Assessing the effect of onshore and offshore wave energy converters on seafloor integrity combining image-based and acoustic methods

I. Muxika, P.A. Vinagre, E. Le Bourhis, E. Villarin, F. Tanguy, C. Niclot, and J. Bald

Abstract— **The European Atlantic Ocean offers great opportunities for the development of projects for renewable energy extraction, and the Marine Renewable Energy sector is developing different technologies for energy converters, including Wave Energy Converters. Besides, the European Commission is adopting measures and politics to increase the installed capacity of ocean energy. However, there are still uncertainties on the potential environmental effects of wave energy converters, which led regulators and stakeholders to perceive their operation as a risky activity.**

To overcome the non-technological barriers that could hinder the development of marine renewable energies, and improve the knowledge on the impacts on the seafloor integrity (among others), SafeWAVE project set an Environmental Research Demonstration Strategy based on the collection, processing, modelling, analysis and sharing of environmental data collected in Aguçadoura (Portugal), Armintza (Spain) and Le Croisic (France) representing different types of technology, locations and project scales.

Video recordings were carried out, using Remotely Operated Vehicles, to identify the environmental impacts of the moorings on the seafloor morphology. That information was completed by side scan sonar campaigns using an Autonomous Underwater Vehicle.

The video recordings were useful also to assess the attraction effect of the moorings to epibenthic invertebrates and fishes, whereas the side scan sonar provided quantitative information on the area affected by physical alteration (<1% of the total area occupied by the devices at Armintza and Le Croisic).

Keywords—**Environmental impacts, SafeWAVE project, Seafloor integrity, Wave Energy Converters.**

I. INTRODUCTION

EUROPEAN countries, among others, are not safe from the global threat posed by climate change and environmental degradation. As a result, the European Commission (EC) has adopted a series of policies concerning climate, taxation, transport, and also energy, with the aim of reducing net greenhouse emissions.

Such policies fall withing the framework of the European Green Deal, presented in December 2019, which has the main goal of making Europe the first climate-neutral continent by 2050. The Grean Deal followed previous activities and policies: the Strategic Energy Technology Plan (SET-Plan) [1], adopted in 2007 to establish an energy technology policy for Europe; and the Energy Union Strategy [2], communicated in 2015 with the objective of helping to provide secure, affordable, and clean energy for EU citizens and businesses.

Aligned with the scope of the Grean Deal, and to help achieve its objectives, the EC adopted a new approach for a sustainable blue economy in the EU [3]. Such approach encompassed, among others, the EU Offshore Renewable Energy Strategy adopted by the EC [4], which establishes concrete targets to develop offshore renewable energy: to have an installed capacity of at least 60 GW of offshore wind and 1 GW of ocean energy by 2030, and 300 GW and 40 GW, respectively, by 2050. Moreover, the transition has been accelerated recently, in response to the invasion of Ukraine by Russia, with the launch of the REPowerEU plan [5], which mainly aims to reduce the European dependency on Russian energy sources.

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However, the Wave Energy (WE) sector, and the Marine Renewable Energy (MRE) in general, are still in an early stage of development. Therefore, there are many uncertainties in terms of the potential effects they may have on the environment and the operation of Wave Energy Converters (WEC) is perceived as a risky activity.

To overcome the non-technological barriers that could hinder the future development of MRE, the WESE project (Wave Energy in Southern Europe) was undertaken in 2018-2021, co-funded by the European Maritime and Fisheries Fund (EMFF) of the European Union. Such project included, among others, the monitoring of the effects of different WEC technologies on the seafloor using image-based (Remotely Operated Vehicle -ROV- equipped with HD video camera) and acoustic methods (Side Scan Sonar-SSS). In the framework of the WESE project the effects on the seafloor morphology of a nearshore oscillating bottom hinged WEC in Peniche (Portugal) and an offshore Oscillating Water Column WEC in Armintza (Spain) were assessed.

The knowledge acquired in WESE is now being increased with a new European project called SafeWAVE, (Streamlining the Assessment of environmental effects of Wave Energy), co-funded by the European Climate, Infrastructure and Environment Executive Agency (Call for Proposals EMFF-2019-1.2.1.1 – Environmental monitoring of ocean energy devices). One of the aims of the project is moving towards filling the knowledge gaps about the potential pressures and impacts caused by the operation of different WE technologies, within a framework that includes the development of: (1) an Environmental Research Demonstration Strategy, (2) a Consenting Planning Strategy, and (3) a Public Education and Engagement Strategy.

