Work Package 4.3

Data analysis of monitoring results

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Titles:

D4.3.1 Report of monitoring phase from both Countries: the documents produced in the previous activities will be collected and summarized in a joint report
D4.3.2 Analysis comparison of the obtained results
D4.3.3 Identification of the reef vocation (tourism, farming, aquaculture, fishing, environmental safeguard, etc)

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EXECUTIVE SUMMARY

Monitoring of reefs is essential for continuous evaluation of their structural and ecological evolution, hence their capacity of sustaining the different economic activities, in line with the principles of the Blue Economy. Indeed, several cases exist of reefs (both natural and artificial) that have gradually lost their effectiveness and attractiveness due to wrong human utilization or environmental events.

This report summarizes the activities performed by Italian and Croatian Adrireef project partners at 7 selected reefs in the Adriatic Sea, where monitoring was carried out from November 2019 to September 2021. The overall obtained data are here collected and discussed. The identification of reef's adequacy towards a particular use, among those expected by the Blue economy sectors, is also evaluated.

During the surveys, 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 were introduced to reflect Case Studies specifics or to address unexpected situations that occurred during practical activities at sea. Advantages and limitations of the tested technologies are also presented, thus providing an insight both for the local management plans and the application of European Directives for the protection of the marine environment.

The obtained results provide a keystone for any stakeholder interested in the sustainable use of natural and artificial reefs in the future, including the issue of sunken ships or reuse of offshore extraction platforms.

Transferability of achieved outputs to stakeholders was ensured by public dissemination of results, a task accomplished using a set of actions and strategies, also described and summarized in this report.

1. INTRODUCTION

Adrireef project WP 4.3 closes the monitoring phase at 7 selected case studies, where integrated innovative monitoring systems of abiotic and biotic descriptors have been tested and evaluated as defined in the previous WP3. The overall data acquired in Italy and Croatia are collected and discussed in this report, with the aim of identifying reefs adequacy towards a particular use among those expected by the Blue Economy sectors (e.g. tourism, scuba diving and snorkeling, citizen science, fishing activity).

The identification process and the detailed description of the selected case studies is reported in WP3.3 final report (Scanu et al., 2019). The list of planned monitoring activities at each site can be found in WP3.4 final report (Montagnini et al., 2019).

In Figure 1 there is a map showing the location of the selected case studies in the cooperation area. Initially 7 sites were selected as case studies: Trezza San Pietro, Paguro wreck, Porto Recanati-Porto Potenza Picena and Torre Guaceto Marine Protected Area in Italy; Plićina Konjsko (Krk Island), Plić Lagnjići (Dugi Otok Island) and Plić Seget (Vis Island) in Croatia. Later another site was added on Vis Island, the natural reef of Cape Stupišća, where benthic communities and fish assemblage were investigated in the period September-October 2020.

In Table 1 a summary of the case studies main characteristics and the list of actually performed monitoring activities is presented. It should be noticed that few modifications have been introduced to what was planned in WP3.4 (i) to reflect case study specifics which became evident after the preliminary surveys, (ii) to address unexpected situations occurred during practical operations at sea. The covid-19 pandemic is also to be taken into account among the unforeseen factors, having caused delays in the delivery of some instruments and the delay or cancellation of some monitoring activities planned for the winter season.

In this report a comparison of the results for the key parameters monitored in all case studies is reported (i.e. geomorphological mapping, water column parameters, water currents, benthic and fish communities). An insight will be given on additional investigations performed only at some locations (e.g. contaminants in seawater, sediment or biota, mussel population structure, environmental load,...), which were selected by project partners on the basis of case studies specifics.

Finally, most of the case studies selected within the Adrireef project can be considered to be representative of several other natural and artificial reefs located in the Adriatic Sea, thus ensuring the transferability of outputs to stakeholders.

Figure 1 - Map of the Case Studies in the project area (from Scanu et al., 2019).

Table 1: Main characteristics of the selected case studies and summary of performed monitoring activities.

Case study	**Trezza San Pietro**	**Paguro wreck**	**Porto Recanati - Porto Potenza Picena**	**Torre Guaceto Marine Protected Area**	**Plićina Konjsko**	**Plić Lagnjići**	**Vis Island Plić Seget**
CS code	**TSP**	**PAG**	**RPP**	**TGU**	**KON**	**LAG**	**SEG**
Reef typology	Natural	Artificial	Artificial	Natural	Natural	Natural with shipwreck	Natural
Reef category	Patch reef (sand bottom with small reef structures protruding from the sediment)	Sunken jack-up drilling rig + additional decommissioned structures	Specifically designed concrete modules geometrically assembled to form structures and concrete poles	Low profile reef and patch reef	Low profile reef (the reef protrudes less than 20 meters from the base substratum)	Sand bottom with reef structures protruding from the sediment	Patch reef (sand bottom with small reef structures protruding from the sediment)
Distance from the coast	8.7 km	20 km	5.6 km	2 km	200 m	1 km	2.8 km
Max depth	17 m	31 m	14 m	29 m	18 m	20 m	80 m
Extension	9850 m^2	0.66 km^2	0.55 km^2	6700 m^2	0.18 km^2	0.60 km^2	0.32 km^2
Time of monitoring	from Nov 2019 to Sept 2021	from June 2019 to July 2021	from June 2019 to June 2021	from June 2019 to July 2021	from Sept 2019 to May 2021	summer 2019 spr./sum. 2020 spr./sum. 2021	June 2020 June 2021

Geomorphological mapping	●	●	●	●	●	●	●
Water currents	●	●	●				
Water column parameters	●	●	●	●	●	●	●
Nutrients		●	●	●	●	●	●
Contaminants in water					●	●	●
Contaminants in sediment		●			●	●	●
Benthic community	●	●	●	●	●	●	●
Fish assemblage	●	●	●	●	●	●	●
Additional investigated parameters		Fouling community volume trough Photogrammetry	Contaminants in biota; Mussel population structure; Photogrammetry		Environmental load; Maritime traffic; Garbage quantities and type; Impact of lost fishing gear.	Environmental load; Impact of lost fishing gear.	Environmental load; Garbage quantities and type.

2. INVESTIGATED PARAMETERS: ADVANTAGES OF THE TESTED MONITORING TECHNIQUES AND COMPARISON OF RESULTS

2.1. Geomorphological mapping

As already summarized in WP3.4 final report (Montagnini et al., 2019), seabed characterization is fundamental to evaluate extension, morphological features and integrity of a reef, producing a valuable base for geomorphological and environmental analysis. In the case of reefs this monitoring method is also useful to verify eventual environmental changes on the adjacent seafloor and on the hard substrates (e.g. subsidence, sediment accumulation, texture, bio-constructors) and, as for artificial reefs, some of those changes which can also affect the physical performance of the reef structures.

During the monitoring phase, geomorphological mapping was carried out at all 7 selected case studies using different technologies. The methods used were non-destructive: acoustic measurements were done using multibeam echosounder and/or side-scan sonar, efficient tools which allow to evaluate the physical performance of reefs without creating any disturbance to the environment. These systems were coupled to other investigation methodologies (e.g. ROV, underwater drones, underwater Structure from Motion photogrammetry, scuba diving) for a variety of purposes. In general, the used technologies proved to be adequate for carrying out a preliminary survey of the study area, aimed at identifying the best spots where more detailed monitoring had to be conducted. Additionally, some of the produced outputs were made available to the wider public in order to increase their awareness of the project results (e.g. interactive maps to be made available online, detailed maps for fishers,...). Carried out activities and achieved goals are summarized in Table 2.

Details on the specific equipment used can be found in the case study final reports (Borme et al, 2021; Mazziotti et al., 2021; Fabi et al., 2021; Barbone et al., 2021; Cackovic et al., 2021a; Pejdo et al., 2021; Cackovic et al., 2021b).

Table 2: Summary of the methodologies used for geomorphological mapping at the selected case studies, including additional performed investigations and goals achieved.

CS code	Applied methodology	Additional investigations	Area covered by survey	Time of survey	Output	Goals achieved
TSP	Multibeam echosounder Reson Seabat 7125	Scuba diving	2 km^2	Sept 2020	Bathymetric map and 3D views of the "San Pietro" outcrop area	Obtained results deepen the knowledge on the "San Pietro" outcrop, widening the areas previously mapped in the context of other research projects (e.g. Interreg TRECORALA). Geomorphological description of the area giving information on sea floor depth range and slope, as well as spatial distribution, morphology and dimensions of the rocky outcrops.
PAG	Multibeam echosounder Reson Seabat 8125	Structure from Motion photogrammetry	0.66 km^2	Aug 2020	Bathymetric map and 3D views of the SCI IT-4070026 Online interactive 3D point cloud of scanned wreck	Detailed morphological description of the SCI area, with particular focus on the central sector where the artificial reef is located. Interactive map made available online as a tool for a wider audience, including diving centres/scuba divers and research institutions.

RPP	Multibeam echosounder Kongsberg EM2040CD		1.25 km^2	Dec 2018 Dec 2020	Bathymetric map Map for fishers	Detailed morphological description of the artificial reef area, including morphological changes occurred over the monitoring years (2019-2020). Characterization of the artificial reef in terms of compliance with the original drawing and evaluation of its structural integrity. Outputs used for planning other investigations and in particular: the continuous water monitoring, by identifying the best location to fix the oceanographic buoy, the visual census and 3-dimensional reconstruction samplings, by identifying 3 suitable sub-areas within the reef. Detailed map of the northern part of the AR produced and distributed to fishers in order to enhance their awareness of the project results.

TGU	Multibeam echosounder from previous BIOMAP project	Scuba diving	0.02 km^2	Aug 2019	Bathymetric maps 2D/3D views of the reef in Q-Gis	Identification of the best spot with coralligenous bio-constructions to be selected as case study, according to the required needs for benthic and fish communities monitoring. Better definition of the morphological features of the selected area.
KON	Side-scan sonar Humminbird Solix 12 CHIRP MSI+ GPS G2	Underwater drone Scuba diving	0.18 km^2	Summer 2019 Spring 2020	Bathymetric maps 2D/3D views of the reef Sea bottom hardness and vegetation maps Sonar images of different sections of the site Video recording and pictures of the reef	Complete geomorphological mapping of the reef and seabed, including depth contour, hardness and vegetation maps used to identify the best spot to be selected as case study. The acquired equipment was used also for specific monitoring activities (e.g. fish assemblage, garbage quantity and type).

LAG	Side-scan sonar Humminbird Solix 12 CHIRP MSI+ GPS G2	Underwater drone	0.60 km^2	June 2019 Aug 2020	Bathymetric maps 2D/3D views of the reef Sea bottom hardness and vegetation maps Video recording and pictures of the reef	Complete geomorphological mapping of the reef and seabed used to identify the best spot to be selected as case study, based on integrity and biological colonization of the site.
SEG	Side-scan sonar Humminbird Solix 12 CHIRP MSI+ GPS G2	Underwater drone	0.32 km^2	June 2020	Bathymetric maps 2D/3D views of the reef	Complete geomorphological mapping of the reef and seabed. The acquired equipment was used also for other specific monitoring activities (e.g. fish assemblage, garbage quantity and type).

2.2. Water column parameters

Measurements of physico-chemical parameters in the water column at selected case studies were carried out at different temporal and spatial scales by (i) fixed near-real time oceanographic observing systems and (ii) by using CTD multiprobes during oceanographic campaigns. Water samples for additional analysis of nutrients, chemical contaminants and microbiological parameters were sampled at the surface and/or bottom layers using buckets/Niskin bottles.

