CHARACTERISATION OF THE POTENTIAL IMPACTS OF SUBSEA POWER CABLES ASSOCIATED WITH OFFSHORE RENEWABLE ENERGY PROJECTS

SPECIES project (2017-2020): Review and perspectives

FRANCE ENERGIES MARINES
Editions

CHARACTERISATION OF THE POTENTIAL IMPACTS OF SUBSEA POWER CABLES ASSOCIATED WITH OFFSHORE RENEWABLE ENERGY PROJECTS

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Preface

Subsea power cables are present throughout our oceans and serve a variety of purposes: connecting islands to the mainland for energy distribution, connecting stand-alone power grids, powering offshore platforms, as well as transporting the power produced by offshore renewable energy (ORE) installations to shore. In 2015, the total length of high-voltage direct current (HVDC) cables on the seabed worldwide was estimated to be 8,000 km, with 70% of these cables being located in European waters (Ardelean and Minnebo, 2015).

Europe also accounted for 5,047 offshore wind turbines at the end of 2019, representing 22.1 GW, with 25 GW planned for 2025 (WindEurope, 2020). Given this exponential development of ORE projects, the number of subsea power cables is increasing considerably. Like any human installation or activity at sea, these cables can cause disruptions to marine life and habitats. However, and despite the fact that they have been present in our oceans since the mid-twentieth century, very few scientific publications address the effects of these power cables on the marine environment (Taormina *et al.*, 2018; Carlier *et al.*, 2019). With the current increase in the number of cables, there is today an urgent need to characterise their potential impacts on marine ecosystems.

It is within this framework that the collaborative project "SPECIES" ("Submarine PowEr Cables Interactions with Environment & associated Surveys") was launched in 2016. The aim of this project was to improve knowledge of the potential interactions between the electric power cables of ORE projects and benthic organisms, which would appear to be the most exposed communities. Coordinated by France Energies Marines and scientifically led by Ifremer, the project brought together a consortium of nine academic and private partners with complementary skills and contributions.

The research was conducted along three main lines:

- *In situ* measurements of the physical effects generated by the cables (e.g., emission of electromagnetic fields, thermal radiation) at different ORE test sites or interconnections in France.
- The study, via *in situ* approaches, of the potential impact of these cables on coastal benthic communities, focusing on different biological compartments (e.g., endofauna, epibenthic communities and crustaceans/fish among benthic megafauna) at different sites in France.
- The study of the potential impact of the cables, and in particular of electromagnetic fields, on the behaviour of certain notable benthic species, using experimental approaches in the laboratory.

The aim of this report is to provide a synthesis of the results of the SPECIES project and the perspectives arising from it. It is divided into six parts:

- A summary of the different effects that can be generated by subsea power cables.
- An overview of the selected study sites.
- Fact sheets covering several scientific questions, and presenting the methods developed and implemented as well as the main results of the project.
- Feedback on the difficulties encountered and the resulting methodological recommendations.
- A review of the project for managers and stakeholders in the ORE sector.
- Perspectives for future research on the same topic.

1 - Effects generated by subsea power cables

This section is mainly based on the content of four scientific articles and reports containing the majority of the bibliographic references used in the writing of this document (Taormina *et al.*, 2018; Albert *et al.*, 2020; Carlier *et al.*, 2019; Copping and Hemery, 2020).

First of all, we must begin by defining the term "effect". An **effect** is a change in an environmental variable (such as noise, temperature, electromagnetic field) outside of its range of natural variability. Where this effect causes observable changes in one or more identified receptors, which can be biological compartments of the ecosystem or processes within this ecosystem, it can be referred to as an **impact**. Although the distinction is highly subjective, these impacts can be described as either "positive" or "negative" for the ecosystem. The purpose of the SPECIES project was to gather scientific data and communicate on the risks of impacts on the ecosystem. To do this, it was first necessary to correctly characterise the effects.

This section presents only the effects associated with the **operational phase** of subsea power cables, as only this phase was studied within the framework of the project. These effects concern the modification of the benthic habitat (considered here as the physical nature and configuration of the seabed), the reserve effect, the emission of heat, and the emission of electromagnetic fields. For more information, the four reference articles cited above also address the effects associated with the cable-laying phase.

1.1 Habitat alteration

The physical presence of an unburied cable, i.e., a cable that is simply laid on the seabed, can result in both the creation of a new artificial habitat and the alteration of the surrounding natural habitat. With respect to the first process, unburied cables and the various associated protection or stabilising structures (such as concrete mattresses, riprap and protection shells) provide a new hard substrate that is subject to biological colonisation (Fig. 1). This phenomenon, which concerns all submerged anthropogenic structures, is commonly referred to as the **reef effect**. The structures are thus colonised by the sessile species of hard substrates (animals and plants) that form the epibenthic community. This process is known as biofouling. Certain mobile species of macrofauna and megafauna, such as fish and crustaceans, may also be attracted to the deployed structures. The extent of the reef effect depends on the size and nature of the structures associated with the cable, as well as on the characteristics of the surrounding natural habitat (types of seabed, currents, depth).

