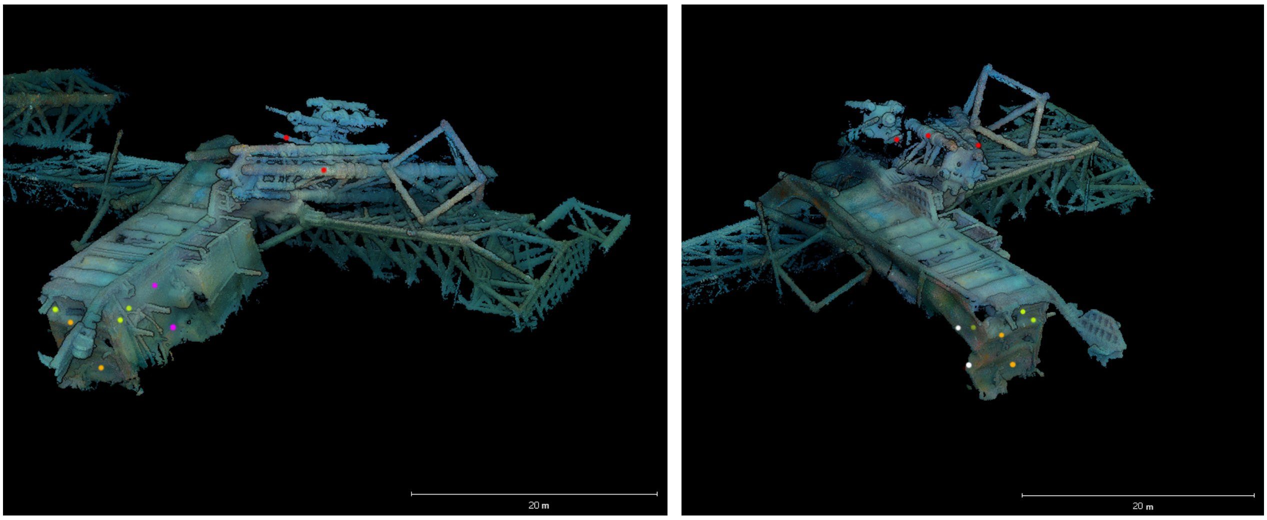


Figure 3.6 - The distribution of the benthic community samples collected around the Paguro wreck. The red dots represent the samples at -12 m; purple dots are the samples collected at -17 m and -21 m across the South West side of the wreck; orange dots the samples collected at -17 m and -21 m at the stern of the wreck; white dots samples from the North East side; yellow dots are the samples collected from the inner walls of the wreck facing the SW and NE walls.

The collected samples were sorted with a siever at 0.5 mm and fixed in 4% formaldehyde solution for the identification. Organisms were identified at the lowest possible taxonomic level and abundances of solitary organisms was estimated as the number of individuals and, for colonial ones, the coverage (cm^2) across the standard sampled surface was calculated.

In order to estimate the biomass, organisms were dried at 60°C for 24h. The carbonatic part of the organisms (i.e. shells and worm tubes) were weighted separately and accounted for the estimation of the fouling community weight at square meter. Shell free dry weight (SFDW), shell free wet weight (SFWW) and whole wet weight (WW) were also reported per square meter.

Data were processed in order to estimate biodiversity in terms of Number of species, Shannon index and evenness among the different sampling sites and after scraping the recolonization. Moreover, data were processed with the biomass parameters obtained from the laboratory analysis.

Table 3.3 - Sampling areas for description of the benthic community settled on the reef. Information on sampling area ID, sampling depth and date of scraping are given.

Sample ID	Depth	1st scraping	2nd scraping
Shallow 1	12 m	29/07/2019	26/11/2020
Shallow 2	12 m	29/07/2019	26/11/2020
Shallow 3	12 m	29/07/2019	26/11/2020
SW	17 m	28/05/2020	26/03/2021
NE	17 m	28/05/2020	24/03/2021
Stern	17 m	28/05/2020	25/03/2021
SW	21 m	28/08/2020	26/03/2021
NE	21 m	28/08/2020	24/03/2021
Stern	21 m	28/08/2020	25/03/2021
Internal 1	21 m	28/08/2020	Not done
Internal 2	21 m	28/08/2020	Not done
Internal 3	21 m	28/08/2020	Not done

3.5. Fish assemblage

The fish community was studied by applying the traditional method of visual census at stationary point. The method is based on the identification, count and size estimation of fish by: i) scientific scuba divers, ii) recording and analysing 360 degree videos, iii) recording stereo videos at stationary points.

Monitoring activities had a seasonal frequency, from spring to autumn (Tab. 3.4). Exact location of the monitoring stations is shown in Figure 3.7.

Table 3.4 - Visual census monitoring events performed at site with different techniques.

Date	Visual census	Video 360 degree	Stereo video
31-Jul-19	x		x
15-Jul-20			x
27-Aug-20	x		x
28-Aug-20		x	
26-Nov-20	x	x	
25-Mar-21			x
26-Mar-21	x	x	
31-Jun-21	x	x	x
01-Jul-21			x

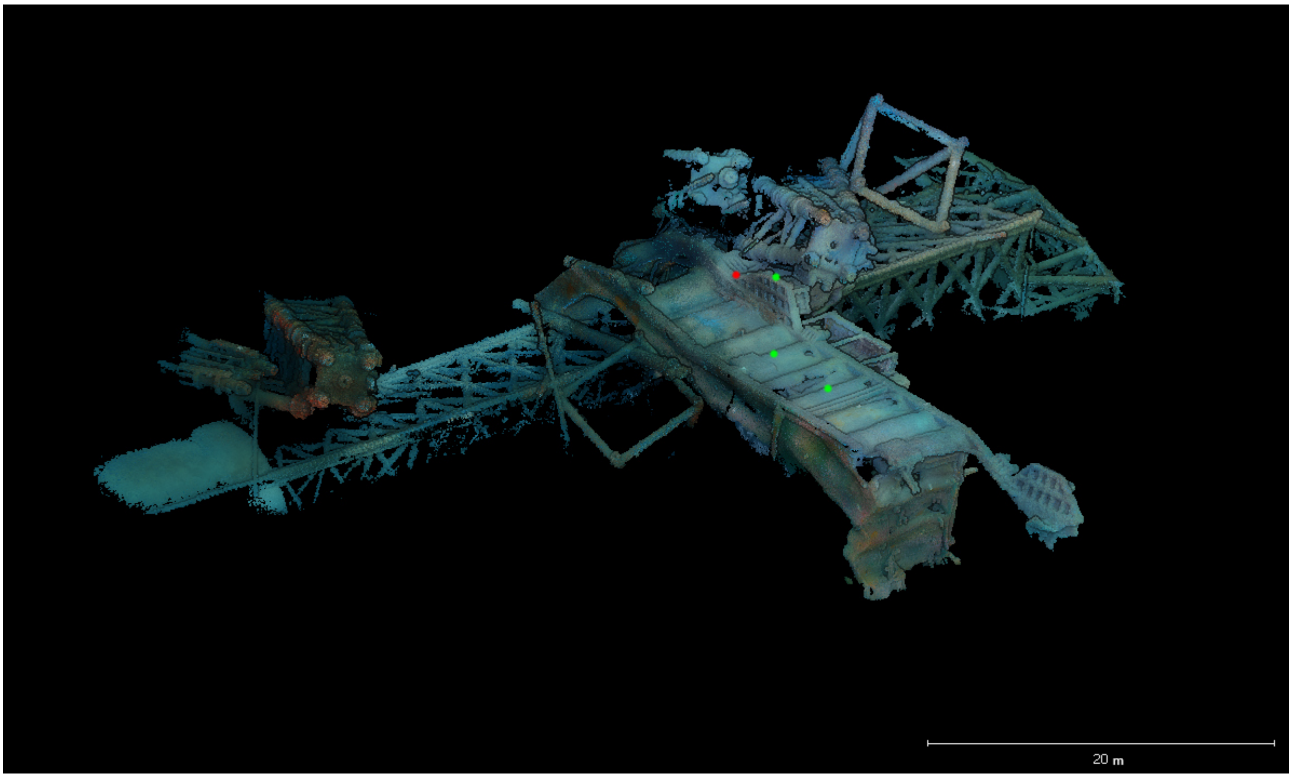


Figure 3.7 - Location of the visual census monitoring performed at the Paguro wreck. The red dot represents the location where the stereo camera was positioned; Green dots are the location where the 360 degrees camera was positioned and the visual census at stationary point was performed with scuba divers.

The 360 degree camera used was a Kandao Qoocam with a dive case recording 8k video format. The camera was positioned in 3 stations across the wreck (Fig. 3.7). Scientific scuba divers' visual census at stationary points were performed at the same locations and direct observations were carried out for 10 minutes. The method is based on census of fishes within a cylinder of 5 m radius by a diver at the selected stationary point. At each sampling point all the species observed within the field of view were recorded. The method provides quantitative data on frequency of occurrence, fish length, fish abundance and community composition.

The 360 degree videos were processed using a virtual reality headset Oculus Quest 2. The operator applied underwater technique to visual census at stationary points in a virtual environment, identifying, measuring and counting fish observed over 2 minutes per direction (Fig. 3.8).

Figure 3.8 - Positioning the 360 degree camera at site.

Stereo videos were recorded using two digital cameras (GoPro Hero) positioned in a front-parallel stereo setup, with a fixed baseline of about 20 cm. The cameras have FullHD image resolution (1920x180 pixel, true colors 24 bpp). A calibration pattern (chessboard) was used, at the beginning of each survey, to estimate the optical and geometrical parameters needed to enable the 3D computation, by scaling the automatically identified objects at the metric system (Fig. 3.8). The calibration pattern, of known size, was slowly moved at a set of different orientations and distances by an operator (Fig. 3.9). Then, the automatic stereo calibration procedure was performed using the OpenCV software library and a configuration file (in YML format) for each survey was produced.

Figure 3.8 - Stereo camera setup and calibration pattern.

Figure 3.9 - Stereo camera calibration procedure at site.

All videos were processed with automatic object detectors based on most popular deep learning algorithms (fasterRCNN, RetinaNet, YOLOv3). Web APIs and interfaces to neural nets implementations were made public, for instance by https://openmmlab.com/ to speed-up application development. Moreover, in the project, a new video processing server has been deployed in order to allow customized learning-based video processing using the PyTorch programming environment. Annotated datasets to train networks were generated by experts belonging to project partners, by using a dedicated graphical image tagging software (LabelImg). Figure 3.10 shows a typical outcome of the supervised tagging procedure.

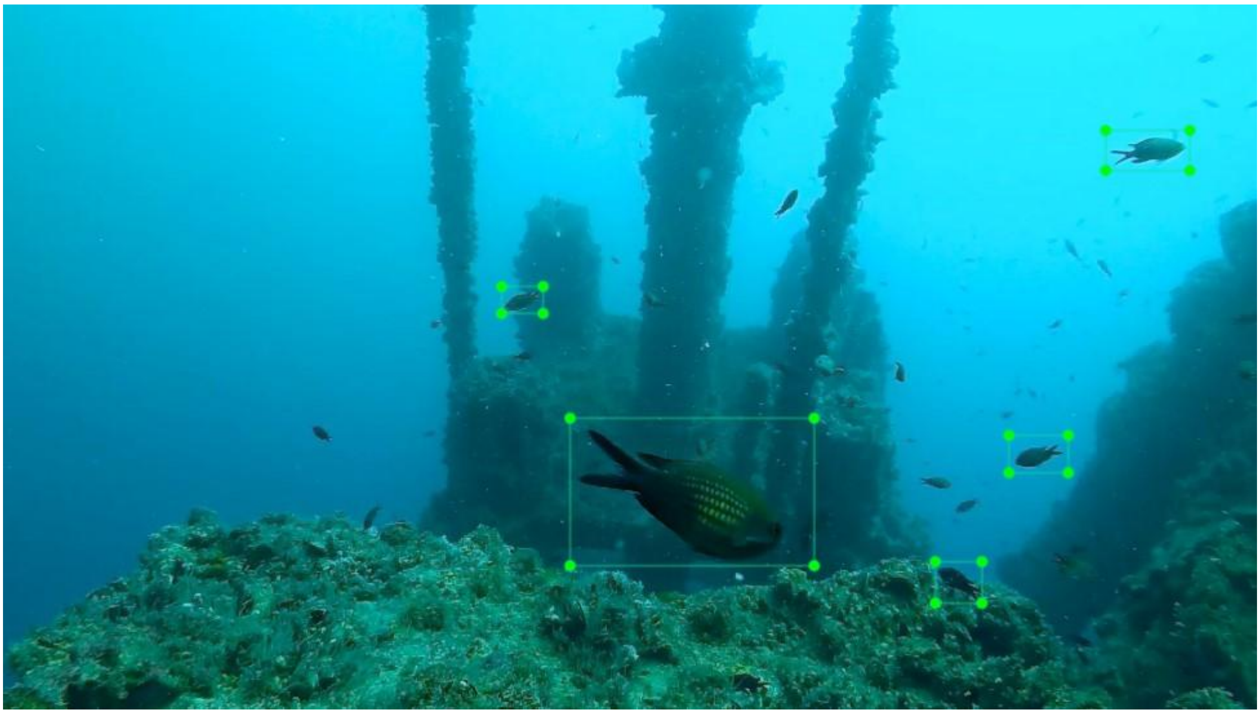


Figure 3.10 - A snapshot of the image tagging procedure.

The datasets include all fish species observed inside the videos. However, due to the small number of individuals available for several classes, to ensure proper training of the classification algorithms, some images from other sources have been used. Figure 3.11 shows a sample for each class included into the Paguro dataset.

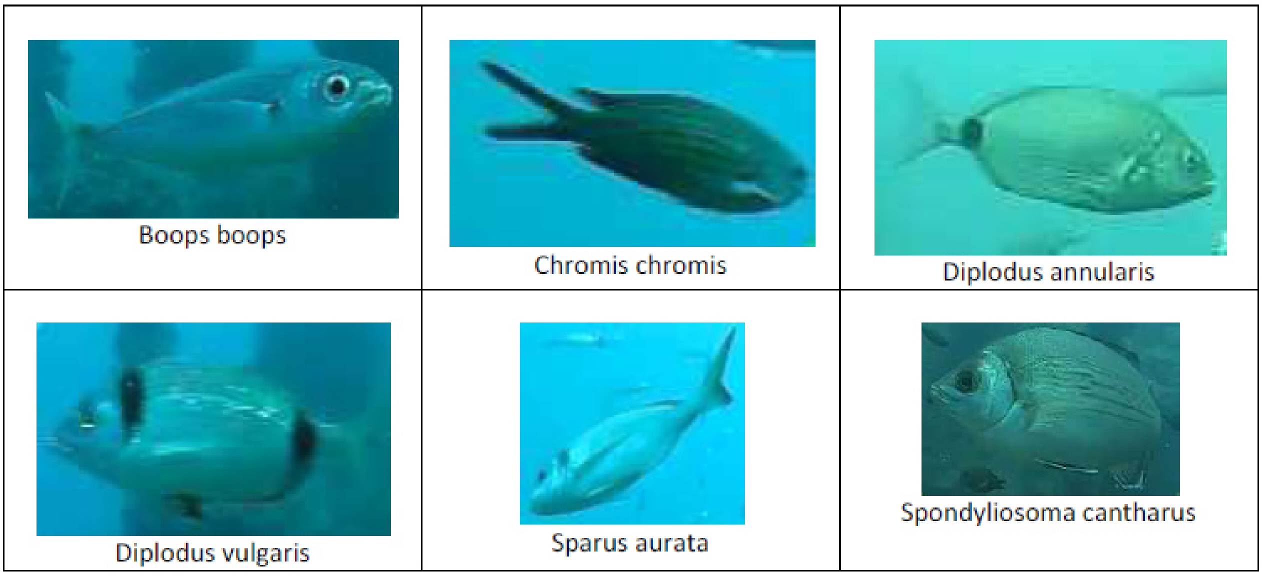


Figure 3.11 - Class samples extracted from the training set.

Deep learning algorithms have been trained on fish species using the transfer learning scheme, in which an already trained generic object detector deep network (e.g. ResNet50) is specialized to cope with the new target classes, without changing most layers of the network itself. Transfer learning allows fast and reliable training of recognition systems by re-using existing large networks. The final output of a video processing task is a report file including all individuals observed inside each frame, their species and (if available) their size. The result can be seen in overlay with the original video in order to appreciate the quality of the detection and recognition steps (Fig. 3.12).

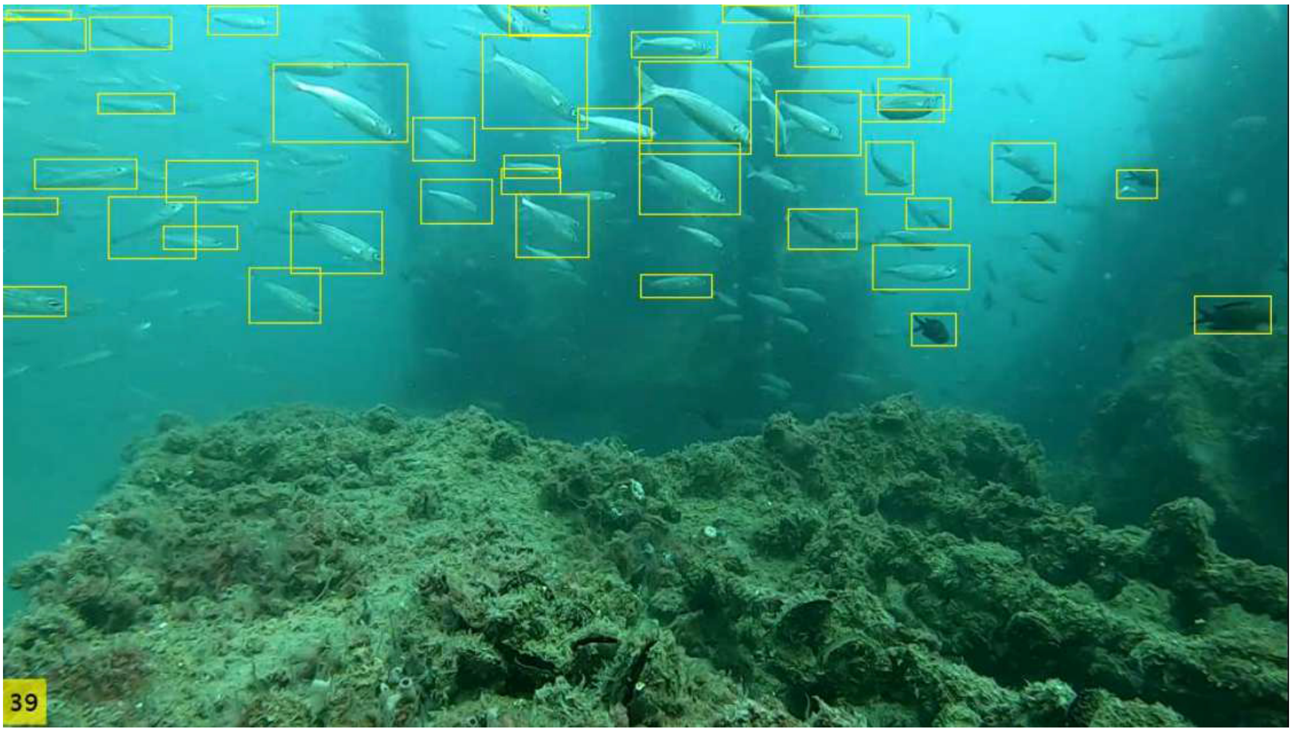


Figure 3.12 - A video processing snapshot with automatic fish detections in overlay.

A statistical report of the video processing can be generated by the MaxN statistics, commonly adopted in the visual census procedures based on computer vision. In this way fish abundance (global or for a given species) is evaluated by dividing the video in small clips of fixed duration (e.g. 10 seconds) and keeping the maximum number of individuals observed in a single frame inside each clip. The final result is a sequence of abundances that can be plotted as a graph (Fig. 3.13). Starting from these data it is possible to derive means and standard deviations of the required abundances.

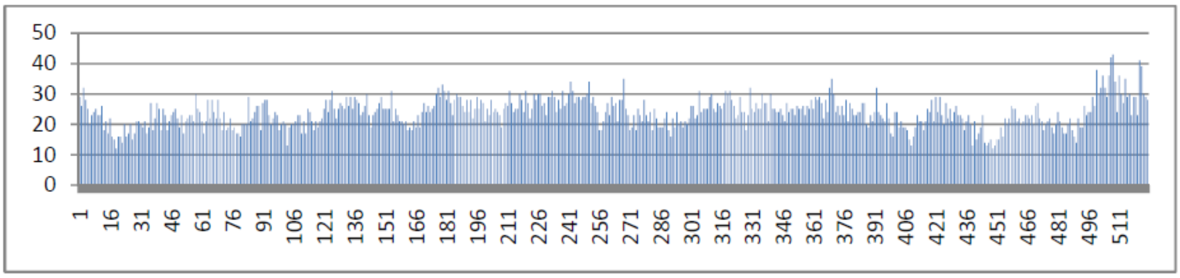


Figure 3.13 - An abundance raw graph with MaxN statistics.

3.6. Photogrammetric survey

Underwater photogrammetry was performed at site aiming to scan the entire submerged structures. The surveys were performed by two scientific scuba divers by using a full frame Sony Alpha 7-mark III camera equipped with a wide lens optic and 15000 lumens video torches over 20 dives. Calibrated dimensional references were designed with aluminium plates and magnetic supports for the easy and stable deployment on the metallic surfaces of the wreck. Because of the large size of the wreck (jack-up leg is 80 m in length and the remaining part of the deck is approximately 50 m in length), its high morphological complexity (high number of members and decommissioned added structures), and the need of operating over several months, the structure was sectioned in several components and scanned independently. Every component was scanned including at least 3 dimensional references (Fig. 3.14).

Figure 3.14 - Operator during photogrammetric survey and dimensional reference used to scale the 3D model generated through data analysis.

Data collected during the photogrammetry surveys were processed in different ways and used for different purposes (Fig. 3.15).

The whole scanned area was processed to generate a scaled point cloud and aligned with the three-dimensional bathymetric data collected at site with the multibeam echosounder. Both were converted and loaded into a dedicated online visualization application based on WebGL technology.

The photographic dataset recorded during the scanning was analysed for segmenting the benthic communities around the wreck and generating a bionomic map.

The high resolution 3D textured model of the scanned areas was optimised to a low number of polygon models preserving roughness detail by using UV maps (i.e. normals, occlusion, displacements). The resulting object was embedded in a 3D seascape scene for producing a virtual reality experience simulating a scuba diving around the wreck.

The experience gained during operations was used to perform two training events on underwater photogrammetry at Paguro wreck for the involvement of volunteer scuba divers. A practical session of underwater scanning at the Paguro wreck followed the training events (Annex III).

Benthos community analysis was integrated with a photogrammetric dataset collected on small areas (approximately 3 m^2) at the same depth ranges where samples were collected for taxonomic identification and biomass estimation. High resolution 3D models were processed and the primitive geometries of the original metallic substratum (i.e. a pipe, a plane) were calculated to estimate the volume of the ongrowing fouling community.