The set up of oceanographic buoy systems for the continuous monitoring of some physico-chemical parameters along the water column with the associated application to transfer the data in real-time has proven to be extremely useful to get a full understanding of the hydrodynamics of the area investigated and to plan other monitoring activities (Fabi et al., 2021). Oceanographic buoy systems were deployed at Case Studies Porto Recanati-Porto Potenza Picena and Trezza San Pietro. Only in Porto Recanati-Porto Potenza Picena the data were disseminated in near-real time to a wider public through dedicated free accessible dashboards, thus allowing other users (e.g. divers, recreational and professional fishers, sailors) to potentially plan in advance their activities. The development of these systems required several steps and was not without difficulties and accidents. In Porto Recanati-Porto Potenza Picena the buoy was deployed in July 2020 and recovered in October 2020 to avoid the risk of damages or loss due to winter storms. Later it was positioned again in May 2021. In Trezza San Pietro, the buoy was stranded by a strong storm in October 2020 after being seriously damaged. The project was fulfilled in August 2021 and data are available for the period August - September 2021. Moreover, turbidity sensors suffered from biofouling which partially prevented their correct functioning. For these reasons, oceanographic buoy systems for continuous monitoring represent a promising technological innovation in the collection of hydrological and water column parameters, nevertheless the characteristics of the deployment site should be carefully evaluated.

Investigated water column parameters were used to describe the general environmental features of the study sites, as well as to evaluate their trophic status in relation to anthropogenic pressures. Project partners discussed in detail those variables potentially affecting Blue economy activities proposed for the specific case study sites (e.g. adequacy of temperature and turbidity during the year for scuba divers).

Table 3 gives an overview of the methods used to collect water column parameters. Details are given concerning number of monitored stations, depths, list of investigated parameters, sampling frequencies.

Table 3: Overview of the methods used to collect water column parameters. Details are given concerning number of stations, depths, investigated parameters, sampling frequencies. ND: not done; NA: not applicable.

CS code	Oceanographic buoy with sensors	Collected parameters	Frequency	CTD multiprobe	Collected parameters	Frequency	Bucket/Niskin bottle	Analysed parameters	Frequency
TSP	1 station surface, 10 and 17 m (bottom depth)	Temperature Salinity Oxygen Turbidity pH Fluorescence	Continuous from Aug-Sept 2021	1 station vertical profiles 0-15 m depth (data acquired from ARPA-FVG)	Temperature Salinity Oxygen Turbidity Chlorophyll pH Conductivity PAR	Monthly from Nov 2019 to Feb 2021	ND	NA	NA
PAG	ND	NA	NA	1 station vertical profiles 0-26 m depth	Temperature Salinity Oxygen Turbidity Chlorophyll pH	Approx. monthly from June 2019 to March 2021	Surface Bottom	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate Total N and P	30/07/2019 23/10/2019 22/01/2020 25/05/2020 27/08/2020 19/10/2020 25/03/2021
RPP	1 station 3.2 m depth	Temperature Salinity Oxygen Turbidity	Continuous July-Oct 2020 May 2021 - ongoing	7 stations vertical profiles 0-15 m depth	Temperature Salinity Oxygen Turbidity Chlorophyll	22/10/2020 20/01/2021 11/05/2021 22/06/2021	Surface Bottom	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate	22/10/2020 20/01/2021 11/05/2021 22/06/2021

TGU	ND	NA	NA	1 station vertical profiles 0-33 m depth (belongs to WFD monit. network)	Temperature Salinity Oxygen Turbidity Chlorophyll pH	Approx. every two months from Feb 2019 to Nov 2020	Surface Bottom	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate Total N and P	Approx. every two months from Feb 2019 to Nov 2020
KON	ND	NA	NA	1 station vertical profiles	Temperature Salinity Oxygen pH fDOM	27/05/2020 09/09/2020 26/02/2021 26/05/2021	Surface	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate TOC	13/09/2019 27/05/2020 09/09/2020 26/02/2021 26/05/2021
LAG	ND	NA	NA	1 station vertical profiles 0-14 m depth	Temperature Salinity Oxygen pH fDOM	29/01/2020 02/06/2020 06/08/2020 09/09/2020	Surface	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate TOC	29/01/2020 02/06/2020 06/08/2020 09/09/2020
SEG	ND	NA	NA	1 station vertical profiles 0-32 m depth	Temperature Salinity Oxygen pH fDOM	18/06/2020 26/06/2021	Surface	Nitrate Nitrite Ammonium Orthophosph. Orthosilicate TOC	18/06/2020 26/06/2021

Figures 2-5 show seasonal vertical profiles of temperature, salinity, turbidity and dissolved oxygen at the case study sites between winter 2019 and spring 2021. Graphical elaboration is based on raw data provided by project partners. One vertical profile per case study (if available) was selected for each season. In Trezza San Pietro and Porto Recanati - Porto Potenza Picena, data collected through oceanographic cruises agreed, in overall, with the values recorded in continuous by the sensors mounted on the buoys. For this reason, only data collected during oceanographic cruises were selected for comparison purposes.

Temperature

Natural winter cooling of seawater followed by spring-summer heating was observed during the survey period at all monitoring sites (Fig. 2). Surface temperatures were minimum in winter, being in the range 6-13°C, and maximum in summer, range 24-28°C. In most case studies there were no significant differences between surface and bottom temperatures. Water column stratification was more pronounced at Paguro wreck, both in summer 2019, when the surface values were 11°C warmer, and in winter 2020, when surface values were 7°C colder than in the bottom layer. In general, seawater temperatures are suitable for scuba diving from spring to autumn, since they fall below 15°C only during the winter season.

Salinity

Salinity values were more stable and homogeneous along the water column throughout the study period (Fig. 3). Few exceptions were registered at Paguro wreck, Trezza San Pietro and Porto Recanati-Porto Potenza Picena, where the effect of freshwater river inputs are more evident. During spring, autumn and winter seasons, surface seawater at these three case study sites reached minimum salinity values: 22.4 psu at Paguro wreck in autumn 2019; 27.8 psu at Trezza San Pietro in spring 2020; 27.2 psu at Porto Recanati-Porto Potenza Picena in winter 2021. Highest salinity was generally observed in Torre Guaceto Marine Protected Area, with a maximum surface value of 38.8 psu registered during summer 2020.

Turbidity

Turbidity data are available only for Italian case studies (Fig. 4). During the study period mean turbidity values along the water column varied between 0.5 and 7.3 NTU. At the surface level the maximum value of 7.2 NTU was recorded in Torre Guaceto in winter 2019, while at the bottom layer the maximum values were all recorded at the Paguro wreck (11.7 NTU in autumn 2019, 10.7 NTU in winter 2020, 10.6 NTU in spring 2020). In general, higher turbidity was observed near the bottom where mixing processes are active. Case study sites can be explored by scuba divers with acceptable satisfaction for most part of the year, especially from spring to autumn. Poor visibility was occasionally reported to represent a limiting factor for specific monitoring activities during the study period (Mazziotti et al., 2021; Fabi et al., 2021).

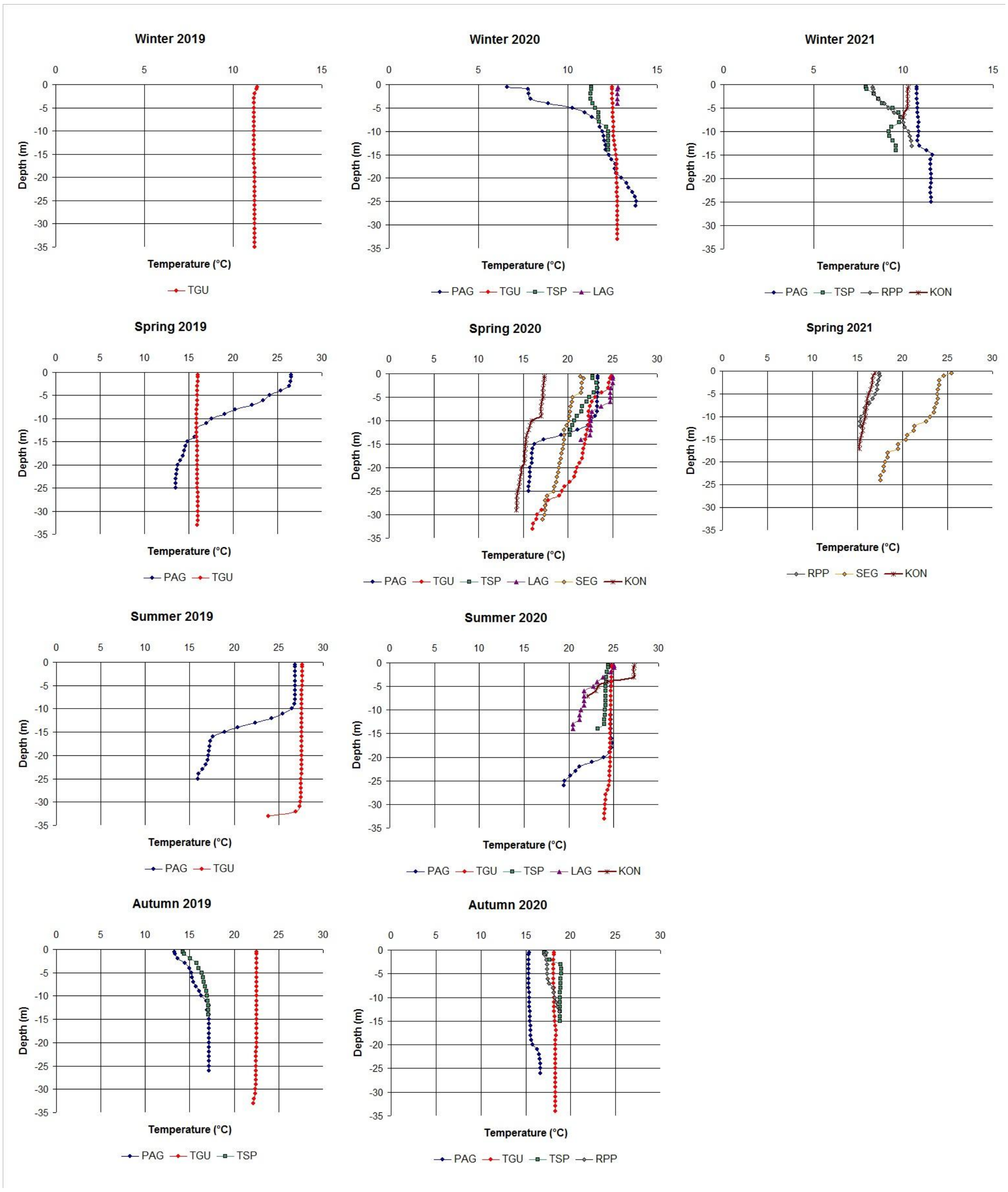

Figure 2: Seasonal temperature vertical profiles at case study sites from winter 2019 to spring 2021.