The presence of cables and associated structures can also alter marine habitats in the immediate vicinity through changes in hydrodynamics and in sediment dynamics. Generally, due to the low heights and volumes of these structures, this disturbance is very localised (< 5 m) and tends to be indicated by the presence of a narrow accumulation of sediment along these structures (Fig. 2).

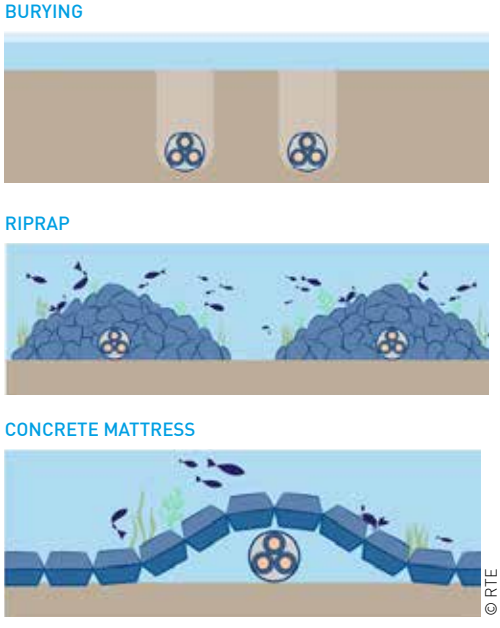

Fig. 1: Main laying techniques for subsea power cables.

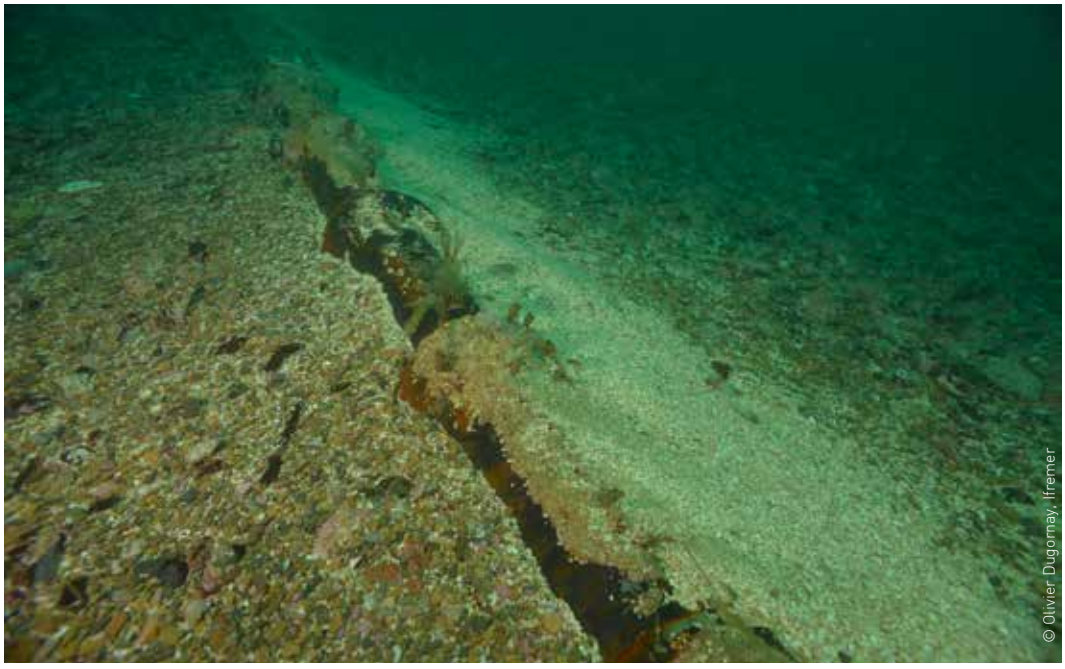

Fig. 2: Accumulation of shell sand along the Paimpol-Bréhat test site power cable.

1.2 The reserve effect

While burying power cables or fitting them with protection systems does not safeguard them against potential damage caused by certain anthropogenic activities (anchoring, dredging, bottom trawling, etc.), these activities can be regulated and even banned by the local authorities in the vicinity of the cables. As these activities have a proven ecological impact on the seabed, banning them can result in an improvement in the environmental status of marine communities compared to those established outside of the cable protection zone. This is the **reserve effect**. This is therefore an indirect effect, often considered as "positive" for the marine ecosystem. The size of this controlled area and the nature of the bans depend on the method of laying of the cable (buried or unburied) and the number of cables present in the area. Typically, these cable protection zones mainly concern unburied cables, and form corridors several hundred metres long on each side of the cable and along the entire length of the cable route.