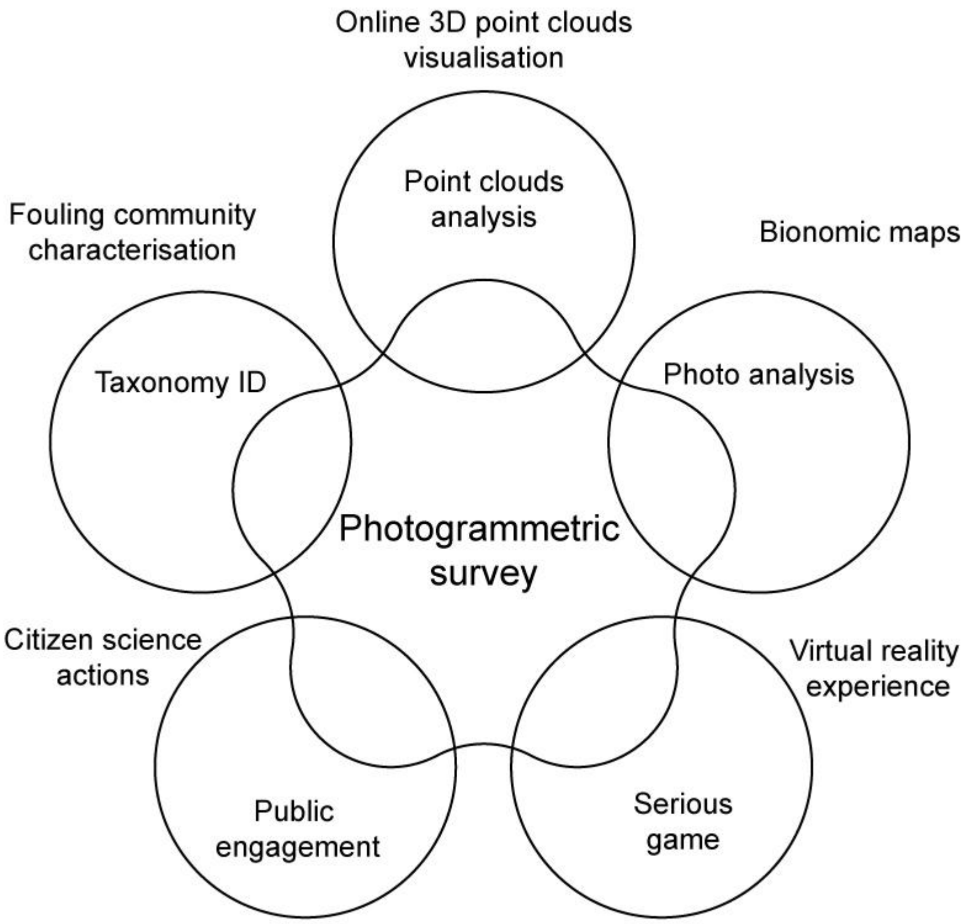


Figure 3.15 - Underwater photogrammetric surveys performed at case study "Paguro wreck" were used for supporting several project outcomes demonstrating the high flexibility of the technology and the possibility to use the same original dataset for several different analyses.

4. RESULTS AND DISCUSSION

4.1. Speed and direction of water currents

The data from the ADCP were successfully collected over one year, from July 2020 to June 2021, thus giving information about the following parameters: temperature, current speed and direction in each cell (1 m) of the water column monitored by the instrument.

Daily averages of current speed and direction were processed and the graphs of these time series are shown in Figure 4.1. In particular, peaks in the daily averages of current speed are highlighted in Table 4.1.

Monthly averages are shown in Figure 4.2. The mean annual current comes from the direction of about 200°, with small deviations among the different seasons. The mean value was 210° in summer, while in spring the direction was shifted to 188° (Tab. 4.2). In addition, the mean annual current speed was 0.10 m sec^{-1}, with peaks highlighted in July 2020 and lows in August and September 2020.

Insights on meteorological-marine phenomena of greater importance are shown in Figure 4.3 and Figure 4.4, where the profile of the water column is reported together with the speed of the currents and their direction in each cell (1 meter) monitored by the ADCP. For instance, in the period 20-23 July 2020, the current reached a speed of 0.4 m sec^{-1} in a depth range between 10 and 20 meters, with a peak of 0.45 m sec^{-1} at 20 meters depth. On 11 October 2020 the currents of 0.5 m sec^{-1} along the whole water column came from 170°. Strong currents from the same direction and speed were detected on January 25th, 2021 at a depth of 15 meters. Strong current events were detected in February, March and April 2021, with currents that reached 0.6 m sec^{-1} from 140°/170°.

A more detailed analysis of the data, which would require more time for proper implementation, could become a useful tool for some applications aimed at potential site stakeholders: study and forecast of extreme and potentially harmful phenomena for the submerged structures; study of the prevailing currents at various depth intervals in order to associate this information with the presence on the wreck of different biotic communities.

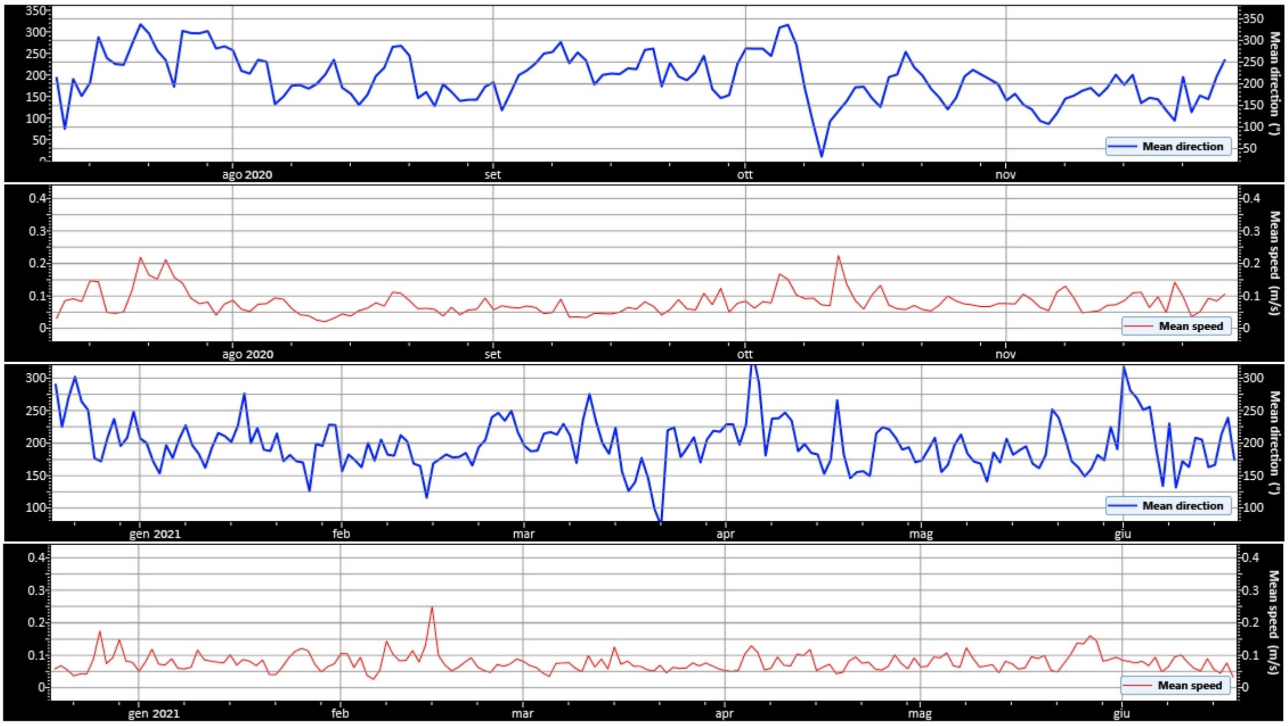
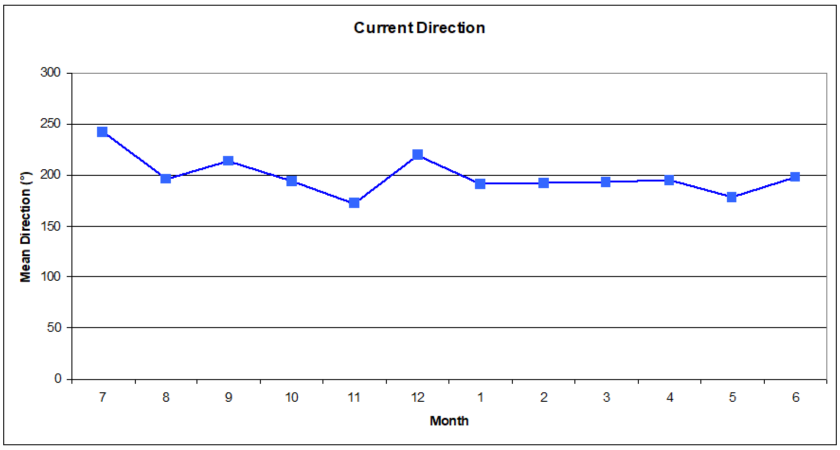


Figure 4.1 - Daily averages of current speed and direction observed during the study period.

Table 4.1 - Peaks in the daily averages of current speed observed during the study period.

Date	Daily mean current velocity (m sec^{-1})	Daily mean current direction (°)
20/07/20	0.219	337
23/07/20	0.211	254
11/10/20	0.224	137
14/02/20	0.249	168
26/05/20	0.161	160



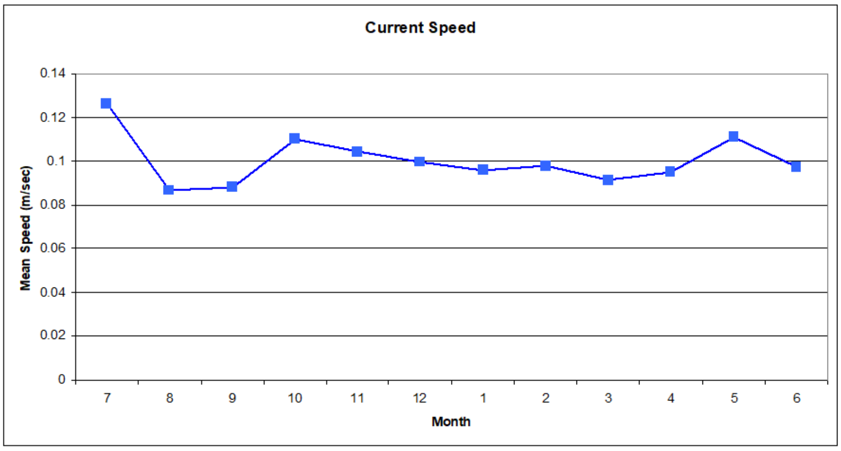


Figure 4.2 - Monthly averages of current speed and direction observed during the study period.

Table 4.2 - Dominant current direction per season during the study period.

Season	**Current direction (°)**
Summer	211
Autumn	193
Winter	200
Spring	188

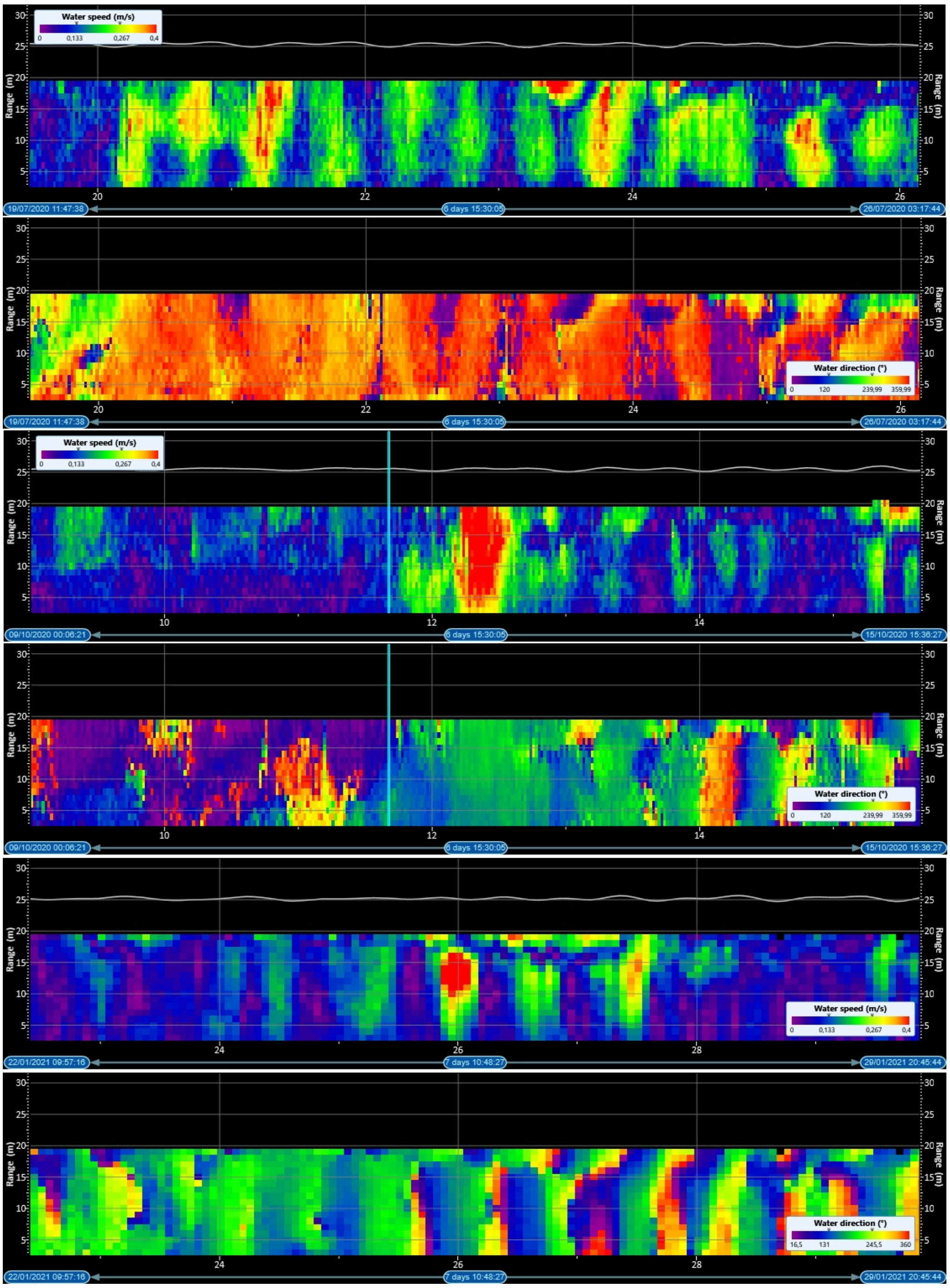


Figure 4.3 - Speed of the currents and their direction along the water column in different time periods.

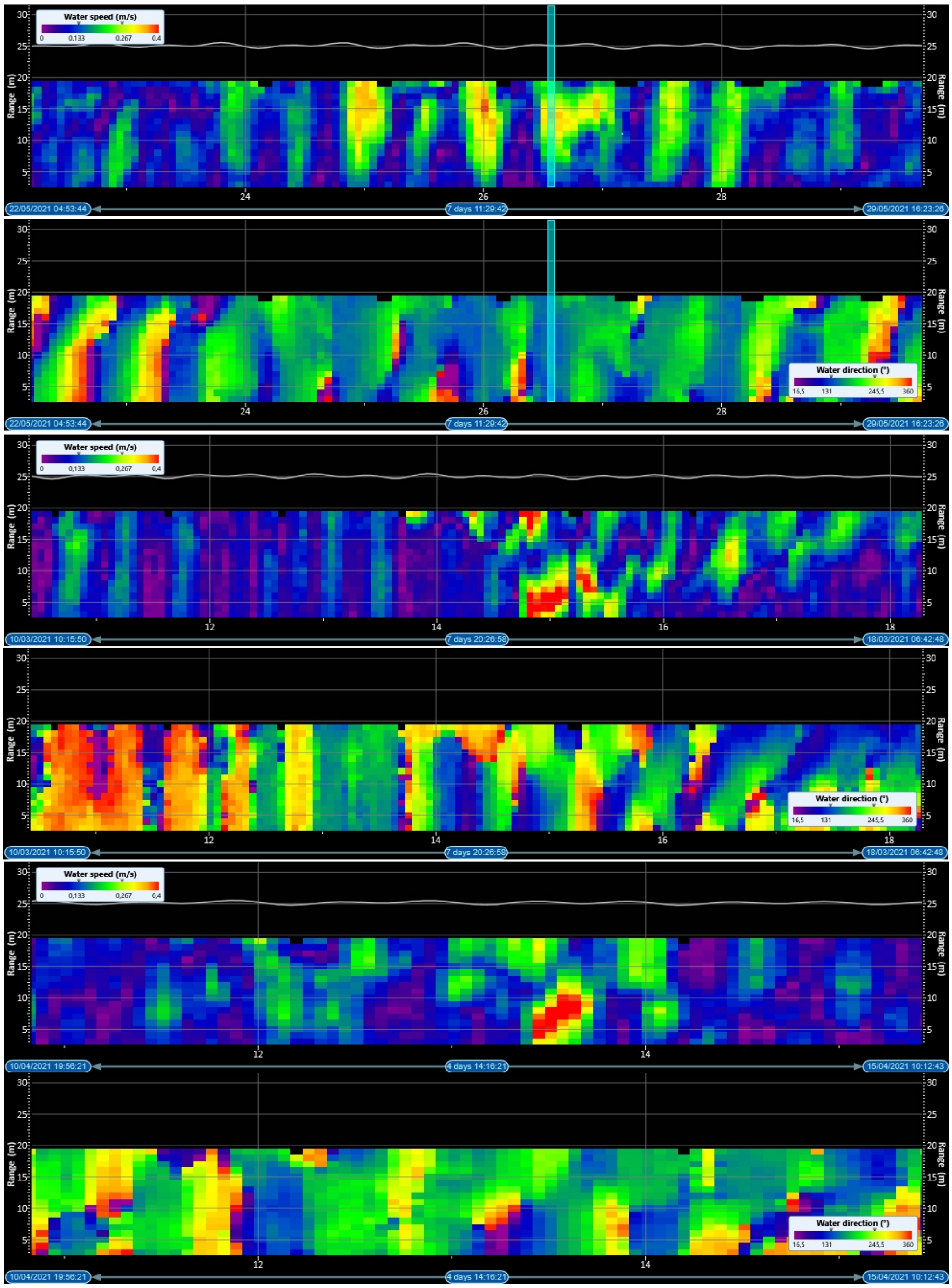


Figure 4.4 - Speed of the currents and their direction along the water column in different time periods.

4.2. Water column parameters

Temperature

Temperature vertical profiles show a clear seasonal cycle of the thermal field, affecting the whole water column; strongly stratified in summer (from June to August 2019 and from May to September 2020) and vertically homogeneous in winter (from October 2019 to January 2020 and from October 2020 to March 2021) (Fig. 4.5).

Seasonal surface temperature excursion exceeded 20 °C due to heat flux exchange with the atmosphere (Fig. 4.6). The minimum temperature value was observed in January 2020 (6.6 °C) and the maximum value in August 2019 (27.3 °C). Both maximum and minimum values were observed on surface/subsurface levels (0-5 m depth) (Fig. 4.5). Temperature at the bottom level ranged between 11.5 and 19.5 °C.

Salinity

The large amount of fresh water from the Po river discharge influenced salinity profiles (Fig. 4.5). Freshwater plume is observed on surface level (between 0 - 5 m depth) with low salinity values (ranging between 22 – 30 psu) in November 2019 and January 2020 (Fig. 4.7). The lowest salinity value (22.37 psu) was observed in November 2019 at the surface level (0.5 m), while the maximum salinity value (38.58) was reached in August 2020 at around 15 meters depth.

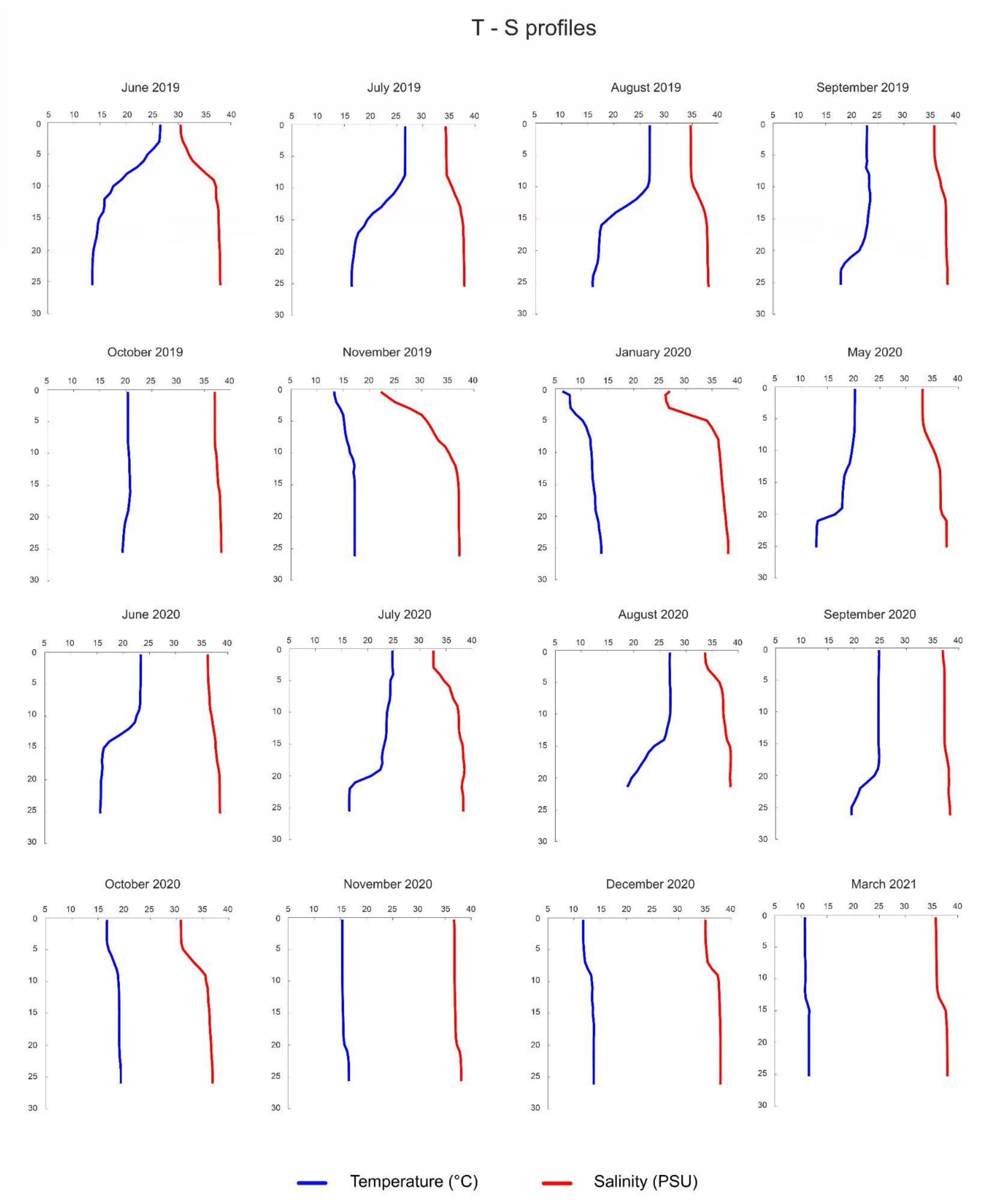


Figure 4.5 - Temperature and salinity profiles along the water column (from June 2019 to March 2021).