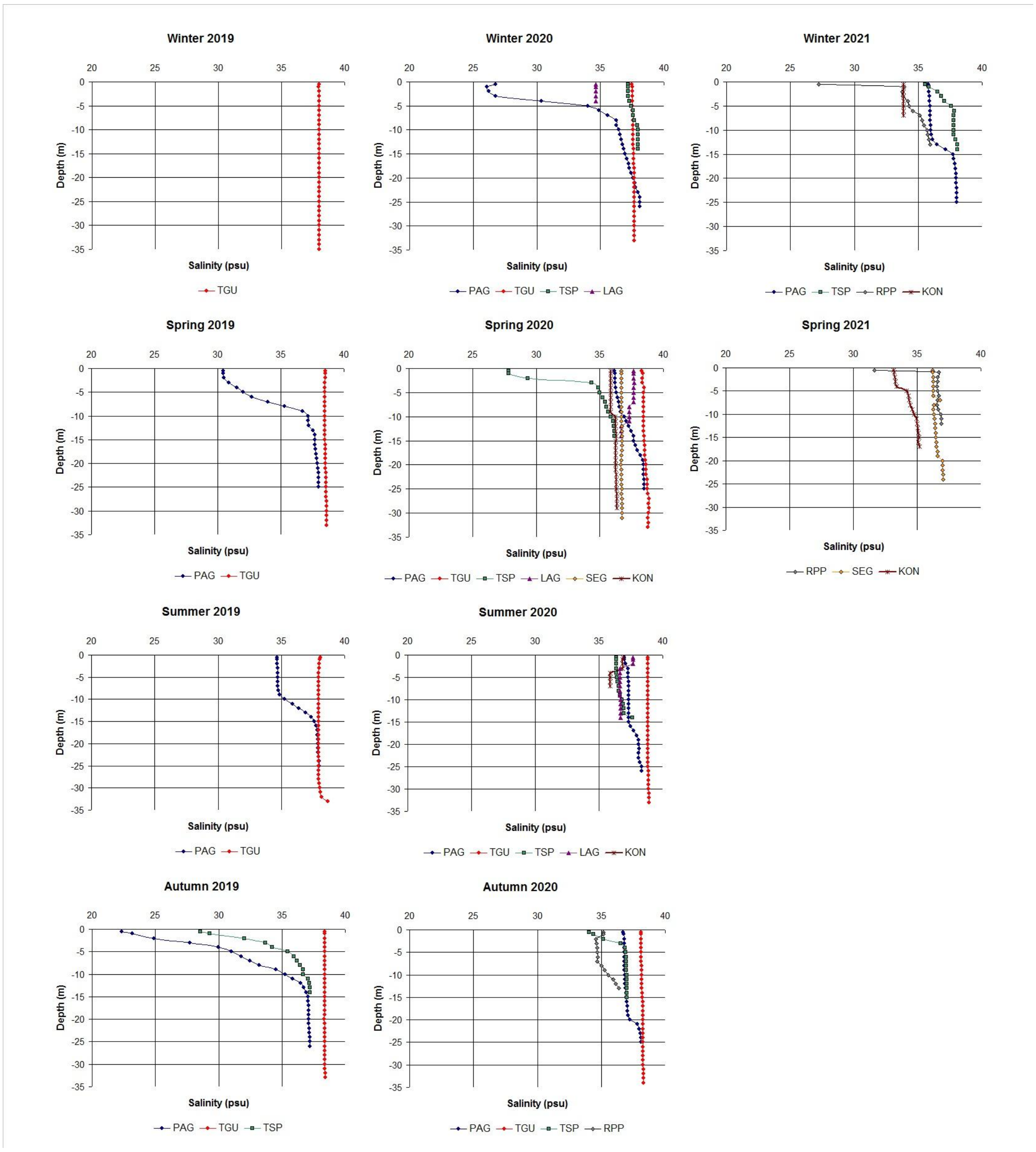

Figure 3: Seasonal salinity vertical profiles at case study sites from winter 2019 to spring 2021.

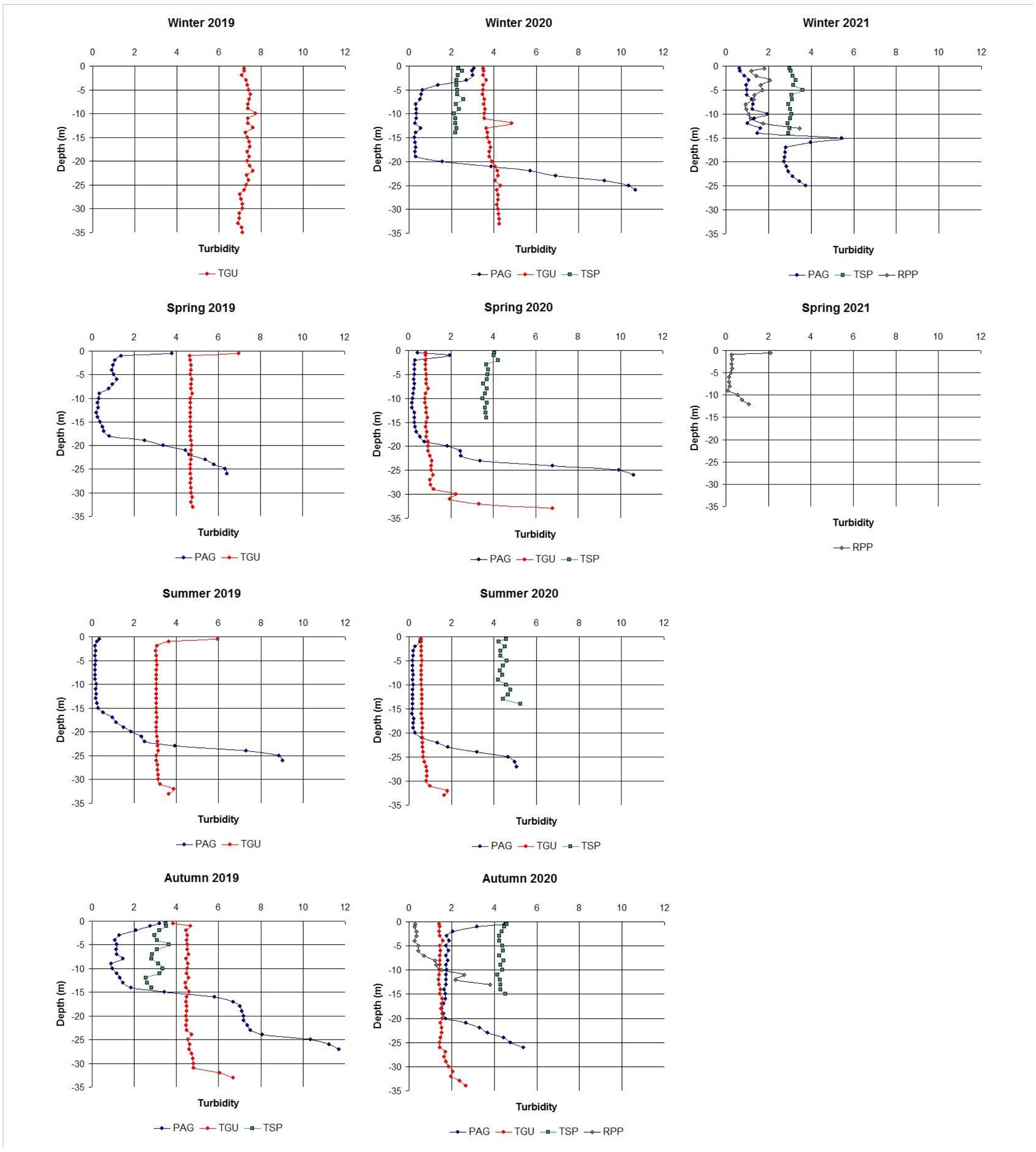

Figure 4: Seasonal turbidity vertical profiles at case study sites from winter 2019 to spring 2021.

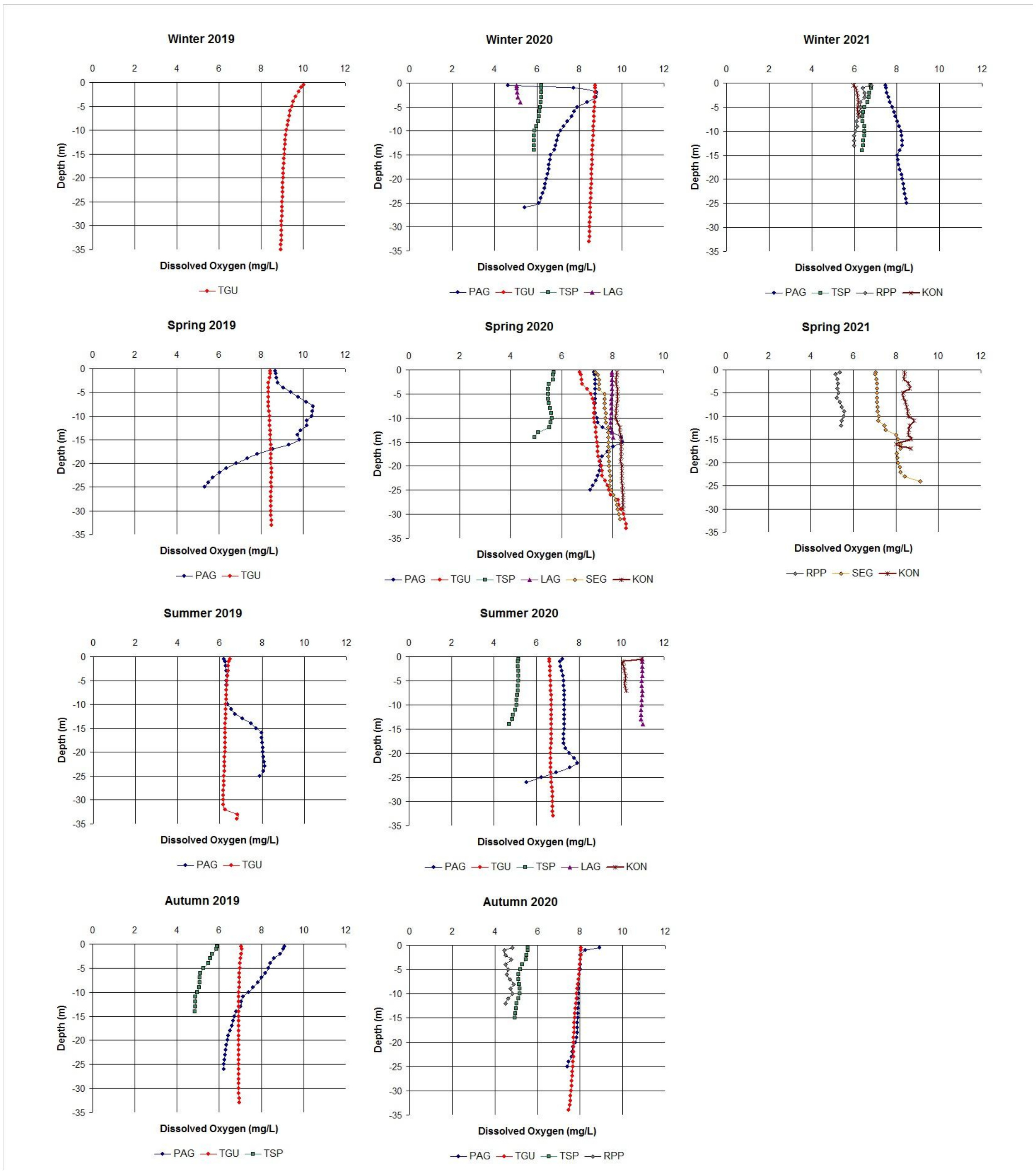

Figure 5: Seasonal dissolved oxygen vertical profiles at case study sites from winter 2019 to spring 2021.

Dissolved oxygen

The vertical dissolved oxygen profiles related to the considered case studies were quite heterogeneous (Fig. 5). In general, the water column was well oxygenated and hypoxic conditions of the bottom layer were only occasionally reported by project partners (Mazziotti et al., 2021).

Nutrients

Nutrients concentration values recorded at case study sites are reported in Table 4. Results are not available for Trezza San Pietro. Only surface data at one monitoring station per case study are shown and discussed.

Ammonium values varied from below the limit of quantification (<LOQ) to 2.43 µM; nitrites from <LOQ to 0.80 µM; nitrates from <LOQ to 20.78 µM; orthophosphates from <LOQ to 0.21 µM; orthosilicates from <LOQ to 26.40 µM. On average, nitrites, nitrates and orthophosphates were higher along the Adriatic western coast, while ammonium and orthosilicates were higher along the eastern one.

NO3 is the most abundant nitrogen form almost anywhere in each season, because autotrophic organisms tend to prefer NH4, NO2 and NO3, in strict order. Nitrates maxima are close to the Po river delta (PAG) and south of it (RPP) and are thus linked with river discharge. The season with highest nitrites and nitrates concentrations is winter.

Values of orthophosphates at the surface are very low almost everywhere, but in the proximity of the river Po, due to the amount of river discharge.

Orthosilicates concentrations are larger than other nutrient salts, reaching higher values in the eastern Adriatic region.

Overall, project partners described the recorded nutrients values as typical for the studied areas, which can be considered in a good trophic state with few exceptions.

