SAFE WAVE

STREAMLINING THE ASSESSMENT
OF ENVIRONMENTAL EFFECTS
OF WAVE ENERGY

DELIVERABLE 2.4
Monitoring of the seabed integrity

Co-funded by the EMFF
programme of the
European Union

WP 2
Deliverable 2.4 Monitoring of the seabed integrity

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SUBMISSION DATE
12| January| 2023

DISSEMINATION LEVEL

PU	Public	X
CL	Classified – EU classified (EU-CONF, EU-RESTR, EU-SEC) under Commission Decision No 2015/444	
CO	Confidential, only for members of the consortium (including Commission Services)	

DOCUMENT HISTORY

Issue Date	Version	Changes Made / Reason for this Issue
22/12/2022	1.0	
12/01/2023	2.0	Corrected version

CITATION

Muxika, I., Vinagre, P.A, Le Bourhis, E., Villarin, E., Tanguy, F., Niclot, C., Bald, J., 2022. Deliverable 2.4 Monitoring of the seabed integrity. Corporate deliverable of the SafeWAVE Project co-funded by the European Climate, Infrastructure and Environment Executive Agency (CINEA), Call for Proposals EMFF-2019-1.2.1.1 - Environmental monitoring of ocean energy devices. DOI: 10.13140/RG.2.2.16170.90561/3. 57 pp.

This Project is co-funded by the European Climate, Infrastructure and Environment Executive Agency (CINEA), Call for Proposals EMFF-2019-1.2.1.1 - Environmental monitoring of ocean energy devices.

CONTENTS

1. SafeWAVE project synopsis

The European Atlantic Ocean offers a high potential for marine renewable energy (MRE), which is targeted to be at least 32% of the EU's gross final consumption by 2030 (European Commission, 2020 (European Commission 2020). The European Commission is supporting the development of the ocean energy sector through an array of activities and policies: the Green Deal, the Energy Union, the Strategic Energy Technology Plan (SET-Plan) and the Sustainable Blue Economy Strategy. As part of the Green Deal, the Commission adopted the EU Offshore Renewable Energy Strategy (European Commission, 2020) which estimates to have an installed capacity of at least 60 GW of offshore wind and at least 1 GW of ocean energy by 2030, reaching 300 GW and 40 GW of installed capacity, respectively, moving the EU towards climate neutrality by 2050.

Another important policy initiative is the REPowerEU plan (European Commission, 2022) which the European Commission launched in response to Russia's invasion of Ukraine. REPowerEU plan aims to reduce the European dependence amongst Member States on Russian energy sources, substituting fossil fuels by accelerating Europe's clean energy transition to a more resilient energy system and a true Energy Union. In this context, higher renewable energy targets and additional investment, as well as introducing mechanisms to shorten and simplify the consenting processes (i.e., 'go-to' areas or suitable areas designated by a Member State for renewable energy production) will enable the EU to fully meet the REPowerEU objectives.

The nascent status of the Marine Renewable Energy (MRE) sector and Wave Energy (WE) in particular, yields many unknowns about its potential environmental pressures and impacts, some of them still far from being completely understood. Wave Energy Converters' (WECs) operation in the marine environment is still perceived by regulators and stakeholders as a risky activity, particularly for some groups of species and habitats.

The complexity of MRE licensing processes is also indicated as one of the main barriers to the sector development. The lack of clarity of procedures (arising from the lack of specific laws for this type of projects), the varied number of authorities to be consulted and the early stage of Marine Spatial Planning (MSP) implementation are examples of the issues identified to delay projects' permitting.

Finally, there is also a need to provide more information on the sector not only to regulators, developers and other stakeholders but also to the general public. Information should be provided focusing on the ocean energy sector technical aspects, effects on the marine environment, role on local and regional socio-economic aspects and effects in a global scale as a sector producing clean energy and thus having a role in contributing to decarbonise human activities. Only with an informed society would be possible to carry out fruitful public debates on MRE implementation at the local level.

These non-technological barriers that could hinder the future development of WE in EU, are being addressed by the WESE project funded by European Maritime and Fisheries Fund (EMFF) in 2018. The present project builds on the results of the WESE project and aims to move forward through the following specific objectives:

1. Development of an **Environmental Research Demonstration Strategy** based on the collection, processing, modelling, analysis and sharing of environmental data collected in WE sites from different European countries where WECs are currently operating (Mutriku power plant and BIMEP in Spain, Aguçadoura in Portugal and SEMREV in France); the SafeWAVE project aims to enhance the understanding of the negative, positive and negligible effects of WE projects. The SafeWAVE project will continue previous work, carried out under the WESE project, to increase the knowledge on priority research areas, enlarging the analysis to other types of sites, technologies and countries. This will increase information robustness to better inform decision-makers and managers on real environmental risks, broadening the engagement with relevant stakeholders, related sectors and the public at large and reduce environmental uncertainties in consenting of WE deployments across Europe;

2. Development of a **Consenting and Planning Strategy** through providing guidance to ocean energy developers and to public authorities tasked with consenting and licensing of WE projects in France and Ireland; this strategy will build on country-specific licensing guidance and on the application of the MSP decision support tool developed for Spain and Portugal in the framework of the WESE project; the results will complete guidance to ocean energy developers and public authorities for most of the EU countries in the Atlantic Arch.

3. Development of a **Public Education and Engagement Strategy** to work collaboratively with coastal communities in France, Ireland, Portugal and Spain, to co-develop and demonstrate a framework for education and public engagement (EPE) of MRE enhancing ocean literacy and improving the quality of public debates.

2. Glossary

AR – Artificial Reef effect

AUV – Underwater Autonomous Vehicle

BiMEP – Biscay Marine Energy Platform

CPO – CorPower Ocean

EPE – Education and Public Engagement

MRE – Marine Renewable Energy

MRED – Marine Renewable Energy Device

MSP – Marine Spatial Planning

ROV – Remotely Operated Vehicle

SSS – Side-scan SONAR – SSS

WE – Wave Energy

WEC – Wave Energy Converter

3. Executive summary

In response to the EU Blue Growth strategy, the technology behind devices that collect and transform the marine energy is evolving in leaps and bounds. However, the potential environmental impacts derived from the installation, operation and decommissioning of such devices are not yet fully known.

Hence, the main aim of the SafeWAVE project is to fill the knowledge gaps related to the environmental effects that may cause the Wave Energy projects. In the framework of this project, Work Package 2 aims to collect, process, analyse, and share environmental data from four priority areas of research: i) Electromagnetic Fields, ii) Acoustics (noise), iii) Seafloor integrity, and iv) Fish communities.

Specifically, the objectives of Task 2.4 and this report derived from that are to: inform on the work undertaken to monitor seafloor integrity; describe the methods for monitoring and data analysis; and show the main results obtained.

In order to fulfil such aims, three sites where WECs are operating in Portuguese, Spanish and French coastal waters were monitored. The WECs installed at each of the sites operate in the basis of different technologies, at different types of locations and at different project scales. Thus, this deliverable will also pay attention to the differences in the impacts caused by the disparities in the conditions.

4. Methods

As mentioned above, three sites were monitored, which represent different conditions both in terms of the technology of the devices installed, and in terms of the geographical and hydrographical conditions. Therefore, the methods applied to, and the main results from each test site will be described in separated subsections.

4.1 Description of test sites

4.1.1 Aguçadoura (Portugal)

The CorPower Ocean (CPO) test site is located within the Aguçadoura test site (https://www.wavec.org/en/test-sites/agucadora-test-sites) in the northwest coast of Portugal (Figure 1).

Figure 1. Location of CPO test site and the closest conservation protected area (Parque Natural do Litoral Norte and SCI PTCON0017) (Source: ICNF).

The implementation area is located at about 6 km from shore. There, the seafloor is mostly sandy and with a relatively flat inclination (0.3°). Depth varies between -43 m and -55 m depth. In regular conditions wave height reaches 2.5 m, rarely it reaches 7-10 m. Current speed ranges between <0.1 $m \cdot s^{-1}$ to 1 $m \cdot s^{-1}$.

Close to the CPO site there is a National Protected Area – 'Parque Natural do Litoral Norte' (PNLN), which overlaps with the Site of Community Importance 'Litoral Norte' (Habitats Directive (HD, 1992), Natura 2000 site code PTCON0017). This protected area is located at 2.8 km North to the onshore substation previously used for the WindFloat device and at 800 m East of the CPO HiWave device.

4.1.2 Armintza (Spain)

The Biscay Marine Energy Platform (hereafter BiMEP, https://www.bimep.com/) area is an infrastructure, located off the coast at Armintza (southeast Bay of Biscay), to support research, technical testing, and commercial demonstration of prototypes of ocean energy collectors and auxiliary equipment (Figure 2).

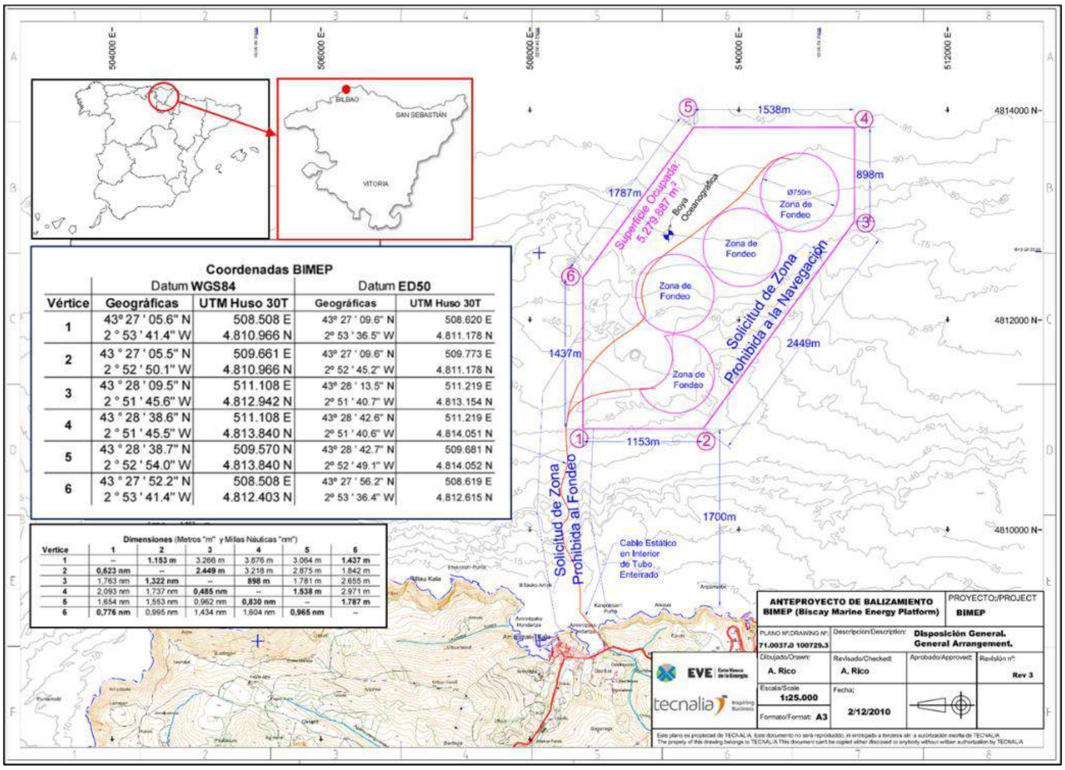

Figure 2. General arrangement of BiMEP (Source: AZTI).

BiMEP provides technology developers with ready-to-use facilities to validate their designs and to test their technical and economic feasibility in an area with suitable wave and wind conditions.

BiMEP occupies a 5.3 km^2 area which is restricted to the shipping and is located at a minimum distance of 1,700 m from shore, close enough for fast access to deployed devices, and at -50 m to -90 m water depth. The seafloor is mainly sandy, with some rocky outcrops close to the eastern and southwestern margins.

4.1.3 Le Croisic (France)

The Centrale Nantes offshore test site (SEM-REV, https://sem-rev.ec-nantes.fr) is located off the coast of Le Croisic (Figure 3; Table 1), in the western coast of France, at approximately 100 km from Nantes. It is a marine restricted area that covers nearly 1 km^2.

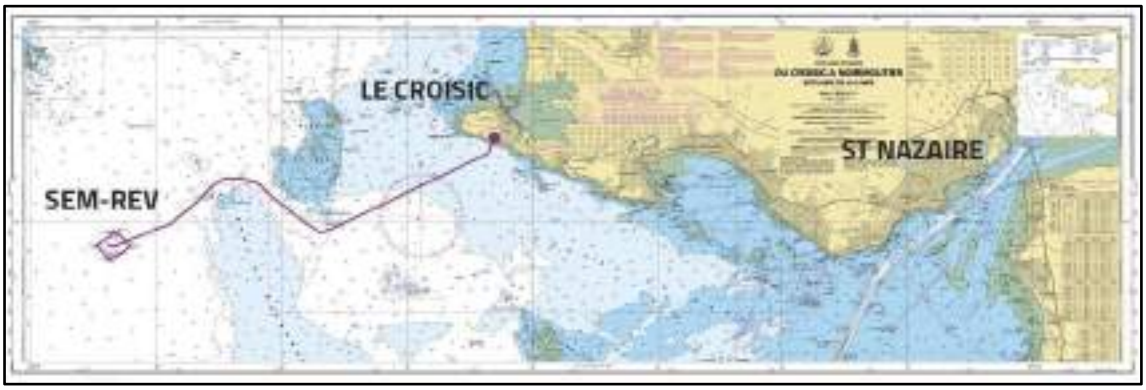

Figure 3. Location of the SEM-REV test site (source: École Centrale Nantes).

Table 1. SEM-REV test site coordinates (WGS 84; Degrees, Decimal Minutes) (Source: ECN).

SEM-REV	Latitude	Longitude
North	47° 14.700'N	2° 46.580'W
East	47° 14.340'N	2° 46.080'W
South	47° 13.940'N	2° 46.880'W
West	47° 14.340'N	2° 47.380'W

The seafloor, at a depth of -32 m to -36 m, is dominated by sands in an area with 12 kW·m^{-1} of mean wave energy and 7.5 m·s^{-1} of mean wind velocity.

It is the first European site, connected to the grid, for multi-technology offshore testing and, apart from the offshore infrastructure, SEM-REV provides facilities on land, with a research centre that includes: offices, a workshop and a reception centre for the oceanographic and meteorological data collected at sea. There is also an electrical substation at 750 m from the research centre that connects the export cable from the test site to the French distribution network.

4.2 Devices

4.2.1 HiWave (CorPower Ocean)

The HiWave (Figure 4) is a point absorber type device with a 300 kW power capacity. It is about 65 m high, with a heaving buoy on the surface which absorbs energy from ocean waves. The buoy is connected to the seafloor using a tensioned mooring system. The foundation is a relatively small (side dimension <9 m) steel frame that sits on the seafloor with three anchoring points that link the mooring lines to anchors.

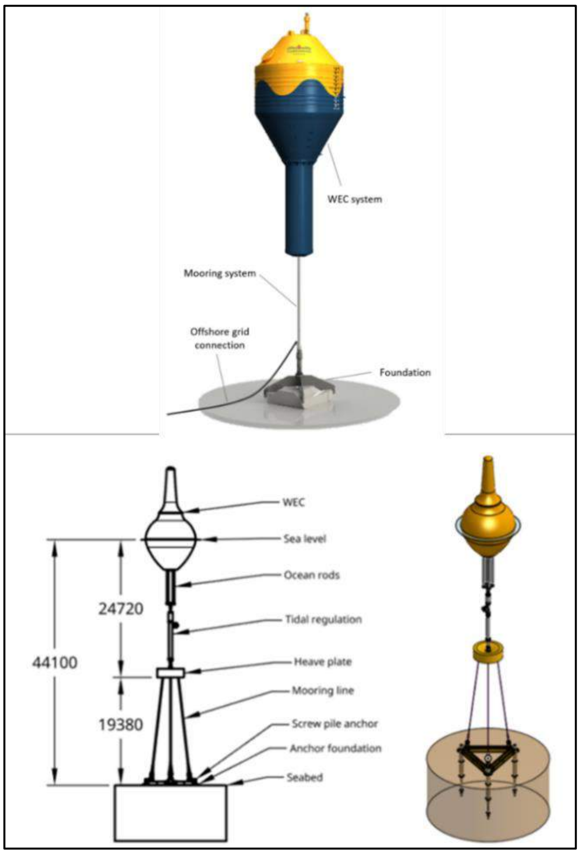

Figure 4. The HiWave WEC configuration (numbers in mm) (Source: CPO).