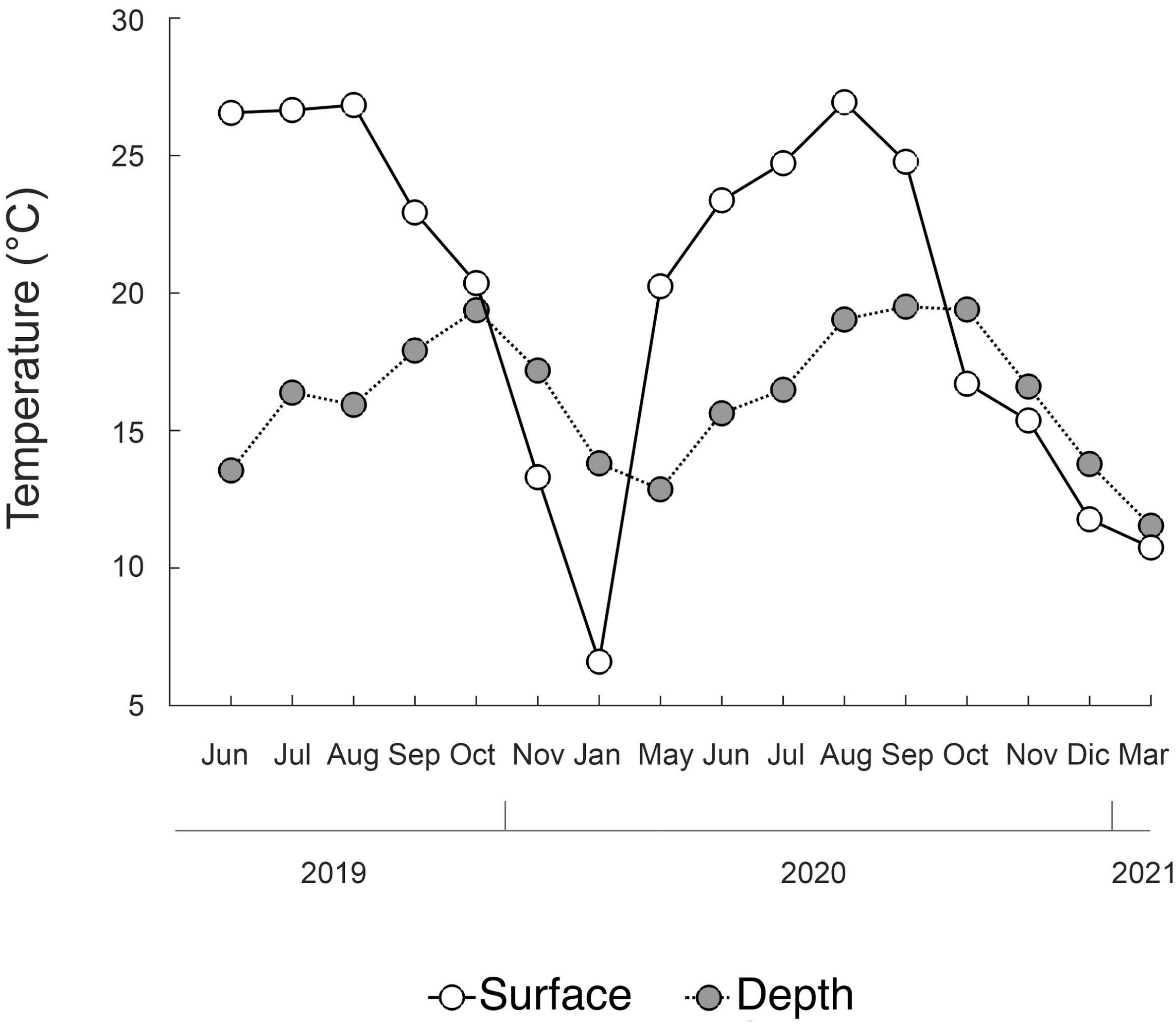


Figure 4.6 - Monthly temperature surface and bottom values (from June 2019 to March 2021).

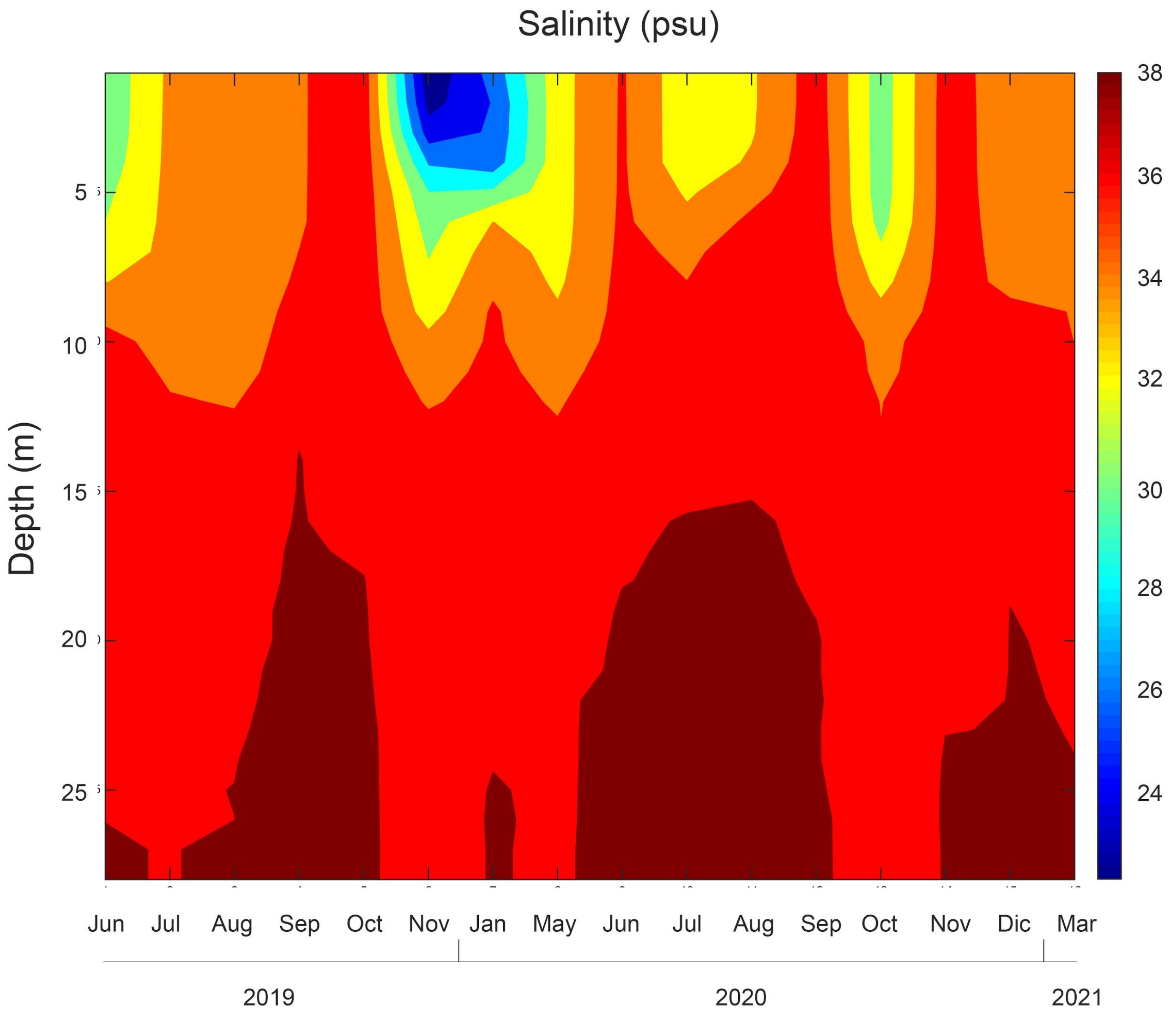


Figure 4.7 - Monthly salinity values along the water column (from June 2019 to March 2021).

Transparency (Secchi disk) and turbidity

Transparency measured with the Secchi disk was generally higher than 5 meters from late spring to early autumn and showed lower values during the rest of the study period (Fig. 4.8). Maximum values (12.5 m) were recorded in June and September 2020. Minimum values (2 m) were recorded from November 2019 to May 2020, after the peaks of the Po river discharges in October/November 2019.

Turbidity vertical profiles (measured in NTU) show a different trend at surface and bottom layers (Fig. 4.9). A clear seasonal cycle can be observed at the surface and is comparable to transparency values. Indeed, the maximum surface turbidity value (6.42 NTU) was recorded in October 2019 and the minimum value (0.34 NTU) in August 2019 and 2020. By averaging the data from the depth range 0-5 m, values below 1.5 NTU are generally observed from late spring to early autumn. At greater depths, especially beyond 15-20 m, turbidity increases and persists at values above 1.5 NTU throughout the year. The maximum turbidity value, 15.33 NTU, was recorded in September 2019 at the bottom layer (-25 m at PG_01 sampling station).

Taking into consideration that the artificial reef "Paguro wreck" extends over a depth range 10-31 m, it is clear that finding good visibility conditions at the deeper levels of the wreck is not frequent, while its shallower part can be explored by scuba divers with acceptable satisfaction for most part of the year. Poor visibility was also a major inconvenience during monitoring activities by scientific divers during the study period.

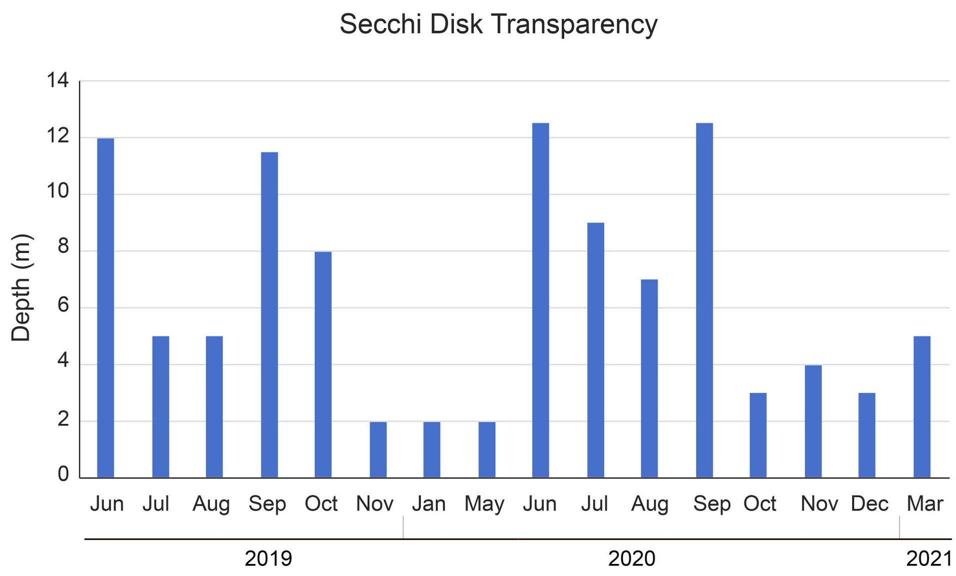


Figure 4.8 - Monthly Secchi disk transparency values (from June 2019 to March 2021).

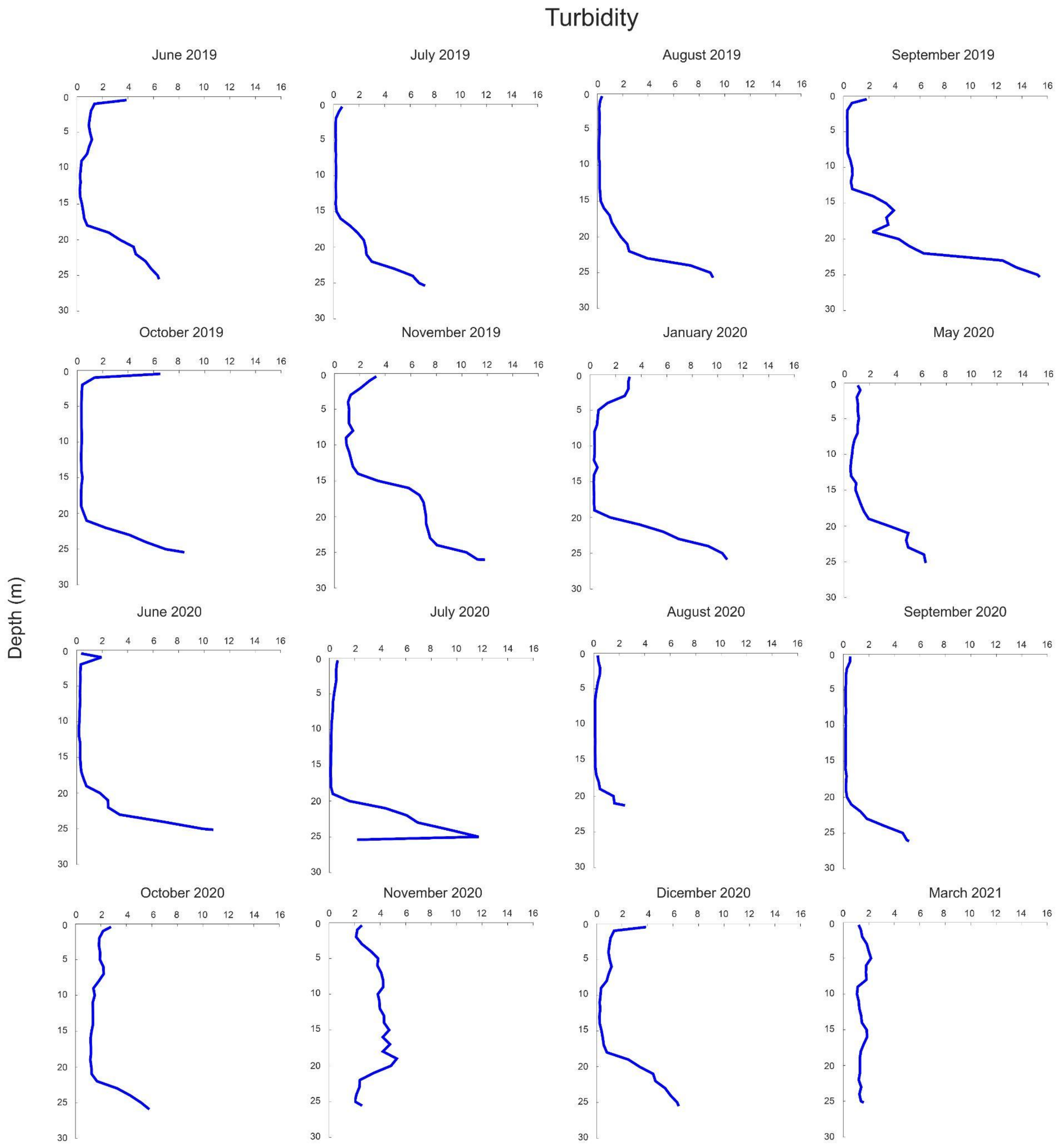


Figure 4.9 - Monthly turbidity values along the water column (from June 2019 to March 2021).

Oxygen

Generally, oxygen shows higher values on surface levels compared to the bottom during all the sampling period (Fig. 4.10). Oxygen values along the water column varied during the study period between 2.2 and 10.5 µg L^{-1} (Fig. 4.12). Oxygen depletion (< 3 µg L^{-1}) was observed at the bottom level in October 2019 and September 2020 (Fig. 4.10).

Chlorophyll “a”

The highest chlorophyll “a” values were observed in January 2020 at the surface level (18.8 µg L^{-1}), corresponding to diatom blooms typical of the study area during winter season; and in June 2020 at 20 m depth (22.8 µg L^{-1}) (Fig. 4.11). Chlorophyll “a” profiles show sub-surface peaks between 5 and 25 meters depth (Fig. 4.12). The minimum chlorophyll ”a” value was observed in November 2019, when low values were observed along the whole water column.

The major drawback of the selected method, use of CTD multiprobe, is the lack of continuous data. However, vertical profiles of the main physico-chemical parameters were periodically collected during the study period and shared in real time using social media to guarantee a useful service for the end-users, especially visitors and scuba divers.

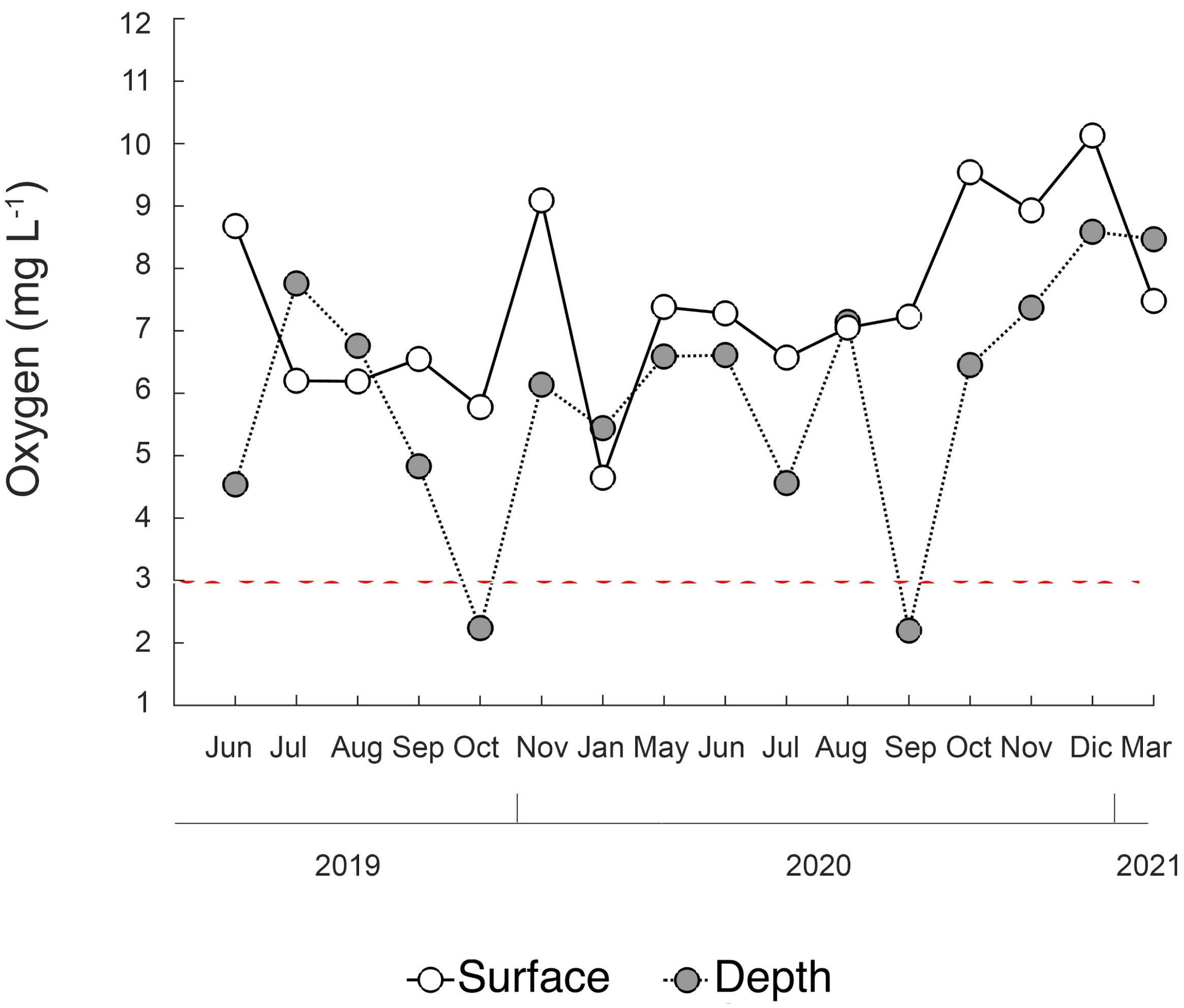


Figure 4.10 - Monthly oxygen surface and bottom values (from June 2019 to March 2021).

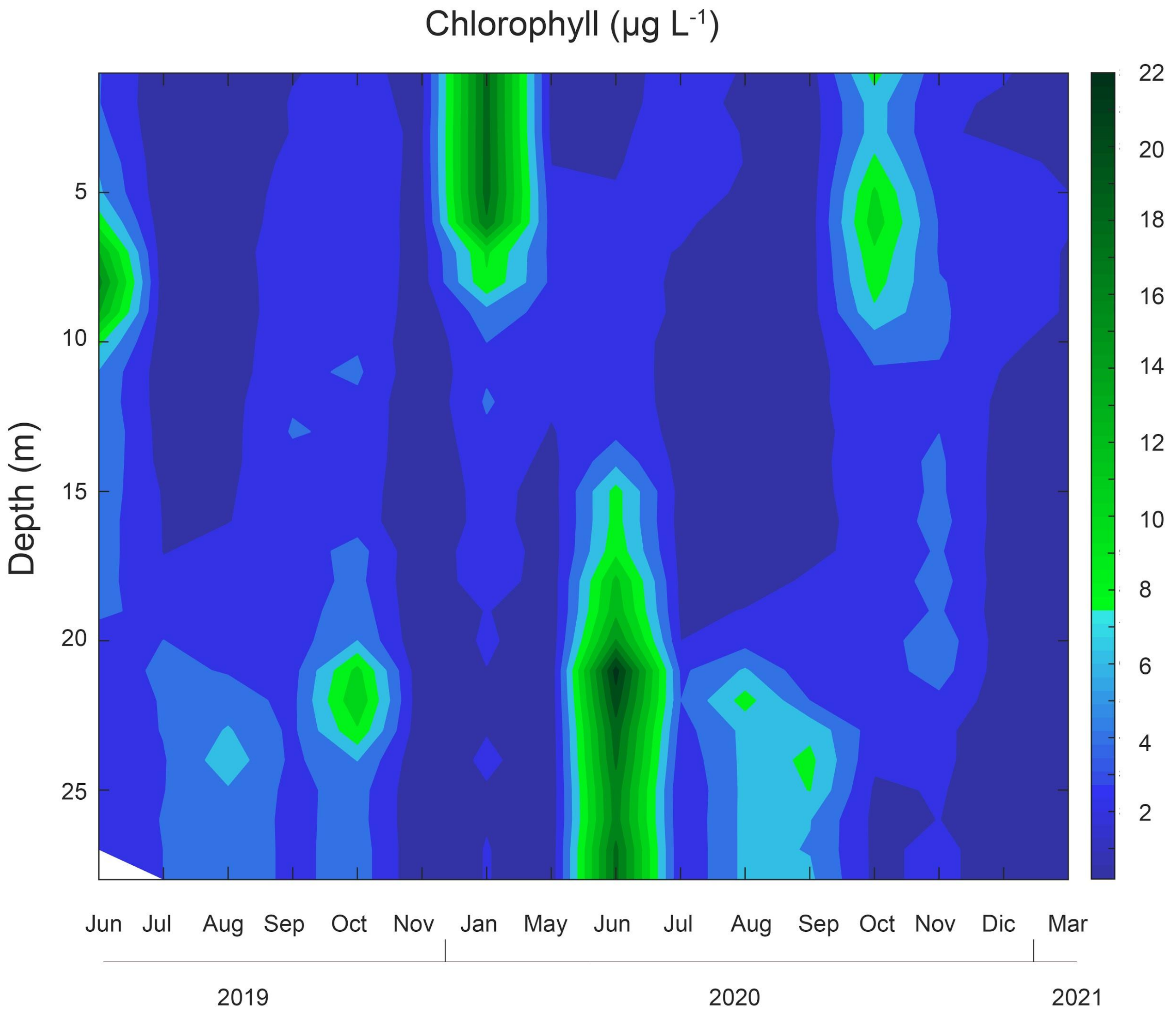


Figure 4.11 - Monthly chlorophyll "a" values (µg L^{-1}) along the water column (from June 2019 to March 2021).