Table 4: Nutrients concentrations (surface values) at case study sites. NA: not applicable.

CS code	Date	SiO4 (µM)	Ntot (µM)	NH4 (µM)	NO2 (µM)	NO3 (µM)	Ptot (µM)	PO4 (µM)
PAG	30/07/2019	2.52	6.32	0.39	0.06	0.30	0.19	0.06
PAG	23/10/2019	0.29	5.15	0.13	<0.004	<0.05	0.14	<0.02
PAG	22/01/2020	9.33	33.50	0.11	0.80	20.78	0.60	0.21
PAG	25/05/2020	3.72	4.70	<0.01	0.04	0.18	0.32	<0.02
PAG	27/08/2020	1.42	9.77	<0.01	0.01	<0.05	0.23	<0.02
PAG	19/10/2020	7.88	11.44	0.06	0.15	5.39	0.71	0.17
PAG	25/03/2021	3.08	18.68	0.05	0.17	2.77	0.58	<0.02
RPP	22/10/2020	4.72	NA	0.17	0.60	3.95	NA	0.03
RPP	20/01/2021	2.21	NA	0.02	0.33	9.92	NA	0.10
RPP	11/05/2021	4.53	NA	0.19	0.12	2.57	NA	0.05
RPP	23/06/2021	2.50	NA	0.02	0.02	0.02	NA	0.03
TGU	19/02/2019	2.24	3.88	NA	0.26	1.28	0.19	NA
TGU	02/05/2019	1.00	3.52	0.64	<0.07	1.10	<0.18	<0.18
TGU	29/08/2019	1.00	4.49	1.03	<0.07	1.35	<0.18	<0.18
TGU	14/10/2019	<0.71	9.47	<0.36	<0.07	<0.18	<0.18	<0.18
TGU	16/12/2019	1.03	17.95	<0.36	<0.07	<0.18	<0.18	<0.18
TGU	31/01/2020	<0.71	18.34	<0.36	0.43	1.28	<0.18	<0.18
TGU	13/05/2020	1.14	37.96	0.64	0.11	<0.18	0.82	<0.18
TGU	30/06/2020	<0.71	7.09	0.43	0.21	<0.18	<0.18	<0.18
TGU	23/07/2020	<0.71	5.20	<0.36	0.07	0.18	<0.18	0.18
TGU	14/10/2020	1.50	3.74	0.43	0.11	<0.18	1.46	<0.18
TGU	13/11/2020	1.03	6.59	0.50	0.11	0.32	1.03	<0.18
KON	13/09/2019	26.40	NA	1.50	0.34	8.30	NA	0.04
KON	27/05/2020	4.00	NA	0.84	0.05	1.41	NA	0.04
KON	09/09/2020	2.79	NA	1.37	0.23	2.31	NA	0.02
KON	26/02/2020	2.27	NA	0.80	0.03	0.73	NA	0.03
KON	26/05/2021	4.18	NA	2.43	0.24	3.34	NA	0.03
LAG	29/01/2020	4.13	NA	0.70	0.09	0.58	NA	0.04

CS code	Date	SiO4 (µM)	Ntot (µM)	NH4 (µM)	NO2 (µM)	NO3 (µM)	Ptot (µM)	PO4 (µM)
LAG	02/06/2020	11.59	NA	1.16	0.06	1.57	NA	0.06
LAG	06/08/2020	12.92	NA	0.08	0.08	2.08	NA	0.07
LAG	09/09/2020	13.21	NA	1.11	0.09	2.54	NA	0.08
SEG	18/06/2020	8.32	NA	0.91	0.05	0.67	NA	0.05
SEG	26/06/2021	6.27	NA	0.80	0.03	0.73	NA	0.03

2.3. Water currents

Currents speed and direction were recorded at three case studies, i.e. Trezza San Pietro, Paguro wreck, Porto Recanati-Potenza Picena using Acoustic Doppler Current Profilers (ADCP).

The ADCP instrument measures the reflection of an acoustic signal from particulate matter drifting in the water column. The amplitude is the strength of the return signal for each beam and it decreases with the distance from the instrument, establishing that way the maximum usable range (Borme et al., 2021). In Trezza San Pietro and Porto Recanati-Porto Potenza Picena, the ADCP had been fixed to the oceanographic buoy system at a fixed depth (at 2 and 3.5 m depth respectively) and installed downlooking. Conversely, at the Paguro wreck, the ADCP was positioned on the seabottom at a depth of 26 m and was uplooking. At all sites, ADCPs were programmed with 1 meter wide cells where the currentometers were measuring the current by means of acoustic signals. Speed, direction and amplitude data were stored as raw data for each of the cells.

At Trezza San Pietro, installation of the ADCP, which had to be fixed to the oceanographic buoy MAMBO 2, encountered a lot of difficulties and accidents. The purchasing of all electronic components was more time consuming than expected. Later, due to the Covid-19 pandemic constraints, it was impossible to reach the buoy, perform routine maintenance and implement the tools foreseen for the project purposes. After that, in October 2020, the buoy was stranded by a strong storm and it was seriously damaged, without the possibility of being repaired in a short time. Finally, the complete system was deployed in summer 2021 and data on intensity and direction of currents along the water column were registered and transmitted since 29 July 2021 (data shown and discussed for the period August-September 2021 in Borme at al., 2021).

At Porto Recanati, ADPC data are available from July 2, 2020 until October 22, 2020 when the buoy was recovered to avoid the risk it could be damaged or lost due to the winter storms. It was positioned again at sea on May, 26 2021 and data are shown and discussed until July, 25 2021 in Fabi et al., 2021.

At the Paguro wreck the ADCP data were successfully collected over one year from July 2020 to June 2021, with only a short break from November 28 to December 18, 2020 due to instrument maintenance. The ADCP is currently still operational at the case study site.

Both in Trezza San Pietro and Porto Recanati-Porto Potenza Picena, data were transferred at land in real time, while at the Paguro wreck data were collected and analysed every 6 months.

Collected data on speed and direction of water currents are discussed in detail in the Case Studies final reports (Borme et al., 2021; Fabi et al., 2021; Mazziotti et al., 2021). As far as the speed of the currents is concerned, only occasionally high peaks have been recorded which could hinder the regular development of the economic activities foreseen for the CSs.

During the investigated period, in Trezza San Pietro, the intensity of the currents was on average below 20 cm s^{-1} along the whole water column. Only occasionally, at depths of 7-8 m or more, peaks were recorded that reached 40-50 cm s^{-1}.

As far as the Paguro wreck is concerned, weather and sea conditions of greater importance were listed as follows: in the period 20-23 July 2020, the current reached a speed of 40 cm s^{-1} in a depth range between 10 and 20 meters, with a peak of 45 cm s^{-1} at 20 meters depth; on 11 October 2020, currents of 50 cm s^{-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 60 cm s^{-1}. In this case, the detailed study of extreme weather and sea conditions could be useful not only to provide useful information to divers and diving centers, but also to analyse those phenomena that may have repercussions on the integrity of the submerged structures.

Finally, in Porto Recanati-Porto Potenza Picena, during the investigated period it was possible to carry out underwater activities in a comfortable way (surface current <20 cm s^{-1}). Only in the occasion of particular sea and weather events the superficial current exceeded the value of 50 cm s^{-1}. However, this appeared to be quite infrequent (7 events during 2020) and had relatively low duration, lasting on average from 12 to 24 hours.

2.4. Benthic community characterization

One of the goals of the Adrireef project WP4 was the evaluation of the biological status of the reefs in terms of species assemblages. Research on the faunal component and macroalgae on hard substrates is important to assess the ecological role of a reef (Falace and Bressan, 1996) as well as studies on functional diversity can be used to investigate the effects of different anthropogenic disturbances on the functioning of marine systems (Diaz and Cabido, 2001). Studies can be also linked to some ecological and biological characteristics of the species such as feeding mechanisms, longevity, body size and mobility to verify eventual changes that could affect communities exposed to stressors such as sewage pollution (Poore and Kudenov, 1978; Grizzle, 1984), anoxia (Beukema et al., 1999) and fishing (Brown and Wilson, 1997; Ramsay et al., 1998; Bremner et al., 2003).

On the other hand, such information that analyzes biodiversity (intended as ecosystem processes, functional traits, biophysical structures, genetic and species diversity, biotic interaction) and their function are useful to evaluate the ecosystem services and related socio economic well-being and values.

Indeed reef may regulate ecological functions of benthic ecosystems from shallow to deeper waters providing a complex network of ecological niches for a large variety of organisms, including endangered and protected species, as well as species of high commercial value (Ingrosso et al., 2018), functioning as habitat for shelter and feeding, spawning and nursery areas, substrata for both larval settlement and juvenile growth (e.g. Tursi et al., 2004; D'Onghia et al., 2010, Seitz et al., 2014). Moreover reefs increase spatial complexity and settlement opportunities playing a pivotal ecological role and enhancing and maintaining high marine biodiversity contributing to ecosystems' goods and services (Boero and Bonsdorff, 2007).

At Adrireef case studies different approaches were used to evaluate benthic biodiversity.

In the area of the Case Study **Trezza San Pietro**, benthic analyses were based on photographic samplings of the macrobenthic community taken both with free technique and with the use of a standard frame for the photodetection of epibenthic flora and fauna. Photographic samplings of fixed frame areas at georeferenced points were performed at different geographic exposition and substrata inclination. The images were analysed with Image Analysis systems considering coverage and species number.

A total of 66 taxa were found on Trezza San Pietro during the winter and summer surveys of which 26 Porifers, 4 Cnidarians, 5 Bivalves, 8 Gastropods, 3 Polychaetes, 3 Crustaceans, 2 Echinoderms, 12 Ascidiaceans. In winter the bivalve *Rocellaria dubia* was the most present in the replicates, but the greatest coverage was due to the sponge *Aplysina aerophoba*. In summer the most present species was the sponge *Chondrosia reniformis* together with undetermined Bryozoans, while the greatest coverage was due to the sponge *Mycale* sp..

Three species of bivalves (*Arca noae*, *Mimachlamys varia* and *Ostrea edulis*) and a sponge (*Spongia officinalis*) are of commercial interest. Three species of sponges found are considered by the Protocol SPA Barcelona Convention: *Tethya auranthium* and *Geodia cydonium* are included in the Annex II (List of endangered or threatened species) and *Spongia officinalis* is included in the Annex III (List of species whose exploitation is regulated). The shallow depths of the rocky outcrops makes diving easy even for the beginners. Nevertheless, the great diversity of sessile fauna makes diving interesting and attractive. Thanks to the presence of cavities and interstices, these sites enhance a significant increase in marine environmental biodiversity. Taken together, these environments host benthic populations recognized as "coralligenous platforms'', but the large variability of conditions and ecological gradients makes it difficult to adopt a unique classification.

Samples of the **Paguro wreck** were collected by scuba divers by scraping off the substrate. 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 at different depth ranges and each portion was scraped twice: at the beginning of the survey and after a certain period of time. This allowed the study of the recolonization of the wreck by benthic organisms. As well as a quali-quantitative analysis of the species, 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.

As a result of the analysis, 60 taxa were identified: the 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.

In the shallow part of the wreck, the benthic community 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 major contribution in terms of biomass is given by the presence of *M. galloprovincialis*, which represents about 80-90% of the WW of the community.

At intermediate depth the most abundant taxa are the Mediterranean zoanthid *Epizoanthus arenaceus* together with encrusting sponges, the bryozoan *Scrupocellaria scruposa*, the amphipod *M. sextone* and the ophiuroid *O. fragilis*. 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 the most abundant taxa are *M. sextone*, *E. arenaceus* and encrusting sponges that include *Crambe crambe*, *Dysidea* spp. and *Spirastella* spp.. 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).