The HiWave project will include the installation of four devices, at about 5 km offshore the Aguçadoura, in two phases (Figure 5, Table 2):

- The first phase (ongoing in November 2022) includes the installation of: four navigation marks (at the corners of the site) to define the test site in January 2022; the electrical (export) cable, the C4 (first device) anchoring system and the export cable quadrant in June 2022; and the C4 WEC and its mooring system, which will be installed as soon as possible. The export cable will be directly connected to the C4 WEC. The C4 is expected to undergo testing at sea for one year, after which the second phase will be started.

- In the second phase, the hub and three other devices – C5.1, C5.2 and C5.3 – will be deployed. The export cable will be disconnected from the C4 and will be connected to the hub. The four WECs will be connected to the hub.

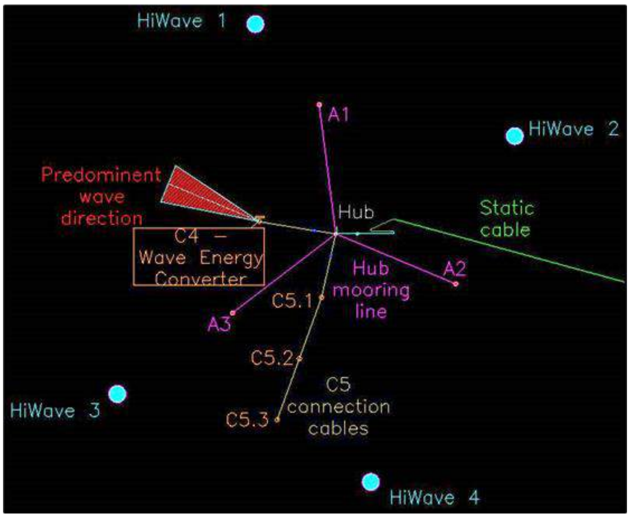

Figure 5. Layout of the HiWave Project (Source: CPO).

Table 2. Planned location of the HiWave equipment (WGS 84; Degrees, Decimal Minutes) (Source: CPO).

Description	Latitude	Longitude
Signaling/Boundaries		
HiWave 1	41° 27.770'N	8° 50.541'W
HiWave 2	41° 27.630'N	8° 50.111'W
HiWave 3	41° 27.310'N	8° 50.770'W
HiWave 4	41° 27.200'N	8° 50.350'W
WEC Equipment		
C4	41° 27.525'N	8° 50.534'W
C5.1	41° 27.429'N	8° 50.431'W
C5.2	41° 27.353'N	8° 50.468'W
C5.3	41° 27.277'N	8° 50.505'W
Collection Hub Equipment		
Anchor – A1	41° 27.770'N	8° 50.541'W
Anchor – A2	41° 27.446'N	8° 50.209'W
Anchor – A3	41° 27.411'N	8° 50.579'W
Hub	41° 27.509'N	8° 50.408'W
Electrical equipment		
Export cable anchor	41° 27.509'N	8° 50.372'W
C4 cable anchor	41° 27.513'N	8° 50.444'W
C5 cable anchor	41° 27.482'N	8° 50.416'W
Export cable quadrant	41° 27.510'N	8° 50.313'W

4.2.2 Penguin II (Wello)

Penguin II is a direct drive wave energy converter. It is a vessel shaped attenuator device with 43.3 m length, 10.6 m depth, 6.8 m draught, 21.8 m beam and a weight of 2.2 t in its current commercially ready configuration, with a nominal power of 0.5-1 MW (Figure 6).

The device is installed using a 6-legged mooring system (Figure 7). Each of the legs consists of two chain clump anchors followed by a catenary fixed to a surface buoy. An upper catenary fixes Penguin II to each of those buoys. Every single mooring leg is 319 m as straight.

Figure 6. Wello Penguin II WEC (Source: Wello).

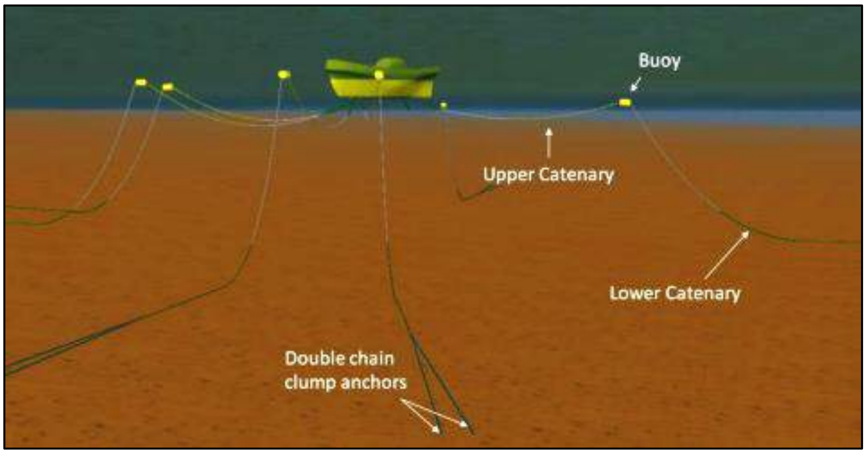

Figure 7. Schematic view of Penguin II mooring components (Source: Wello).

The mooring system was deployed at BiMEP in May 2021, following the scheme depicted in Figure 8 and with the clump anchors at the coordinates listed in Table 3. The Penguin II device was then deployed in June 2021. In December 2021, the device was decommissioned for maintenance.

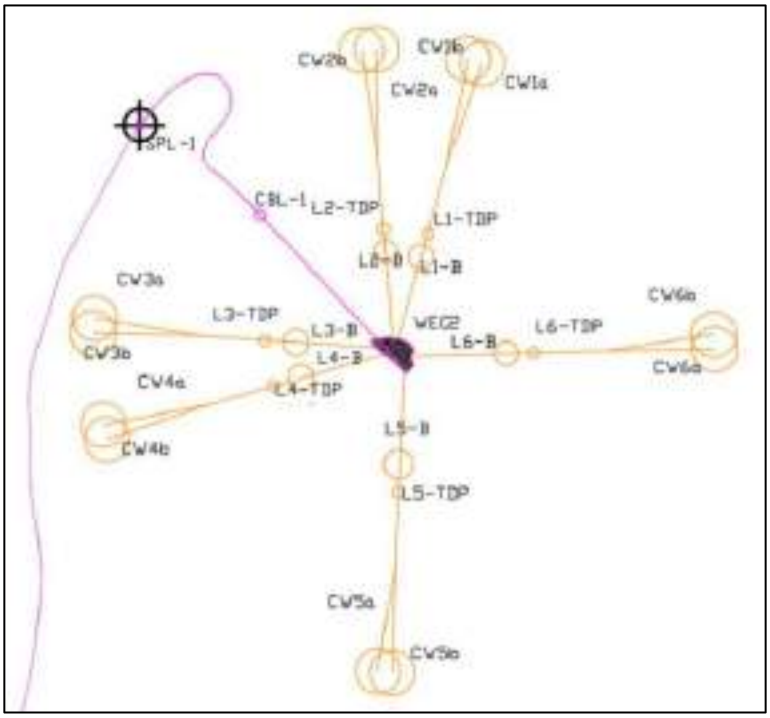

Figure 8. Schematic view of positioning of the mooring system (Source: Wello).

Table 3. Penguin II mooring and cable coordinates (WGS 84; Degrees, Decimal Minutes) (Source: Wello).

	Code	Description	Latitude	Longitude
	WEC2	Centre of Penguin	43° 27.820'N	2° 52.990'W
Mooring Leg 1	CW1a	Clump Weight 1a	43° 27.960'N	2° 52.930'W
	CW1b	Clump Weight 1b	43° 27.960'N	2° 52.940'W
Mooring Leg 2	CW2a	Clump Weight 2a	43° 27.970'N	2° 53.000'W
	CW2b	Clump Weight 2b	43° 27.970'N	2° 53.010'W
Mooring Leg 3	CW3a	Clump Weight 3a	43° 27.840'N	2° 53.190'W
	CW3b	Clump Weight 3b	43° 27.830'N	2° 53.190'W
Mooring Leg 4	CW4a	Clump Weight 4a	43° 27.790'N	2° 53.190'W
	CW4b	Clump Weight 4b	43° 27.780'N	2° 53.180'W
Mooring Leg 5	CW5a	Clump Weight 5a	43° 27.670'N	2° 53.000'W
	CW5b	Clump Weight 5b	43° 27.670'N	2° 52.990'W
Mooring Leg 6	CW6a	Clump Weight 6a	43° 27.82'N	2° 52.780'W
	CW6b	Clump Weight 6b	43° 27.83'N	2° 52.780'W
Cable	SPL-1	BiMEP to WE Splice	43° 27.930'N	2° 53.160'W
	CBL-1	Cable Point 1	43° 27.890'N	2° 53.080'W

Regarding the umbilical system, it is a Lazy-S with a mid-water arch, which consists of a buoy and two 2.1 m length cable bend stiffeners (DETAIL 2 in Figure 9). This arc is at about 20 m water depth and at 55 m from the device (horizontally). In total, the system is 563 m long.

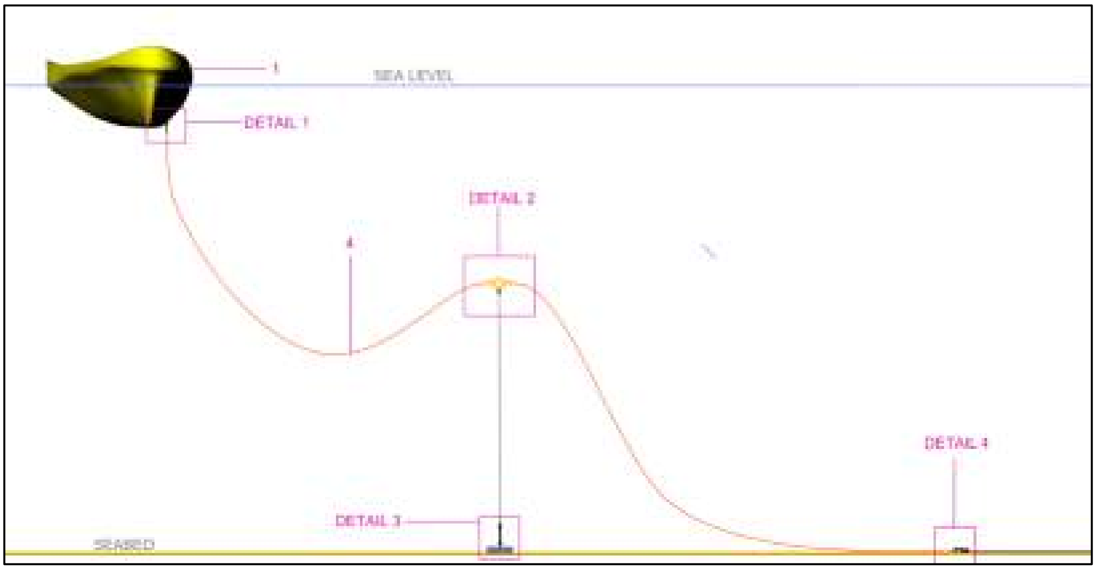

Figure 9. Penguin II umbilical system overview (Source: Wello).

4.2.3 WAVEGEM (GEPS Techno)

The WAVEGEM (Figure 10) is a hybrid autonomous energy recovery platform, developed by GEPS Techno, with a 150 kW power capacity. It is 21 m long and 14 m wide, with a height of 7 m. The device converts float motions into electric power through the circulation of seawater in closed loop, via a low-speed turbine.

Figure 10. GEPS Techno WAVEGEM (Source: GEPS Techno).

WAVEGEM uses a four-point synthetic mooring system, which includes steel chains, nylon lines and sand anchors, following the scheme represented by Figure 11.

WAVEGEM was deployed in SEM-REV in August 2019 (anchors and mooring lines were installed in July 2019) for a first testing period, in the location defined by the coordinates in Table 4, being removed in July 2020. The device was then reinstalled in October 2020 for a second testing period that lasted until November 2021. The moorings remained on the seafloor since the first installation. In the end of January 2022, nylon sections were removed and only anchors and bottom chains remained on the seafloor.

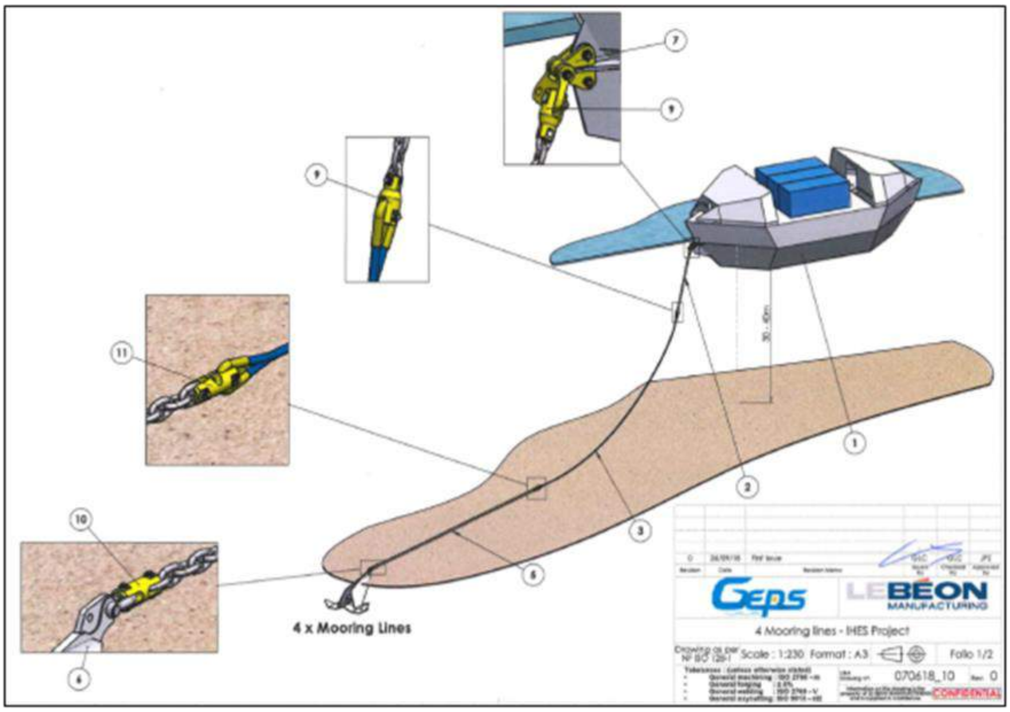

Figure 11. Simplified specification layout of the WAVEGEM mooring lines (Source: GEPS Techno).

Table 4. WAVEGEM equipment coordinates (WGS 84; Degrees, Decimal Minutes) (Source: ECN).

Point	Latitude	Longitude
WAVEGEM	47°14.099'N	2°46.820'W
Anchor 1 (Southeast)	47°14.081'N	2°46.649'W
Anchor 2 (Southwest)	47°13.999'N	2°46.949'W
Anchor 3 (Northwest)	47°14.113'N	2°47.006'W
Anchor 4 (Northeast)	47°14.201'N	2°46.690'W

4.3 Monitoring

The seafloor integrity monitoring plan, together with the monitoring plans for the remainder of the priority areas of research (electromagnetic fields, acoustics, and fish communities), was defined in the Deliverable 2.1 in the framework of the Task 2.1 of the SafeWAVE project (*Development of Environmental Monitoring Plans*) and described by Vinagre *et al.* (2021).

In the case of the seafloor integrity, such monitoring plan encompassed two main techniques, i.e., video imaging using a Remotely Operated Vehicle (ROV) and side-scan SONAR (SSS) imagery. However, their application at each of the sites differed and, moreover, some setbacks prevented the monitoring to be carried out as planned by Vinagre *et al.* (2021). Hence, the surveys carried out at each of the testing sites and WEC, together with the equipment used, are described in the following subsections.