This paper pretends to inform on the work undertaken in SafeWAVE project to monitor the seafloor morphology, and to present the main results obtained.

II. Methods

A. Study areas

Aguçadoura test site (Fig. 1) is located in the northwest coast of Portugal at 6 km from shore, close to two overlapped protected areas: *Parque Natural do Litoral Norte* National Protected Area and *Litoral Norte* Natura 2000 site (Site of Community Importance PTCON0017). The seafloor is mostly sandy and with a relatively flat inclination and depth varies between 43-55 m.

Although four point-absorber type devices, called HiWave, are foreseen to be installed, none has been installed yet at the time of presenting this paper.

The Biscay Marine Energy Platform test site (BiMEP; http://www.bimep.com; Fig. 2) is located in the southeast Bay of Biscay (Spain), at a minimum distance of 1,700 m from the shore. The seafloor is at a depth of 50-90 m, and is mainly sandy, with some rocky outcrops close to the eastern and southwestern margins.

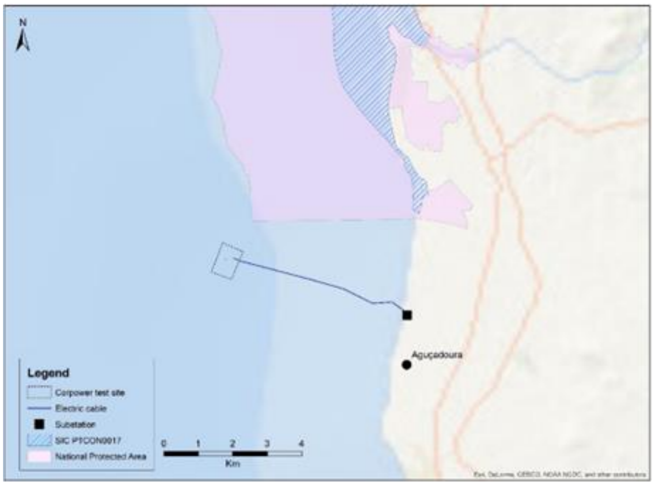

Fig. 1. Aguçadoura test site (square), Parque Natural do Litoral Norte conservation area (shaded in purple) and Portuguese Litoral Norte Natura 2000 site (diagonal hatching). Source: ICNF.

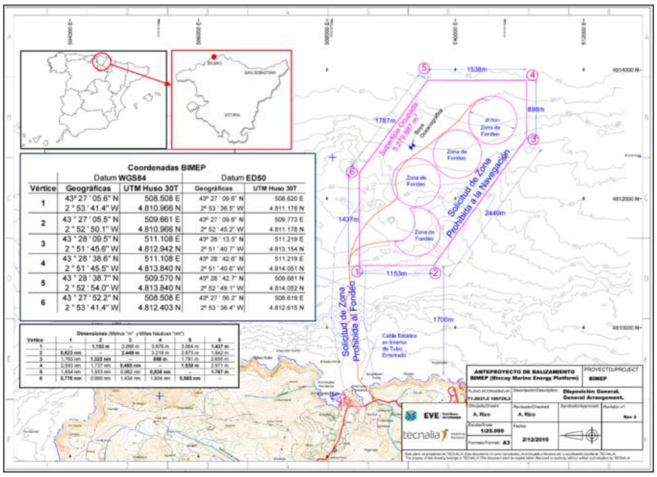

Fig. 2. Biscay Marine Energy Platform test site, off the coast of Armintza (Spain). Source: AZTI.

Fig. 3. Centrale Nantes offshore test site, off the coast of Le Croisic (France). Source: École Centrale Nantes.

A direct drive wave energy converter, called Penguin II, was installed, using a 6-legged mooring system. Each of the legs consisted of two chain clump anchors followed by a catenary fixed to a surface buoy. An upper catenary fixed Penguin II to each of the buoys. The umbilical system was a Lazy-S with a mid-water arch (at 20 m from the surface).