Overall, the results of this study are comparable with those obtained by Ponti et al. (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. The benthic community, thanks to a multitude of biodiversity, lends itself to diving activities, where it is possible to observe species belonging to different groups of sessile organisms such as porifera, molluscs and cnidarians. This rich assemblage results as a unique environment in the area where it is located. In fact, it is one of the few hard bottom locations in the area with a structural complexity of the system. The presence of a well developed benthic population also represents a feeding source for reef-dwelling fish with a consequent enrichment of the fish assemblage.

At site several innovative mapping and monitoring technologies and methods were tested. Underwater photogrammetry was successfully carried out for both mapping large areas of the wreck and executing highly detailed 3d reconstruction of small surfaces aiming at: i) generate a large 3D map of the most representative benthic communities, ii) create a three dimensional model of the site as reference for the ongoing modifications caused by the sea corrosion, iii) estimate the volume occupied by the fouling community at different depths which has an effect of the dragging resistance of the structure to water currents. The photogrammetric monitoring was overall successful but significantly limited by the sea water conditions. In fact at site, the water horizontal visibility is frequently very low (< 1m) and the deeper areas (<-25 m) in close proximity of the bottom present a continuous layer of very low visibility (<0.3 m) where no good quality images were successfully collected over the monitoring.

The investigations aimed to describe the benthic colonization at **Porto Recanati-Porto Potenza Picena** were focussed on the concrete pyramids of the artificial reef. The samples were collected during June and July of each year from 2019 to 2021 by scuba divers. The photos were analyzed using an Image Analysis software in order to investigate taxa composition and average coverage. Since no living specimens were collected, the identification at species level was only possible for a few taxa. The percentage of living habits and the percentage of each taxon found in the overall sampling period in the areas were calculated to estimate the community composition and main living habits. Moreover, the structure and distribution of the mussel (*Mytilus galloprovincialis*) population settled on the artificial substrates was also investigated.

In total, 32 taxa were found during the whole sampling period; 56% of the taxa were colonials and 34% were solitaries. Bryozoa and Porifera represented the most numerous taxonomic groups, each contributing to 19% of the total number of taxa, followed by Anthozoa (16%), Crustacea (9%), Gastropoda (6%), Bivalvia (6%), Polychaeta (6%), Ascidiacea (3%), Hydrozoa (3%), Echinodermata (3%) and other taxa (each < 1%).

The species *Mytilus galloprovincialis*, *Epizoanthus* sp., Schizoporelloidea nd., and *Hydrozoa* nd. were more abundant in 2019, while Porifera nd. and Algae nd. in 2020. Moreover *Mytilus galloprovincialis* and Algae nd., indeed, were the taxa that mostly contributed to the composition of the benthic population on the horizontal surfaces, while *Epizoanthus* sp., Hydrozoa nd. and Schizoporelloidea nd. mostly populated the vertical surfaces of the investigated structure. The data processed on the populations *Mytilus galloprovincialis* showed that the population of mussels settled on the surfaces may lead to a final commercial biomass of 33.8 Kg/m^2.

Overall, the coverage data show a good colonization of the structures by benthic taxa. The occurrence of a diversified community, similar to that settled on natural rocky bottoms, as well as the presence of species of interest make the artificial substrates attractive for scuba divers. Moreover, the presence of a benthic population represents a feeding source for the fish community, which makes the area also suitable for the recreational and professional fisheries.

In the **Torre Guaceto** Marine Protected Area, a photographic sampling of standard area frames was used to evaluate the biological status of the reefs in terms of species assemblages and coverages, with a stratified sampling that took into account the north-south gradient and the inclination of the reef.

Four scientific surveys were carried out, two in the autumn period and two during the summer season with a total of 72 photographic samples collected, on which the analyzes were carried out. In order to estimate the coverage of the benthic community an image analysis software has been used. Moreover, the possible benthic ASPIM species present in the study site were also recognized.

The image analysis of photographic samples acquired for the evaluation of the benthic communities gave as a result the identification of 61 taxa. The most represented taxa were the red macroalgae (Rhodophyta) of the genera *Peyssonnelia* and *Mesophyllum*, considered as the main builders of the coralligenous bioconstructions. Moreover, filamentous algae, the so-called "Turf", were the second group recognized, mostly in the images from the summer surveys. Porifera was the third phylum most represented in the reef with 23 different taxa. Most of them are erected species as *Axinella cannabina*, *A. damicornis* or *A. polypoides*.

Another commonly recorded porifera is the encrusting *Spirastrella cunctatrix*. Several erected Briozoa were also identified, the most common *Myriapora truncata* and *Pentapora fascialis*. As regards the Cnidaria, *Parazoanthus axinellae* and *Leptopsammia pruvoti* have been recognized in the analysis. The green algae *Caulerpa cylindracea* is the only alien species recognized while among the ASPIM species *A. polypoides*, *A. cannabina*, *Sarcotragus foetidus* and *Spongia (Spongia) officinalis* have been found.

Moreover, the greatest number of identified individuals was recorded with the video transect methods, video camera ROV and the video camera held by the divers. Overall in the study case area a total of 17 ASPIM species have been identified: A*xinella cannabina, Axinella polypoides, Cladocora caespitosa, Hippospongia communis, Paracentrotus lividus, Sarcotragus foetida, Spongia agaricina, Spongia officinalis, Caryophyllia (Caryophyllia) smithii, Eunicella singularis, Eunicella cavolini, Leptopsammia pruvoti, Myriapora truncata, Muraena helena, Phorbas tenacior, Reteporella grimaldii, Sabella spallanzanii*.

The analysis of the benthic community highlights a well preserved reef characterized by numerous species typical of the coralligenous habitat bioconstruction such as calcareous algae and porifera, bryozoans, cnidarian; in particular, the sponges of the genus *Axinella* are frequent and create an environments interesting for divers. The relatively high number of ASPIM species identified could be interesting for developing some citizen science projects combining the new exploration of the MPA reefs and the diving activities. From the point of view of natural beauty, the site shows some interesting peculiarities as fine seascapes and different formations such as ravines and cavities created by the bioconstructions, very attractive for recreational diving activities.

In the coralligenous assemblages at **Lagnjići** location and **Stupišća** (Vis Island) , photosampling was done in areas of 2,5 m^2 within the same depth range. Such sampling enables further acquisition of data on the presence and abundance of target species, the structural complexity based on the cover of species/categories contributing to basal layer (including encrusting organisms, boring sponges, turf, bare rock and sediment), intermediate layer (massive or bush-like organisms below 15 cm in height), bioconcretion (through estimation of cover of encrusting calcareous algae and macroinvertebrates contributing to build up of the coralligenous outcrops) and bioerosion. Additionally, photosampling of replicates of 0.5 m^2 were done to ensure a more reliable identification of organisms together with a Visual census and video analysis along random transects.

Overall, at Lagnjići location and Stupišća a total of 99 macrobenthic taxa were identified from photographs: 26 macroalgae (9 Chlorophyta, 14 Rhodophyta, 3 Ochrophyta), 1 protozoan, 33 sponges, 10 anthozoans, 1 hydrozoan, 4 polychaetes, 1 bivalve, 1 gastropod, 12 bryozoans and 10 ascidians. Based on this photosampling effort, the highest number of taxa was recorded at Stupišće on the Vis Island (74 taxa) and the lowest at Lagnići (63 taxa). The most species rich taxonomic group was the Porifera on Lagnići location (Dugi Otok Island), while the group of algae was the richest taxonomic group at Stupišće (Vis Island).

The basal layer of coralligenous assemblage at Lagnjići site is largely dominated by encrusting Peyssonneliales, which represent the main algal builder. In the intermediate layer, *Flabellia petiolata* is the main algal contributor. Moreover, in this layer, massive sponges such as *Chondrosia reniformis*, *Aplysina cavernicola*, *Ircinia oros*, *Ircinia* sp. and category of black keratose sponges are represented. Whereas encrusting bryozoans are the main animal builders in the basal layer, branchy bryozoans such as *Myriapora truncata* and *Smittina cervicornis/Aedonella pallasi* fulfill this role in the intermediate layer. The erect layer is formed exclusively by the yellow gorgonian *Eunicella cavolini*, contributing to the upper-medium level of structural complexity. In other sites of Lagnjići green algal turf and mixed turf are also found among constituents of the basal layer. In the site of Stupišća (Vis Island) the basal layer of coralligenous assemblage is predominantly formed by encrusting coralline algae such as *Lithophyllum* and encrusting Peyssonnaliacea. Out of other algal species in the basal layer, notable is the frequency of occurrence of *Palmophyllum crassum*. Encrusting bryozoans and serpulids are the most abundant animal species in the basal layer and the main animal builders here. Sponges were rarely present in the sample. In the basal layer there was also considerable abundance of mixed algal and animal (e.g. Hydrozoans). Like the Lagnjići site, the erect layer was formed exclusively by gorgonians, both the yellow gorgonian resulting in the level of structural complexity evaluated as the upper medium to high.

To assess gorgonian population structure and conservation status, the methodology by Linares et al. (2008), developed in the Western Mediterranean and readily applied in other parts of the Mediterranean, including the Adriatic Sea (Kipson et al. 2015, Sini et al. 2015), was used. The density, size, biomass and injury rates were chosen as the main descriptors. As a result the upper distributional limit of *E. cavolini* at Lagnjići site was 20-25 m depth. In Vis Island *E. cavolini* was mainly noted from 22 m depth, although few individual colonies could be observed at 18 m depth. In addition few individual colonies of *P. clavata* were present at 26 m depth, but their greater abundance was noted from 35 m depth. In all cases, the lower distributional limit of studied gorgonian species coincided with the end of the vertical wall, which was 39-40 m at Lagnjići location and 42 /45 m depth at Vis Island.

Field activities were carried out also on the location **Konjsko**, close to the eastern side of the Krk Island.

The protocols by Garrabou, Bensoussan and Azzurro (2018) were applied in order to reveal the conservation status of surveyed populations. Target species of this protocol are the ones sensitive to climate-related stressors, are easy to identify underwater and are sufficiently abundant in the surveyed area. Sponges *Petrosia ficiformis* and *Aplysina* spp. were selected as target species as well as scleractinian solitary corals *Balanophylia europaea* and *Leptopsammia pruvoti* and the yellow cluster anemone *Parazoanthus axinellae*. Observations were made along the imaginary transect at the selected depth. Each specimen of selected species was counted and was noted if it is affected, i.e. if any tissue necrosis is present or polyps of hard coral are bleached/dead.

At the studied site, sponge *Petrosia ficiformis* was present both on the well-lit cascading walls as well as within more sciaphilic crevices and overhangs. On the location Konjsko in the bathymetric range of 12-18 m sponge *Aplysina* spp. was present within more sciaphilic crevices and overhangs, as well as on well-lit vertical walls. It was even observed on a mobile substrate, such as on the carapace of the crustacean *Maja verrucosa*. The last examined sponge in this study was *Chondrosia reniformis* and it showed excellent conservation status, with no injured or sick specimens observed at 3 m depth, nor in a depth range from 11 to 19 m. Out of target coral species, *Leptopsammia pruvoti* and *Parazoanthus axinellae*, when found, were present in sufficient abundance over a relatively small area, which made their assessment fairly straightforward. Besides sponges and corals, *Halocynthia papillosa* was the only ascidian species assessed. This species, although common, is usually present in very low density.

Out of all examined species, sponge *Petrosia ficiformis* was in the worst state, showing the highest proportion of affected specimens. The yellow gorgonian *Eunicella cavolini* was thriving in the study location, although in very low abundance.

Data comparison

SIMPER analyses were carried out to identify the taxa contributing to the similarity in the different study sites of the community's composition. Indeed, due to high variability within the monitoring data set due to different sampling approaches, study sites were classified obtaining a subset of species on the basis of a SIMPER similarity analysis (Clarke and Warwick, 2001).