4.3.1 HiWave (CorPower Ocean)

Regarding the video monitoring, Vinagre *et al.* (2021) planned a baseline survey between June and July 2021, to be conducted with a ROV around the locations pre-defined for each of the WECs together with approximately 80 m long transects along the locations estimated for the mooring lines and anchors. A second survey was foreseen after one year of operation of the C4 WEC, in the summer of 2022, to cover the same locations as previously, thus, allowing for a comparison of pre-operational and operational surveys. However, the deployment of the C4 is still being prepared.

In the present report, the baseline (pre-operational) characterisation of the seafloor at Aguçadoura is described based on previous surveys in the area.

Two geophysical surveys were conducted in 2016 (carried out by the Portuguese Hydrographic Institute) and 2020 (AtlanticLand, 2020, *in* IAS, 2021) to characterise the bathymetry with multibeam echosounder, detected anomalous elements at the seafloor, and magnetic anomalies associated with the expected location of the cable installation area.

More recently, CorPower Ocean conducted two surveys with ROV:

- Survey 1 – October 2021: The aim of this survey was to identify the existence of any cultural patrimony and geomagnetic anomalies in the installation points and areas surrounding the anchor, WECs, and navigation buoys, as well as along the offshore cable laying route. It was carried out using a Seaeye Falcon ROV.

- Survey 2 – January 2022: This was a dedicated electrical cable route survey which covered several sections of the cable. It was conducted hours before installing the cable using a Magnum Plus Work Class ROV.

During the operational phase of HiWave, both ROV and SSS surveys are expected. For the latter, the Autonomous Underwater Vehicle (AUV) COMET-300 of RTSYS (partner in the project) will be used holding a SSS (see details in Vinagre *et al.*, 2021). The data and results from these surveys will later update the present report.

4.3.2 Penguin II (Wello)

Two video sampling surveys were planned in BiMEP: one once the Penguin II device was installed and in operation (summer 2021) and a second one after one year of operation (spring to summer 2022).

Finally, a single survey was carried out in July 2022, approximately one year after the deployment of the device. Unfortunately, in November 2021 the Penguin II suffered a breakdown and it was decommissioned in December 2022. Thus, as the WEC was not re-deployed and there was no certainty about short-term plans, the survey was undertaken with no device in the area. However, when Penguin II was removed, the moorings and the umbilical system were left and, as planned, the landing point of the lower catenaries, their routes till the anchors and the anchors were recorded in video.

The survey was carried out with a SIBIU Pro (see description in Vinagre *et al.*, 2021) in 13 and 14 of July 2022.

Besides, as planned, a SSS survey was performed on 2 and 3 of August 2022. As mentioned above, the Penguin II was no longer deployed, but the moorings and the umbilical cable were not removed. The AUV COMET-300 of RTSYS with a coupled SSS was used (see details in Vinagre *et al.*, 2021). Two surveys were carried out:

- 2 August: the AUV was programmed so that it carried out parallel transects that allowed the detailed inspection of each of the mooring lines (including lower catenary and anchors) (Figure 12). Three immersions were undertaken (one to cover mooring legs 1 and 2, another one for the mooring legs 3 and 4, and a third one for the mooring legs 5 and 6). The AUV navigated at an altitude of 10 m and a high frequency SSS.

- 3 August: the AUV was programmed to carry out, in a single immersion, six transects that allowed full cover of the area occupied by the Penguin II device, moorings and umbilical system, at a lower resolution. For this purpose, the AUV navigated at an altitude of 30 m and a low frequency SSS.

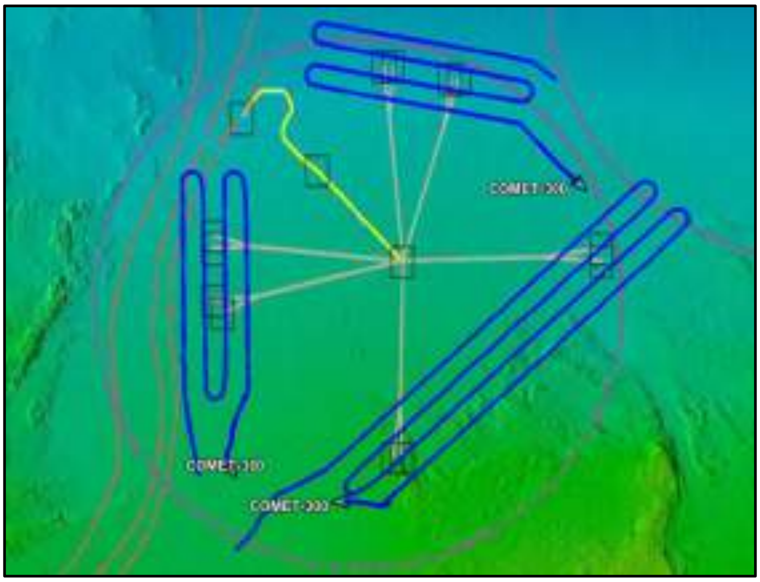

Figure 12. Navigation map of the COMET-300 in the first survey carried out on the 2nd of August 2022. The routes followed by the AUV are represented in blue.

4.3.3 WAVEGEM (GEPS Techno)

SSS and ROV surveys were carried out at SEM-REV test site, around the mooring lines of WAVEGEM in the framework of SafeWAVE project.

After Deliverable 2.1 in which the monitoring plan was detailed, two video surveys were planned in SEM-REV (Vinagre *et al.*, 2021), one in spring to summer 2021 (operational phase) and the other one after the decommissioning of the device.

The first survey (operational phase) was carried out on the 2nd of July 2021. Two ROVs were used: a Revolution ROV (by Deep Trekker; see description in Vinagre *et al.*, 2021) inspected the mooring line corresponding to the Anchor 1 (southeast) before it faced engine problems; a M2 ROV (by Chasing) inspected the mooring line corresponding to Anchor 4 (northwest). This later ROV rates a maximum of 100 m water depth, is equipped with a 4K camera. Unfortunately, the visibility was poor during the survey and the videos recorded did not provide much information.

The second survey was undertaken on the 22nd of May 2022, once the device and the moorings (except the anchors and bottom chains) were removed, using a Revolution ROV. Again, the visibility was poor due to the presence of suspended material. Therefore, only Anchor 1 was inspected.

Regarding the SSS survey, one campaign was carried out the 9th of June 2021, with WAVEGEM in operation, using the AUV COMET 300 by RTSYS. Two surveys were undertaken:

- In the first survey, the AUV navigated at an altitude of 10 m above the bottom and the range of the SSS was 50 m at each side of the COMET 300. Figure 13 shows the route followed by the AUV.
- During the second survey, the COMET 300 navigated at an altitude of 6 m and the range of the SSS was 30 m at each side of the AUV. Figure 14 shows the route followed by the AUV in this second survey.

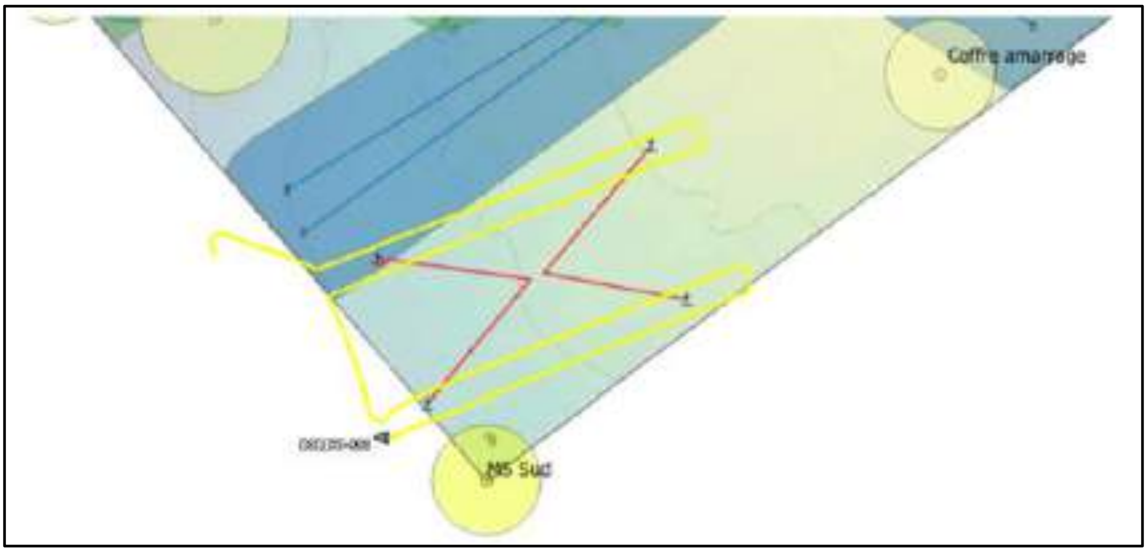

Figure 13. First navigation map of the COMET-300 (10 m above bottom) in the first survey carried out on the 9th of June 2021. The route followed by the AUV is represented in yellow.

A second campaign was carried out on the 4th of May 2022, once the WAVEGEM device was decommissioned (but anchors and bottom chains still remained), also with the AUV COMET 300. For this campaign a single survey was undertaken, with the

AUV navigating at an altitude of 10 m and a SSS range of 50 m at each side of the COMET 300. Figure 15 shows the route followed by the AUV.

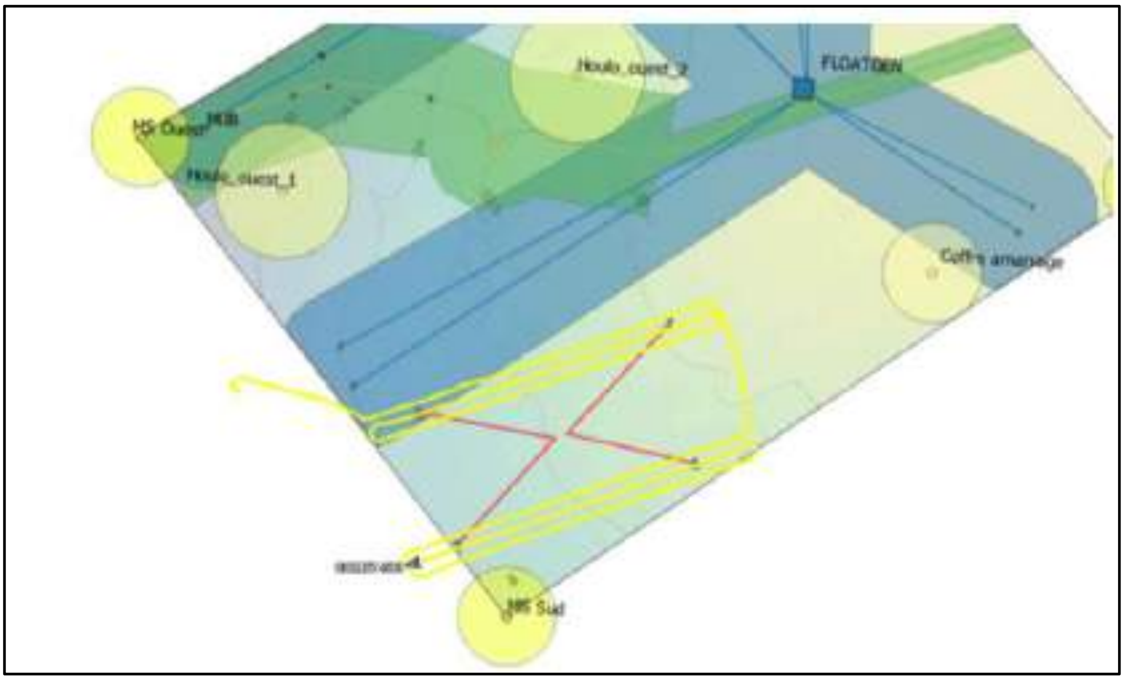

Figure 14. Second navigation map of the COMET-300 (6 m above bottom) in the first survey carried out on the 9th of June 2021. The route followed by the AUV is represented in yellow.

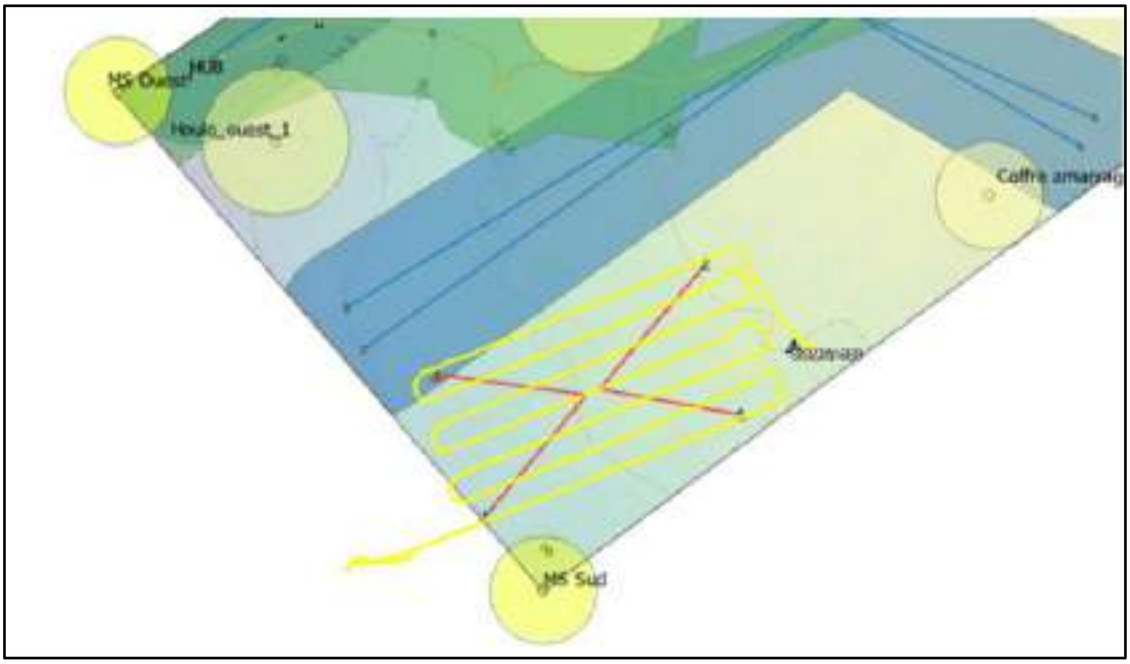

Figure 15. Navigation map of the COMET-300 in the second survey carried out on the 4th of May 2022. The route followed by the AUV is represented in yellow.

Another survey is planned to be completed in the first trimester of 2023, once the bottom chains and the anchors are removed.

5. Results

As mentioned above, due to the differences in the sampling schemes from the three sites the results will be analysed independently in the subsections below.

5.1 Aguçadoura (Portugal)

In 2016, the bathymetry at the installation area of the CPO WECs varied between the -41 m and -47 m depth. The whole area was covered by fine sand and presented ripples with NW-SE orientation. The side-scan sonar identified 27 'objects', part of which were associated with the PELAMIS (anchor, lazy wave cable, and other unidentified objects) (IH, 2016, in IAS, 2021).

In 2020, the multibeam echosounder survey identified 23 'objects' in the WECs and cable installation areas (AtlanticLand, 2020, *in* IAS, 2021) (Figure 16). No interpretation of those objects was provided, but it was mentioned that 8 of them were not corresponding to bathymetric anomalies.

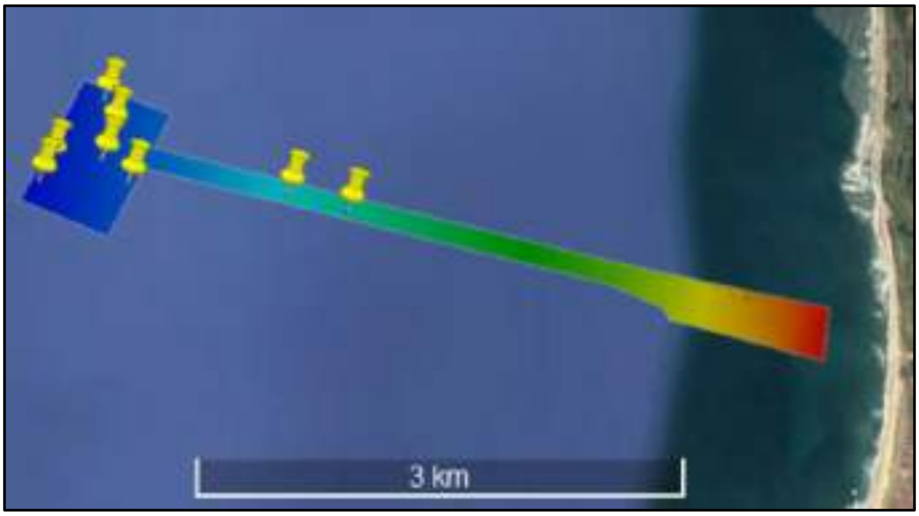

Figure 16. Area covered by the multibeam echosounder survey in 2020. Yellow pins mark the 8 'objects' not corresponding to bathymetric anomalies.