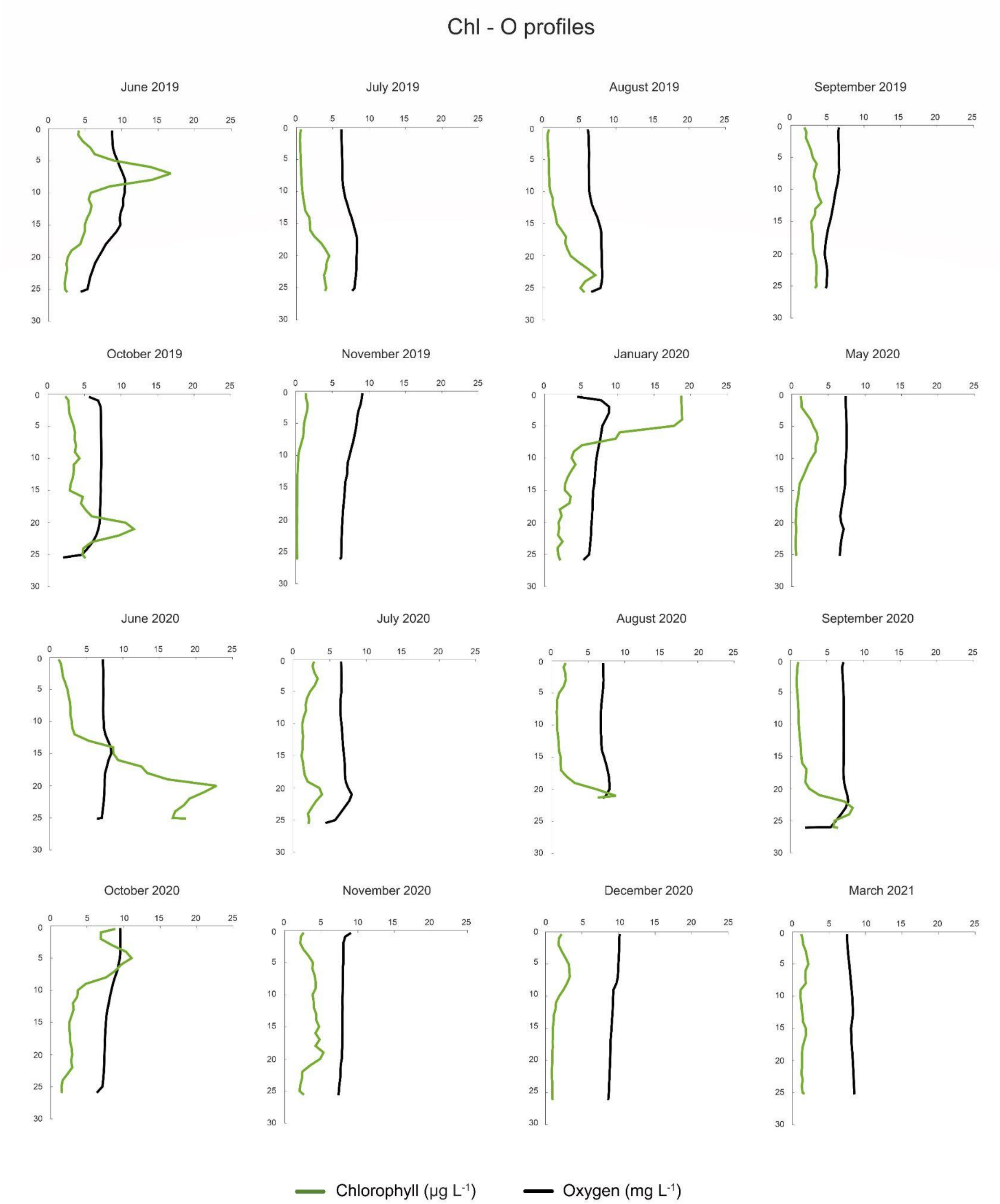


Figure 4.12 - Oxygen (mg L^{-1}) and chlorophyll "a" (µg L^{-1}) profiles along the water column (from June 2019 to March 2021).

Nutrients

Total phosphorus varied between 3.54 and 19.96 µg L^{-1}, while orthophosphate between <0.44 and 6.91 µg L^{-1}. Total phosphorus and orthophosphate reached the highest values at the surface level in January and October 2020, while at the bottom level the highest values were observed in August 2020 (Fig. 4.13).

Total Nitrogen resulted in higher amounts at the surface level compared to the bottom level throughout the study period (Fig. 4.14). The maximum value was detected in January 2020 at the surface level (941 µg L^{-1}).

Nitrogen components abundance varied during the study period. Generally nitrates was the most abundant component both in surface (between 26.72 % to 96.20 %) and bottom level (between 30.72 % to 92.43 %) (Fig. 4.15). Ammonium was more abundant than the other components in July and October 2019 at the surface level (respectively 51.40 % and 71.18 %) and in May 2020 and March 2021 at the bottom (respectively 57.57 % and 52.31 %). Nitrites were generally present in the lower percentage. The maximum nitrites percentage was 15.56 % in May 2020 at the surface and 22.21 % in January 2020 at the bottom.

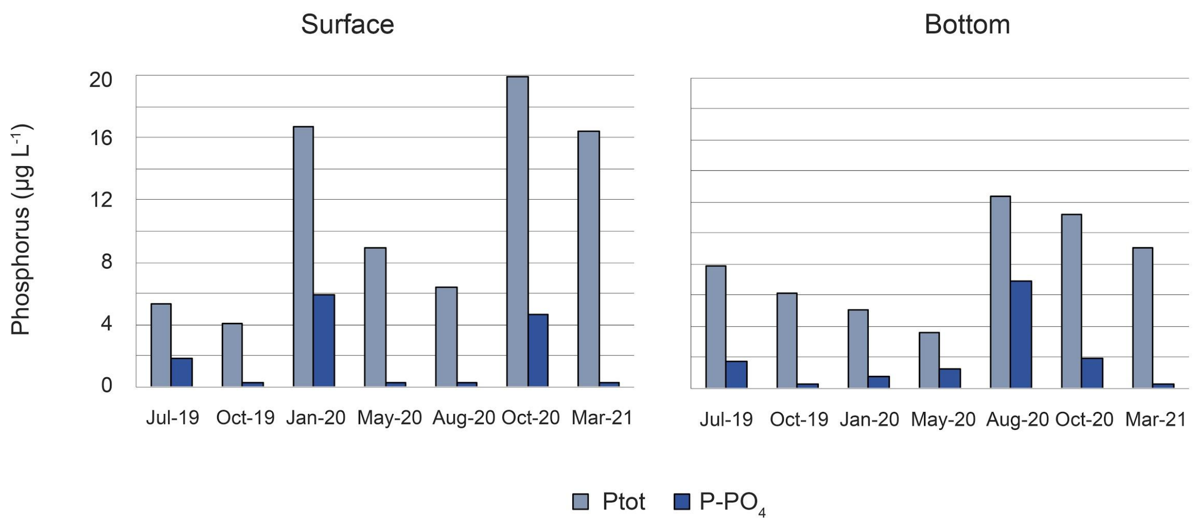


Figure 4.13 - Total phosphorus (Ptot) and orthophosphate (P-PO4) (µg L^{-1}) detected on surface and bottom level.

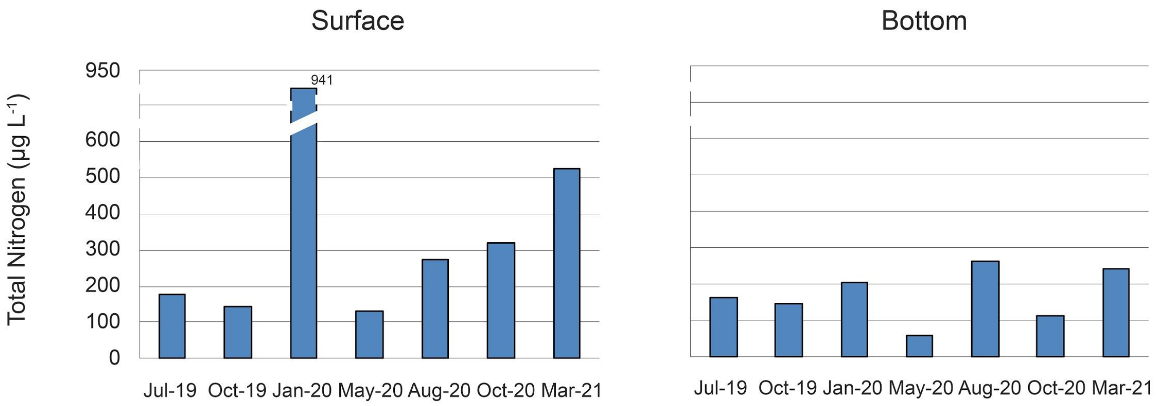


Figure 4.14 - Total nitrogen (µg L^{-1}) detected on surface and bottom level.

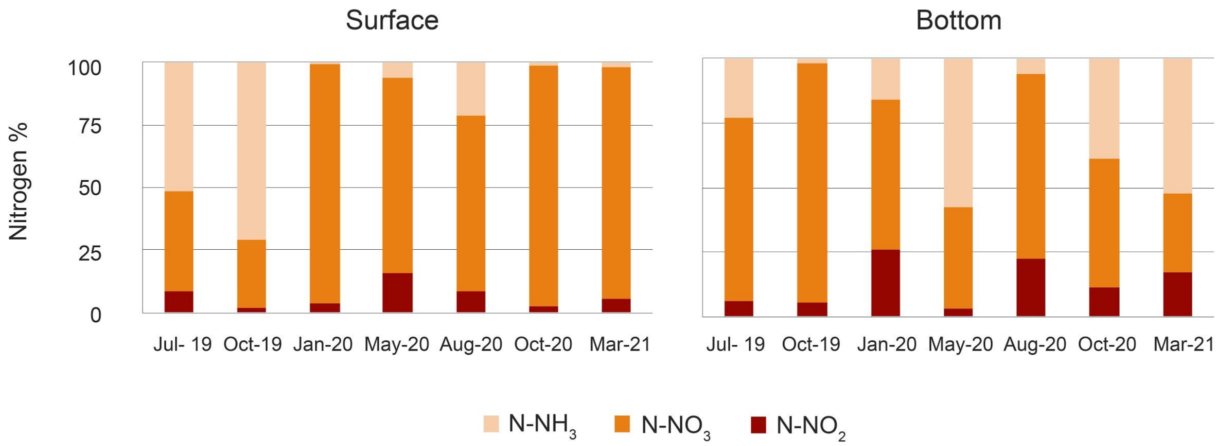


Figure 4.15 - Nitrogen components percent (N-NH3, N-NO3 and N-NO2) analyzed on surface and bottom level.

Generally, silicates were observed in higher amounts at the bottom compared to the surface level (Fig. 4.16). Only in January and October 2020 silicates showed higher concentrations at the surface level compared to the bottom. The highest silicates value was detected in August 2020 (407 µg L^{-1}) at the bottom, while at the surface level the highest value was observed in January 2020 (262 µg L^{-1}).

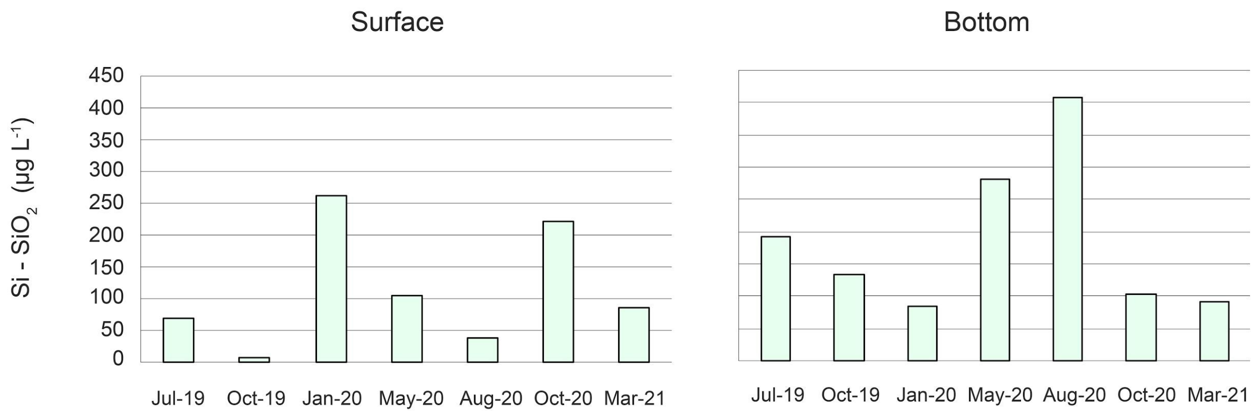


Figure 4.16 - Silicates Si-SiO2 (µg L^{-1}) detected on surface and bottom level.

The data collected confirm that the area of the "Paguro wreck" is generally in a good trophic state. However, despite the distance from the coast of about 11 nm, it is occasionally affected by the inputs from the Po river, which lead to temporary dystrophic conditions, especially in the autumn-winter period in correspondence with the Po discharge peaks.

4.3. Contaminants in sediment

Inorganic and organic pollutants

During the study period, 72 structurally diverse pollutants (metals and organometals, organochlorine pesticides, PAHs, dioxins and dioxin-like compounds, PCBs) were monitored in two marine sediment samples collected at the study site “Paguro wreck” (monitoring station PG_01). The aim was to give an initial assessment of the presence of pollutants in this site of community importance, once a gas extraction platform and now an underwater scuba diving destination for more than 50 years, rich in marine organisms. Additionally, concentration levels of inorganic and organic compounds were compared to published data in the region Emilia-Romagna, including the ARPAE database as well as the Environmental Quality Standards set in the relevant national legislation (Legislative Decree 172/15).

Metals and organometals

Environmental heavy metals are considered pollutants to humans and living organisms and are regulated by European Directives such as the Water Framework Directive. The priority metals, namely Cd, Hg and Pb are associated with different uses. Cd and Pb are used in batteries and electronic equipment. Pb was also used in fuel as an engine lubricant until 2000 when it was banned. Mercury has been used in medicine, as an antibacterial agent and in the chlorine–alkali industry. Tributyltin (TBT) and other organotin compounds are contaminants found globally, throughout the marine environment. Organotins have many applications, such as coatings, anti-odour/antifungal additives, pesticides, biocides in marine antifoulant paints, catalysts, wood treatments and preservatives. Extensive use in antifouling paints on watercraft led to the widespread distribution of TBT in water, sediment and biota.

The values of metals and organometals reported in Table 4.3 are comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive (ARPAE, 2017) and are all below the Environmental Quality Standards (EQSs) set in Legislative Decree 172/15.

Total chromium, as well as nickel, zinc and copper, are not only of anthropogenic origin but they constitute an important natural background in the sediments of the Emilia-Romagna coast. For this reason, the detected concentrations of total chromium do not represent an overshoot of the legislative limits mentioned above.

Table 4.3 - Concentration of metals and organometals at the study area "Paguro wreck". For comparison, the Environmental Quality Standards (EQS) according to Legislative Decree 172/15 are shown.

	As mg kg^{-1} dw	Cd mg kg^{-1} dw	Cr mg kg^{-1} dw	Cr VI mg kg^{-1} dw	Hg mg kg^{-1} dw	Ni mg kg^{-1} dw	Pb mg kg^{-1} dw	TBT µg kg^{-1} dw
EQS	*12*	*0.3*	*50*	*2*	*0.3*	*---*	*30*	*5*
26-06-2019	8.7	0.11	82.8	0.5	0.31	49.8	28.5	4.3
26-06-2020	6.3	0.11	80.0	---	0.22	50.9	28.1	2.1

<u>Organochlorine pesticides (OCPs)</u>

Organochlorine pesticides (also called chlorinated hydrocarbons) are organic compounds attached to five or more than five chlorine atoms. They represent one of the first categories of pesticides ever synthesized and are used in agriculture. Most of them are usually used as insecticides for the control of a broad range of insects, and have a long-term residual effect in the environment. Common examples of these pesticides include DDT and its metabolites, cyclodiene insecticides (aldrin, dieldrin, ...), hexachlorocyclohexane (alfa-, beta-, gamma-HCH (lindane)), hexachlorobenzene.

Overall, the concentrations of the organochlorine pesticides at the study site were very low, often below their individual detection limits and never exceeding the Environmental Quality Standards (EQSs) set in Legislative Decree 172/15. Detectable concentrations were recorded only for hexachlorobenzene (HCB), ∑DDE and ∑DDD (Tab. 4.4).

The diffusion of DDT metabolites, despite being found in low concentrations, is in line with the historical and abundant use of these chlorinated compounds in Italy starting from the 1940s for the control of vectors of diseases such as typhus and malaria and in the postwar period for crop protection. The rules on the use of DDT as a pesticide have become extremely restrictive since 1981 and since 1986 the use of this product has been prohibited in the EU. DDT and its metabolites, as well as other pesticides, are compounds that can persist in the environment for long periods due to their slow decay rates and their accumulation in the sediments. DDE is the DDT degradation product most commonly found in the environment as it is more resistant to further biotransformation reactions.

Table 4.4 - Concentration of some organochlorine pesticides at the study area "Paguro wreck". For comparison, the Environmental Quality Standards (EQS) according to Legislative Decree 172/15 are shown.

	Aldrin µg kg^{-1} dw	**Dieldrin µg kg^{-1} dw**	**HCB µg kg^{-1} dw**	**Alfa HCH µg kg^{-1} dw**	**Beta HCH µg kg^{-1} dw**	**Gamma HCH µg kg^{-1} dw**	**∑DDT µg kg^{-1} dw**	**∑DDD µg kg^{-1} dw**	**∑DDE µg kg^{-1} dw**
EQS	*0.2*	*0.2*	*0.4*	*0.2*	*0.2*	*0.2*	*1.0*	*0.8*	*1.8*
26-06-2019	<0.10	<0.10	0.12	<0.10	<0.10	<0.10	<0.10	0.13	0.33
26-06-2020	<0.10	<0.10	0.17	<0.10	<0.10	<0.10	<0.10	0.59	0.93

PAHs

PAHs are a large group of organic compounds, both natural but mainly anthropogenically produced, that have been receiving increased attention because of their potential carcinogenicity, mutagenicity and teratogenicity to aquatic organisms. European Directives such as WFD regulate the presence of these compounds in water. PAHs can enter the marine environment through atmospheric deposition, urban run-off, industrial discharges or oil spills. Their presence is associated with big settlements and/or harbour activities and in general, anthropogenic activities.

In sediment samples from the site "Paguro wreck", total PAHs (PAH_{16}) concentration varied from 144 to 398 µg kg^{-1} during the study period (Tab. 4.5). These values are comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive and are well below the EQS set in Ministerial Decree 260/10, now superseded by Legislative Decree 172/15.

In 2019, total PAHs were represented exclusively by high molecular weight molecules, with 4 or more rings. High molecular weight PAHs are indeed more resistant to degradation and can be efficiently transported and accumulated in sediments. On the contrary, in 2020 the detected concentration of total PAHs was double compared to the previous one with a contribution equal to about 20% of low molecular weight PAHs (3-ring compounds).

Table 4.5 - Concentration of PAHs at the study area "Paguro wreck". For comparison, the Environmental Quality Standards (EQS) according to Legislative Decree 172/15 are shown.

	Anthracene µg kg⁻¹ dw	Benzo[a]pyrene µg kg⁻¹ dw	Benzo[b]+[j]fluoranthene µg kg⁻¹ dw	Benzo[k]fluoranthene µg kg⁻¹ dw	Benzo[ghi]perylene µg kg⁻¹ dw	Indeno[1,2,3-c,d]pyrene µg kg⁻¹ dw	Fluoranthene µg kg⁻¹ dw	Naphthalene µg kg⁻¹ dw	PAH_{16}* µg kg⁻¹ dw
EQS	*24*	*30*	*40*	*20*	*55*	*70*	*110*	*35*	*800***
26-06-2019	<2.0	10.6	26.9	6.8	17.6	18.8	19.5	<2.0	144
26-06-2020	11.4	23.2	46.6	15.4	35.2	18.0	64.8	<2.0	398

*Sum of 16 individual PAH compounds: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo[a]anthracene, Chrysene, Benzo[b]+[j]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Indeno[1,2,3-c,d]pyrene, Dibenzo[a,h]anthracene, Benzo[ghi]perylene

**EQS according to Ministerial Decree 260/10

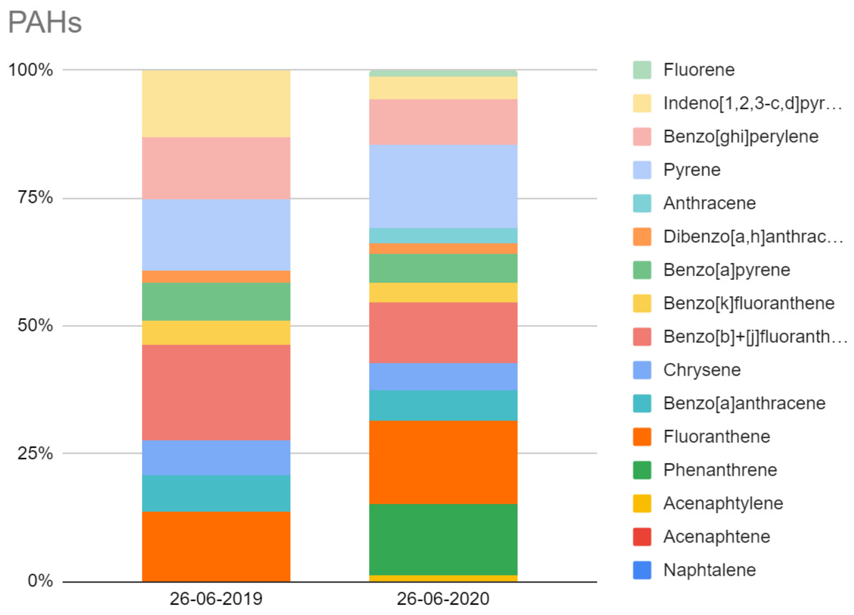


Figure 4.16 - PAHs concentration pattern as percentage of the total PAHs (sum of 16 individual PAH compounds) in sediment at the study area "Paguro wreck" .