To identify the percentage contribution of each taxon to the observed value of the Bray-Curtis dissimilarity, SIMPER analyses, based on untransformed data matrix were done with a cut-off for cumulative contributions equal to 99%. For each sampling site a subset of species were selected by SIMPER representing the species that contribute in similarity in terms of percentage and reflect the faunistic characteristics of the sampling sites. The subset of species were ordinated using principal coordinate (PCO) analyses in order to generate an ordination of the similarity of benthic communities (Bray-Curtis similarity) between study cases. Moreover, cluster analysis was performed.

The results show the similarities of the study cases according to the benthic communities sampled during the phases of the Adrireef project. Although the different study sites have been analyzed with different methods of investigation, the method of comparison carried out with the SIMPER analysis defines the main characteristics that determine the structure of the biological systems.

The SIMPER test results performed on the data matrix for each study site revealed a subset of species in terms of similarity useful to compare the structure of the communities. The results show in percentages which are the species that characterize each study site. Thus, whether coverage, abundance, or biomass was analyzed, a comparable subset of species was obtained.

As can be denoted by the data elaboration, there are biological communities with high similarity, which cluster together in the cluster analysis and in the PCO graph (Figures 6-7).

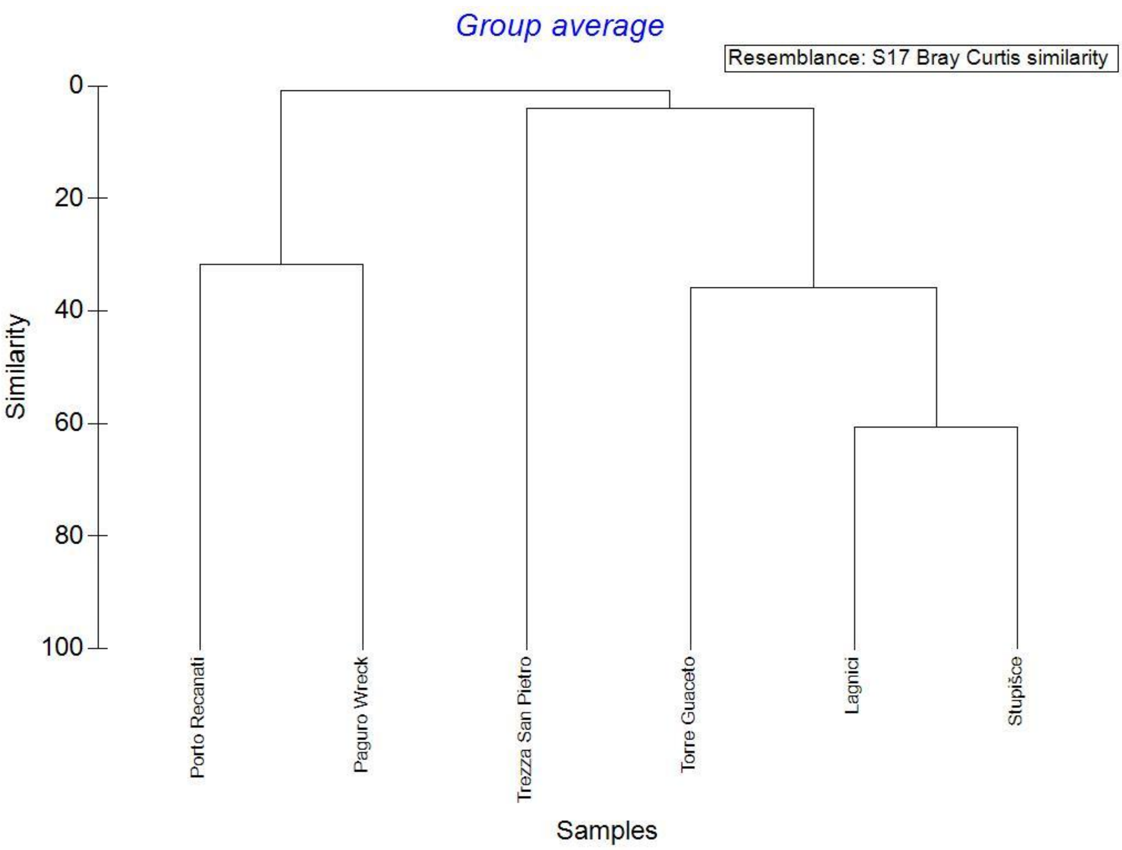

Figure 6: Cluster analysis on benthic communities of the study cases.

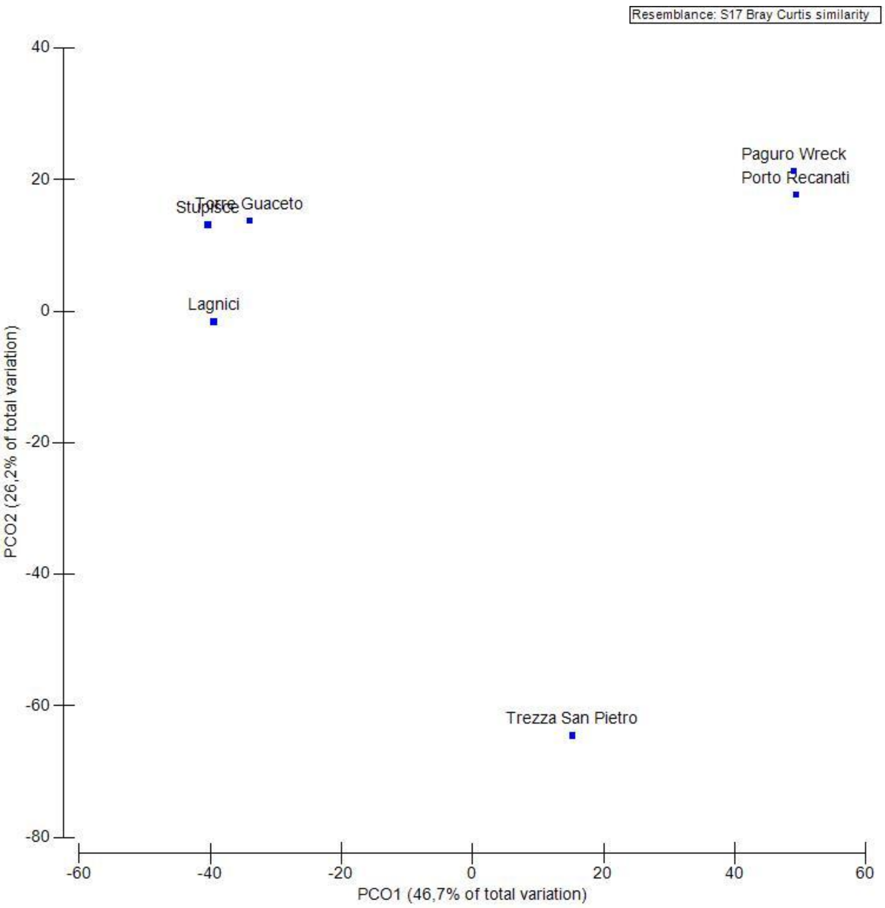

Figure 7: PCO analysis on benthic communities of the study cases.

An observable cluster in the graphical representations include the localities Torre Guaceto, Lagnjići location (Dugi Otok Island) and Stupišće sites (Vis Island). These localities are close from a biological point of view as they are characterized by coralligenous communities and hard bottoms of biogenic origin mainly produced by the accumulation of calcareous encrusting algae.

Another cluster identified includes the Porto Recanati case study and the Paguro wreck. These sites appear to have similarities in terms of the characteristics of benthic communities. Their similarity is probably due to analogous biogeographical origin of the study cases (both are located on the north western coast of the Adriatic Sea) and above all, both sites are characterized by being artificial reefs. Moreover the species that most characterize the areas are filter-feeding organisms: the most abundant and common in both sites are mussels, which, due to the high number of nutrients in the areas, are able to proliferate and create mussel facies in which a large biodiversity settles. Frequent and common in both sites are cnidarians of the genus *Epizoanthus*, bryozoans and numerous encrusting sponges.

The case study Trezza San Pietro shows a peculiar habitat that appears different from the other locations. This kind of environment appears rich in sponges and sessile organisms different from the other study cases of the Adrireef project.

Finally, the results obtained for the Konjsko location were not included in the comparison analysis because the monitoring activities were performed only on target species and not on the whole community.

Benthic community and site vocation

The knowledge of the different benthic communities characterizing the case study sites is an important factor to be taken into consideration when defining reef vocation, a process that requires the understanding of the goods and services that the ecosystem is able to provide in a vision of sustainable maintenance of the natural resource.

From the elaborations carried out, deriving from taxonomic analytical activities on the community, the presence of three main clusters can be observed: one is characterized by the presence of a predominant coralligenous community, another cluster is composed by communities more typical of artificial reefs, and finally there is the “trezze” environment. The sustainable use of these different sites is directly related to these characteristics. All the selected locations are potential underwater tourist attractions with different degrees of interest. For example, many areas of coralligenous are used (or could potentially be used) for recreational scuba diving, due to the presence of aesthetically important habitats, characterized by forests of gorgonians, a variety of sponges, cnidarians and other organisms of high aesthetic value. The Paguro wreck has a less valuable benthic community denoted by the absence of coralligenous habitat. Nevertheless, the wreck itself with its associated biodiversity, much diverse from the surrounding environment, assumes a high aesthetic value. The same can be true for the artificial reef of Porto Recanati, which, despite not having communities comparable to those of the coralligenous from an aesthetic point of view, or despite not having the charisma of the history of a wreck, is an interesting study site for the high biodiversity easily observable in a diving experience. On the basis of these considerations, the need for a correct management of the human activities identified for promotion should be emphasized. The coralligenous environments must be preserved and the indiscriminate mooring of boats, which causes their degradation, should not be allowed.

2.5. Fish assemblage

The characterization and monitoring of the fish community associated with the reefs is one of the goals of the project-WP4 and informs on the biological status of the case study sites.

The great variability of natural and artificial reefs characteristics (i.e. geographical position, depth range morphological complexity, geology) largely determines the associated benthic community which shapes the supported fish community.

Among the project study sites, the natural reefs are characterized by calcareous formations of biogenic origin. This unique habitat known as coralligenous is produced by the accumulation of encrusting algae growing in dim light conditions.

Coralligenous banks are flat outcrops that show convoluted structure over an horizontal substrate with a variable thickness that ranges from 0.5 to several (3–4) meters (Gibson et al., 2006). These benthic substrates are typical for the case studies of Torre Guaceto and Trezza San Pietro.

Coralligenous rims develop on vertical cliffs with a variable thickness ranging from 20–25 cm to >2 m, increasing from shallow to deep waters (Gibson et al., 2006). The Croatian case studies (Stupišća, Lagnjići, Konjsko) present coralligenous rims structures over the cliffs.

Coralligenous communities represent a 'hot spot' of species diversity in the Mediterranean Sea that attracts both scuba diver tourists and fishermen supporting local economies and communities (Boero and Bonsdorff, 2007; Ingrosso et al., 2018). However, it is well known that traditional and recreational fishing have an impact on coralligenous communities by causing changes in the composition of the community and by reducing the tridimensional complexity of the coralligenous community through physical abrasion with fishing gears (Gibson et al., 2006).

The artificial reef case studies listed in the project show highly diverse characteristics. At Porto Recanati-Porto Potenza Picena artificial reefs are concrete piles of 5 blocks (2 m per side) positioned in 2001 at 5.6 km to the coast at the average depth of -13.5 m on a sandy bottom. The structure are designed to increase the structural complexity of the natural substrate, to host large species (i.e. *Conger conger,* Scorpaenidae) and to attract pelagic fish species as well as to promote the larval settlement. Moreover the primary goal of the artificial reef at Porto Recanati is to protect the area from trawling. Conversely the artificial reef Paguro wreck is a metallic structure sunk in 1965 at 12 nautical miles from the shore on a muddy substrate. The underwater reef ranges from -8 m to -27 m. The structure is highly convoluted and offers different microhabitats according to the environmental conditions changes (i.e. light exposition, main current direction, water salinity). The structure offers refuge and shelter to a large number of fish species which conduct the entire or part of their life cycle on and around the wreck. Moreover, large pelagic predators (i.e. Odontocetae) are attracted by the fish schools surrounding the wreck. Several studies highlighted that the offshore communities of fish and invertebrates are generally similar to those on coastal natural reefs but have greater densities of fishes, and larger individual sizes for many species (Love and Schroeder, 2006; Scarborough Bull et al., 2008).