The survey in October 2021 was conducted using a ROV to confirm the identity of such 'objects' and anomalies. During this survey, visibility underwater was estimated as 4-5 m. No elements corresponding to the previously found anomalies, nor any equipment from previous projects, were observed at the seafloor. Unfortunately, not all the targeted 'objects' and magnetic anomalies could be monitored due to the presence of fishing gear, unauthorized within the CPO site (IAS, 2021).

The dedicated survey of January 2022 (monitored locations are presented in Figure 17 and Table 5) rendered very similar results to the survey of October 2021.

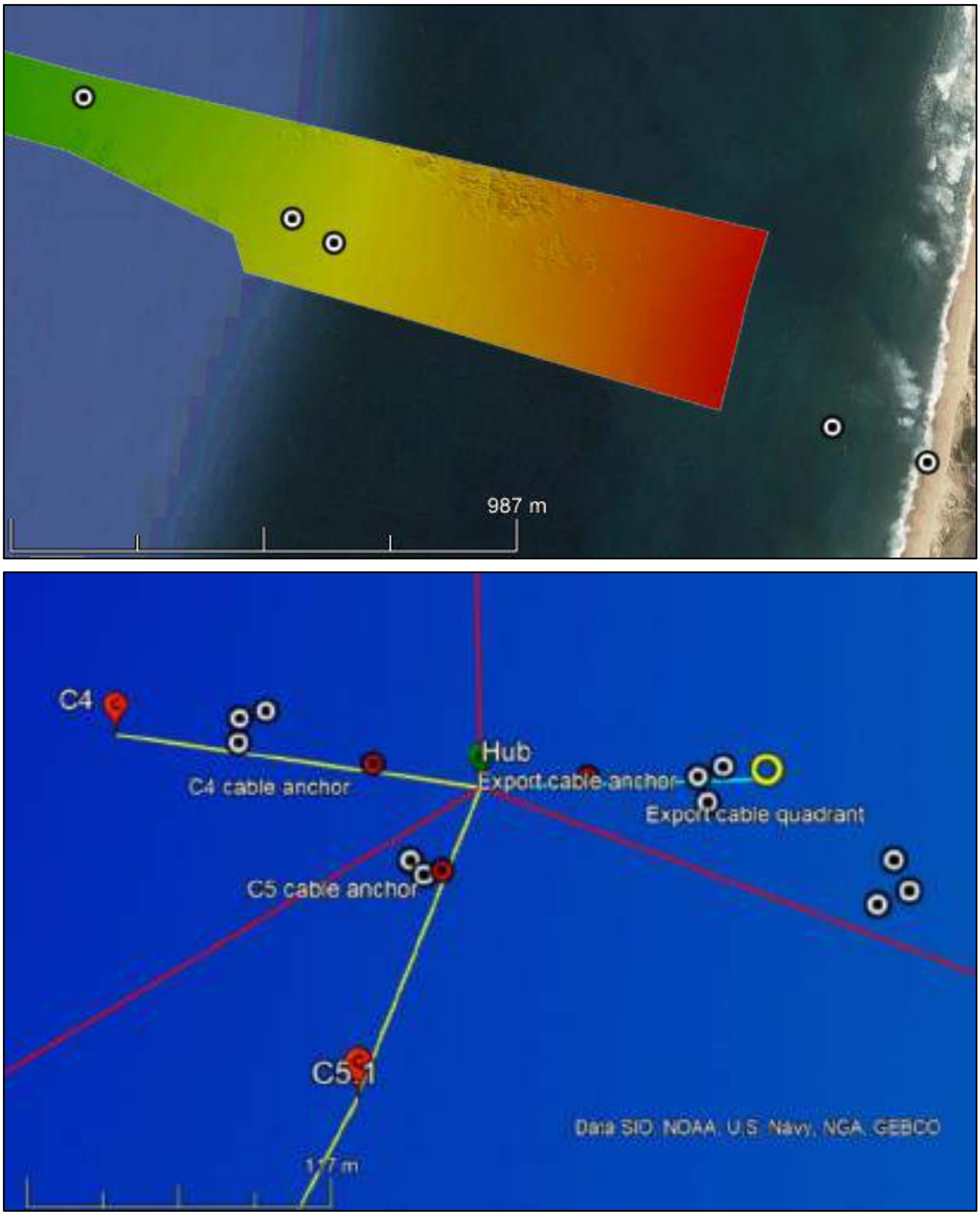

Figure 17. ROV monitoring locations (white circles) in the survey of January 2022. Top: Along the cable route. Bottom: Within the WECs installation area.

Table 5. Coordinates of the ROV monitoring locations (WGS 84; Degrees, Decimal Minutes) (Source: CPO).

Description	Latitude	Longitude
Start of 200 m of cable protection	41° 26.664'N	8° 46.748'W
End of 200 m of cable protection	41° 26.700'N	8° 46.883'W
Start of 500 m of cable protection	41° 26.918'N	8° 47.667'W
End of 500 m of cable protection	41° 27.048'N	8° 47.982'W
Cable location at 14 m contour (LAT)	41° 26.892'N	8° 47.605'W
Sandbag 1	41° 27.511'N	8° 50.327'W
Sandbag 2	41° 27.508'N	8° 50.335'W
Sandbag 3	41° 27.501'N	8° 50.332'W
Sandbag 4	41° 27.485'N	8° 50.272'W
Sandbag 5	41° 27.477'N	8° 50.268'W
Sandbag 6	41° 27.473'N	8° 50.278'W
Sandbag 7	41° 27.528'N	8° 50.483'W
Sandbag 8	41° 27.526'N	8° 50.492'W
Sandbag 9	41° 27.519'N	8° 50.490'W
Quadrant approximate position	41° 27.481'N	8° 50.421'W
Static to Jumper dry-mate connection approximate position	41° 27.485'N	8° 50.426'W

Overall, in both surveys the seafloor is dominated by sandy sediments with natural ripple marks (Figure 18). Observations also included:

- Macroalgae moving with the current/wave action (down to about -11 m depth) in the October 2021 survey (Figure 19);
- Often observations of crabs (cf. Family Polybiidae/Portunidae) (down to -45 m depth) in both surveys (Figure 20 and Figure 21);
- Seldom observations of (mostly razor clam) shells (down to -45 m depth) in both surveys (Figure 22);
- A school of (non-benthic) small fish (above the ROV at -9 m depth) in the October 2021 survey (Figure 23);
- Seldom observations of squids (down to -45m depth) in the January 2022 survey (Figure 24).

Figure 18. Sandy bottom with ripple marks; at -26.2 m depth, recorded in the ROV survey of October 2021.

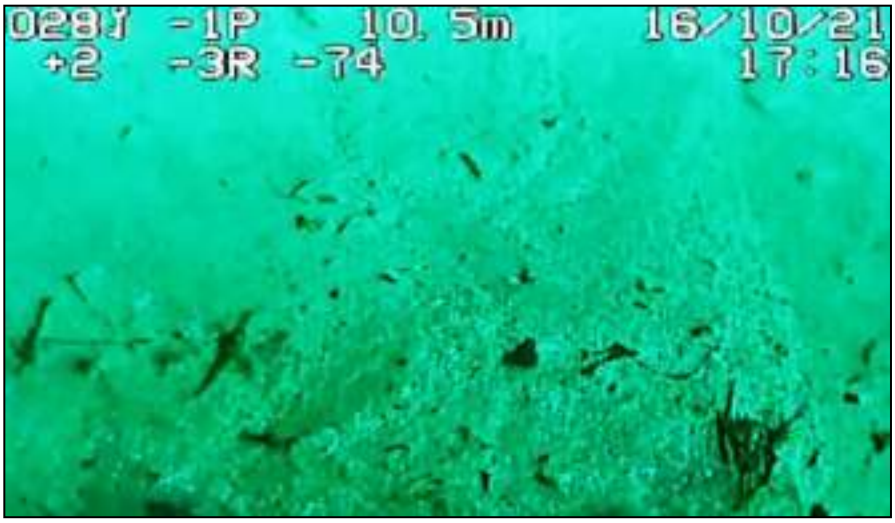

Figure 19. Macroalgae moving with the current over a sandy substrate covered by small shells at -10.5 m depth, in the ROV survey of October 2021.

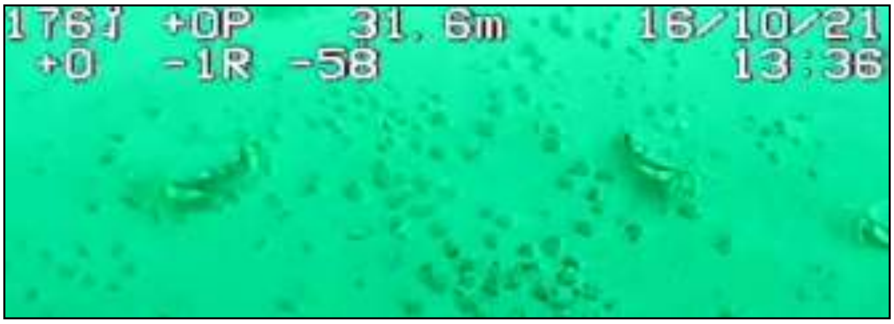

Figure 20. A few crabs feeding at -31.6 m depth, in the ROV survey of October 2021.

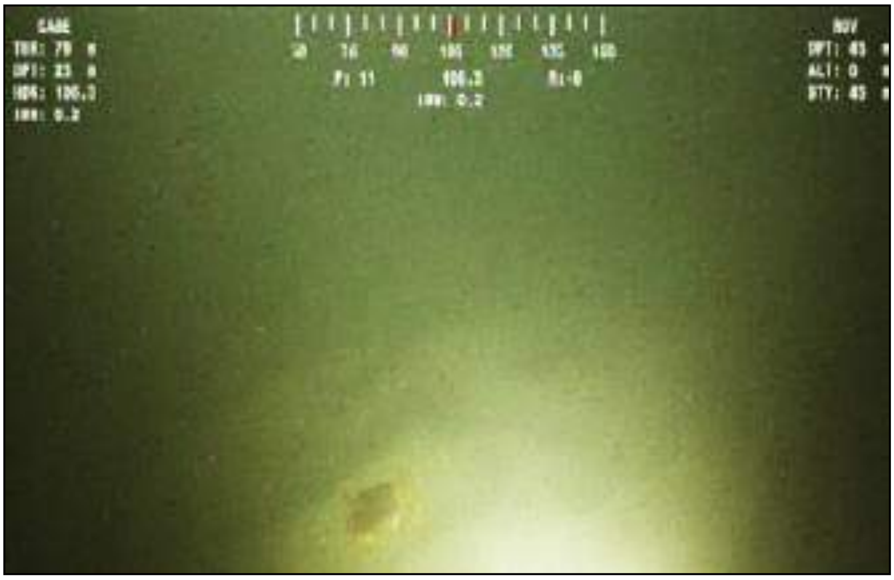

Figure 21. A crab sighting at -45.0 m depth, in the ROV survey of January 2022.

Figure 22. Sandy bottom with a few razor clam (cf. Solenidae) shells at -25.6 m depth, in the ROV survey of October 2021.

Figure 23. Small fishes above the ROV at -9.0 m depth, in the ROV survey of January 2022.

Figure 24. A group of squids (~15 individuals) at a sandbag near the sea bottom; at -44.0 m depth, in the ROV survey of January 2022.

5.2 BiMEP (Spain)

For the interpretation of the results, it cannot be ignored that the Penguin II was operating for approximately five months and that it was recovered seven months after, on December 19, 2021. Between December 2021 and July 2022 several storm events occurred that could affect the seafloor, removing the footprints caused by the moorings (at least, three events in early January, mid-February and early April).

The information on the videos recorded is uploaded to the MARENDATA portal (https://marendata.eu) and they can be visualized in the YouTube channel of AZTI (https://www.youtube.com/playlist?list=PLE4V8Cu7O0dlPYhoWAcCRPWhkTdyxqd6b).

5.2.1 ROV

As described for Aguçadoura, in BiMEP the seafloor is also dominated by sandy sediments forming ripple marks in north-northwest to south-southeast direction with 1-1.5 m wavelength approximately. In deeper areas the ripple marks look better ordered and characterized by higher wavelength and amplitude than in shallower areas (Figure 25 and Figure 26).

That implies a better apparent sorting in particle sizes between crests and valleys in deeper areas, with higher differences between the fine sediments in the crests and the coarser sediments (with large amounts of shells) in the valleys.

The chain weights of mooring legs 1 and 2 are the ones that lie deepest (approximately -75 m), north from the Penguin II device location. These weights act as attractors for fishes, e.g.: an European conger (*Conger conger*) in the CW2b chain weight (Figure 27), and a female cuckoo wrasse (*Labrus mixtus*) and a shoal of poutings (*Trisopterus luscus*) close to the weights of mooring leg 1 (Figure 28 and Figure 29) were recorded.

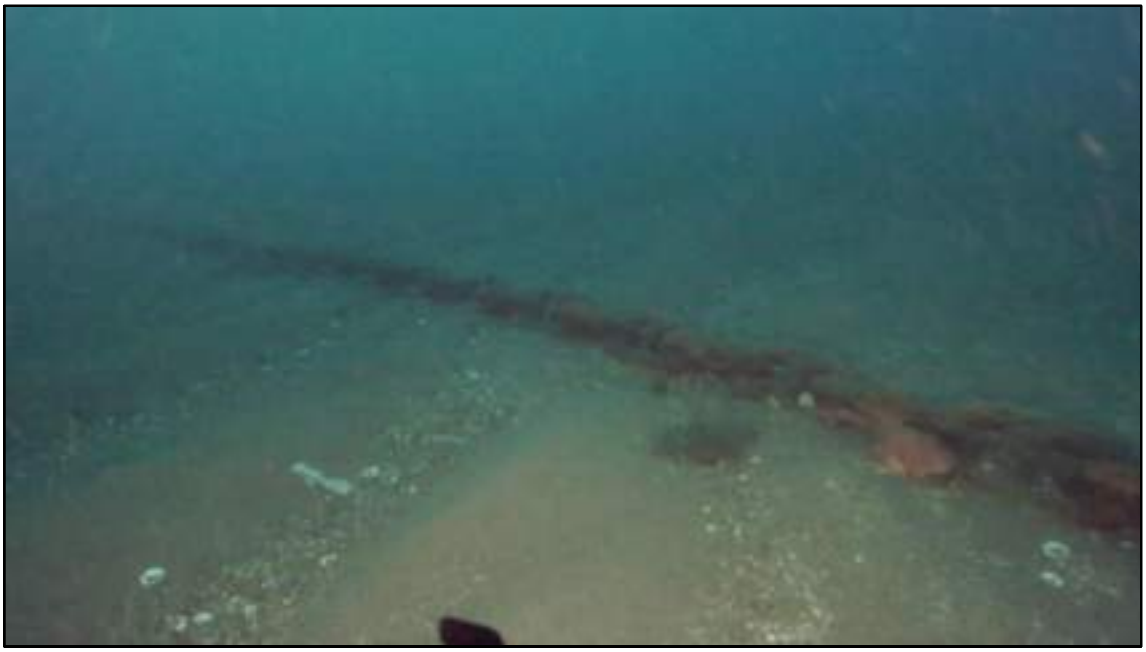

Figure 25. Mooring leg 2 chain and ripple marks next to it.

Figure 26. Ripple marks close to mooring leg 5.

Figure 27. European conger (*Conger conger*) protected in the CW2b chain weight.