The Centrale Nantes offshore test site (SEM-REV; https://sem-rev.ec-nantes.fr; Fig. 3) is located off the coast of Le Croisic, in western France. The seafloor is at a depth of 32-36 m and is dominated by sands.

A hybrid autonomous energy recovery platform, called WAVEGEM, that converts float motions into electric

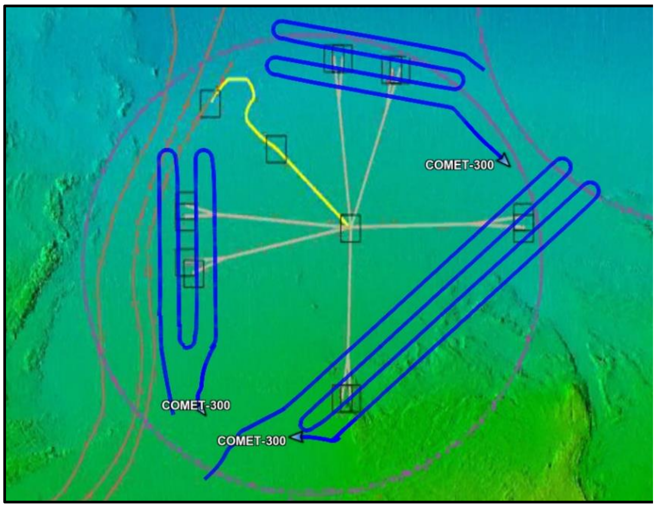

Fig. 4. Transects (in blue) followed by COMET-300 in each of the immersions for a detailed inspection of the mooring lines of the Penguin II device.

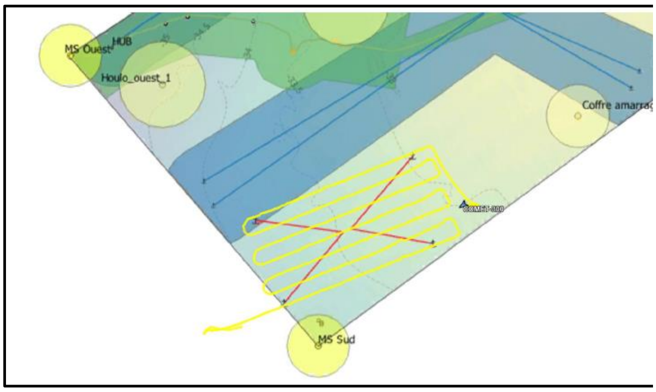

Fig. 5. Navigation map of the COMET-300 in the second survey carried out at SEM-REV, once WAVEGEM was decommissioned. The route followed by the AUV is represented in yellow.

power was installed, using a four-point synthetic mooring system. It included steel chains, nylon lines and sand anchors.

B. *Monitoring*

The monitoring for the seafloor integrity assessment was undertaken with two different techniques: video imaging by means of a Remotely Operated Vehicle (ROV), and side-scan SONAR (SSS) using an Autonomous Underwater Vehicle (AUV).

At the moment of preparing this paper, HiWave was not still deployed at Aguçadoura. As a result, only the information from two pre-operational surveys carried out in October 2021 and January 2022 were available. Such surveys covered areas surrounding the locations where the anchors, WECs, navigation buoys and several sections of the electrical cable route. They were conducted using a Seaeye Falcon and a Magnum Plus Work Class ROV, respectively. The SSS survey was not carried out at present, as it was aimed during the operational phase only.

Two ROV surveys were planned at BiMEP: one once Penguin II was installed and in operation and a second one after one year of operations. However, the device suffered a breakdown and was decommissioned some months after the deployment and was not re-installed. As a result, a single survey was carried out in July 2022 (seven months after decommissioning). The landing point of the lower catenaries, their routes till the anchors and the anchors were left, and they were recorded in video using a SIBIU Pro ROV.

Moreover, a SSS survey was performed at BiMEP in August 2022 using the AUV COMET-300 by RTSYS. The survey consisted of three immersions (Fig. 4) in which the AUV navigated at an altitude of 10 m and a high frequency SSS for a detailed inspection of each of the mooring lines, and a fourth immersion at an altitude of 30 m and low frequency SSS for a full coverage of the Penguin II device area.