Dioxins and dioxin-like compounds and PCBs

Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) are serious threats to the environment due to their ubiquitous nature, toxicity and strong resistance to biodegradation. It is known that these compounds have a strong affinity for sediment particles, particularly ab/adsorption onto high surface area sediments like organic rich particulates, making coastal sediments an ideal repository. Sources of PCDD/Fs in the environment are numerous, although they usually originate as unwanted trace contaminants in industrial processes, and not from direct manufacture. Atmospheric sources include combustion of wood and waste from incinerator plants, and coal fired power stations. Effluent wastes from industrial processes, most notably from solid waste incineration and from the pulp and paper industry, also contain PCDDs and PCDFs. Chlorinated pesticides, dry cleaning distillation residues, automobile exhaust emission and combustion of landfill gases are also known sources of PCDD/Fs. The strong chemical resistance of PCDD/Fs to biodegradation and their relatively low solubility in water means that both chemical families have long residence times in the marine environment, and the potential to accumulate in sediments.

PCBs are a group of man-made organic chemicals that are very persistent and present a varied range of harmful effects on marine organisms. Although they were banned in many countries in the mid-1980s, they are still found in sediments due to the disposal of old electrical and hydraulic equipment containing PCBs.

The concentrations of individual polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) at the study site were very low, almost always below their detection limits. However, the sum of total equivalent dioxins and dioxin-like compounds found in 2020 was higher than the EQS set in Legislative Decree 172/15. This result is not in line with those usually found in sediments collected along the Emilia-Romagna coast and is mainly due to the presence of the PCB 126. PCB 126 is a dioxin-like PCB with the highest Toxic Equivalency Factor (TEF) amongst the PCBs (TEF=0.1); the next most potent PCB congener, PCB 169, has a TEF more than three-fold lower. Despite its relatively minor contribution as a constituent of PCB mixtures by weight, the potency of PCB 126 underlies its toxicological significance as the major contributor to the toxic equivalent in common PCB mixtures. This result should be confirmed by further investigations at the study site.

Total PCBs (PCB_{13}) were found instead at concentrations ranging from 6.08 to 6.67 µg kg-1. These values are comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive and are below the EQS set in Legislative Decree 172/15.

Table 4.6 - Concentration of Dioxins and dioxin-like compounds and PCBs at the study area "Paguro wreck". For comparison, the Environmental Quality Standards (EQS) according to Legislative Decree 172/15 are shown.

	TE PCDDs ng kg^{-1} dw	TE PCDFs ng kg^{-1} dw	TE PCB-DLs ng kg^{-1} dw	∑ TE PCDDs PCDFs PCB-DLs* ng kg^{-1} dw	PCB_{13}** µg kg^{-1} dw
EQS	---	---	---	*2*	*8*
26-06-2019	<LOQ	<LOQ	0.066	0.066	6.08
26-06-2020	0.118	0.088	7.077	7.283	6.67

*List of congeners and related equivalent toxicity factors (EPA, 1989) and list of dioxin-like PCB congeners (WHO, 2005)

**Sum of 13 individual PCB compounds: PCB 28, PCB 52, PCB 77, PCB 81, PCB 101, PCB 118, PCB 126, PCB 128, PCB 138, PCB 153, PCB 156, PCB 169, PCB 180

Sediment grain size

In Table 4.7 the results of the grain size analysis relating to the PG_01 monitoring station are summarized. No differences can be observed between the sample taken in 2019 and that taken in 2020. In fact, the fine component of the sediment (% silt + clay) prevails in both, with the silty fraction slightly exceeding the clayey one.

These results support the results of the chemical analyzes and could be used if a more detailed comparison is made between samples collected in different areas of the regional coastal strip. In this case it would be interesting to evaluate the total organic carbon content as well.

Table 4.7 - Grain size characterization at the study area "Paguro wreck".

Date	% Gravel	% Sand	% Silt	% Clay
26-06-2019	0.0	2.3	51.1	46.6
26-06-2020	0.0	0.1	54.8	45.1

4.4. Benthic community settled on the reef

In total, 60 taxa were identified. Phylum Annelida is the most represented with 19 species identified, followed by Mollusca (15 species), Arthropoda (12 species), Porifera (5 species), Cnidaria (4 species), Bryozoa (2 species), Echinodermata (2 species) and one species for phylum Nemertea and Sipuncula (Tab. 4.8)

The scraping of the benthic community in the depth range from -10 m to -14 m shows the presence of filter feeders as the edible mollusc *Mytilus galloprovincialis*, the sponge *Halicona mediterranea* and encrusting sponges (eg. *Crambe crambe*) together with detritivorous vagile species (*Monocorophium sextone*, *Ophiotrix fragilis* and *Amphipolis squamata*). It is worth noting also the presence of *Epizoanthus arenaceus*. The calculated biomass reaches about 320 g m^{-2} (SFDW) and 2.5 kg m^{-2} (SFWW) , and 8.5 kg m^{-2} (WW) when the weight of carbonatic parts were included. In this case, the major contribution in terms of biomass is given by the presence of *M. galloprovincialis*, which represents about 80-90% of the WW.

From -15 m to -18 m depth the most abundant taxa are the Mediterranean zoanthid *E. arenaceus* together with encrusting sponges, the bryozoan *Scrupocellaria scruposa* the amphipod *M. sextone* and the ophiuroid *O. fragilis*. In this depth range the biomass reaches about 170 g m^{-2} (SFDW) and 0.9 kg m^{-2} (SFWW), and 4.5 kg m^{-2} (WW). Also in this case, a great contribution in biomass is given by *M. galloprovincialis* and *Ostrea edulis*, which being massive species, with their contribution, dominate the community in terms of biomass.

In the deepest bathymetry range (-20 m) the most abundant taxa are *M. sextone*, *E. arenaceus* and encrusting sponges that include *Crambe crambe*, *Dysidea* spp. and *Spirastella* spp.. There are also other species such as the isopod *Uromunna petiti*, the serpulid *Pomatoceros triqueter* and the ophiuroid *O. fragilis*. Here the biomass reaches about 347 g m^{-2} (SFDW) and 1.9 kg m^{-2} (SFWW), and 10.5 kg m^{-2} (WW). Here, when present, *O. edulis* represents 95% (about 8.9 kg m^{-2} WW) of the WW. Secondly, *O. fragilis*, albeit with a small value in terms of WW, is the species that contributes most to the biomass value (up to 10% of WW).

In the internal part of the wreck, at -20 m depth, the most abundant species are *E. arenaceus* and *Dysidea* spp. and other numerous encrusting sponges. Here the biomass reaches about 60 g m^{-2} (SFDW) and 0.45 kg m^{-2} (SFWW), and 1.3 kg m^{-2} (WW).

Table 4.8 - List of taxa.

PHYLUM	TAXON	
Annelida	*Aphelochaeta* sp.	*Polydora hoplura*
	Caulleriella viridis	*Prionospio* sp.
	Dodecaceria concharum	*Protocirrineris* sp.
	Exogone naidina	*Protula* sp.
	Filograna implexa	*Serpula vermicularis*
	Glycera tesselata	*Sphaerosyllis hystrix*
	Harmothoe spinifera	*Spirobranchus triqueter*
	Lumbrineris coccinea	*Syllis gracilis*
	Marphysa sanguinea	*Timarete* sp.
	Platynereis dumerilii	
Arthropoda	*Alpheus macrocheles*	*Monocorophium sextonae*
	Balanus trigonus	*Plumulojassa ocia*
	Cerapopsis longipes	*Stenothoe monoculoides*
	Elasmopus rapax	*Uromunna petiti*
	Ericthonius brasiliensis	*Trygaeus communis*
	Janira maculosa	*Pilumnus hirtellus*
Bryozoa	*Schizoporella errata*	*Scrupocellaria scruposa*
Cnidaria	*Actinaraea* indet.	*Epizoanthus arenaceus*
	Corynactis viridis	Idrozoa indet.
Echinodermata	*Amphipholis squamata*	*Ophiothrix fragilis*

PHYLUM	TAXON	
Mollusca	*Anomia ephippium*	*Modiolus barbatus*
	Arca noae	*Musculus subpictus*
	Arca tetragona	*Mytilus galloprovincialis*
	Arcidae sp.	*Ostrea edulis*
	Bittium scabrum	*Rocellaria dubia*
	Hiatella arctica	*Striarca lactea*
	Mimachlamys varia	
Nemertea	*Nemertea* indet.	
Porifera	*Sycon* sp.	*Spirastrella spp.*
	Dysidea spp.	Encrusting sponge sp. 1
	Haliclona (Reniera) mediterranea	
Sipuncula	*Phascolosoma (Phascolosoma) granulatum*	

The biotic indices calculated (Number of Species, S; Shannon index, H; and species evenness, J) from the communities initially scraped show a constant number of species for the three analyzed bathymetries (Tab. 4.9; Fig. 4.17). The values have an average of 23 species for the bathymetrics -12 m and -21 m, up to an average of 25 species for the intermediate bathymetric. Only inside the wreck, the number of species is reduced with an average of 16 species. This lower value is probably the consequence of a lower intake of particulate matter, or of nourishment for the filtering species characterizing fouling, resulting in a limiting factor for the growth of organisms. Furthermore, it should be noted that in the superficial environments the Shannon diversity has lower values, together with a lower Evenness of the species compared to the deeper environments. What is observed is linked to the biocenosis characterizing the environment on its surface. In fact this environment is dominated by a *Mytilus* facies, where small amphipod organisms like *M. sextone* dominate and survive more easily in this biocenosis. Deeper environments, on the other hand, are more

diversified, and this diversity is also contemplated in terms of the Evenness (J) and therefore of the Shannon index.
The recolonization of the substrate in the different depths highlights how a small number of species is present (Tab. 4.9; Fig. 4.17). The average number of the species varies from 14 to 18 after the recolonization process. Although there is a smaller number of species, a greater Evenness and Shannon index are observed. In fact, recolonization proceeded in a process in which dominant taxa are absent.

Table 4.9 - Taxa number (S), Shannon (H) and Evenness (J) of the sampled communities.

		1st scraping			2nd scraping		
Sample ID	**Depth**	**S**	**J**	**H**	**S**	**J**	**H**
Shallow 1	12 m	26	0.584	1.93	16	0.7143	2.175
Shallow 2	12 m	23	0.371	1.164	21	0.7648	2.167
Shallow 3	12 m	22	0.6264	1.936	17	0.884	2.198
SW	17 m	25	0.4958	1.596	24	0.6583	2.092
NE	17 m	29	0.6634	2.234	12	0.8844	2.198
Stern	17 m	22	0.5393	1.667	15	0.8381	2.269
SW	21 m	23	0.7383	2.315	20	0.77	2.327
NE	21 m	27	0.7389	2.435	15	0.699	1.893
Stern	21 m	19	0.6913	2.036	8	0.7632	1.587
Internal 1	21 m	19	0.4348	1.28	NA	NA	NA
Internal 2	21 m	16	0.4556	1.263	NA	NA	NA
Internal 3	21 m	12	0.599	1.267	NA	NA	NA

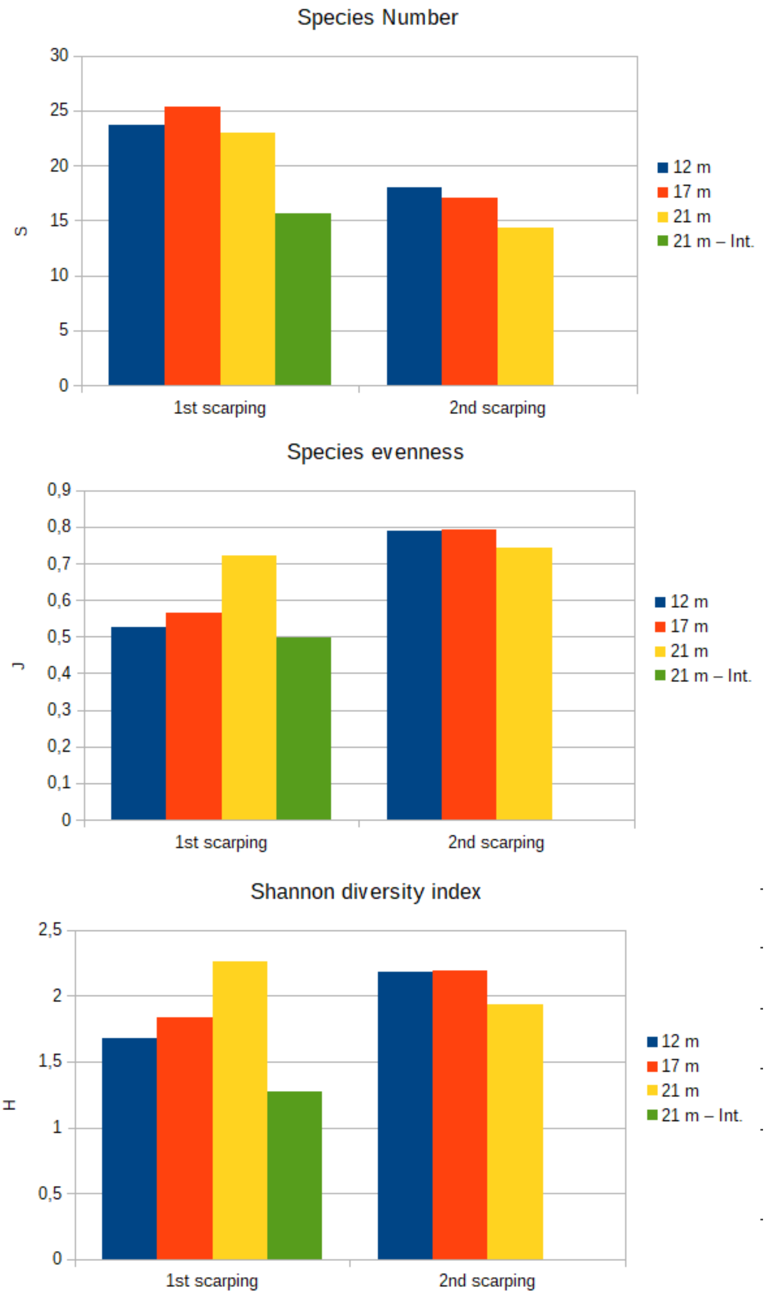


Figure 4.17 - Taxa number (S), Shannon (H) and Evenness (J) of the sampled communities.

Considering the community biomass, expressed in SFWW, SFDW and WW, it is to be noted that after the first scraping, the community does not recover the pre-scraping values in terms of biomass (Tab. 4.10). In terms of biodiversity, the indices obtained during recolonization are close to equilibrium conditions, due to the absence of dominant species. Conversely, when greater biomass is observed, biodiversity indices are significantly reduced. This difference is due to the absence of biostructuring species which constitute the stable community in the Paguro wreck. This is the case, for example, of the presence of *M. galloprovincialis* in the most superficial facies, where the WW reaches values of 8.5 kg m^{-2}, and which after the second scraping and after monitoring during the recolonization process, does not exceed 0.2 kg m^{-2}. This concept is valid for all sites where *Mytilus* or *O. edulis* dominated the pre-scraping community with their biomass. Their absence significantly reduces the analyzed biomass parameters.

Table 4.10 - SFWW, SFDW, WW of the sampled communities.

		1st scraping			2nd scraping		
Sample ID	**Depth**	**SFDW g m^{-2}**	**SFWW kg m^{-2}**	**WW kg m^{-2}**	**SFDW g m^{-2}**	**SFWW g m^{-2}**	**WW g m^{-2}**
Shallow 1	12 m	311	2.314	7.413	25	120	142
Shallow 2	12 m	259	2.302	8.591	29	143	189
Shallow 3	12 m	352	2.363	7.411	13	64	79
SW	17 m	74	0.314	0.341	28	125	535
NE	17 m	134	0.636	1.510	11	65	443
Stern	17 m	171	0.912	4.622	10	45	50
SW	21 m	53	0.230	0.618	23	114	514
NE	21 m	347	1.995	10.297	10	54	64
Stern	21 m	169	0.904	4.644	9	58	433
Internal 1	21 m	64	0.453	1.321	NA	NA	NA
Internal 2	21 m	22	0.120	0.127	NA	NA	NA
Internal 3	21 m	16	0.085	0.087	NA	NA	NA

The difference between communities, considering the biomass in terms of WW between the first scraping and the second one, is evident in the nMDS graph (Fig. 4.18). As shown, the communities at the first scraping remain clustered to the left of the graphic representation, where clusters of samples taken at 12 meters, characterized by a high *Mytilus* biomass, are evident (bottom left). Secondary scraping in the same areas has communities displayed on the right side of the graphical representation. Again, the 12-meter communities remain clustered and separated from those of other bathymetries, indicating that the recolonization process is dictated by depth-related factors.

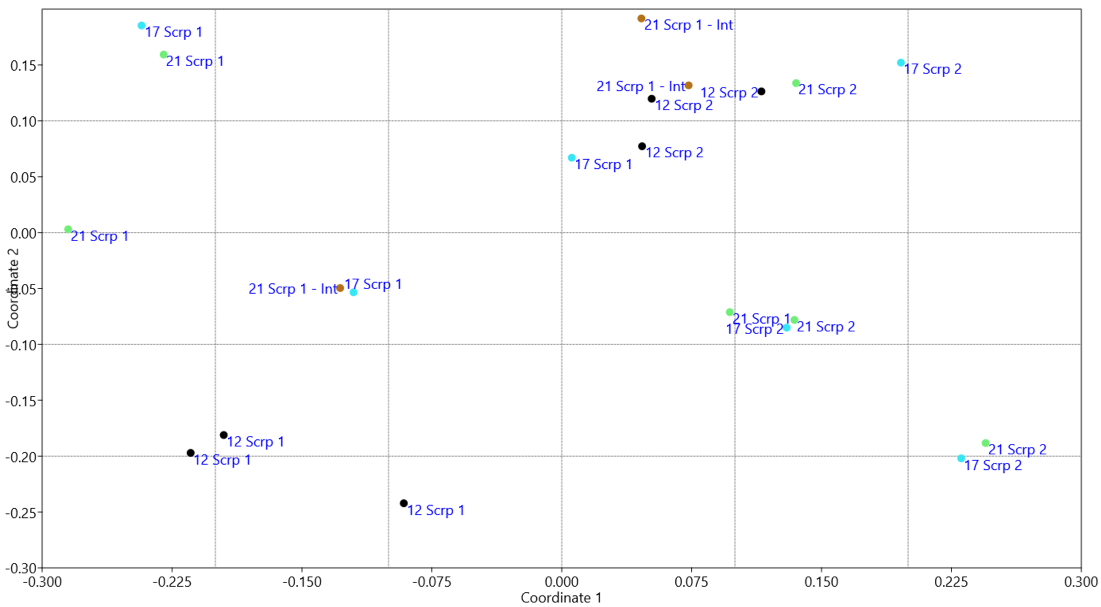


Figure 4.18 - nMDS of the sampled communities.

Overall, the results of this study are comparable with those obtained by Ponti and collaborators (2000): the community at the "Paguro wreck" is dominated by mussels, oysters, cnidarian and sponges that provide a suitable habitat for settlement of other sessile filter-feeders and endobiotic species, as well as a refuge for crustaceans and brittle stars. Furthermore, the sedimentation in what is a community characterized by a high three-dimensionality due to massive species, causes an entrapment of sediments among the shells enriching a fauna with predators and detritivorous species. Differences in terms of communities according to various depths may reflect water stratification during summer and the potential establishment of dystrophic conditions near the bottom as hypothesized by Ponti et al. 2002.

4.5. Fish assemblage

Fish community at the sampling stations is mainly represented by pelagic and demersal fish species. *Boops boops* and *Chromis chromis* are the most abundant species living in the wreck over the whole year (Fig. 4.19). *Diplodus annularis, Diplodus vulgaris, Oblada melanura, Serranus scriba, Spicara maena, Sciaena umbra, Scorpaena scrofa, Sparus aurata* are the most iconic species that were observed during the summer period in addition to *B. boobs* and *C. chromis*. Changes in dimensional class ranges were observed for *C. chromis* over the year; summer period showed high frequency of small size individuals (0 to 2 cm in length) demonstrating that the species completes its living cycle at site.

During operations at site, infrequent species were also observed and reported; *Thunnus thynnus, Seriola dumerili, Sarda sarda* are attracted to the wreck for hunting local reef fishes and were observed especially during the summer period when water horizontal visibility reached 10 metres.

During the project, a large set of stereo video clips (each one lasting about 10min) was recorded and all were processed by a video processing server hosted at ARPAE premises (Fig. 4.19; Fig. 4.20). The server includes:

- a fish detection algorithm based on the FasterRCNN network, trained for the above cited species, producing a bounding box (Region of Interest, ROI) and a class label for each detected individual;
- a stereo processor able to compute an estimate of fish length by exploiting the geometrical properties of the stereo camera.

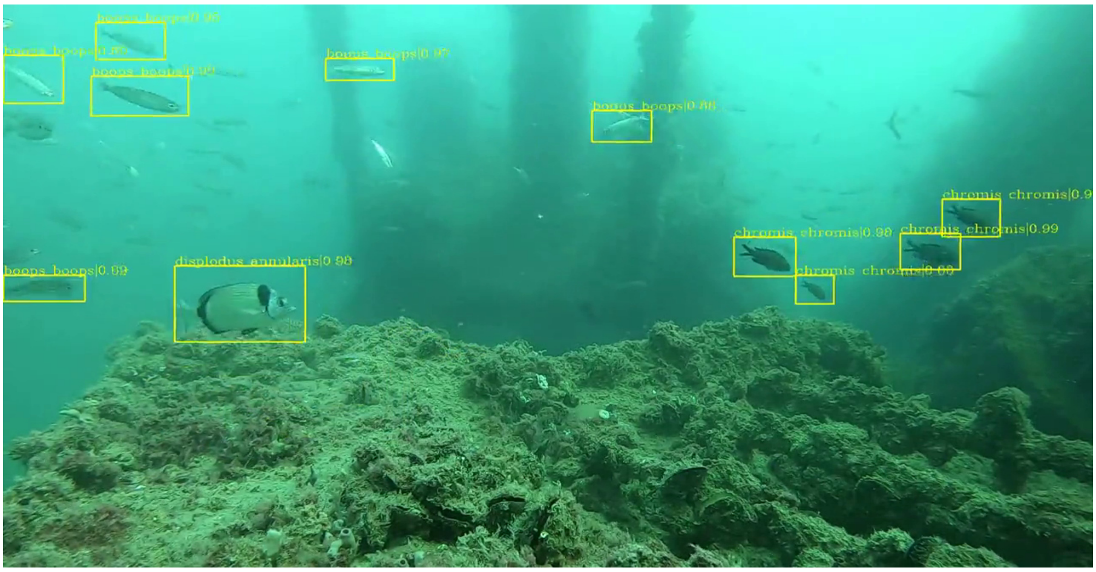


Figure 4.19 - Example of a stereo video frame processed to identify fish species.