1.3 Heat emission

When an electric current passes through a cable, some of this energy is transformed into thermal energy: this is known as Joule heating. In the case of unburied subsea cables, the constant flow of water effectively dissipates this heat and confines it to the surface of the cable. With buried cables, however, this thermal radiation can heat the sediments in the immediate vicinity. The spatial extent and the magnitude of the heat produced can be highly variable depending on the technical characteristics and the power rating of the cable, the type of current concerned (AC or DC), and the nature of the sediments. The most cohesive sediments (such as compacted silt) generate the highest levels of heat (up to several tens of degrees Celsius over several tens of centimetres) due to their lower thermal conductivity. However, very few studies have measured heating *in situ* near operating subsea power cables, the majority of the available data coming from numerical models.

1.4 Modification of electromagnetic fields

The electric current flowing through the cables results in the production of electromagnetic fields, which include the electric field (measured in volts per metre) and the magnetic field (measured in Tesla units). Due to its configuration, an underground or subsea cable does not directly emit an electric field because it is surrounded by a grounded metal screen. The magnetic field depends on the intensity of the electric current in the cable and the laying parameters (especially the geometry). It decreases rapidly with distance (Fig. 3). For monopolar cables and cables with a separate DC bipolar configuration, the magnetic field strength decreases according to the relation 1/d, where d is the distance from the centre of the cable. In the case of a three-phase AC cable, or a cable with a bundled DC bipolar configuration (two cables in opposite phase), the fields generated by each of the cables compensate for each other and the field decreases according to the relation $1/d^2$.

The magnetic field emitted by a DC cable is static over time but its strength varies with the intensity of the electric current. The earth's magnetic field is itself a static field (except for variations due to solar winds), in the range of 50 µT in France. In contrast, in the case of AC power, a sinusoidal current flows through the cables at a given frequency (50 or 60 Hz), causing the magnetic fields to also vary over time at the same frequency. The magnetic fields, by induction effect in electrically conductive elements (such as sea water or living organisms), generate an "induced" electric field of a few µV/m outside the cable.

LEARN MORE

Taormina B., Bald J., Want A., Thouzeau G., Lejart M., Desroy N., Carlier A. (2018)
A review of potential impacts of submarine power cables on the marine environment: knowledge gaps, recommendations and future directions.
Renewable and Sustainable Energy Reviews, Vol 96, 380–391.
https://doi.org/10.1016/j.rser.2018.07.026

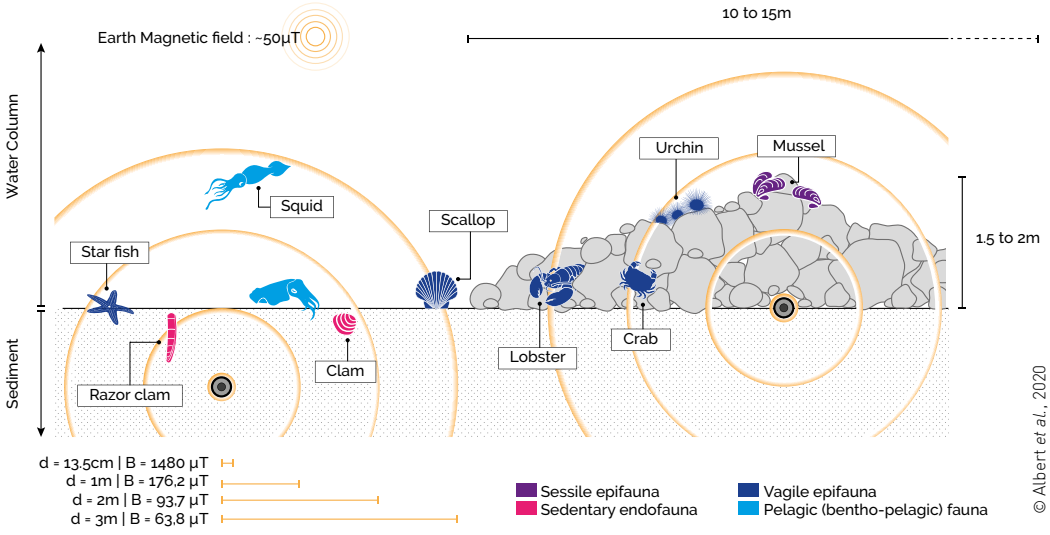

Fig. 3: General distribution of certain invertebrate species on the seabed, and theoretical magnetic field strengths emitted by 225 kV cables (buried at 1 m and unburied) with an electric current of 1,000 A (diameter: 27 cm).