At SEM-REV two video surveys were conducted: an operational survey in July 2021 using a Revolution ROV which recorded one of the mooring lines and a M2 ROV that recorded a second mooring line; and a survey once the device and the moorings were removed, in May 2022, using a Revolution ROV.

Additionally, two SSS surveys were carried out. The first one, undertaken in June 2021, with WAVEGEM in operation, inspected the anchors in two immersions (one at an altitude of 10 m, and with a range of 50 m at each side of the COMET-300, and a second one at an altitude of 6 m and a range of 30 m at each side). The second one, carried out in May 2022, once WAVEGEM was decommissioned, all the area covered by the device was inspected in a single immersion (Fig. 5), with the AUV navigating at an altitude of 10 m and a range of 50 m at each side.

III. RESULTS

The seafloor at Aguçadoura is dominated by sandy sediments, with ripple marks with NW-SE orientation (Fig. 6). At both ROV surveys carried out in Aguçadoura, similar features were recorded, including: macroalgae at least down to about -11 m water depth, several individuals of Polybiidae/Portuniidae (Fig. 7) and bivalve shells (mostly Solenidae) down to -45 m water depth, and some pelagic species (a school of fishes at -9 m water depth in October 2021 and some Teuthida at -45 m water depth in January 2022).

In BiMEP, the seafloor is also dominated by sandy sediments, with ripple marks in NNW-SSE orientation and 1-1.5 m wavelength (Fig. 8), being the wavelength and amplitude higher in deeper areas.

The chain weights act as attractors for fishes and European congers (*Conger conger*), cuckoo wrasses (*Labrus mixtus*) and shoals of poutings (*Trisopterus luscus*) were recorded close to them (Fig. 9, 10 and 11). Regarding physical alterations, there is a slight accumulation of fine sands next to the chain weights (Fig. 12), which is more evident at shallower depths.

The catenaries lie on the sediment, partially buried in some sections and there is no evidence of important physical alterations to the substrate, apart from a slight accumulation of fine sediment next to the chains (<1 m). As the chain weights, the catenaries also act as attractors for

Fig. 6. Sandy bottom with ripple marks at -26 m depth, recorded in the ROV survey of October 2021 at Aguçadoura.

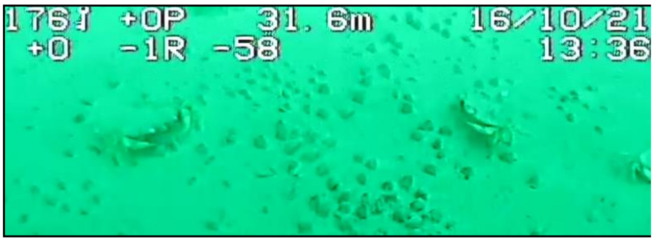

Fig. 7. Polybiidae or Portunidae feeding at -32 m water depth, at Aguçadoura.

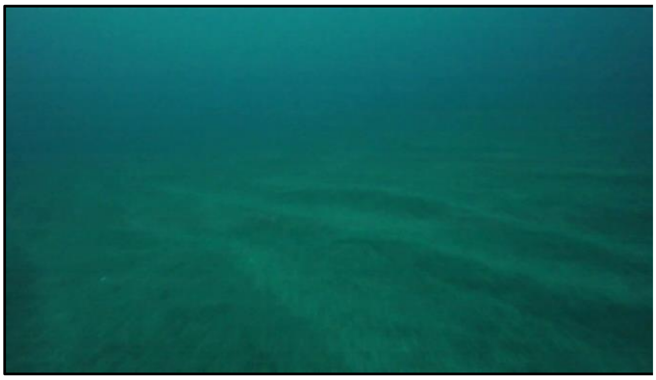

Fig. 8. Ripple marks at BiMEP, at -60 m water depth.

Fig. 9. European conger (*Conger conger*) in one of the chain weights, at BiMEP.

fauna (Fig. 13) and some sections are covered by turfy fouling. It should be highlighted that a section of the shallower catenary lied on a rocky outcrop (Fig. 14).

The low frequency SSS data confirmed the location of the six mooring lines and the mooring chains, and also the presence of some rocky outcrops in the area (Fig. 15). Moreover, the high frequency SSS data confirmed the presence of the ripple marks and the footprints of the

Fig. 10. Female cuckoo wrasse (*Labrus mixtus*) near one of the chain weights, at BiMEP.