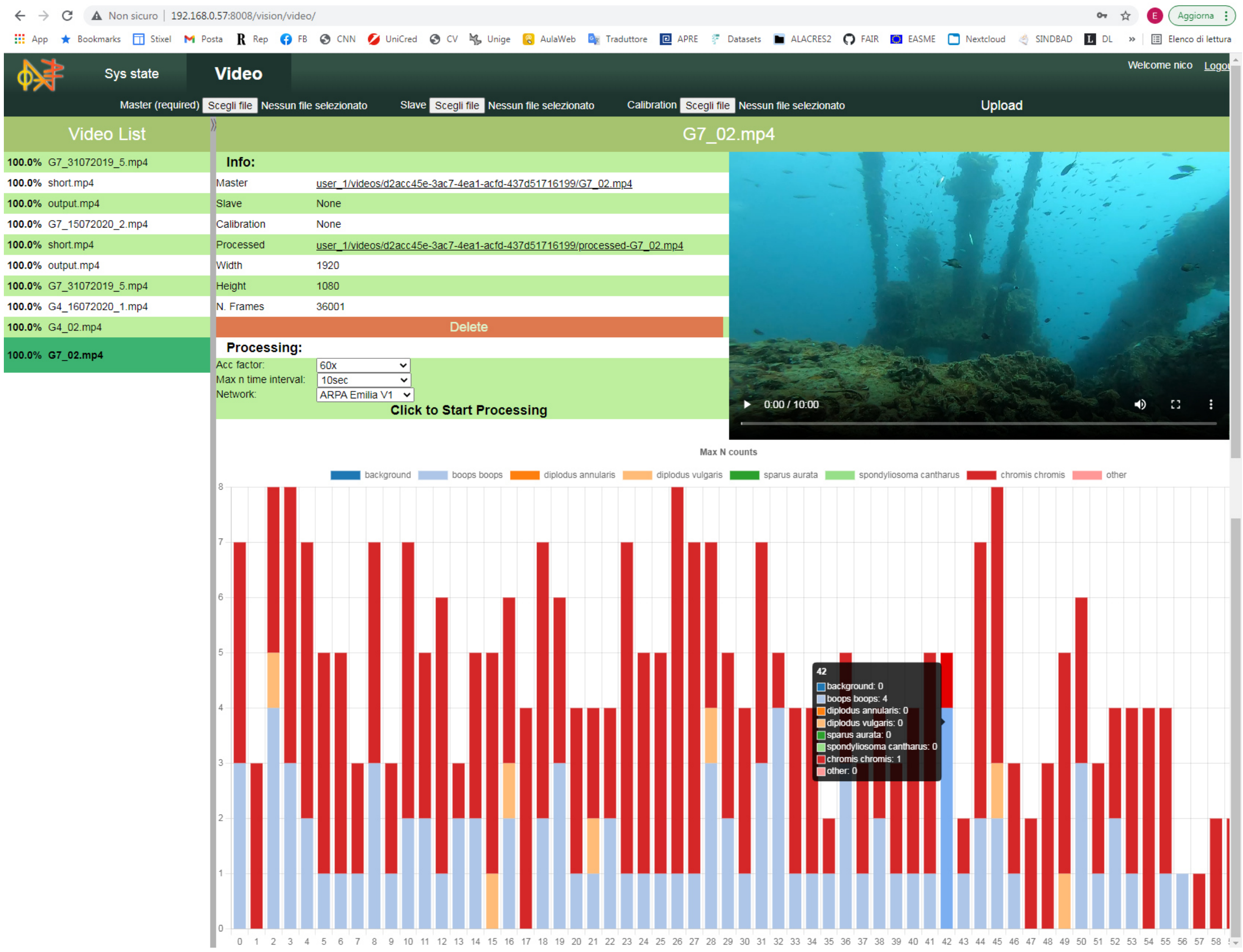


Figure 4.20 - A sample window of the video analysis tool deployed for the project.

All raw data have been statistically analyzed in order to produce the required abundances. The main results are summarized in Table 4.11.

Table 4.11 - Abundance counters for the analyzed stereo-videos.

		Boops boops		*Chromis chromis*		*Diplodus annularis*	
Stereo video ID	**Date**	**Abundance**	**St. dev.**	**Abundance**	**St. dev.**	**Abundance**	**St. dev.**
PG_stereo_01	31/07/2019	69.0	8.7	12.3	1.2	0.3	0.1
PG_stereo_02	15/07/2020	2.8	0.4	24.6	1.3	1.2	0.2
PG_stereo_03	27/08/2020	9.3	2.3	14.1	2.2	2.3	0.2
PG_stereo_04	01/07/2021	37.1	1.6	3.5	0.2	3.6	0.1

To get a numerical accuracy estimate of the detector, over a population of fish extracted by an operator from a set of sample images, some statistical quantities commonly used in computer vision and image analysis were computed. Being the true and detected fish represented by a set of boxes (or ROIs), different values of overlap (measured by Intersection Over Union, IOU) were set in order to evaluate how many true fishes are detected. Results are summarized in Figure 4.21.

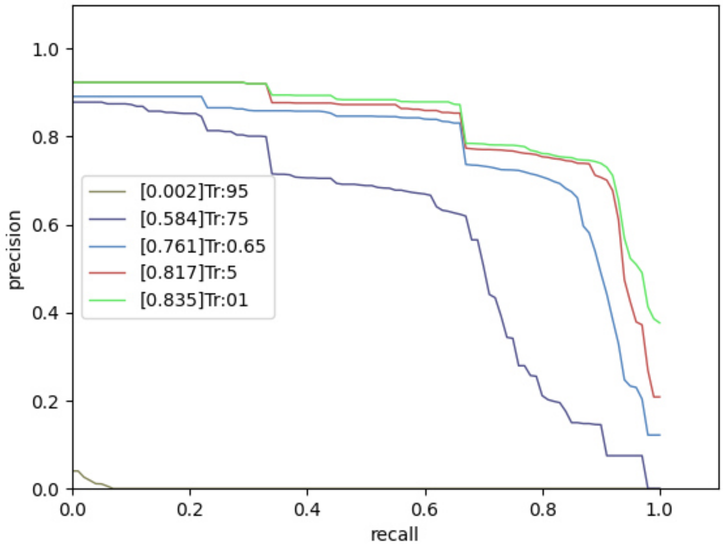


Figure 4.21 - Statistical analysis of the fish detector.

The plot represents all possible values of precision (capability to identify true object) and recall (capability to reject false object) estimators, for different values of IoU threshold. Ideal values should be both close to 1, but in real cases a tradeoff should be selected. However, values around 0.8-0.9 can be reached, expressing the fact that most true objects (nearly 90%) can be detected, ensuring at the same time that the number of false objects is small.

Results of the automatic procedure for fish counting based on deep learning are encouraging, keeping into account the inherent complexity of the task. Due to the very good quality of the image data, the system learns to detect most of the fishes that are clearly visible, even when they are quite close to each other. However, when a dense school of fish is present, the total counts appear to be underestimated. The same argument applies for fishes distant from the camera, because the selection of a tradeoff in which only clearly identifiable fishes are kept by the detector was preferred, in order to avoid possible false alarms occurring if a less restrictive threshold on detection confidence was used. In this way all detected individuals correspond to real fish, even if some fish could be missed when too close or partly occluded.

The same neural network used for fish detection is also able to classify each ROI, providing a class label among those defined during the training phase. Classification performances are very good for the most abundant ones (i.e. *Boops* and *Chromis*), but the lack of sufficient data for other species did not allow a complete statistical test for all of them. However, the implemented *fasterRCNN* deep network seems sufficiently robust to cope with a larger number of classes, and the system deployed at ARPAE will be able to continue acquiring data in the future, hoping to get enough images to start classifying more species than today. Moreover, it is possible to include data coming from similar installations and to merge them in order to increase the learning base and to retrain the network.

A complete comparison of different counting methods is not so easy, as they work differently while actually counting slightly different things. Looking at video data of a set of frames, automatic counts show a clear correlation with the human counts and in that sense automatic UVC is competitive with visual inspection of the video, as it costs less in terms of time and required effort. However, it is not well defined which is the space zone to be inspected by different methods. Human eyes typically go farther because an expert is able to see a fish even where the signal is very low. An automatic system based only on pixel values and very good training data is not able to replicate this type of acuity without generating false alarms. Automatic abundances are very good when analyzed in a relative way, because abundances ratio between different video clips are more closely related to the same quantity estimated by humans. So a possible strategy to exploit UVC automation should be to calibrate the automatic counters in order to match the human ones on a few clips and then to correct the automatic estimates of many other similar videos using a fixed calibration formula.

Lastly, the stereo system is able to provide a statistical estimate of the mean length of a fish species inside a clip. This data is not a methodological one, because there are many possible sources of error inside the processing chain. First of all, the video clips are synchronized only manually at the nominal frame rate of the two cameras and so there is no perfect identity of time acquisition times. Fish size is approximated by a segment lying over the image, but a fish may be oriented in many possible ways and it may change the apparent shape of its body, inducing an error in a purely geometric length estimate. Moreover, due to the partial overlap between cameras' fields of view, not every fish seen in one image has a counterpart into the other one, and this induces another limitation of the stereo approach. This fact typically occurs for fish close to the camera, so there is a minimum distance under which stereo is impossible. Finally, stereo accuracy (and also visibility in water) decreases with distance from the cameras, and so the size estimates are reliable only under a maximum distance. For the Paguro installations the stereo procedure is possible, with acceptable accuracy, only between about 1m and 5m.

However, for a sufficiently large population, and using the median as a robust statistical estimator, the obtained data provide reasonable length values for *Boops boops* and *Chromis chromis*. So it is possible to assign an averaged median length to a fish population, filtering away most error sources. The dispersion around the median is evaluated by the median of absolute differences. Table 4.12 shows the dimensional values obtained in a specific experiment carried on in July 2021. A more detailed analysis involving other dates is still ongoing.

Table 4.12 - Average median length values for the fish population at "Paguro wreck".

Species	Median Length [mm]	Absolute Difference [mm]
Boops boops	152	17
Chromis chromis	123	15
Diplodus vulgaris	140	20

Results of stereo video analysis were compared with those obtained by using traditional Visual Census technique and 360 degree videos analysis. The main results for different seasons are summarized in Tables 4.13 and 4.14. The data represent the mean abundances for size classes found during the investigations carried out in the autumn and summer seasons.

Table 4.13 - Results from traditional Visual Census and 360 degree video surveys performed during summer.

SUMMER		Size classes											
		0-2 cm	**2-4 cm**	**4-6 cm**	**6-8 cm**	**8-10 cm**	**10-12 cm**	**12-14 cm**	**14-16 cm**	**16-18 cm**	**18-20 cm**	**20-25 cm**	**30-35 cm**
Video 360 degrees	*Boops boops*						250		60	50			
	Chromis chromis	50	40			30	45		65				
	Diplodus annularis							5	3.5				
	Diplodus vulgaris						1	8	8	30			
	Oblada melanura							25	26.7				
	Scaena umbra						1		4				
	Serranus hepatus						1		1				
	Serranus scriba							2	1.5		2		
	Spicara maena						2	3					
Visual census	*Boops boops*							250	40	70			
	Chromis chromis		30			20	123.3						
	Diplodus annularis						5	5					
	Diplodus vulgaris								20	13.5			
	Oblada melanura							20	40				
	Sciaena umbra											4	7
	Scorpaena scrofa											1	
	Serranus hepatus						2						
	Serranus scriba								1	1	1		
	Spicara maena							3					

Table 4.14 - Results from traditional Visual Census and 360 degree video surveys performed during autumn.

AUTUMN		**Size classes**											
		0-2 cm	**2-4 cm**	**4-6 cm**	**6-8 cm**	**8-10 cm**	**10-12 cm**	**12-14 cm**	**14-16 cm**	**16-18 cm**	**18-20 cm**	**20-25 cm**	**30-35 cm**
Video 360 degrees	*Boops boops*								43.3				
	Chromis chromis						43.3						
Visual census	*Boops boops*								85				
	Chromis chromis					30		45					
	Diplodus vulgaris								5				
	Sciaena umbra											3	2
	Scorpaena notata					10							
	Serranus hepatus							2					

Traditional Visual Census allowed us to identify more species and specimens probably due to the capacity of human eyes to capture more details as not affected by limiting video quality (i.e. resolution). The 360 degree video analysis showed similar results to traditional Visual Census, but a lower number of species and specimens were identified, especially during the autumn season characterized by lower visibility compared to the summer season. The differences in the results obtained by applying the two techniques are reduced during the summer season when the visibility conditions are not limiting. This is further evidence that the quality of the video can affect the outcome of the investigation by reducing the possibility to identify fishes far from the lens.

The results obtained by applying the three different techniques (stereo-video, 360° video and traditional Visual Census) are comparable from a qualitative rather than a quantitative point of view, as the methodological bases are substantially different. Taking into consideration the summer data as available for all three applied techniques, the automatic analysis of the stereo-videos allows to detect 3 main species (*Boops boops, Chromis chromis* and *Diplodus vulgaris*) while it does not allow a detailed characterization of the fish community by size classes. The other two techniques provide information not only on the abundances divided by size classes but also on a greater number of species, allowing a more detailed characterization of the fish assemblage present in the investigated site.

In light of the results obtained, the 360° video technique seems to be the best in cost-benefit terms, showing results very similar to the traditional Visual Census. Although strongly influenced by the transparency of the water column, the 360 degree video analysis allows the characterization of the fish community a posteriori, thus avoiding the presence of expert Scientific Divers in the field and reducing operating costs.

With regard to the stereo-camera technique, the processing phase is very complex and requires calibrated cameras in order to obtain reliable length measurements divided by size classes. At the moment, this method allows us to obtain the average size of the specimens divided by species but not the abundances by size classes. The stereo-camera experimental method certainly has great potential but the results are not yet comparable with the other applied methods which are instead more effective for the detailed characterization of the fish community of a site.

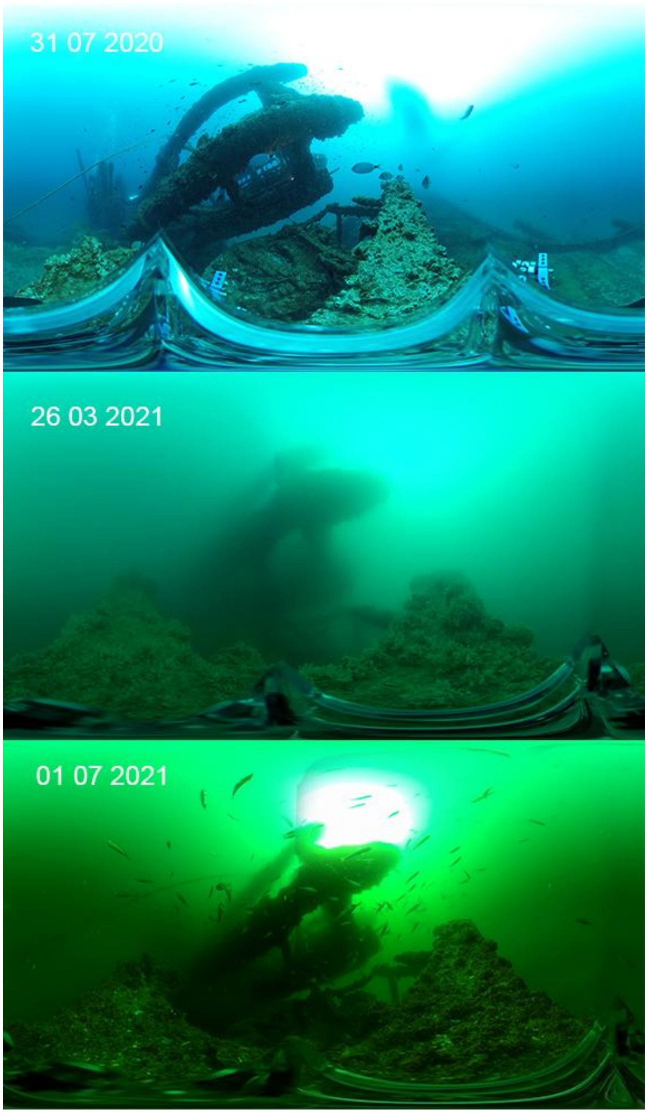


Figure 4.22 - Frames extracted from 360 degree videos recorded at stationary point for visual census. The images show the large variability in water color and horizontal visibility.

4.6. Photogrammetric survey

The dataset resulting from underwater photogrammetry surveys, including those collected with the participation of scuba diver volunteers coordinated by the Municipality of Ravenna (LP), was processed to generate a 3D scaled and optimised model for mobile devices of the sunk jack-up rig and of the decommissioned structures. A Virtual Reality based app was developed using the generated 3D model within a virtual seascape environment (Fig. 4.23). The App was developed for standalone virtual reality headset Oculus Quest 2 and is populated with schools of animated models of the most iconic fish species described at site. The product was delivered with the collaboration between the Municipality of Ravenna and ARPAE.

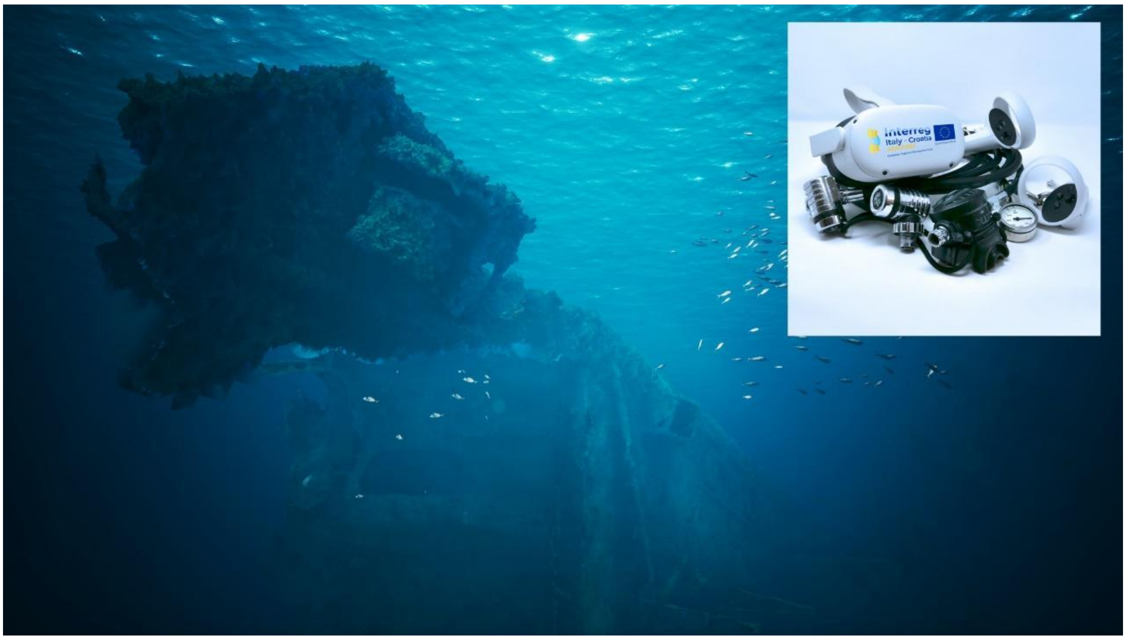


Figure 4.23 - View of the virtual reality app during the exploration of the Paguro wreck with the Oculus Quest 2 headset.

The georeferenced point cloud generated with the multibeam echosounder covering an area of 7.1 He, was aligned with the point cloud of the areas of the wreck mapped through underwater photogrammetry. The output will be uploaded to a dedicated online platform where users can view and interact with the scaled dataset (Fig. 4.25). Over the 2 years of surveys performed at site, structural modifications of the wreck caused by offshore weather conditions and seawater corrosion were registered (Fig. 4.24).

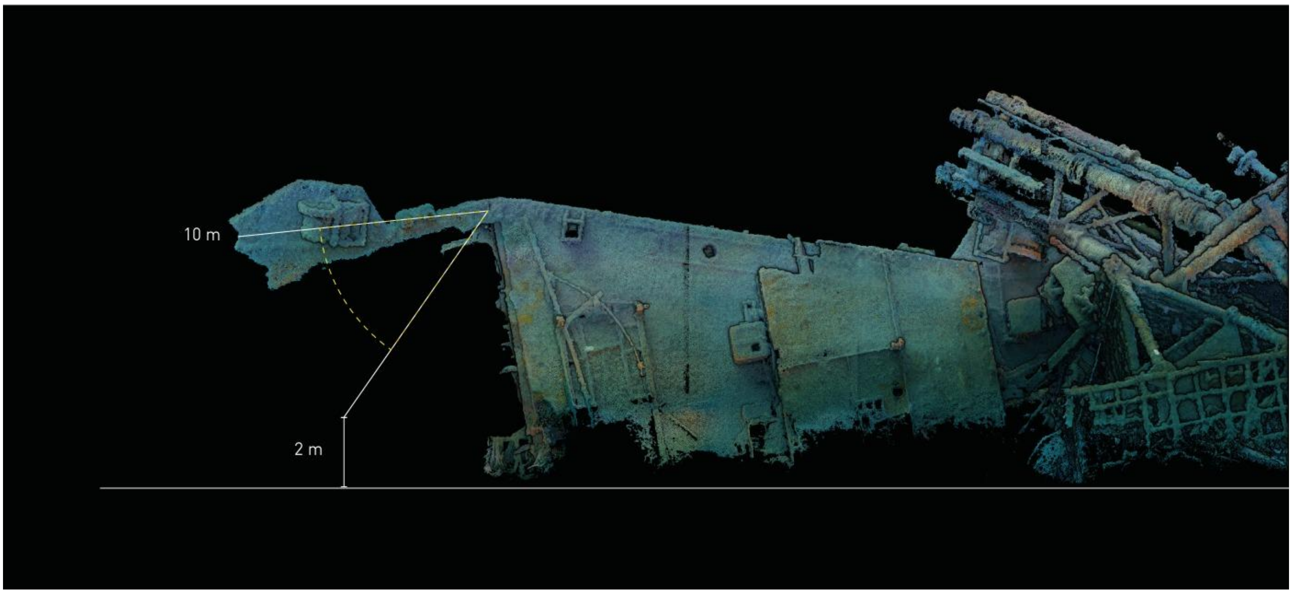


Figure 4.24 - North Eastern side of the Paguro wreck; the pinnacle has been found pending along the side after the winter 2021.

The observed changes showed the fragility of the entire structure which is collapsing at a not estimated rate. The collected data will provide information on the ongoing structural changes of the wreck and will contribute to ensure safety at site.