The fish assemblage at **Trezza San Pietro** was assessed by Underwater Visual Census (UVC) with scuba divers operating along strip transects on a seasonal basis in three different locations (Northern, Central, Southern site parts). Pictures and videos were used to support further data analysis on fish species identification. Visual Census was repeated 3 times in each season and location during 2020. A total of 20 fish species were identified. The most frequent species were *Diplodus vulgaris*, *Gobius bucchichi*, *Parablennius rouxi* and *Serranus hepatus*, *Trisopterus minutus* and the most abundant were *Diplodus annularis* and *Diplodus vulgaris*. A seasonal variation in the fish community composition has been described, where the most abundant species where *Chromis chromis* and *Trisopterus minutus* in summer and autumn, whereas *Parablennius rouxi*, *Gobius bucchichi* and *Parablennius tentacularis* were described as the most abundant during the spring and *Trisopterus minutus*, *Diplodus annularis* and *Diplodus vulgaris* during the winter.

At **Porto Recanati-Porto Potenza Picena**, the fish community was characterized and monitored using a combination of visual census methodologies: i) scuba divers visual census, ii) visual census performed through remotely operated vehicle (ROV). The survey was performed at three locations at the northern, central and southern portion of the artificial reefs area during the summer 2020 and 2021, autumn 2020 winter and spring 2021. The surveys were performed at the block pyramids, along transects connecting pyramids and at the pole locations. When possible, the monthly samplings in the 3 sub-areas (area A, B and C) were conducted on the same day in order to have the same sea conditions. A total of 27 fish species were identified. The demersal fishes *Boops boops* and *Trachurus trachurus* were the most abundant followed by Blenniidae and Sparidae. Pyramids were the most populated locations with pelagic and demersal fishes.

At the **Paguro wreck** three different visual census methodologies were performed to assess and monitor the fish community: i) Visual census at stationary points with scientific scuba divers at 3 different locations; ii) 360 degree video recorded at stationary points at three different locations on the wreck; iii) stereo videos recording at one location o the wreck for automatic image classification, species identification and size estimation.

The visual census performed with a 360 degree video camera was successfully tested. The results showed that the 360 degree video technique is promising and effective also considering the cost-benefit terms. Although the recorded video quality is 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.

Results from visual census performed by scuba divers and the results from 360 degrees video analysis provided similar results in terms of taxa and estimated sizes. The results of the parameter "abundance" were generally higher for the video 360 degree analysis, probably because the operator has the possibility to stop and play the video for a more accurate count of the fish individuals. Results showed a community dominated by 6 species (*Chromis chromis, Boop boops, Diplodus annularis, Diplodus vulgaris, Oblada melanura, Serranus scriba*) with other less abundant taxa typical from the site such as *Sciaena umbra, Scorpaena scrofa, Sparus aurata* and the pelagic predators *Thunnus thynnus, Seriola dumerili, Sarda sarda.*

At **Torre Guaceto**, the fish community was assessed and monitored by carrying out an underwater visual census (UVC) at Stationary Point Count at 3 locations across the site considering the geographic exposition (Northern part, Central part, Southern part) and the coralligenous patchyness characteristics. The sampling was performed by 3 scuba divers at the same time. The monitoring has been performed seasonally since 2019. Fish taxa, abundance and size at 10 centimeters classes were recorded according to the guidelines provided by the WP leader for the harmonization of the visual census results. A remote operated vehicle was also tested to perform visual census at site during two surveys, in November 2020 and June 2021. During the surveys, a GOPRO 8 and a GOPRO MAX 360° were used to record high quality videos which were then used to validate the visual census surveys performed by scuba divers. Despite the high performances of both the ROV and the cameras used, the noise caused by the vehicle during operation had a negative effect on the natural behaviour of the fishes. Also the paint colours of the vehicle were supposed to scare the fishes.

The monitoring results showed a stable fish population where different size classes were observed for all the taxa; 18 species were identified, most of them typically from the coralligenous habitat. Same "flag" species as *Dentex dentex, Sciaena umbra* and *Pagrus pagrus* have been observed also, confirming the importance of the investigated reef as a valuable natural habitat and biodiversity hotspot, useful for a sustainable recreational diving activity.

Visual census at **Lagnjići** location (Dugi Otok Island), **Stupišća** site (Vis Island) and **Konjsko** were performed by applying two protocols developed within the Interreg project MPA Adapt (Garrabou, Bensoussan and Azzurro 2018). The sampling protocols allow monitoring the fish community and to highlight the presence of alien species as indicators of climate change. The results show that the southern island Vis is more affected by the presence of thermophilic and alien species than the northern Dugi Otok Island. Common species at all sites included *Diplodus vulgaris*, *Sarpa salpa, Serranus scriba* and *Coris julis* and the thermophilic alien species, *Thalassoma pavo* was recorded at Dugi Otok Island with few individuals and at Vis Island where the species is more abundant. At Konjsko only *Coris julis, Serranus scriba* and *Diplodus* *vulgaris* were chosen for assessment. *Coris julis* was the most abundant species in the examined 5-10 m depth range at the Konjsko 1 site. Thermophilic alien fish species were not recorded on the Krk Island.

At **Plićina Konjsko**, **Plić Lagnjići** and **Plic Seget** location on Vis Island the fish census method applied were: i) Baited Remote Underwater Video (BRUV), ii) Underwater Visual Census (UVC), iii) Remote Operated Vehicle (ROV).

A total of 21 fish species were found on the Seget site during two surveys. *Chromis chromis, Boops boops* and *Spicara smaris* were the most abundant species representing more than the 50% of all individuals observed. The most abundant demersal species were *Diplodus annularis, Dentex dentex, Coris julis* and *Muraena helena.* The species observed with the BRUV method were 19 whereas 2 species were identified with the ROV.

A total of 44 species were found on Lagnjići site while 13 fish species were found on Konjsko site. At both locations 2 surveys were conducted; one during spring 2020 and the second during spring 2021. The most abundant species in booth sites by the number of individuals are mesopelagic species that live in schools like *Chromis chromis, Boops boops* but also *Diplodus vulgaris* as representative of bathypelagic species. They represent > 70% of all individuals on the sites.

Data comparison

The clustering analysis performed on the data provided from PPs highlighted the similarities across the monitored fish community of the study sites. A SIMPER analysis was performed to define the main structure of the fish community resulting in a subset species to be used for further comparative analysis with other sites (Fig. 8-9).

The similarities observed between the artificial reefs Paguro Wreck and Porto Recanati-Porto Potenza Picena for the benthic community is also reflected on the fish community. A second cluster of sites characterized by coralligenous habitat and associated communities is represented by the sites Torre Guaceto, Seget and Konjsko which present a greater level of similarity. Conversely, Trezze San Pietro showed the most unique characteristics of the fish community.

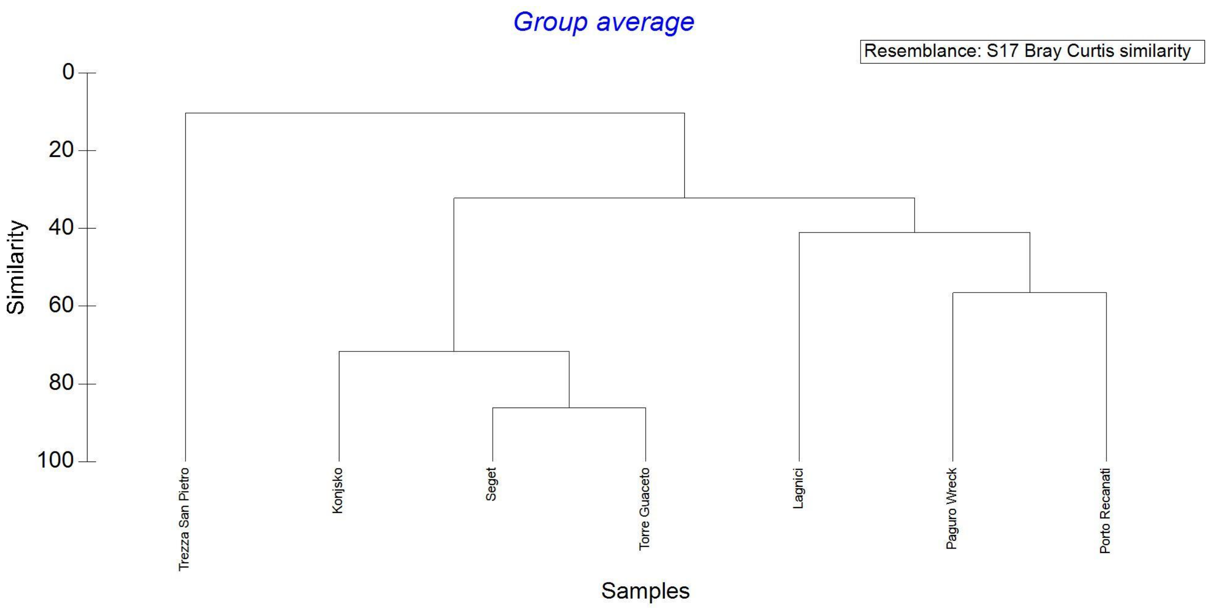

Figure 8: Cluster analysis on fish communities of the study cases.

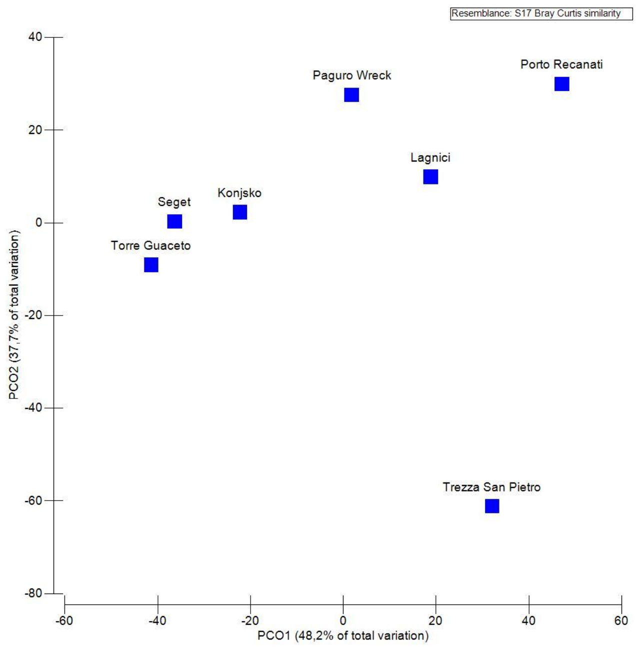

Figure 8: PCO analysis on fish communities of the study cases.

2.6. Additional investigated parameters

- Pathogenic bacteria and contaminants in seawater

The presence of *Escherichia coli* and other faecal coliforms in seawater was investigated in **Plićina Konjsko**, **Plić Lagnjići** and **Plić Seget**. PAHs and PCBs were also determined at the same locations. Water quality was always excellent.

- Contaminants in sediment

In **Plićina Konjsko**, **Plić Lagnjići** and **Plić Seget**, PAHs and PCBs were also determined in sediment.

At the **Paguro wreck**, during the study period 72 structurally diverse pollutants (metals and organometals, organochlorine pesticides, PAHs, dioxins and dioxin-like compounds, PCBs) were analysed in two marine sediment samples collected at the study site. Observed concentrations were comparable to those normally determined in sediment samples collected along the coast of Emilia-Romagna for the purposes of the Water Framework Directive and were generally below the EQSs set in Legislative Decree 172/15.