Fig. 11. Shoal of poutings (*Trisopterus luscus*) around one of the chain weights, at BiMEP.

Fig. 12. Sand accumulation in the western side of one of the chain weights, at BiMEP.

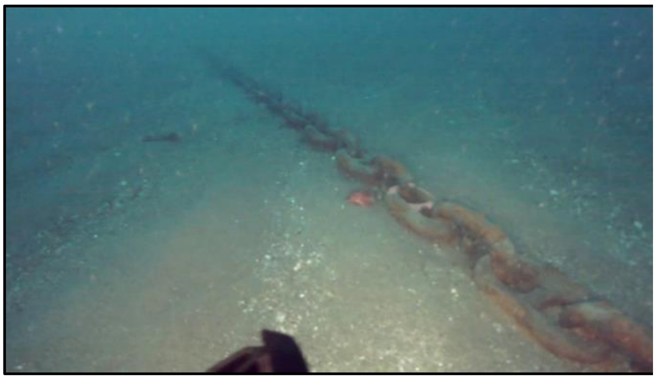

Fig. 13. Red gurnard (*Cheilodonichthys cuculus*) under one of the chains, at BiMEP.

catenaries. SSS data allowed to determine a total width of the traces of the catenaries of 1-1.5 m, being less visible close to the chain weights (Fig. 16).

Fig. 14. Section of the shallower catenary on a rocky outcrop, at BiMEP.

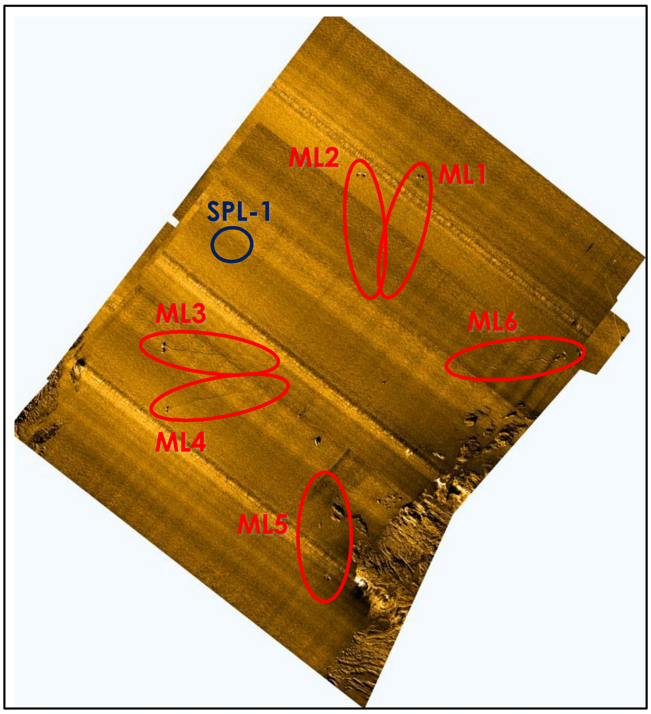

Fig. 15. Low frequency SSS, at BiMEP. The mooring legs are indicated with red circles; the dark blue circle indicates the BiMEP to the device splice.

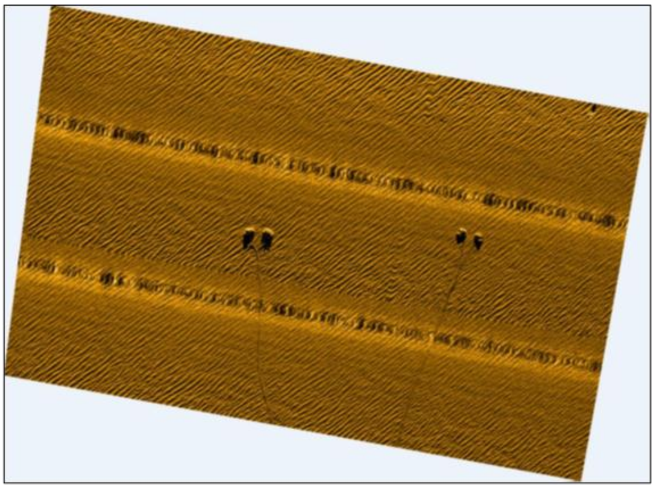

Fig. 16. High frequency SSS image covering the area occupied by the two deepest mooring legs, at BiMEP.