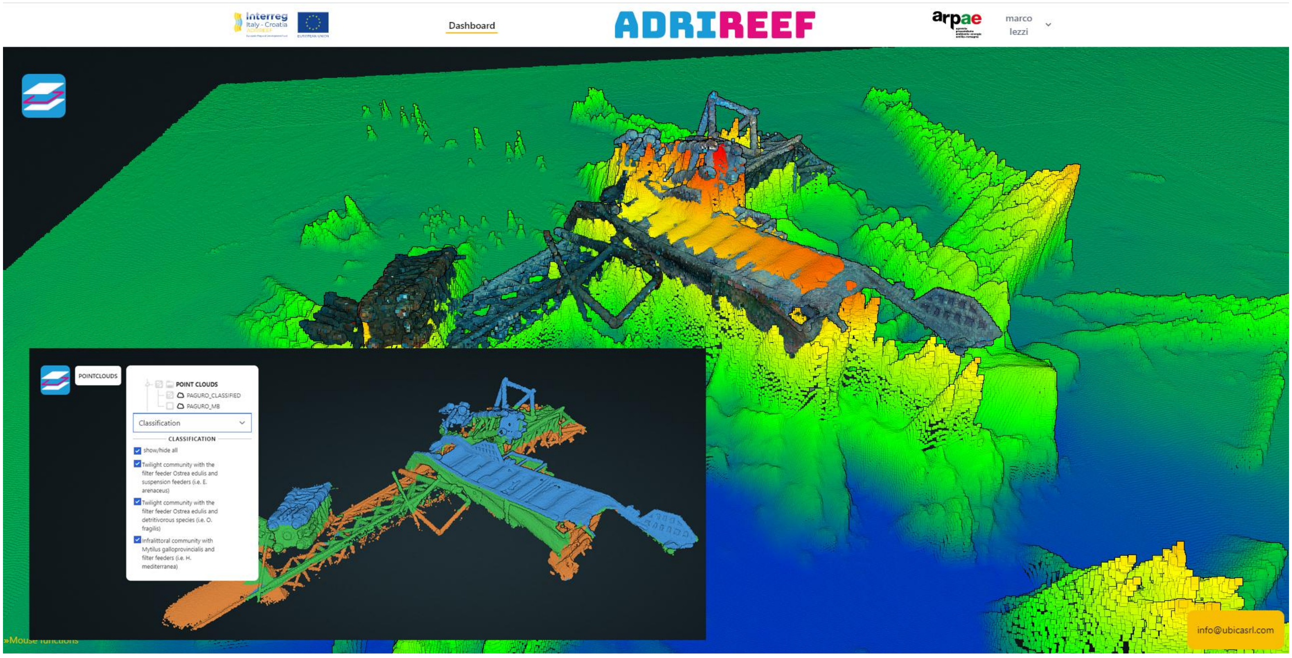


Figure 4.25 - The online platform to interact and view the 3D point clouds of the mapped areas of the Paguro and surrounding structures. In blue the bathymetric survey performed with multibeam echosounder; in red the areas mapped through underwater photogrammetry.

The point cloud of the mapped area of the wreck was classified according to the biocenosis and the composition of the benthic community. The twilight community and the infralittoral community were identified; the first mainly represented by the presence of the filter feeder *Ostrea edulis* and detritivorous species (i.e. *O. fragilis*) that populated the deeper areas and the sheltered part of the wreck. Inside the structures where low light conditions and low water circulation are key factors, the presence of *O. fragilis* is generally substituted with a continuous pattern of *E. arenaceus.* The infralittoral community is dominated by *M. galloprovincialis,* and several species of sponges (i.e. *H. mediterranea*).

The reference areas mapped with photogrammetric techniques and processed to estimate the volume occupied by the fouling community showed that the higher volumes were associated to the shallower community where *M. galloprovincialis* is dominant (74.5k cm^3) (Fig. 4.26). Deeper communities showed a lower level of biogenic contribution to the three dimensionality of the structure; between -15 m to -18 m the estimated volume reached 52.4k cm^3, and from -19 m to -23 m the estimated volume was 32.7k cm^3 where the biomass associated is lower and the shellfish sparser.

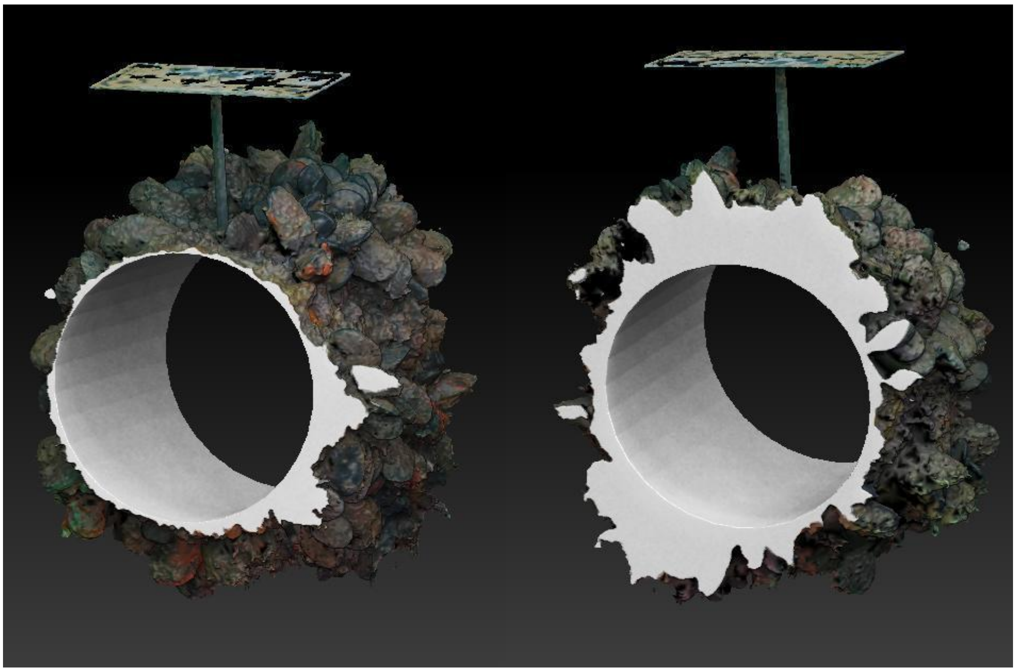


Fig. 4.26 - The volumetric estimation of the fouling community at the depth range of -10 m to -14 m has been calculated by fitting a cylinder within the scanned area for extruding the volume occupied by a standard dimensioned pipe of 55 cm in diameter. The highly dense point cloud has been interpolated to generate a high number of polygon meshes for the calculation of the internal volume.

5. CONCLUSIONS

The “Paguro wreck” was studied from June 2019 to July 2021 with a multidisciplinary approach for investigating abiotic and biotic characteristics of the site. A preliminary bathymetric survey with the multibeam echosounder was carried out for planning the underwater sampling of scientific divers. Physical and chemical water parameters were measured regularly as well as the water column currents. Traditional (i.e. photographic sampling on standard surface, visual census) and new methods (i.e. underwater photogrammetry, stereo videos recording) were applied to characterize the benthic and fish communities.

The main findings of this study were as follows:

- A bathymetric survey with a multibeam echosounder was carried out at the “Paguro wreck” and it covered the whole area identified as SCI IT-4070026. It was useful in order to obtain bathymetric maps and 3D images of the site and for planning the underwater sampling of scientific divers.
- An integrated monitoring system was set up, which included the deployment of a vertical acoustic current profiler (ADCP). Data on current speed and direction in each cell (1 m) of the water column were successfully monitored by the instrument over one year, from July 2020 to June 2021, thus providing information on daily / monthly averages, current intensity peaks at different depths and an overview of the most important meteo-marine phenomena, useful for divers / diving centers and which may have repercussions on the integrity of the submerged structures.
- Vertical profiles of the main physico-chemical parameters were periodically collected during the study period and shared in real time using social media to guarantee a useful service for the end-users. The water temperature is particularly cold only during the winter months, while poor visibility is the major concern for scuba divers, especially at the deeper levels of the wreck. This hampered also monitoring activities. Nutrient, chlorophyll and dissolved oxygen concentrations confirm that the area of the “Paguro wreck” is generally in a good trophic state. However, despite the distance from the coast of about 11 nm, it is occasionally affected by the inputs from the Po river, which lead to temporary dystrophic conditions, especially in the autumn-winter period in correspondence with the Po discharge peaks.
- During the study period, 72 structurally diverse pollutants (metals and organometals, organochlorine pesticides, PAHs, dioxins and dioxin-like compounds, PCBs) were monitored in two marine sediment samples collected at the study site. Observed concentrations are comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive and are generally below the EQSs set in Legislative Decree 172/15.
- Concerning the benthic community settled on the reef, 60 taxa were identified in total, thus confirming the attractiveness of the site for scuba divers. In general, as previously observed by other authors, the benthic community is dominated by mussels, oysters, cnidarian and sponges that

provide a suitable habitat for the settlement of other sessile filter-feeders and endobiotic species, as well as a refuge for crustaceans and brittle stars. Differences in community structure and biomass can be observed across depths.

- Fish community at site is composed by demersal hard bottom fishes (i.e. *Chromis chromis, Diplodus annularis, Diplodus vulgaris, Oblada melanura, Serranus scriba, Spicara maena, Sciaena umbra, Scorpaena scrofa, Sparus aurata*) and pelagic species (i.e. *Boob boobs*, *Thunnus thynnus, Seriola dumerili, Sarda sarda).* Seasonal variation in body size of some species was observed (i.e. *Chromis chromis*), demonstrating that the wreck provides suitable ecological niches for the entire life cycle of some demersal species and doesn't limit it's ecological role at refuge to predation or food source. New methods of visual census have been tested and the resulting data demonstrated a large overlap between them. Traditional visual census observations provided greater diversity as human eyes are not affected by limiting video quality (i.e. resolution), which reduces the possibility to identify fishes far from the lens.
- Underwater photogrammetry has been largely deployed at site and performed over different surfaces to map at different resolutions the rig and its benthic communities. Photogrammetry has been used to integrate traditional sampling methods (i.e. benthic community assessment) with new outputs (i.e. benthic community interactive 3D map), to develop innovative communication products (i.e. virtual reality scuba diving experience) and to involve local stakeholders and scuba diver volunteers to participative underwater mapping events.

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ANNEX I - Relative abundances of benthic taxa at the “Paguro wreck”

A semi-quantitative score abundance from 1 to 4 was assigned to every benthic taxon found during monitoring activities at the “Paguro wreck”:

1 - Rare species.

2 - Frequent species frequent, with reduced and abundance biomass;

3 - Species with moderate abundance and biomass;

4 - Iconic species, species with high abundance and biomass;

PHYLUM	TAXON	SCORE
Annelida	*Aphelochaeta* sp.	2
	Caulleriella viridis	2
	Dodecaceria concharum	1
	Exogone naidina	1
	Filograna implexa	2
	Glycera tesselata	1
	Harmothoe spinifera	1
	Lumbrineris coccinea	1
	Marphysa sanguinea	1
	Platynereis dumerilii	2
	Pilumnus hirtellus	2
	Polydora hoplura	1
	Prionospio sp.	1
	Protocirrineris sp.	1
	Protula sp.	1
	Serpula vermicularis	1

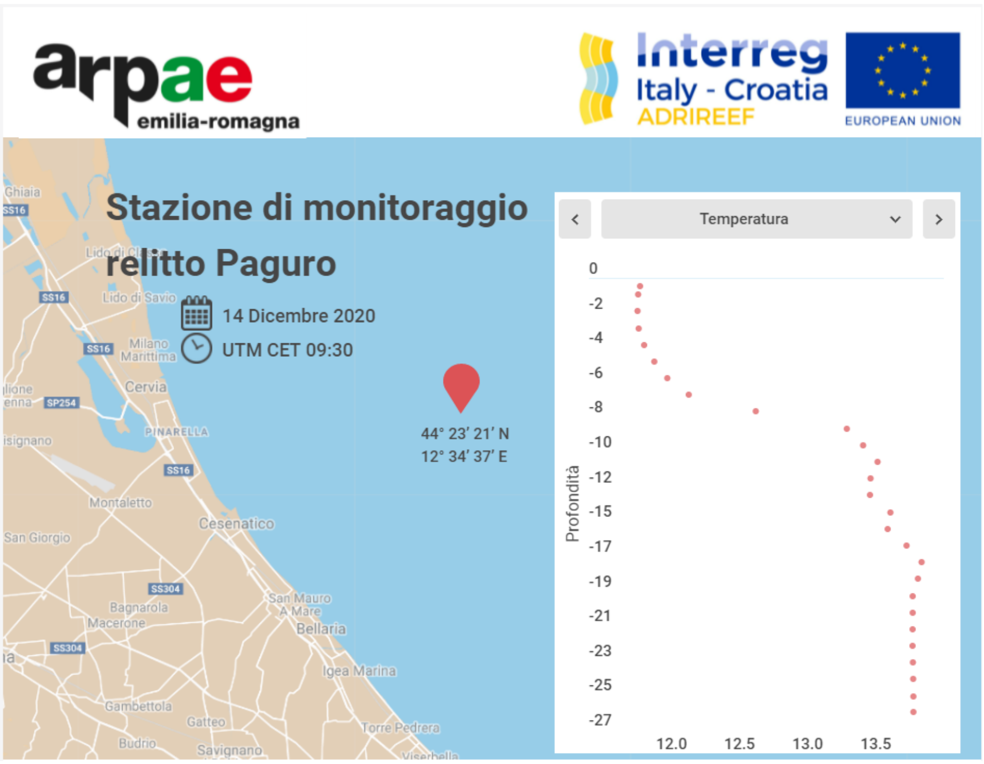
	Sphaerosyllis hystrix	*1*
	Spirobranchus triqueter	*3*
	Syllis gracilis	*2*
	Timarete sp.	*1*
Arthropoda	*Alpheus macrocheles*	*2*
	Balanus trigonus	*3*
	Cerapopsis longipes	*1*
	Elasmopus rapax	*2*
	Ericthonius brasiliensis	*2*
	Janira maculosa	*2*
	Monocorophium sextonae	*2*
	Plumulojassa ocia	*2*
	Pilumnus hirtellus	*1*
	Stenothoe monoculoides	*2*
	Uromunna petiti	*2*
	Trygaeus communis	*1*
Bryozoa	*Schizoporella errata*	*1*
	Scrupocellaria scruposa	*2*
Cnidaria	*Actinaraea* indet.	*2*
	Corynactis viridis	3
	Epizoanthus arenaceus	4
	Idrozoa indet.	2
Echinodermata	*Amphipholis squamata*	*2*

	Ophiothrix fragilis	4
Mollusca	*Anomia ephippium*	2
	Arca noae	1
	Arca tetragona	1
	Arcidae sp.	1
	Bittium scabrum	1
	Hiatella arctica	2
	Mimachlamys varia	1
	Modiolus barbatus	1
	Musculus subpictus	2
	Mytilus galloprovincialis	4
	Ostrea edulis	4
	Rocellaria dubia	2
	Striarca lactea	1
Nemertea	*Nemertea* indet.	1
Porifera	*Sycon* sp.	1
	Dysidea spp.	3
	Haliclona (Reniera) mediterranea	3
	Spirastrella spp.	2
	Encrusting sponge sp. 1	4
Sipuncula	*Phascolosoma (Phascolosoma) granulatum*	1

ANNEX II - Images and data transferred at land and visualized through different media

Images and data collected during the monitoring activities were made accessible to the wide public as follows:

- About 2 hours of **Full HD videos** were recorded during the period July-September 2019. A selection of video clips were shared with the Municipality of Ravenna and used to feed WP2 (D2.7.1). The material included aerial and underwater environment, monitoring operations,...
- To provide a user-friendly interface and straightforward reading of the collected monitoring data, a web-service (www.infogram.com) was selected. It allows publishing **interactive charts** with customized interfaces on social media. The data, imported as csv file format into the web editor, are organized in different sheets to generate graphs. A drop-down menu allows the user to switch between graphs. The data from 12 sampling events have been published online through Adrireef facebook page since July 2019. The fast procedure allowed posting the results (i.e. vertical profiles of temperature, salinity, dissolved oxygen, pH and chlorophyll “a”) in a short time after the sampling events.



Links to the shared infographics are listed below:

https://infogram.com/water-column-parameters-25032021-1hxr4zy5jyqo2yo?live,

https://infogram.com/water-column-paramenters-25-112020-1hzj4o73z7yo6pw?live

https://infogram.com/water-column-parameters-at-paguro-wreck-19-10-2020-1hd12y98p9kw6km?live

https://infogram.com/water-column-parameters-21092020-1hxr4zyodxko2yo?live

https://infogram.com/arpae27082020-1h7z2lqnx80g6ow?live

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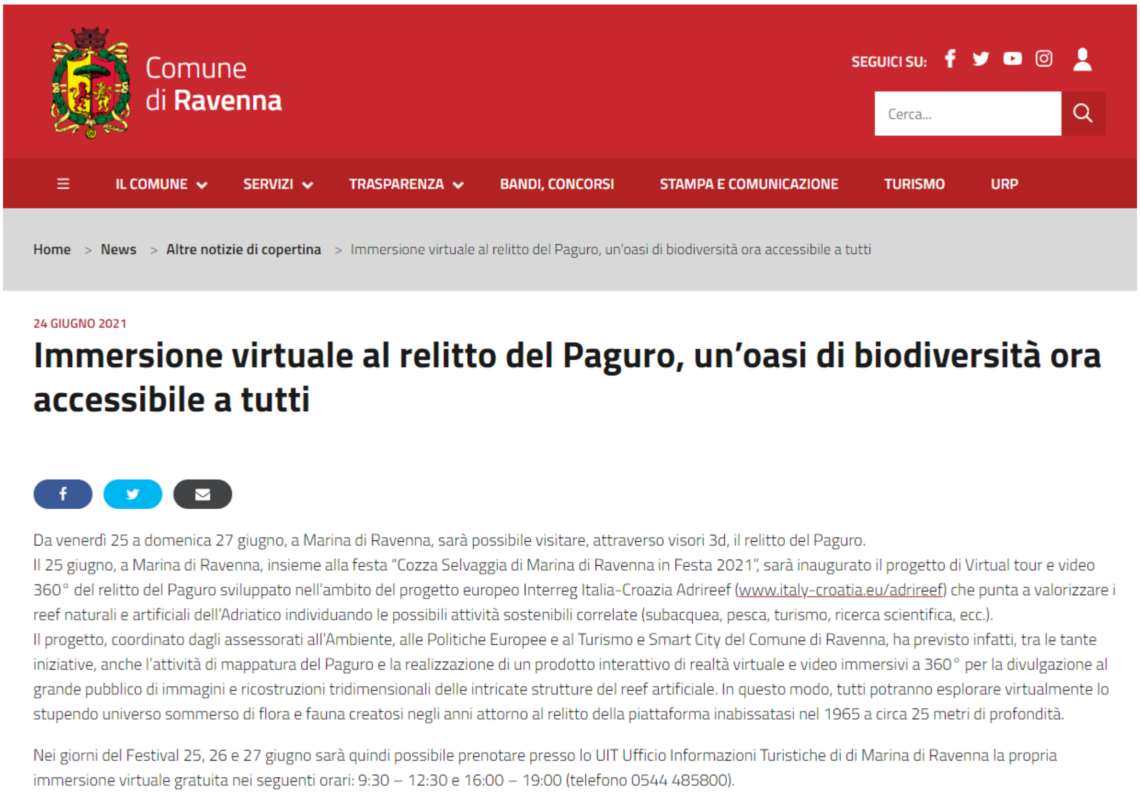
https://infogram.com/water-column-paramenters-25-112020-1hzj4o73z7yo6pw

https://infogram.com/arpae27082020-1h7z2lqnx80g6ow

https://infogram.com/arpae15072020-1h8n6mqpz1rz2xo

- Photogrammetric surveys were performed on the study site aiming at mapping the largest possible part of the wreck and generating a 3D scaled and optimised model for mobile devices of the sunk jack-up rig and of the decommissioned structures. These activities included at one stage the engagement of volunteer scuba divers, who contributed in mapping the wreck using photogrammetric techniques. The **citizen science events** were coordinated by the Municipality of Ravenna (LP). The **online webinars** and **offshore activities** were intended to promote the site as a tourist attraction. For more details see **ANNEX III**.

- A **Virtual Reality based app** was developed using the generated 3D model within a virtual seascape environment. The App was developed for standalone virtual reality headset Oculus Quest 2 and is populated with schools of animated models of the most iconic fish species described at site. The product was delivered with the collaboration between the Municipality of Ravenna and ARPAE.



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24 GIUGNO 2021

Immersione virtuale al relitto del Paguro, un'oasi di biodiversità ora accessibile a tutti

Da venerdì 25 a domenica 27 giugno, a Marina di Ravenna, sarà possibile visitare, attraverso visori 3d, il relitto del Paguro.
Il 25 giugno, a Marina di Ravenna, insieme alla festa "Cozza Selvaggia di Marina di Ravenna in Festa 2021", sarà inaugurato il progetto di Virtual tour e video 360° del relitto del Paguro sviluppato nell'ambito del progetto europeo Interreg Italia-Croazia Adrireef (www.italy-croatia.eu/adrireef) che punta a valorizzare i reef naturali e artificiali dell'Adriatico individuando le possibili attività sostenibili correlate (subacquea, pesca, turismo, ricerca scientifica, ecc.).
Il progetto, coordinato dagli assessorati all'Ambiente, alle Politiche Europee e al Turismo e Smart City del Comune di Ravenna, ha previsto infatti, tra le tante iniziative, anche l'attività di mappatura del Paguro e la realizzazione di un prodotto interattivo di realtà virtuale e video immersivi a 360° per la divulgazione al grande pubblico di immagini e ricostruzioni tridimensionali delle intricate strutture del reef artificiale. In questo modo, tutti potranno esplorare virtualmente lo stupendo universo sommerso di flora e fauna creatosi negli anni attorno al relitto della piattaforma inabissatasi nel 1965 a circa 25 metri di profondità.

Nei giorni del Festival 25, 26 e 27 giugno sarà quindi possibile prenotare presso lo UIT Ufficio Informazioni Turistiche di di Marina di Ravenna la propria immersione virtuale gratuita nei seguenti orari: 9:30 – 12:30 e 16:00 – 19:00 (telefono 0544 485800).

- Point clouds generated with the multibeam echosounder and underwater photogrammetry were aligned. The output will be uploaded to a dedicated **online platform where users can view and interact with the scaled dataset**. The link to the online platform will be made available soon.

ANNEX III - Detailed report on Virtual Reality products and immersive experiences

Activities coordinated by the **Municipality of Ravenna (LP)**.

Report attached as pdf file.

UBICA s.r.l.