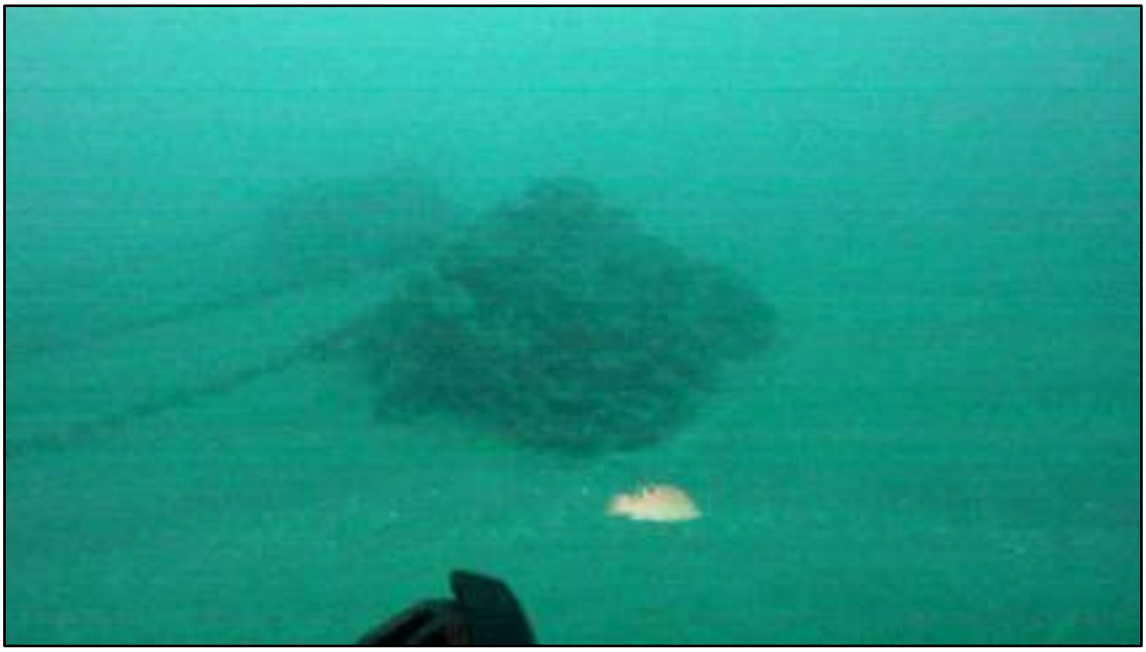

Figure 28. Female cuckoo wrasse (*Labrus mixtus*) near mooring leg 1 chain weights.

Figure 29. Shoal of poutings (*Trisopterus luscus*) swimming around one of the chain weights of mooring leg 1.

Regarding the seafloor, there is not any alteration beyond the presence of the chain weights as potentially colonizable hard substrata in a soft bottom environment. The ripple marks maintain their structure even next to the chains (Figure 30) and no physical alteration is observed.

Figure 30. Ripple marks close to one of the chain weights of mooring leg 1.

The lower catenary lies on the sediment (Figure 31), partially buried in some sections. No evidence of physical alteration of the substrate is observed apart from a slight accumulation of fine sediment at the sides of the chain. This accumulation is evidenced by the absence of coarse sediment fringes corresponding to the valleys of the ripple marks, but is limited to the first centimetres at both sides of the catenary.

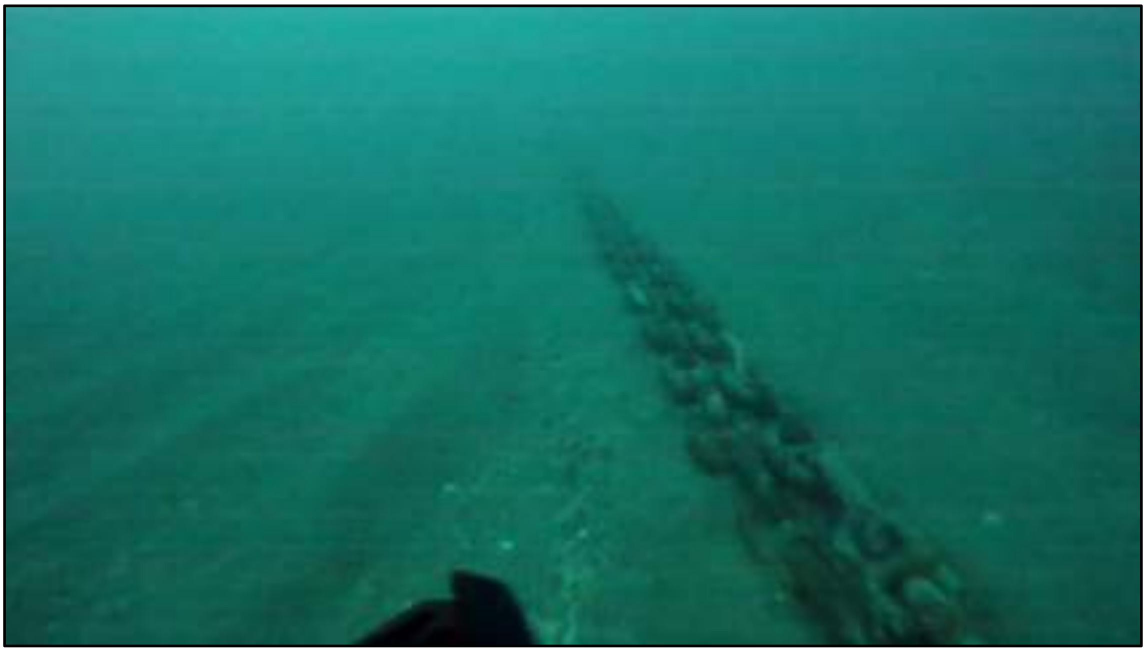

Figure 31. The lower catenary of the mooring leg 1, lying on the bottom.

The catenaries act also as attractors of fauna. As an example, some red gurnards (*Chelidonichthys cuculus*; Figure 32) and a striped red mullet (*Mullus surmulletus*; Figure 33) were observed next to the lower catenary of the mooring leg 1.

Finally, the figures show that the chains conforming both the lower catenaries and the weights are covered by turfy fouling.

It should be noted that, when Penguin II was recovered for maintenance, the lower catenaries were abandoned in place and now lie on the bottom. In the case of the mooring leg 2 a girth, probably used for the recovery, was even recorded attached to the chain (Figure 34). There is no evidence of disturbance, different from the rest of the catenary, for this sections that were dropped when the device was removed.

The chain weights of mooring legs 3, 4 and 6 lie at approximately -70 m water depth. Mooring legs 3 and 4 are located west from the Penguin II device location, whereas mooring leg 6 is located east. These weights also act as attractors for fishes, and

European congers (*C. conger*), cuckoo wrasses (*Labrus mixtus*) and shoals of poutings (*T. luscus*) were recorded too.

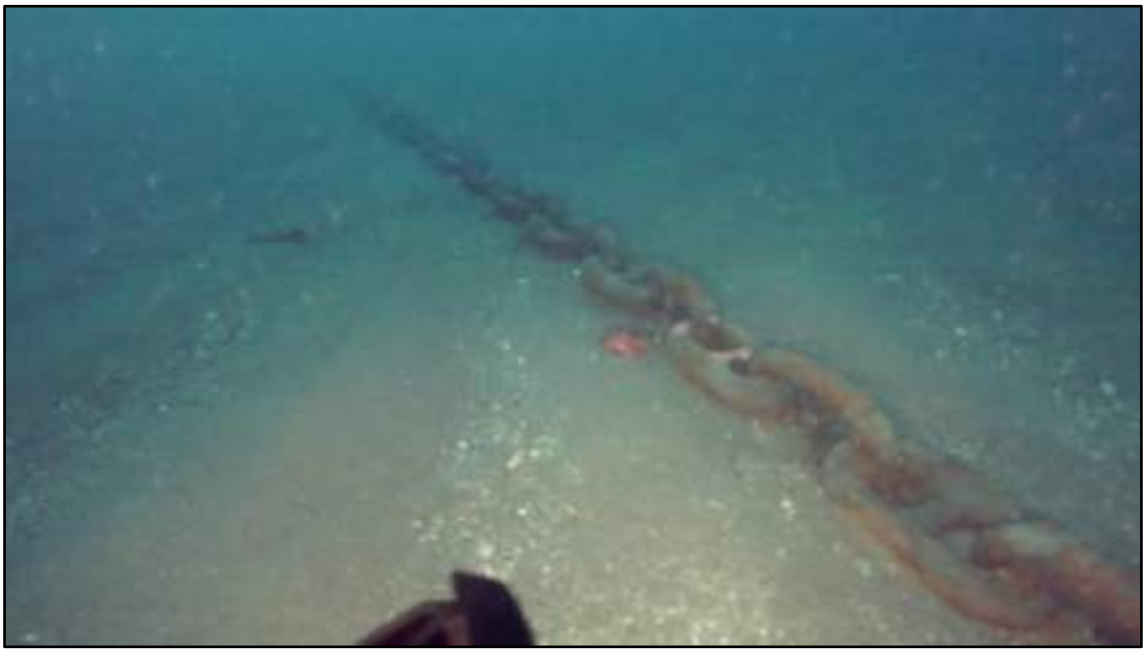

Figure 32. Red gurnard (*Chelidonichthys cuculus*) next to the lower catenary of mooring leg 1.

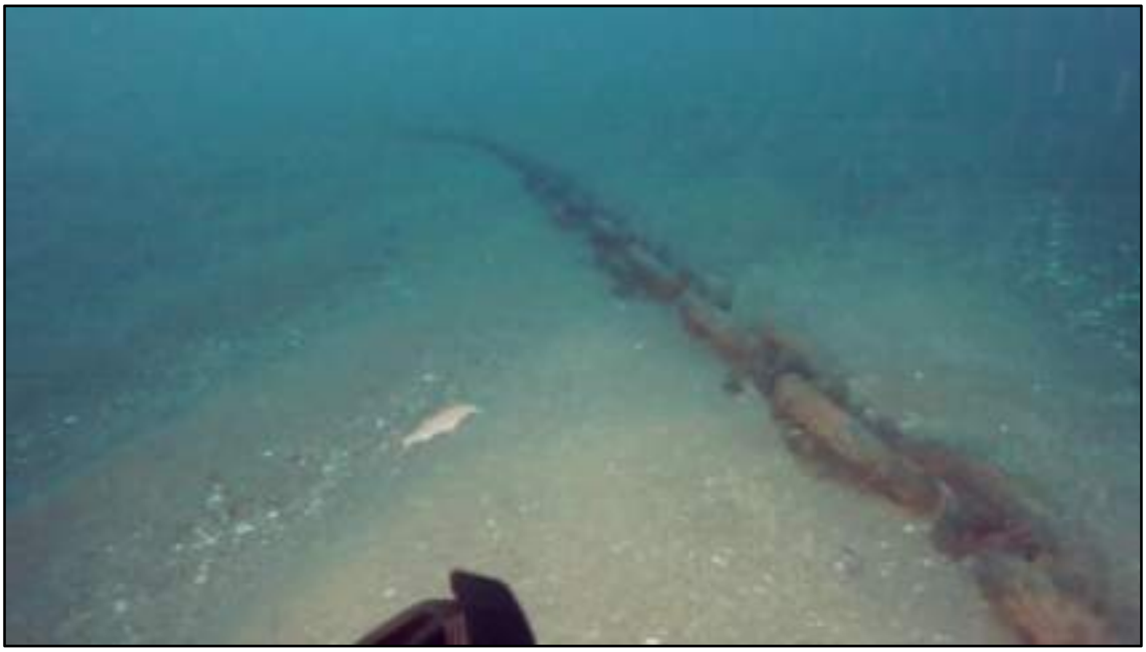

Figure 33. Striped red mullet (*Mullus surmuletus*) near the lower catenary of the mooring leg 1.

Figure 34. A girth attached to the upper end of the lower catenary of the mooring leg 2.

Regarding the seafloor, as described above for the deepest moorings there is not any alteration beyond the presence of the chain weights as potentially colonizable hard substrata, and the slight accumulation of fine sediment at the sides of the catenary.

The catenaries act also as attractors of fauna. As an example, some red gurnards (*C. cuculus*) and unidentified starfishes (Echinodermata, Asteroidea; Figure 35) were observed.

In the particular case of the mooring leg 6, the disturbance to the seafloor is not so clear as for the rest of the moorings (Figure 36). This is probably due to the lower amplitude of the ripple marks (already mentioned above). As they are not so well defined as the ripple marks in the western and the northern areas, the footprints of the lower catenary and the chain weight of the mooring leg 6 may be partially masked.

As mentioned for the mooring legs 1 and 2, the chains from the mooring legs 3, 4 and 6 are also colonized by fouling.

Finally, the mooring leg 5 is the one that is located shallowest, being the chain weights at 60 m water depth, approximately. A slight accumulation of fine sands is observed next to the chain weight CW5a, in its western side (Figure 37). Besides, the chain weight act also as attractors for fauna (Figure 38) Apart from that, no disturbance is appreciated on the seafloor.

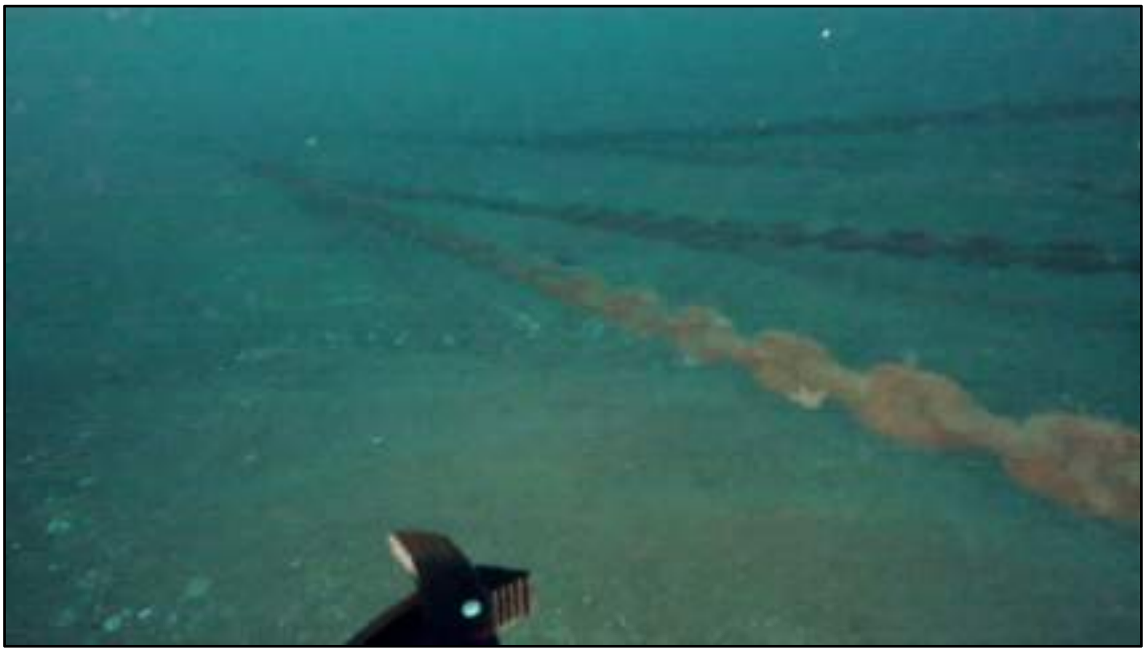

Figure 35. Unidentified starfish (Echinodermata, Asteroidea) attached to one of the chains to the chain weight CW4a.