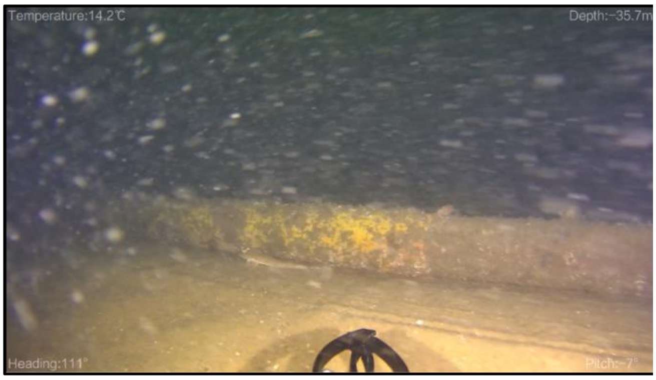

Fig. 17. Footprint of a section of a mooring line, at SEM-REV.

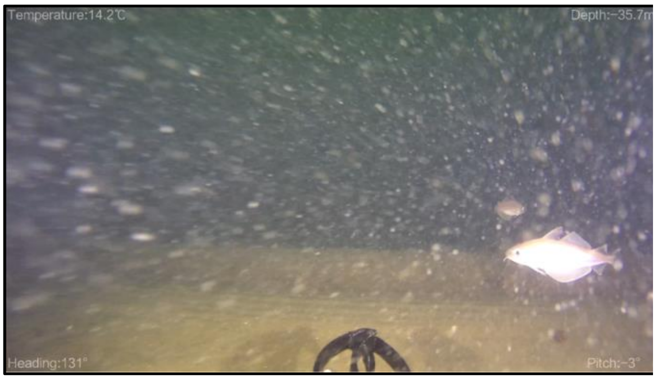

Fig. 18. Pouting (*Trisopterus* sp.) close to a mooring line, at SEM-REV.

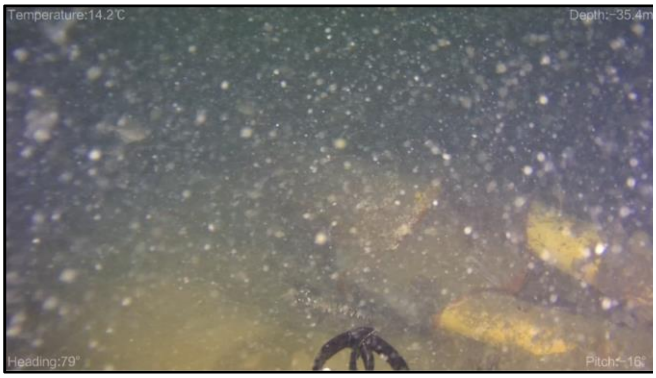

Fig. 19. Lobster (*Homarus gammarus*) under a mooring line, at SEM-REV.

The SEM-REV test site is also located on sandy bottoms with ripple marks. The low visibility at the time of the surveys carried out limited the operations undertaken with the ROVs. However, it could be determined that some sections of the mooring lines were buried into the sediment. In the areas where the catenaries were visible, the footprint was limited to nearly 10-20 cm at each side of the lines (Fig. 17). Such sections acted as attractors for fauna and many Gadidade and Gobiidae were observed (Fig. 18), as well as a lobster (*Homarus gammarus*) (Fig. 19).

SSS results from the survey undertaken in the operational phase evidenced that floating sections of the mooring lines swept the seafloor (Fig. 20). From the images it could be determined that the area affected by each of the lines was approximately 200-400 m^2 (0.2-0.4% of the total area occupied by the device). Conversely, after partial decommissioning, the footprints observed in the operational phase were removed, and the mooring lines and anchors were at least partially buried into the sediment.