Interreg Italy - Croatia ADRIREEF EUROPEAN UNION

Time Schedule events details:

Date	Activity
20/08/2020	Title: First webinar for training volunteers to carry out underwater photogrammetric surveys at the Paguro wreck.
	Description:
	The webinar intended to provide volunteers with a basic understanding of the Structure from Motion photogrammetry and practical guidelines on how to use the owned camera in the most proficient way for collecting good quality images for photogrammetric data analysis. Webinar was planned to take about 1 hour and was scheduled at 9pm. The contents of the webinar included a general presentation of the Adrireef project,the history of the Paguro wreck and its environmental peculiarities. The presenters introduced the activities ongoing at the site where Arpae is actively involved in mapping and monitoring the wreck by applying both, traditional and innovative methods.
	Event promotion:
	The webinar was promoted by using the Facebook Adrireef page, mailing lists and by publishing news on local and regional newspapers from the 10th August 2020. Four Facebook posts were published to promote the event. One post was published after the event, the 21st August 2020. The posts were shared also on Linkedin and Twitter. The 13th August the newspaper "Corriere di Romagna (ed. Ravenna-Imola)" and the "Il Resto del Carlino (ed. Ravenna)" published the news of the event. The event was also promoted on 13 online news web portals.
	Attendees:
	The registered subscribers were 42 and the attendants to the event were 19 people.
30/09/2020	Title: Second webinar for training volunteers to carry out underwater photogrammetric surveys at the Paguro wreck.
	Description:
	The webinar was structured and planned as a copy of the first event with little changes and improvement followed by the previous experience.

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Time Schedule events details:

Date	Activity
20/08/2020	Title: First webinar for training volunteers to carry out underwater photogrammetric surveys at the Paguro wreck.
	Description:
	The webinar intended to provide volunteers with a basic understanding of the Structure from Motion photogrammetry and practical guidelines on how to use the owned camera in the most proficient way for collecting good quality images for photogrammetric data analysis. Webinar was planned to take about 1 hour and was scheduled at 9pm. The contents of the webinar included a general presentation of the Adrireef project,the history of the Paguro wreck and its environmental peculiarities. The presenters introduced the activities ongoing at the site where Arpae is actively involved in mapping and monitoring the wreck by applying both, traditional and innovative methods.
	Event promotion:
	The webinar was promoted by using the Facebook Adrireef page, mailing lists and by publishing news on local and regional newspapers from the 10th August 2020. Four Facebook posts were published to promote the event. One post was published after the event, the 21st August 2020. The posts were shared also on Linkedin and Twitter. The 13th August the newspaper “Corriere di Romagna (ed. Ravenna-Imola)” and the “Il Resto del Carlino (ed. Ravenna)” published the news of the event. The event was also promoted on 13 online news web portals.
	Attendees:
	The registered subscribers were 42 and the attendants to the event were 19 people.
30/09/2020	Title: Second webinar for training volunteers to carry out underwater photogrammetric surveys at the Paguro wreck.
	Description:
	The webinar was structured and planned as a copy of the first event with little changes and improvement followed by the previous experience.

	Event promotion:
	The event was promoted with 2 posts on facebook starting from the 9th September 2020. The posts were shared also on Linkedin and Twitter.
	Attendees:
	The registered subscribers were 58 and the attendants to the event were 39 people.
9/10/2020	<u>Title: First coordinated event for photogrammetric survey at the Paguro wreck</u>
	Description:
	The event was planned to be organised with the logistic participation of the Dive Planet diving centre at Rimini. According to the number of participants, the operator offered a different service: one single dive at the Paguro for less than 5 scuba divers volunteers at 65€ each; two dives at the Paguro for more than 5 scuba divers at 120€ each. Ubica's technicians coordinate the event by doing a pre-dive planning to define the areas of interest for the photogrammetric mapping and organise divers working groups.
	Attendees:
	Only one volunteer communicated the intention of participating at the event and therefore the event was canceled.
10/10/2020	<u>Title: Second coordinated event for photogrammetric survey at the Paguro wreck</u>
	Description:
	The event was planned with the logistic support of the Motobarca Elisa and the coordination of the Associazione sportiva Sub Delfinus. Motobarca Elisa supported the event by offering a cost reduction to the volunteers; a full-day trip inclusive of two dives at Paguro was offered for 35€ per diver.
	Attendees:
	5 volunteers carried out 9 dives during the day spending about 7.5 hours underwater collecting a total of 3500 pictures of the wreck. Divers worked in specific areas of the site according to their own experience and equipment characteristics. Datasets were collected during the way back to the harbour and processed the days after the event.

Subscribers analytics

The volunteers registration included a questionnaire for collecting information on the participants. The questionnaire was published on Google Form platform (Figure X and Table 1).

Figure 1: Template used for the registration procedure using the Google Form platform

Table 1:Data collected during the volunteers registration.

Name and surname
Contact email
Indicare livello più alto di certificazione subacquea
Indicare il numero medio di immersioni annue
Indicare club o associazione sportiva di appartenenza
Hai mai fatto immersione subacquea al relitto Paguro?
Credi di saperti orientare facilmente sul relitto Paguro?
Saresti interessato a contribuire nella raccolta dati fotogrammetrici al relitto Paguro dedicando una giornata di immersioni?
Pensi di coinvolgere altri partecipati?

The questionnaire was filled by 100 people. 42 registered at the first webinar (20th August 2020) and 57 registered for the second webinar (30th September 2020).
Data collected were plotted for a general understanding of the webinar audience (Figure 2, 3 and 4).
Details of the registered volunteers are reported in Annex 1.

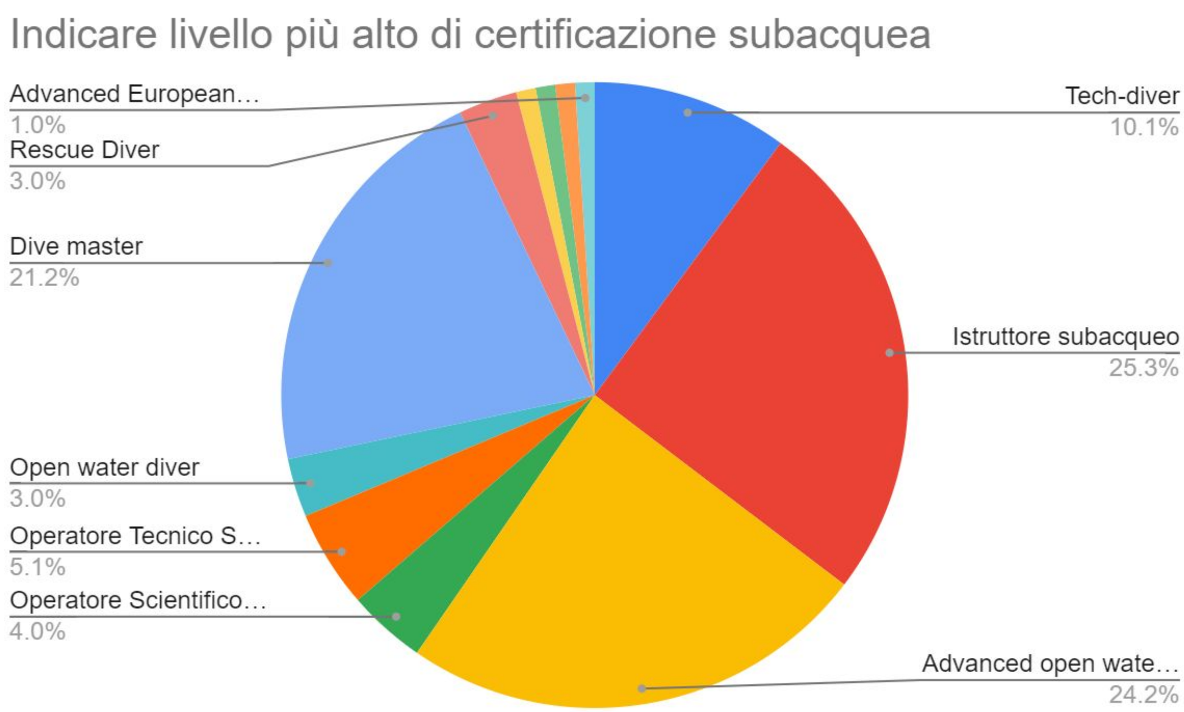

Figure 2: the graph shows the highest scuba diving certification owned by the registered volunteers.

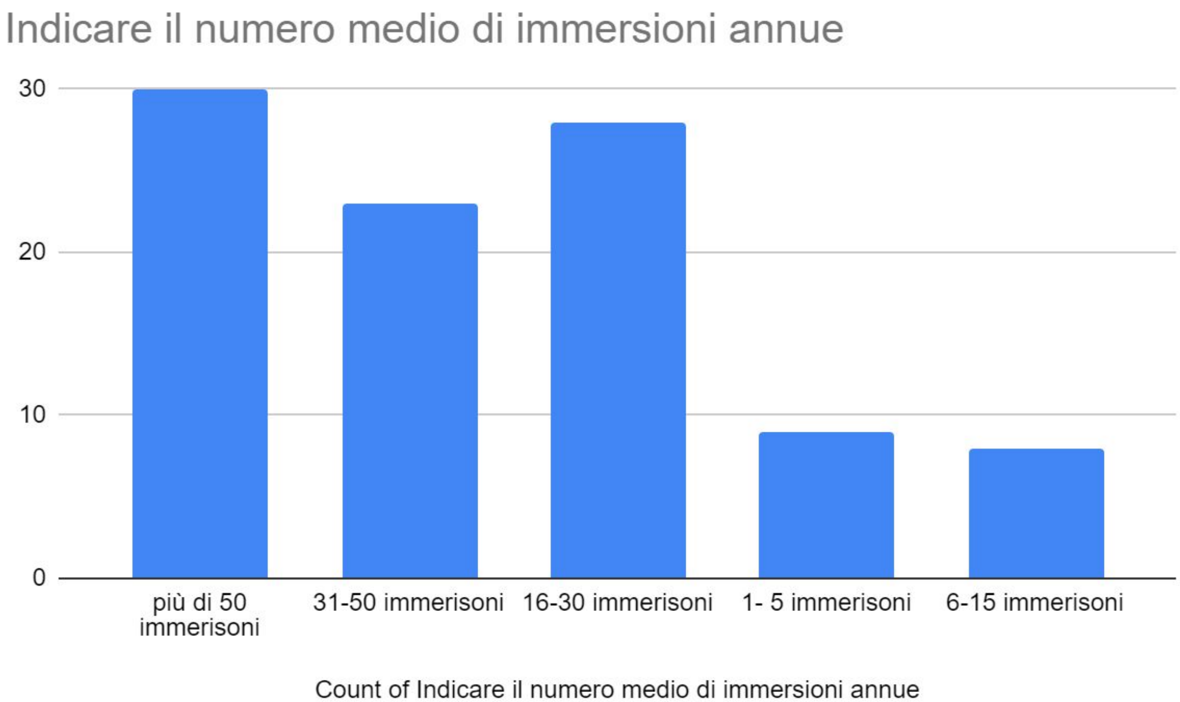

Figure 2: the plot shows how many dives per years the volunteers are use to do and inform on the experience level of the participants.

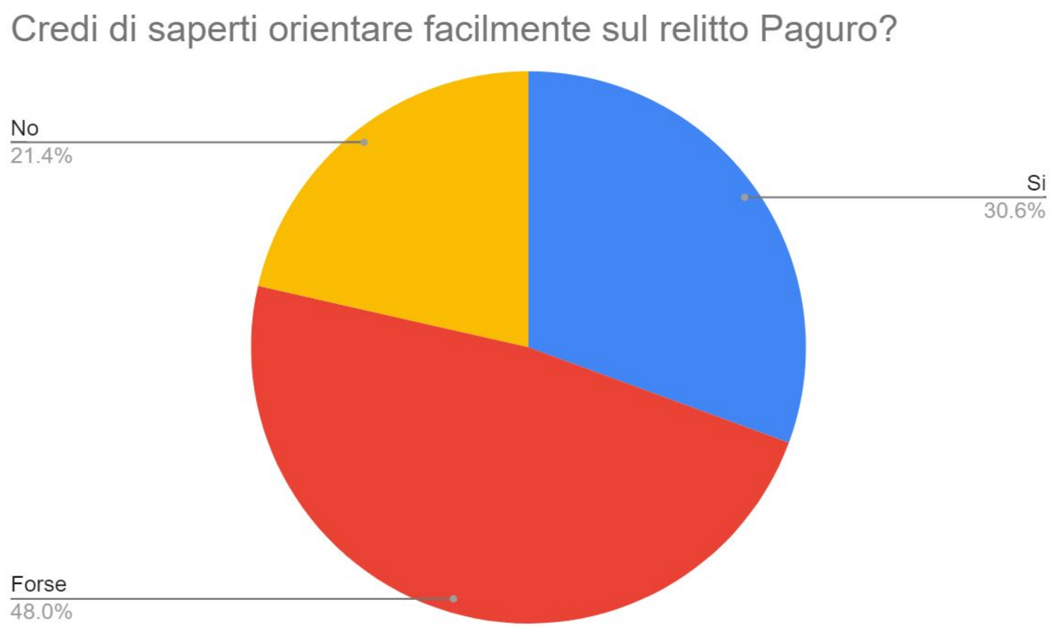

Figure 3: The plot informs on the experience of the registered volunteers in diving the Pguro wreck.

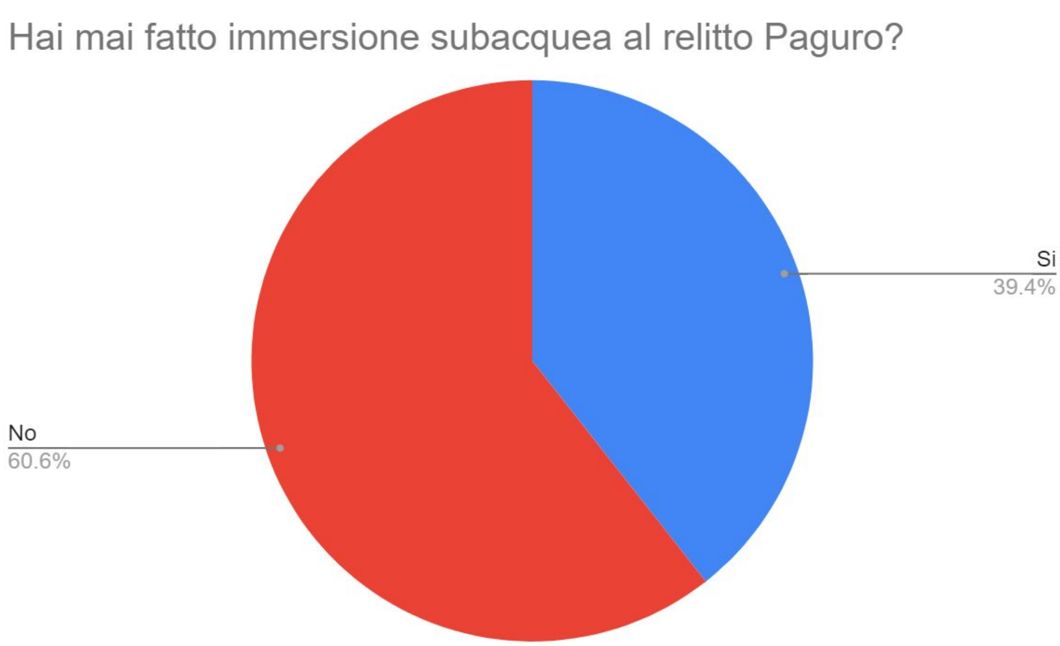

Figure 4: The plot informs on the experience of the registered volunteers in diving the Paguro wreck showing that the event reached not only local scuba divers.

Outcoming contents for VR headset:

360 degrees videos:

During the coordinated event at the Paguro wreck and during the monitoring events carried out over the summer 2020, the Ubica's technicians recorded 360 degree video clips which will be included as contents into the VR product (Figure 1).

Example 360 degrees video clips are published at the following links:

- https://www.youtube.com/watch?v=zkgiFe9LCz4&feature=youtu.be
- https://www.youtube.com/watch?v=hjOuhMlfTt4

The videos recorded will be included in the communication product for the immersive experience with VR headset.

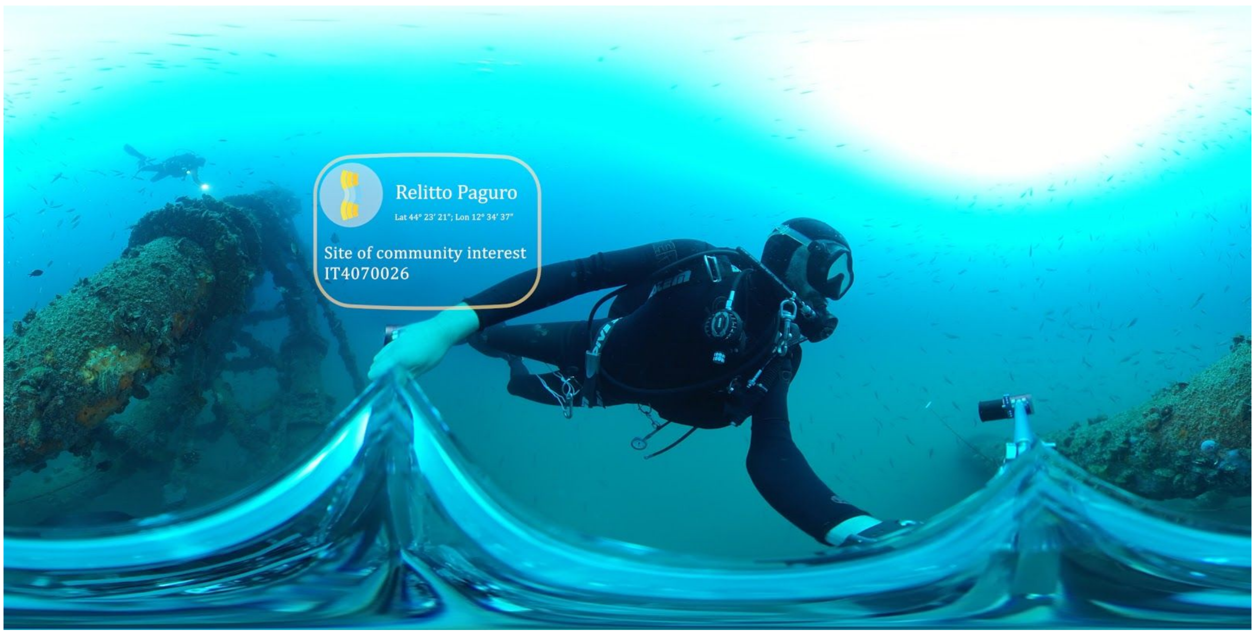

Figure 1: frame extracted from a 360 degrees video recorded at the Paguro wreck. The frame size 5.7K and the video was record at 30 frames/second.

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Immersive exploration at Paguro wreck:

The 3D model generated from photogrammetric processes are at this stage representing the most of the wreck and were obtained from the data sampled with Arpae and with the participation of volunteers scuba divers. The 3D model has been optimised by simplifying the Mesh and generating normal maps and displacement maps. The model of the entire wreck has been segmented in several parts and for each of them were calculated photographic quality textures dimensioned 8192x8192 pixels which is the bigger texture maps supported in Oculus Quest 2 VR headset (Figure 2).

Figure 2: section of the southern side of the wreck represented as simplified mesh textured with normal map and displacement map applied. The model shows high morphological complexity even if the mesh is much simpler and therefore is associated with a smaller file.

The testing phase included the production of a standalone application for Oculus Quest 2 for navigating different sections of the wreck and simulating underwater environmental conditions. The results of the tests demonstrate that the optimization was adequately performed and the device supported light control functions including the possibility of displaying the normal maps and the displacements maps which contribute to providing the realistic effect and the 3D complexity of the simplified mesh (Figure3).

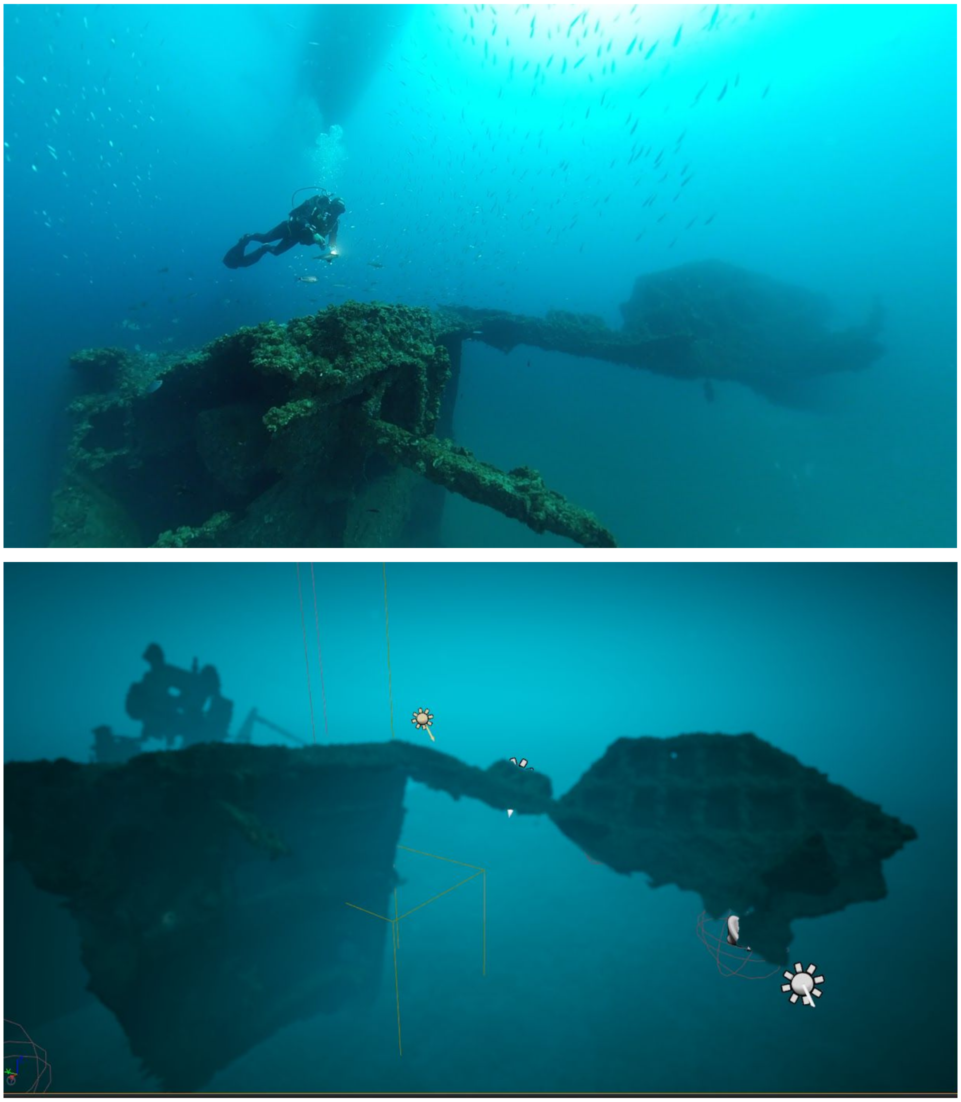

Figure 3: on top a view of the southern side of the Paguro wreck during field work. At the bottom a view of the 3D model generated from photogrammetric data collection f the same southern side of the wreck, during the development of the application for VR experience