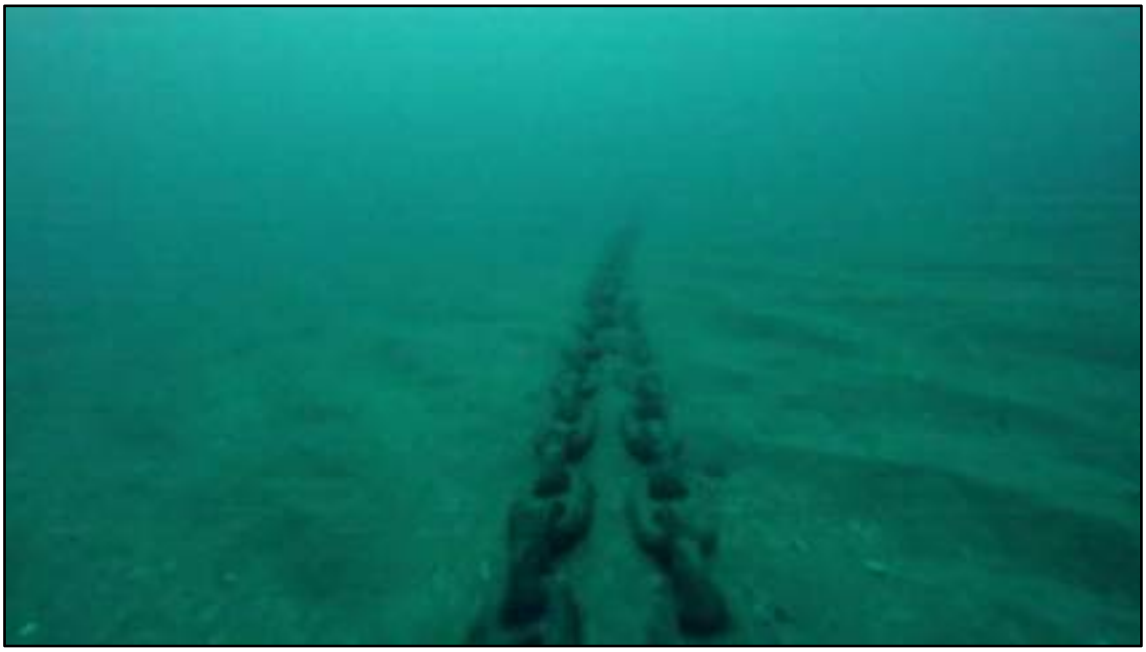

Figure 36. Lower catenary of the mooring leg 6.

Figure 37. Sand accumulation in the western side of the chain weight CW5a.

Figure 38. European conger (*Conger conger*) looking for protection between the chains of weight CW5b.

As indicated for the rest of the mooring legs, the lower catenary of the mooring leg 5 is also partially buried into the sediment along some sections (Figure 39). In the sections that it is over the sediment, some accumulation of sands is observed at the sides of the chain (Figure 40).

Figure 39. Unidentified starfish (Echinodermata, Asteroidea) on one of the links of the lower catenary of mooring leg 5, in a section that is partially buried into the sediment.

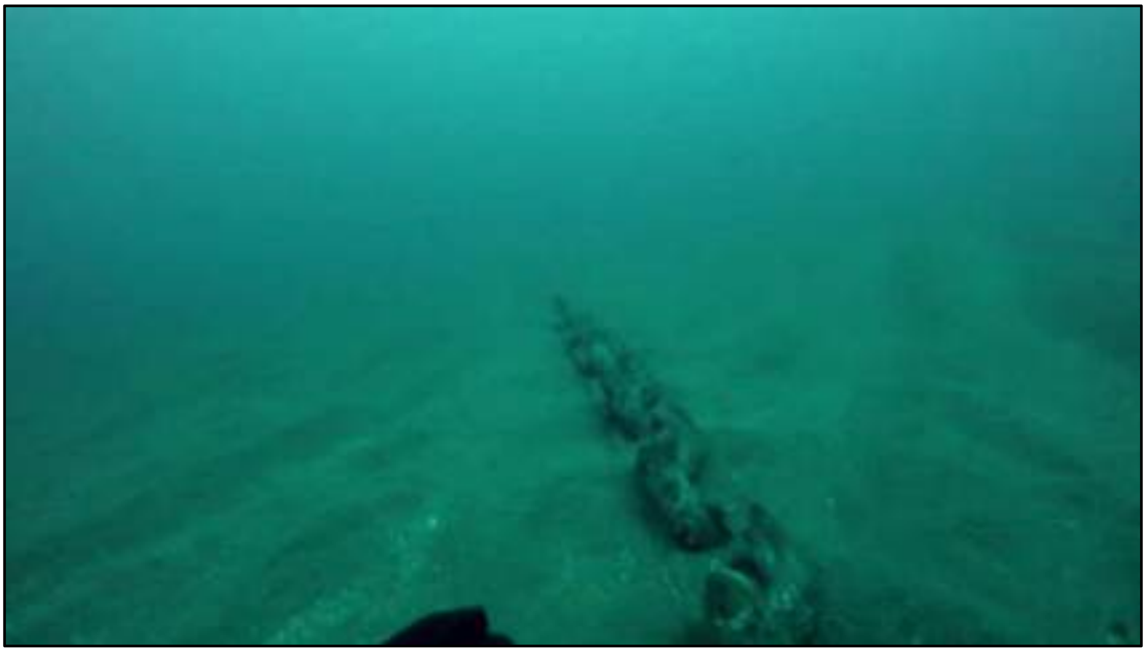

Figure 40. Accumulation of sand at the sides of the lower catenary of mooring leg 5.

As for the rest, the lower catenary of the mooring leg 5 also works as attractor for fauna (Figure 39 and Figure 41). Besides, both the lower catenary and the chain weight, are covered by turfy fouling.

A distinctive feature of the lower catenary corresponding to the mooring leg 5 is that, when the Penguin II device was recovered for maintenance, some sections of the catenary that were dropped, fell onto outcrops (Figure 42). However, as such outcrops do not show important biological cover (in terms of structure complexity and abundance), disturbance is not appreciated.

Figure 41. Red gurnard (*Chelidonichthys cuculus*) next to the lower catenary of mooring leg 5.

Figure 42. Section of the lower catenary corresponding to mooring leg 5 settled on outcrops.

5.2.2 Side Scan Sonar

The low frequency SSS was useful to identify the entire lower catenaries and chain weights of the six mooring legs, together with the SPL-1 connector and the rocky outcrops in the study area (Figure 43). The ripple marks are also glimpsed, although they are not apparent.

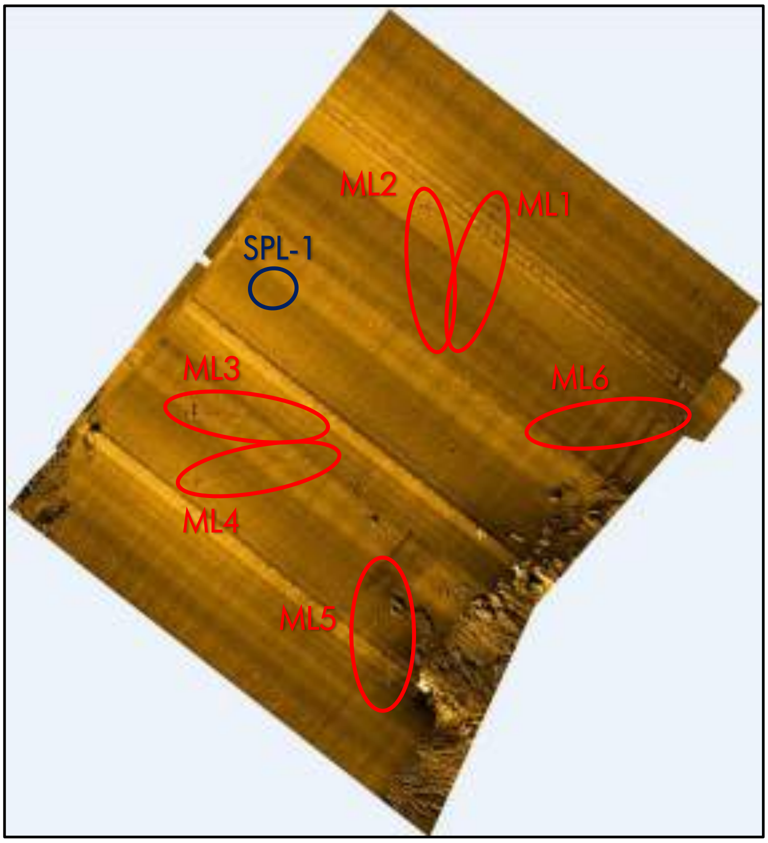

Figure 43. Low frequency side scan sonar covering all the study area. The Mooring legs (ML) 1 to 6 are indicated with red circles; the BiMEP to WE splice (SPL-1) is indicated with a dark blue circle.

The SPL-1 connector is seen as a highly reflective 3.5 m length and 1.5 m wide spot. Nor the cable connecting to the Penguin II device and neither the export cable to land are clearly visible in the SSS image.

In the high frequency SSS images the ripple marks structuring the seafloor are much more evident (Figure 44). In the same way, the catenaries and footprints associated are also more marked. Thus, the width of the traces of the catenaries can be determined in 1-1.5 m, approximately. However, such footprints are less visible in the first half of the catenary (starting from the chain weights; Figure 45). This could be a consequence of the catenary being buried into the sediment in a higher degree compared to the catenaries corresponding to the rest of mooring legs. But it could be also explained, as mentioned for the videos recorded with the ROV, by a lower amplitude of the ripple marks and a slight accumulation of sands in the western side of the chain. Moreover, some accumulation of sediments can be appreciated in the north-western side of the chain weight CW5a (Figure 45), mentioned also for the video recordings.

Finally, the high frequency SSS images also show the section of the catenary of the mooring leg 5 that is furthest from the chain weights lying over two outcrops (Figure 45). This section of the chain was probably above the sediment before Penguin II was removed from the site.

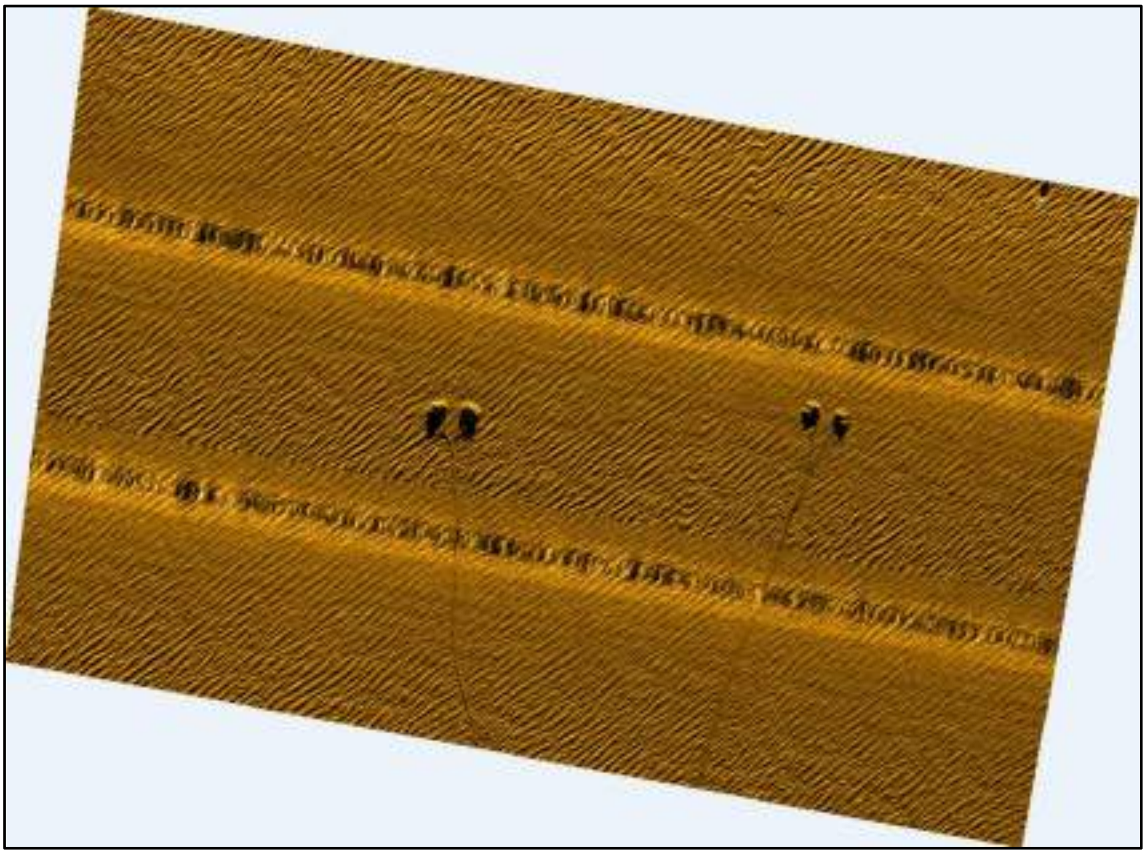

Figure 44. High frequency side scan sonar image covering the area occupied by mooring legs 1 (right) and 2 (left).

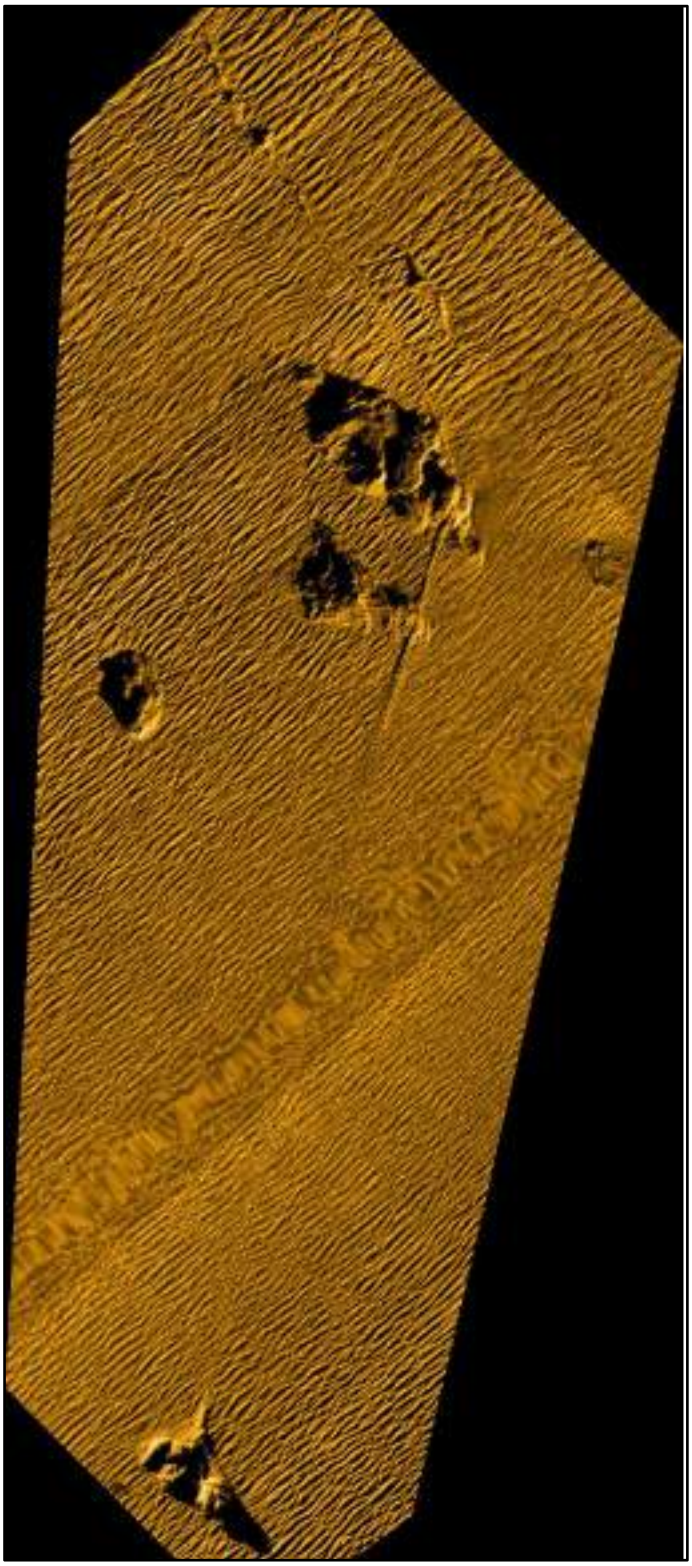

Figure 45. Chain weights (bottom) and lower catenary of mooring leg 5. In the upper part of the figure the catenary lies over two outcrops.