- Pathogenic bacteria and contaminants in biota

At **Porto Recanati-Porto Potenza Picena**, the concentrations of chemical contaminants, toxins and pathogenic microorganisms were estimated in *Mytilus galloprovincialis* settled on the artificial reefs, accordingly to the EC Regulations 466/01, 853/04, 854/04, 2073/05, 1881/06 and UE Regulation 1259/2011. These analyses were carried out with samples from 2020 and 2021 demonstrating the low contents of contaminants and pathogens to support the suitable human consumption. This aspect, associated with the abundance of mussels, could constitute the premises for the possible development of a recognizable quality brand (Fabi et al., 2021), which is totally in line with WP4 outputs transferability requirements.

- Volume occupied by the fouling community through Photogrammetry

At the **Paguro wreck**, the volume of the benthic community ongrowing the submerged structures was estimated by processing scaled and high resolution 3D models of the metallic wreck fitted with primitive geometries representing the metallic surfaces (i.e. planar surfaces for a deck and cylinders for pillars). The primitive geometries were dimensioned starting from scratched to metal parts of the wreck and then were used to clip the photogrammetric models; the left volumes were then measured and reported to 1 square meter. The calculations were performed on 3D high resolution models from areas of the wreck at different depth ranges.

- Mussel population structure

At **Porto Recanati-Porto Potenza Picena**, the density of mussels ongrowing the pyramids and the poles of the artificial reef were scanned using photogrammetry to describe the patterns of biomass and density distribution of mussels for implementing a sustainable harvesting strategy. Because of the poor visibility conditions in the area, the data collection provides low quality images which do not generate adequate results.

- Environmental load (tourism, maritime traffic, diving centers, fishing activities, including garbage quantity and type)

The socio economic activities most representative for the study sites **Plićina Konjsko**, **Plić Lagnjići** and **Plić Seget** were analysed and the critical points identified in order to assess the human pressures acting on the marine environment and to support and promote the site vocations in line with blue economy principles, as well as to identify sectors where dedicated management would be beneficial.

Presence of garbage on the seabed and a build-up rate from human activities were monitored by using remotely operated vehicles (ROV) on the beginning and the end of the peak season to inform on the human footprint associated with plastic litter at sea.

- Impact of lost fishing gear

The protocol Ghost Med programme (Ruitton et al. 2019) was applied at sites **Plićina Konjsko**, **Plić Lagnjići** and **Stupišća** in order to assess the impact of abandoned fishing gears and to provide indication on the opportunity of their removal from the marine environment.

2.7. Images and data transferred at land and visualized through different media

- Porto Recanati

A fixed buoy equipped with a solar panel, rechargeable battery, a data logger and a router + 4G antenna was moored at the AR. This setting enabled continuous sampling, and real-time data transmission of a few water column parameters from the core of the reef.

To visualize the data collected from the meteo oceanographic buoy, a set of dashboards were implemented using a web open source visualization and analytics platform. Three different platforms were developed:

- AdriReef Porto Recanati (https://gr.irbim.cnr.it/adrireef). A complete and detailed version with objects and graphs of all recorded weather and marine parameters was designed for scientific communications;
- Progetto AdriReef: Barriera artificiale Porto Recanati - Porto Potenza Picena (https://gr.irbim.cnr.it/adrireefpt). It was implemented for the Porto Recanati tourism site for providing a simple and easy tool adequate for a larger public;
- Kiosk Version (https://gr.irbim.cnr.it/adrkiosk/play/3?kiosk) with a dedicated format suitable for Totems. It includes 3 sections that cycle repeatedly: a header with a promotional video, the project logos and a map with the buoy position, a section with meteo parameters and another with water parameters and currents.

- Torre Guaceto

Visual census performed with the ROV was based on the recording of immersive 360 degree videos which has also been used for creating Virtual Reality communication contents to promote the site and the Torre Guaceto Marine Protected Area.

- Paguro Wreck

Data of chemical and physical parameters collected during the monthly monitoring events at site were promptly processed and published within a few hours on the Facebook project Adrireef page with interactive and user-friendly plots.

The 360 degrees videos recorded at site during operations and for visual census purposes were edited to generate virtual reality immersive videos and a photographic tour enriched with several audio and video contents for promoting the site peculiarities, the monitoring activities performed and the results achieved.

A dedicated 3D server based tool to interact with a 3D model of the site of the Paguro wreck was developed and published in the ARPAE website. The viewer hosts data from the Multibeam bathymetric field campaign and those achieved through the photogrammetric surveys. The models were also processed to highlight the different benthic communities overgrowing the wreck and the areas which were damaged during the monitoring period because of the sea corrosion.

The high resolution model of the small portions of the wreck used for the benthic community volume calculations were also reprocessed and optimised to be on online interfaces and published through the ARPAE website.

A virtual reality application was designed and developed for simulating scuba diving at site. The entire wreck area mapped with photogrammetry was reprocessed and optimised to keep the highest quality in details and texture for being processed within a 3D environment enriched with animated models of fishes and a realistic light condition. The application was designed for the stand alone virtual reality headsets Oculus Quest. The application was presented in June 2021 by the Comune di Ravenna during the event “Sagra della Cozza Selvaggia” at Marina di Ravenna.

3. REEFS ADEQUACY FOR A PARTICULAR USE

The study cases vocations were summarised from the reports provided by project partners. By processing the gathered information it was possible to detail on the ongoing human activities, the human activities that should be promoted at site because they follow the principles of the Blue Economy, and those that are not sustainable and therefore need to be banned or carefully managed (Table 5).

Table 5: Summary of the ongoing human activities at sites, the activities that should be promoted and are in accordance with the site vocation, and the activities that are not sustainable and need to be avoided or carefully managed.

Case Study	ACTIVITIES		
	Currently allowed	**To be promoted**	**To be avoided**
Trezza San Pietro	Recreational scuba diving, scientific research, ocean literacy. Artisanal fishery is allowed but it is forbidden in some specific areas of the SIC (hard bottom substrata).	Recreational scuba diving, recreational fishing and professional small-scale fishery should be managed; free diving, scientific research and ocean literacy should be promoted.	Trawl fishing, boats mooring, other living resource use which is not managed.
Paguro wreck	Recreational scuba diving, scientific research.	Recreational scuba diving, scientific research, ocean literacy, virtual tourism.	Recreational and professional fishing, snorkeling.
Porto Recanati - Porto Potenza Picena	No activities are currently allowed, but the reef is illegally exploited.	Recreational fishing and/or professional small-scale fishery (fish and mussels), recreational scuba diving based on a management plan developed in agreement with the local stakeholders.	Underwater recreational fishing.

Torre Guaceto	Snorkeling, scientific research.	Recreational scuba diving, snorkeling, scientific research, ocean literacy.	Recreational and professional fishing, boats mooring.
Plićina Konjsko	Recreational scuba diving, recreational and professional fishing.	Recreational scuba diving, ocean literacy.	Uncontrolled maritime summer traffic.
Plić Lagnjići	Recreational diving, touristic boat trips, snorkeling, recreational and professional fishing.	Recreational scuba diving, snorkeling and freediving, recreational fishing, professional small-scale fishery, scientific research, ocean literacy.	Fishing lines and gears that impact on gorgonians and coralligenous habitat, anchoring.
Vis- Seget	Recreational scuba diving (for advanced divers), recreational and professional fishing.	Recreational fishing and professional small-scale fishery, recreational scuba diving (only for advanced divers), scientific research, ocean literacy.	Free-diving and snorkeling, boats mooring, fishing lines and gears that impact on gorgonians and coralligenous habitat.
Vis- Stupišća	Touristic boat trips, recreational scuba diving, recreational fishing and small-scale fishery.	Recreational scuba diving, snorkeling, scientific research and ocean literacy.	Boats mooring, fishing lines and gears that impact on gorgonians and coralligenous habitat.

4. CONCLUSIONS

This report summarizes the activities performed by Italian and Croatian Adrireef project partners at 7 selected reefs in the Adriatic Sea, where monitoring was carried out from November 2019 to September 2021. The overall obtained data are here collected and discussed. The identification of reef's adequacy towards a particular use, among those expected by the Blue economy sectors, is also evaluated.

During the surveys, 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 were introduced to reflect Case Studies specifics or to address unexpected situations that occurred during practical activities at sea. Advantages and limitations of the tested technologies are also presented, thus providing an insight both for the local management plans and the application of European Directives for the protection of the marine environment.

The main findings of this study were as follows:

1. Geomorphological mapping was carried out at all 7 selected case studies using different technologies. The methods used were non-destructive: acoustic measurements were done using multibeam echosounder and/or side-scan sonar, efficient tools which allow to evaluate the physical performance of reefs without creating any disturbance to the environment. These systems were coupled to other investigation methodologies (e.g. ROV, underwater drones, underwater Structure from Motion photogrammetry, scuba diving) for a variety of purposes. In general, the used technologies proved to be adequate for carrying out the preliminary survey of the study area, aimed at identifying the best spots where more detailed monitoring had to be conducted. Moreover, they provided a detailed characterization of the artificial reefs in terms of compliance with original drawings and evaluation of their structural integrity. Additionally, some of the produced outputs were made available to the wider public in order to increase their awareness of the project results (e.g. interactive bathymetric maps made available online, detailed bathymetric maps for fishers,...).
2. Measurements of physico-chemical parameters in the water column at 7 selected case studies were carried out at different temporal and spatial scales by (i) fixed near-real time oceanographic observing systems and (ii) by using CTD multiprobes during oceanographic campaigns. Water samples for additional analysis of nutrients, chemical contaminants and microbiological parameters were also sampled at the surface and/or bottom layers. Investigated water column parameters were used to describe the general environmental features of the study sites, as well as to evaluate their trophic status in relation to anthropogenic pressures. Those variables potentially affecting Blue economy activities proposed for the specific case study site (e.g. adequacy of temperature and turbidity during the year for scuba divers) were discussed in detail.

3. Currents speed and direction were recorded at three case studies, i.e. Trezza San Pietro, Paguro wreck, Porto Recanati-Potenza Picena using Acoustic Doppler Current Profilers (ADCP). The most relevant weather and marine conditions events were described and it was concluded that only occasionally high peaks in current intensity have been observed which could hinder the regular development of the economic activities foreseen for the CSs. The detailed study of these parameters is useful not only to provide information to reef end-users, but also to analyse phenomena that may have repercussions on the integrity of submerged artificial structures.
4. Investigations on the benthic communities were carried out using different survey methodologies with the aim of increasing the knowledge on the biodiversity of the case study sites and, consequently, on the potential ecosystem functions provided by the habitat they represent. Three main clusters were observed: sites characterized by a predominant coralligenous community, artificial reefs and the "trezze" environment. The sustainable use of these sites is directly related to these characteristics. Their inherent vulnerability should be taken into account when promoting any commercial exploitation, in order to avoid uncontrolled use that leads to an environmental deterioration.
5. Fish surveys were performed at sites with several traditional and innovative sampling methods aimed at visual taxa identification, counting and individual size estimation. The seasonal variability of the fish community composition has been highlighted among sites where seasonal sampling was performed. The similarities found between the survey sites mirror those identified also for the benthic communities. Artificial reefs support peculiar fish communities probably because of the geographical position, the depth range, and the composition of the artificial substratum (metallic or concrete).
6. A series of additional investigations have been carried out by project partners, such as the analysis of contaminants in various environmental matrices (seawater, sediment and biota), the volume occupied by the fouling community or the mussel population structure through photogrammetry, the environmental load including the impact of lost fishing gear.
7. All performed investigations were directed at a more comprehensive definition of reef vocations, which included an indication of human activities that should be promoted at site because they follow the principles of the Blue Economy, and those that are not sustainable and therefore need to be banned or carefully managed.

These findings provide a keystone for any stakeholder interested in the sustainable use of natural and artificial reefs in the future, including the issue of sunken ships or reuse of offshore extraction platforms.

Transferability of achieved outputs to stakeholders was ensured by public dissemination of results, a task accomplished using a set of actions and strategies, also described and summarized in this report.

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