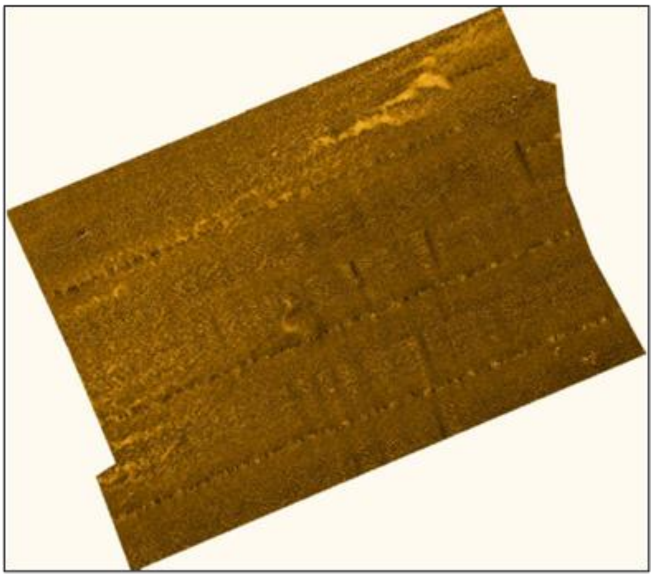

Fig. 20. SSS image covering the total area occupied by WAVEGEM, at SEM-REV, after partial decommissioning.

IV. Discussion

Video recordings and SSS imagery are complementary techniques for the assessment of the impacts caused by mooring lines and anchors on the seafloor morphology. SSS provides a wide and georeferenced view of the seabed and allows to identify and measure the elements lying on the bottom. Conversely, video recordings provide a close-up to the elements of interest and allow to identify impacts that cannot be detected by SSS (effects on fauna and flora).

Besides, SSS overcomes an important limitation of optical techniques which is its performance in low visibility conditions (high turbidity, low light intensity, etc.).

The results obtained in the framework of the SafeWAVE project show that in the operational phase, which only could be assessed at SEM-REV, the physical alteration to the seafloor was limited to 10-20 cm at both sides of the lines and to the area where the lines landed, where the floating sections of the lines swept the sediment along wider areas. Conversely, in the post-operational survey, even with some of the elements of the mooring lines remaining, physical alterations to the seafloor were no longer observed. Conversely, at BiMEP, a slight physical alteration to the seafloor was observed even eight months after decommissioning, which could be masked by at least three storms that took place between the decommissioning of the Penguin II and the ROV and SSS surveys.

At this point, it should be highlighted that WAVEGEM (SEM-REV) was at 32-36 m depth, whereas Penguin II (BiMEP) was at 60-75 m depth. Hence, differences on hydrodynamics associated with the depth in the area could affect the seafloor recovery processes, making it slower at higher depths where the seafloor is more stable.

Nevertheless, from the SSS images, it can be estimated that the area affected by these impacts in BiMEP was 1,200-1,600 m^2, for a total area occupied by the Penguin II device of 0.2 km^2, which represents 0.6-0.8%. Similarly, the footprints of the mooring lines at SEM-REV add up to 900 m^2 for a total occupation area of 0.1 km^2, which represents 0.9%.

Finally, physical alteration was not detected in SEM-REV six months after decommissioning, but was observed in BiMEP eight months after decommission. This can be indicative of the influence of bathymetry in the area, as a result of the difference of local dynamics, on the seafloor morphology recovery rates.

Regarding the effects on biological assemblages, which cannot be assessed by SSS, the video recordings show that the presence of chains, anchors, and other compoenents increases the spatial heterogeneity and complexity, providing hard substratum where sessile organisms requiring non-mobile substrata can attach, which attracts motile fauna to feed. Moreover, some animals are attracted for shelter [6]. However, it is still in discussion whether such effect is due to aggregation from the neighbouring area or a real increase of biomass and biodiversity [7]. Nevertheless, the settlement of new species could have an impact on the local species through competition, predation, parasitism, among others [7]. Furthermore, it is important to highlight that the artificial structures may allow for non-native species to settle, with potential ecological and economic consequences [8,9].

V. Conclusions

The main impacts observed by video surveys and SSS can be summarized as:

- Artificial reef effect as a consequence of the introduction of new hard substrates that allow organisms to settle and grow. Moreover, this causes a call effect to motile fauna that come to feed. Finally, the added complexity of both biofouling and the artificial structures attracts some animals looking for refuge from predators.
- Changes in the seafloor morphology due to the movement of the chains in the operational phase and to local change of sedimentation and currents patterns.

However, due to the small areas affected compared to the total areas occupied by the installations (<1%), such effects can be considered non-significant.

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