5.3 SEM-REV (France)

At SEM-REV test site, ROV and SSS surveys were carried out around the moorings of WAVEGEM. These surveys took place during the operational phase (June (SSS) and July (ROV) 2021) and after partial decommissioning of the device (May (ROV and SSS) 2022). The device was removed from water in November 2021 and part of the mooring lines (nylon and top chains) was removed in January 2022. Thus, during the surveys of May 2022 bottom chains and anchors still laid on the seafloor.

5.3.1 ROV

The SEM-REV test site is located on a medium sandy bottom. Little ripple marks can be observed, with accumulation of coarser sediments and shell fragments.

The two ROV surveys took place with poor visibility conditions (great level of turbidity). Thus, it was not possible to have a wide overview around mooring assets. Moreover, it was not possible to inspect all the anchors with the ROV (only 1 or 2 per survey). Hence, the surveys focused on visible assets (i.e., which were not totally buried).

The anchors and the mooring lines were in place since summer 2019. Bottom chains and almost all anchors were buried due to sedimentary movement, which allowed to only see few chain links.

Despite the poor visibility, no significant alteration of the seabed is noteworthy. As it can be seen in Figure 46, the footprint of the mooring line (#4 NE) is approximately 10-20 cm from each part of the line, along a few meters.

Thanks to video recordings, it is possible to observe vertical movement of the mooring line (due to current and waves) regularly without having contact with the seabed.

Within 2 years (2019 to 2021), bottom chains were completely buried and the ROV survey allows distinguishing only some chain links, as shown in Figure 47.

The mooring assets not totally buried attract fauna, especially in a soft bottom environment. Many Gadidae are observed (*Trisopterus* sp. and *Trisopterus luscus*) (Figure 48, Figure 49 and Figure 50). Close to the mooring line, Gobiidae are observed as well (Figure 46). Furthermore, a lobster finds shelter under a connection piece partially buried (Figure 51).

Mooring assets not buried are colonized by biofouling (calcareous tubeworms together with soft fouling).

Figure 46. Scraping of the connexion piece between nylon and bottom chain on the seabed (mooring line #4 – 02/07/2021). A Gobiidae can be seen close to it.

Figure 47. Bottom chain (#4) almost totally buried – only few chain links are visible (02/07/2021).

Figure 48. Pouting (*Trisopterus* sp.) close to the mooring line #4 (NE) (02/07/2021).

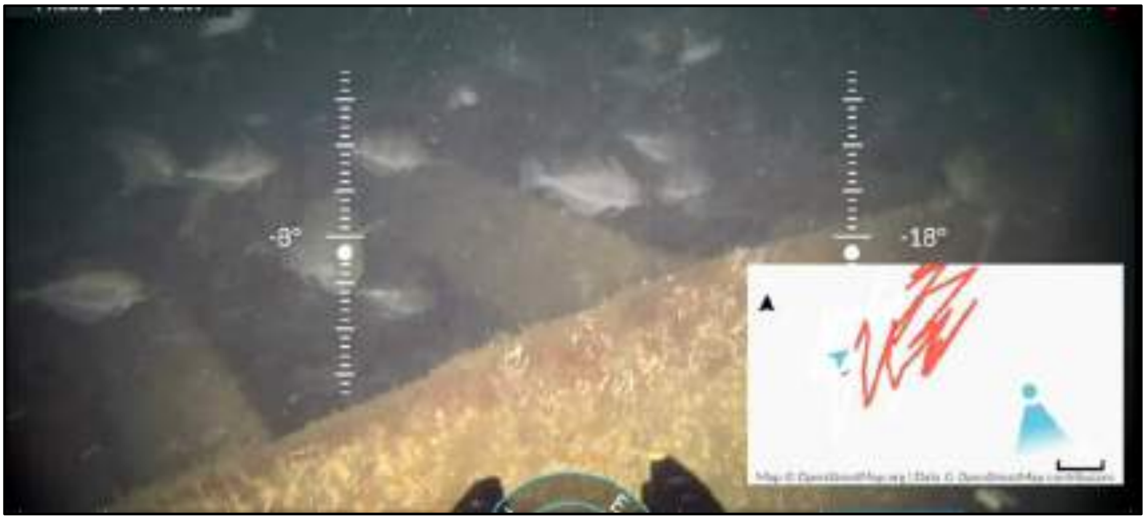

Figure 49. Shoal of poutings (*Trisopterus* sp.) above the anchor #1 (SE) (02/07/2021).

The ROV survey of 10th of May 2022 did not provide much information due the poor visibility. Only the anchor was filmed. Some biofouling on the anchor and the attraction of fish (Gadidae, Trisopterus *sp.*) around the anchor can be observed.

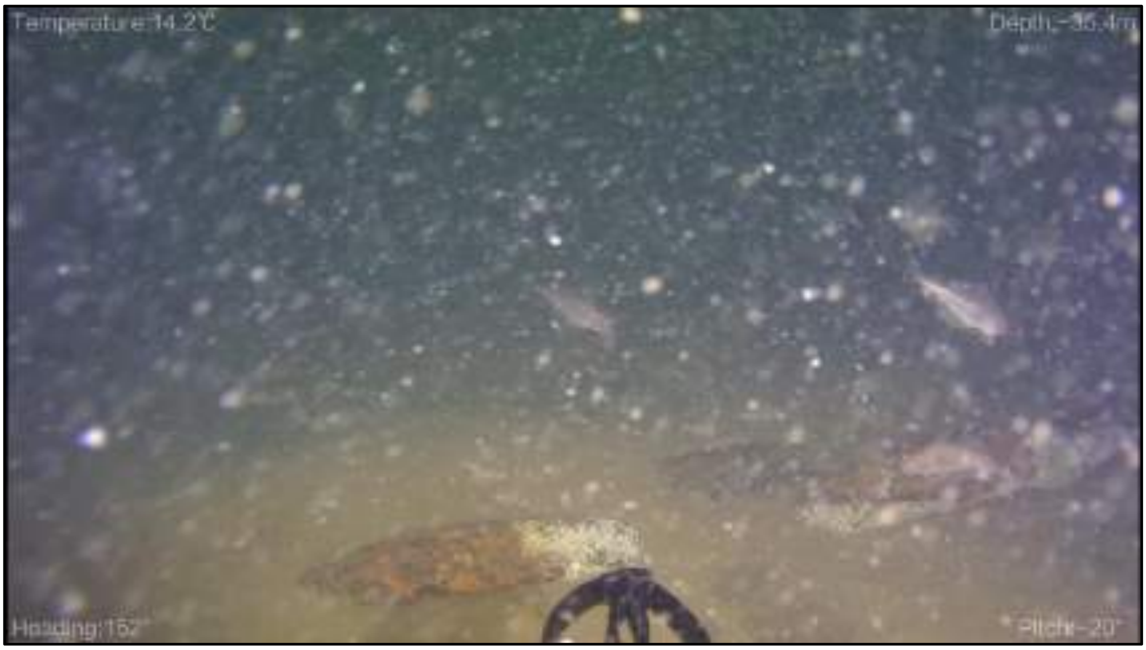

Figure 50. Some Gadidae above the bottom chain #4 (NE) (02/07/2021).

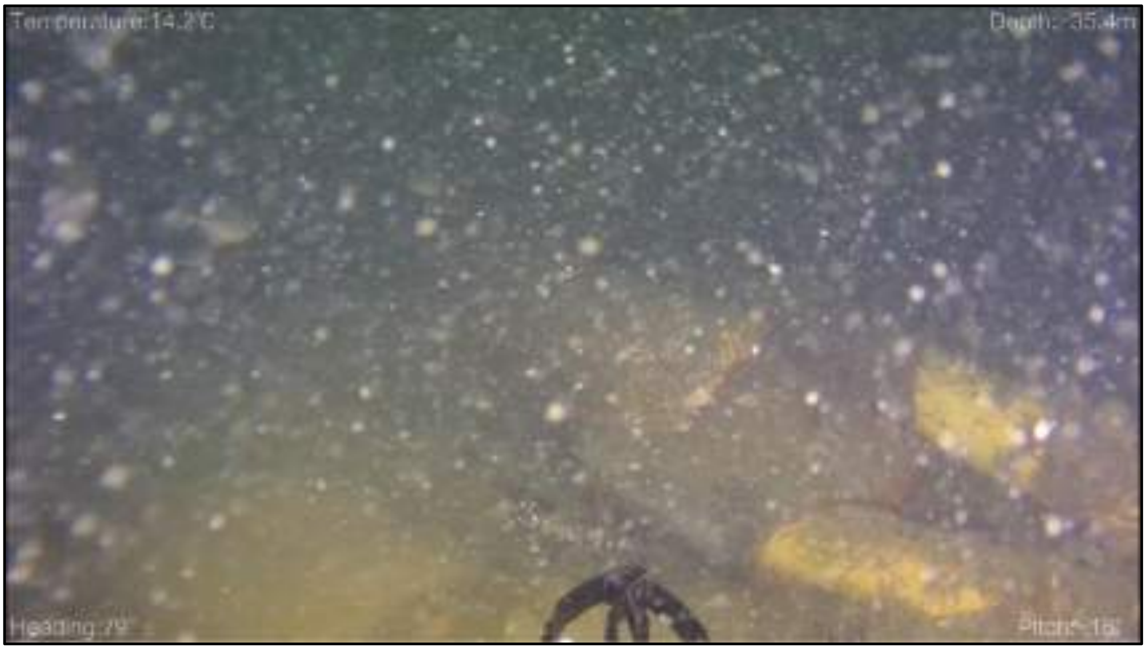

Figure 51. Lobster under a connection piece between the bottom chain and anchor #4 (NE) (02/07/2021).

5.3.2 Side Scan Sonar

Two SSS surveys were carried out at SEM-REV test site. For the first one, during the operational phase (09/06/21), two navigations were performed at two different altitudes above the seafloor.

SSS results are shown in Figure 52 and Figure 53 (first navigation: AUV 10 m above seabed), and in Figure 54 and Figure 55 (second navigation: AUV 6 m above seabed).

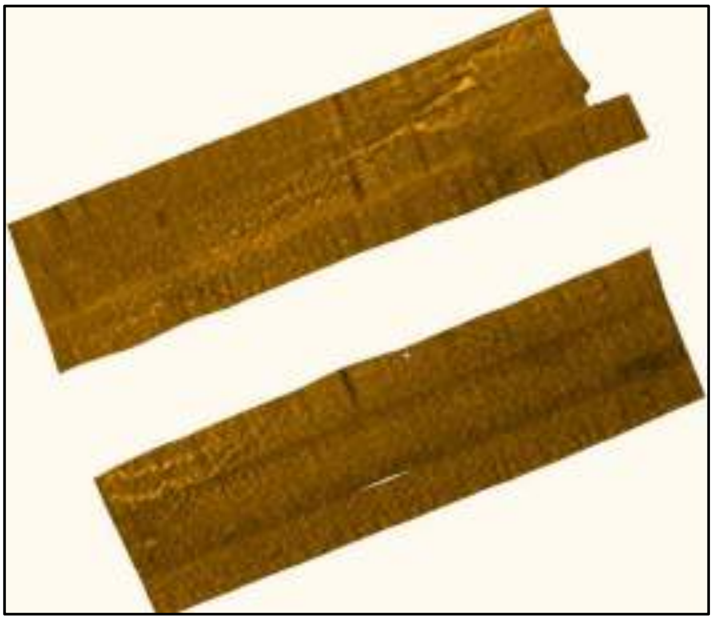

Figure 52. SSS data of the entire area (nav#1 – 09/06/21).

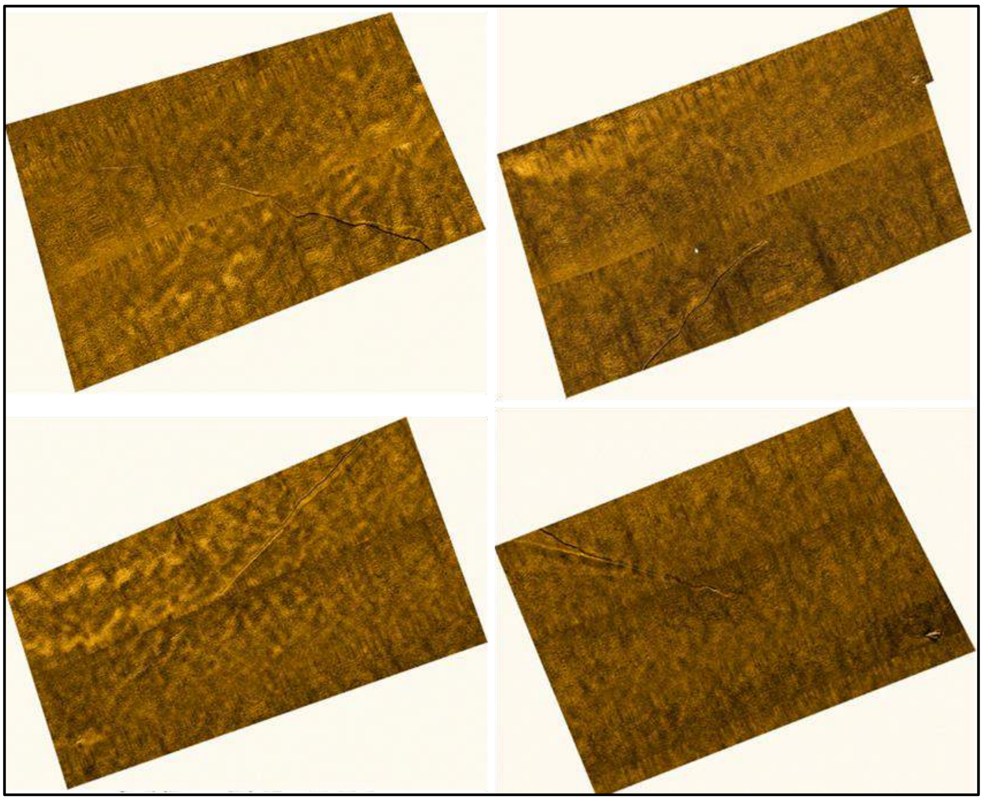

Figure 53. SSS data of each mooring line (nav#1 – 09/06/21). Top left: NW anchor; Top right: NE anchor; Bottom left: SW anchor; Bottom right: SE anchor.

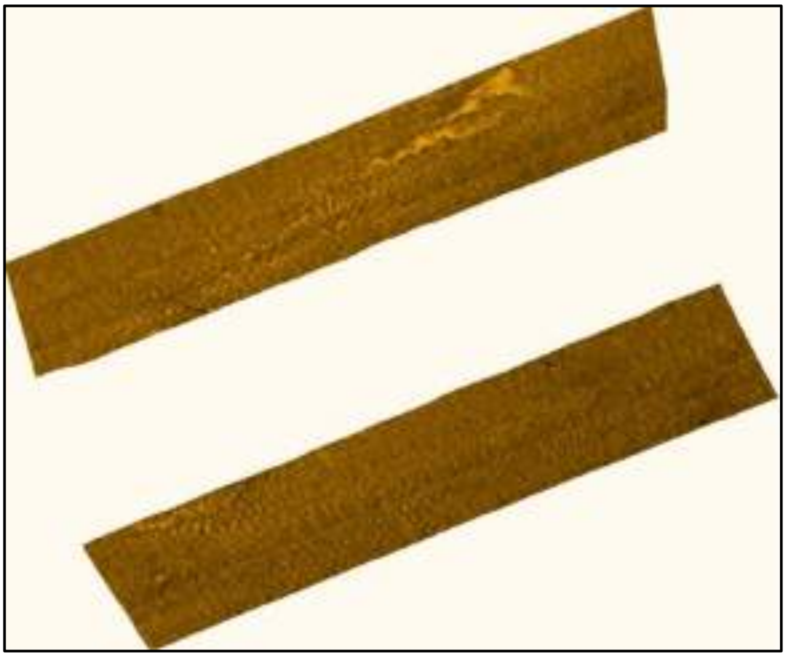

Figure 54. SSS data of the entire area (nav#2 – 09/06/21).

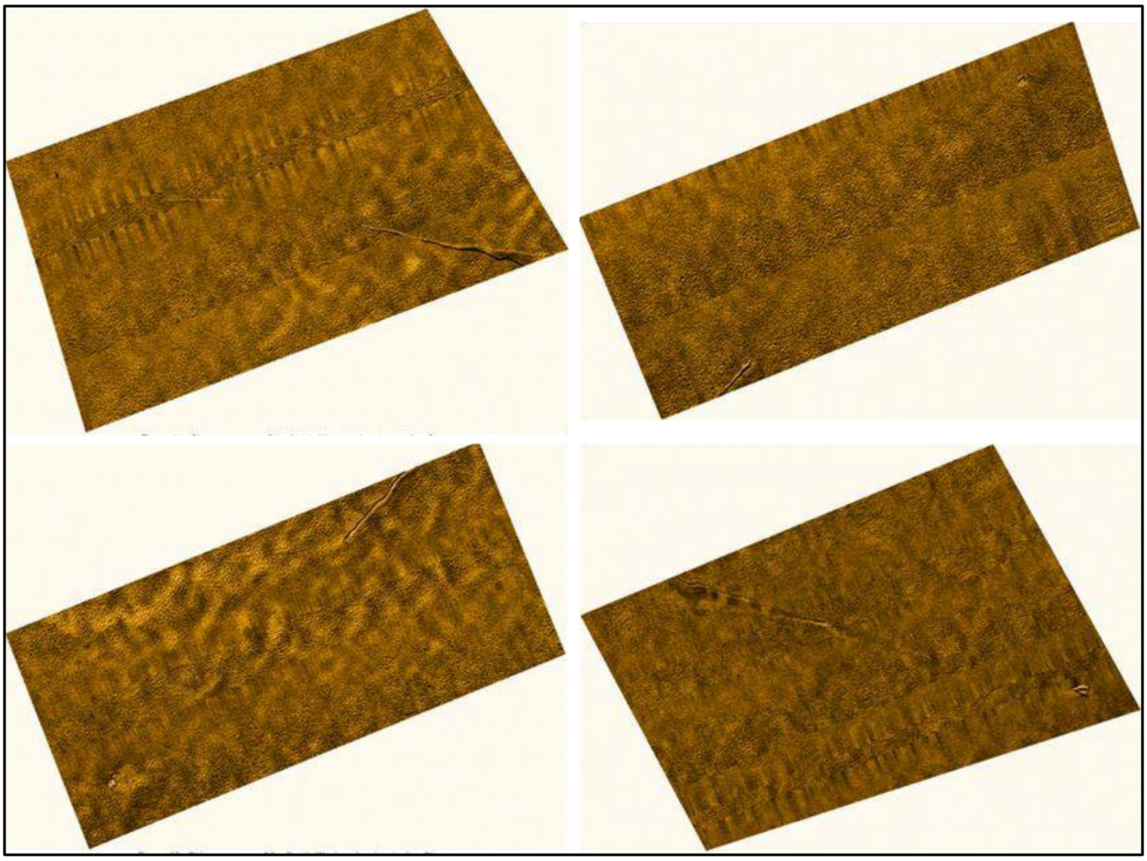

Figure 55. SSS data of each mooring line (nav#2 – 09/06/21). Top left: NW anchor; Top right: NE anchor; Bottom left: SW anchor; Bottom right: SE anchor.

During these navigations, the WAVEGEM platform was on the site, and the trace of the mooring lines on the seafloor can be seen. The mooring lines moved dependent on the tide.

Regarding the SSS results, floating sections of the mooring line seem to scrape the seafloor, as, for instance, it can be seen in Figure 56 (SE mooring line). Due to the configuration of the campaign, it was not possible to have a total overview of mooring lines, but the footprint of scraping for SE mooring line is at least 400 m^2, representing 0.4% of the total area occupied by device.

For the other mooring, footprint seems smaller (Figure 57): approximately 300 m^2 (0.3% of total area) for SW mooring line and approximately 200 m^2 (0.2% of total area) for NE mooring line.

Figure 56. SSS data of mooring line #1 (SE) - zoom on footprint (09/06/21).

Figure 57. Zoom on footprint - SSS data of mooring line #2 (SW on the left) and mooring line #4 (NE on the right) (09/06/21).

No footprint is measurable on the NW mooring line (Figure 58).

Figure 58. No measurable footprint - SSS data of mooring line #3 (NW) (09/06/21).

The SSS surveys during operational phase reveal the footprint of the floating section of the mooring lines. Other sections (close to seabed) were totally or partially buried or just above the seafloor.

SSS results of the second campaign carried out the 4th of May 2022 are shown in Figure 59 and Figure 60.

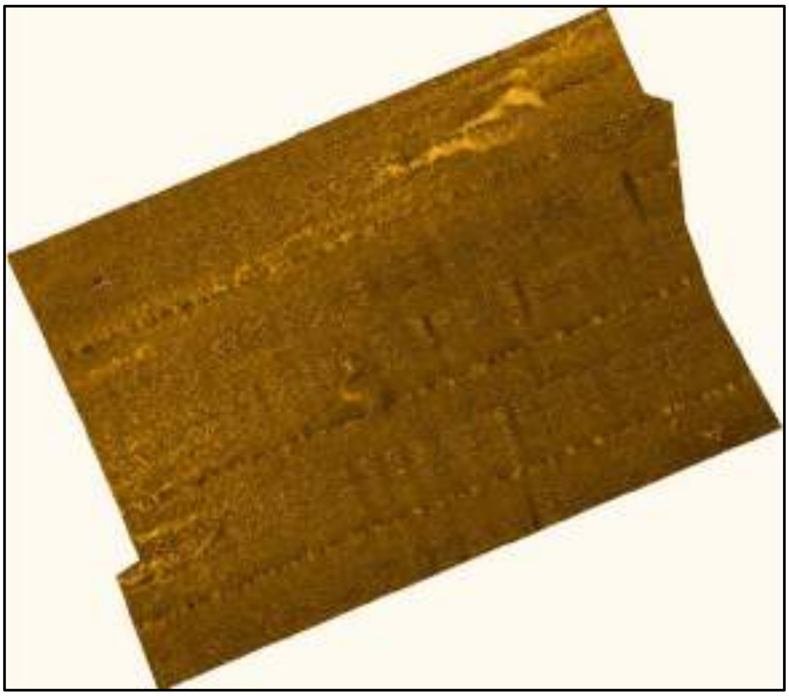

Figure 59. SSS data of the entire area (04/05/22).

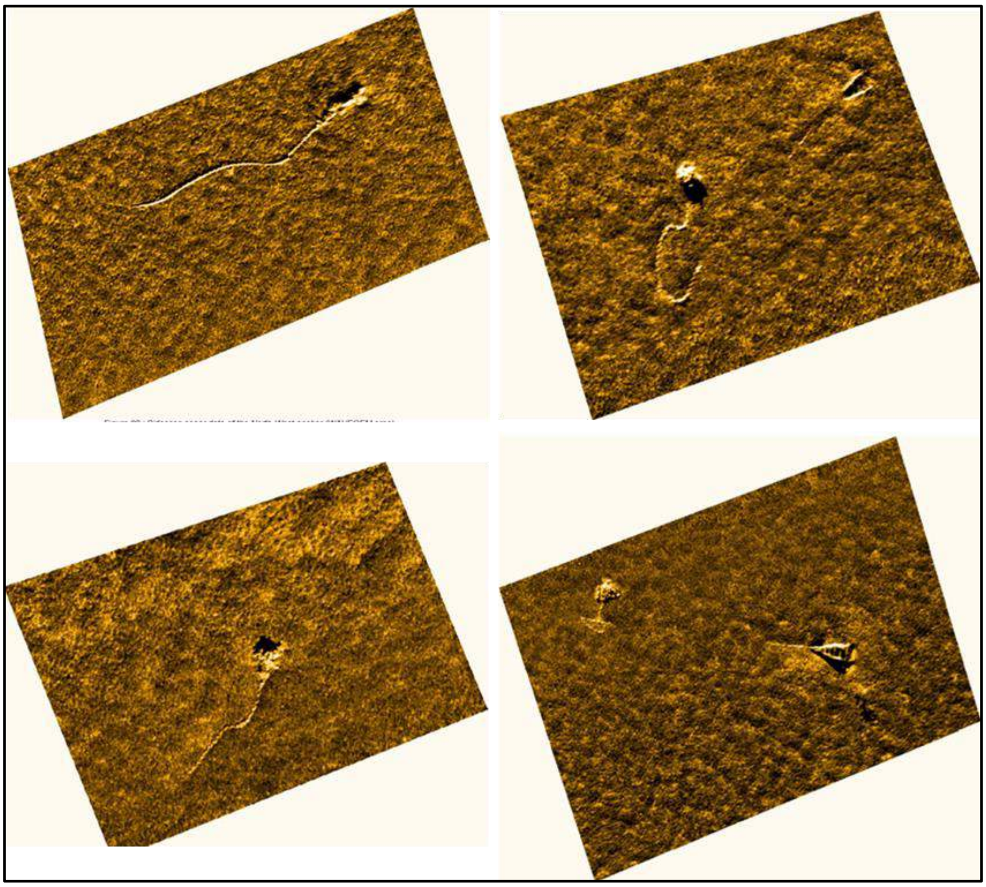

Figure 60. SSS data of each mooring line (04/05/22). Top left: NW anchor; Top right: NE anchor; Bottom left: SW anchor; Bottom right: SE anchor.

Regarding SSS results of the campaign done after the partial decommissioning (anchor and bottom chains remained) footprints of the floating part of the mooring are no longer observed, three months after removal of nylon and top chain. These floating parts were laid on the bottom between November 2021 and end of January 2022.

The SE and NE anchors were partially buried like in the previous survey, and bottom chains laid on the seafloor and put as a pile chain.

The NW and SW anchors were not detected, probably being out of the scope of the SSS and/or totally buried. It was observed that the chains lay in a pile on the bottom.

After partial decommissioning, there is no alteration beyond the presence of remaining parts of the moorings. The footprints observed previously disappeared.

6. Discussion

A proxy to the quantification of the impacts on the seafloor integrity can be made combining the results of the video and the SSS surveys. The SSS provides a wide overview of the impact of the mooring lines on the seafloor, and georeferenced images of the seafloor where the elements identified can be measured. Besides, the video recordings provide a close-up into the mooring lines and the seafloor and permit confirming the type of impact identified in the SSS images and identifying other types of impact that cannot be detected by the SSS (e.g., attractor effect for fauna).

As an example, during the operational phase, which only could be monitored for WAVEGEM in SEM-REV, from the SSS images it could be concluded that some parts of the mooring lines (deepest sections of nylon) seemed to lay on the seafloor. However, the ROV surveys evidenced that those sections remained above the seafloor, without relevant footprint on it. Besides, due to the low visibility, the ROV surveys during the operational phase did not provide information about the footprint under floating parts of the moorings. Therefore, the SSS results could not be confirmed. This highlights one of the limitations of optical techniques compared to acoustic ones: the quality of the information obtained by optical techniques depends on factors affecting the visibility (turbidity, suspended solids, amount of light, etc.).

Regarding the post-operational surveys carried out both in BiMEP and SEM-REV, it should be noted that the decommissioning operations were not complete, as some elements remained in place (lower sections of the mooring lines, and weights and anchors). Both devices, the Penguin II and WAVEGEM, were removed nearly eight and six months respectively before the surveys with ROV and AUV were carried out. On the other hand, it should be highlighted that Penguin II device and its mooring and mooring lines were located at 60-75 m depth, whereas WAVEGEM was at 32-36 m depth. That, together with the poor visibility experienced during the ROV campaign in SEM-REV lead to differences in the results described for both case studies. Hence, after partial decommissioning, alterations of the seafloor were no longer observed by the SSS in SEM-REV. Conversely, although two main impacts were identified in BiMEP, they could be masked by at least three storms that took place between the decommissioning of the Penguin II and the ROV and SSS surveys and which could give rise to sediment mobilisation and the removing of the footprints caused by the moorings in the operational phase.

On the one hand, the presence of the lower catenary and the chain weights increases the spatial heterogeneity, providing hard substratum where sessile organisms requiring non-mobile substrata can attach. This causes a call effect over motile fauna that is attracted to feed (e.g., see Figure 39 in p. 38). Besides, some fauna can also be attracted by the shelter offered mainly by the chain weights, as is the case of the several European congers identified from the videos recorded (e.g., see Figure 38 in p. 37). Such effect was already identified by Lin and Yu (2012), who described the 'positive environmental enhancement' because of the 'artificial reef effect' (AR): promotion of the growth of epiphytes and epifauna, increase of biomass and local biodiversity, attraction of fishes, refuge from predators, change on sedimentation and currents acting as 'centres of nutrients', etc. Previously, this effect was also discussed by Langhamer *et al.* (2010), who pointed out that there was still discussion whether the increase in biodiversity caused by the AR is due to aggregation from the neighbouring area or a real increase.

Nevertheless, Langhamer *et al.* (2010) also highlighted that the settlement of new species in the area attracted by the artificial substrates could have an impact on the local species through the interaction schemes (competition, predation, parasitism, etc.). Furthermore, the artificial structures may allow for non-native species to settle (if they are already present in the area), with potential ecological and economic consequences (e.g., Coates *et al.*, 2014; Dannheim *et al.*, 2020).

Additionally, the increase of diversity and biomass where lower values are usually found (sandy substrates) may contribute to increased loading of organic matter in the area, with potential consequences in the structure of the communities and the trophic web (Langhamer *et al.*, 2010).

On the other hand, although the lower catenaries were partially buried into the sediment in some stretches, some footprint was identified at the sides of the chains in form of alteration of seafloor morphology. In fact, as mentioned above, the ripple marks that characterize the sandy bottoms in the area are absent along narrow bands that contain the lower catenaries. This effect was observed both in the video recordings and the SSS. However, it cannot be established with certainty whether: the remotion of the ripple marks was an effect of the chains moving and dragging during the operational phase; or an effect of the local change on sedimentation and currents, as described by Langhamer *et al.* (2010), and Lin and Yu (2012). Nevertheless, compared to the footprints of the moorings of the WEC MARMOK-A-5, which impact on seafloor integrity was assessed in the framework of the WESE Project (Muxika *et al.*, 2020) based on video recordings in the operational phase, the later would be the most probable effect.

From the SSS images, the area affected by these impacts in BiMEP can be approximately estimated in relation to the total area occupied by the installation of the device (assuming the chain weights represent the edges of the occupation polygon). In this way it can be considered that the Penguin II device occupied a total area of 20 Ha. From that total area, the chain weights and catenaries impact on 0.12-0.16 Ha, including the presence of such elements and the footprints. That represents 0.6-0.8% of the area occupied by the device.

Similarly, in the survey to monitor the operational phase, which was the carried out in SEM-REV only, the footprints of the mooring lines add up to 900 m^2 for the area that was monitored. Considering a total occupation area of 0.1 km^2, the impacted area represents 0.9%.

Finally, the fact that alteration was not detected in SEM-REV six months after decommission, but it was in BiMEP still eight months after decommission, may indicate an effect of the total depth of the area. This result could indicate that more dynamic environments in shallower locations, such as those of SEM-REV test site, could favour the attenuation of the footprint produced by moorings and mooring lines.

7. Conclusions

Although the impacts over the seafloor integrity could not be assessed at the Aguçadoura test site for the HiWave-5 device, from the information collected in BiMEP and SEM-REV (Penguin II and WAVEGEM devices, respectively) the impacts observed by video surveys and side scan sonar, can be summarized in:

- Artificial reef effect: the introduction of new substrates in the marine environment allows for many organisms (fauna and flora) to settle and grow and contribute to increase local biomass and biodiversity. These artificial reefs also attract fauna from higher trophic levels, such as fish. Furthermore, the added complexity of the biofouling assemblages and the artificial structures themselves provide refuge to some animals (e.g., lobsters) from predators. Although not monitored in the framework of the present project, this could lead to changes in the structure of communities and trophic webs, and could also favour the development of non-native species assemblages.
- Changes in the seafloor morphology (e.g., removal of natural ripples) due to dragging of the chains during the operational phase, and/or an effect of the local change on sedimentation and currents, caused by the presence of the mooring lines.

Due to the small area affected by the mooring lines, compared to the total area occupied by the installations (<1%), those impacts could be considered as non-significant over seafloor integrity. At the same time, they should be put into perspective and assessed considering other positive effects over biological diversity and populations of commercial species, by the declaration of a wide no-take zone of the installation area, and the potential negative effect caused by the introduction of energy (noise).

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