2 - Overview of the study sites

Five different sites in France were selected for this study. Three were offshore renewable energy test sites: Paimpol-Bréhat in the Côtes d'Armor department, Fromveur off Ushant in the Finistère department, and SEM-REV off Le Croisic in the Loire-Atlantique department. The other two sites were power connection sites completely unrelated to ORE systems.

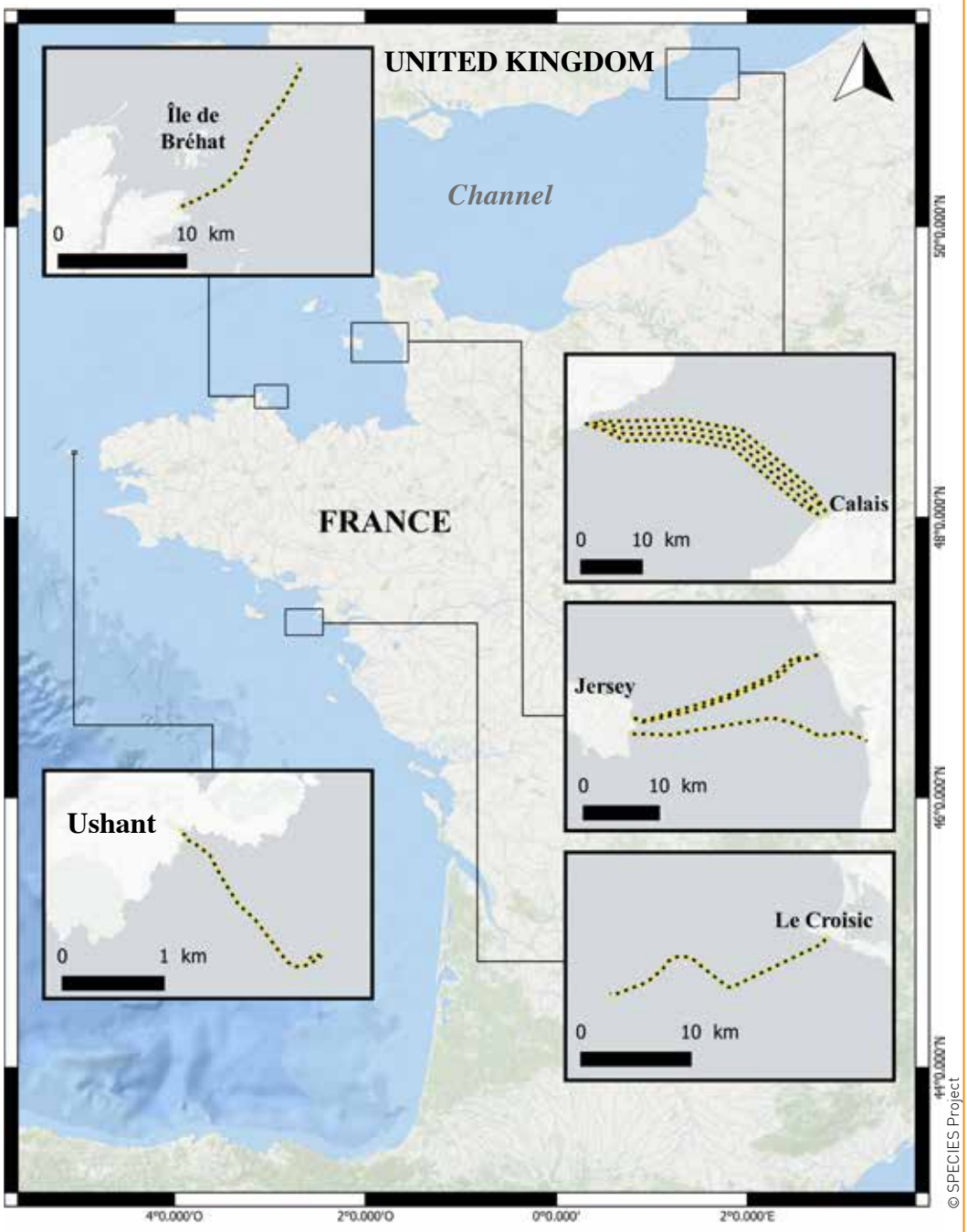

Fig. 4: Location of the five study sites.

2.1 Test sites dedicated to offshore renewable energy

Paimpol-Bréhat tidal energy test site power cable

Power:
8 MVA

Voltage:
10 kV

Type:
Direct current

Date laid:
2012

Description:
The Paimpol-Bréhat tidal energy test site is located off the coast of Paimpol (Brittany, France) in the La Horaine shellfish reserve. The connection between the tidal energy demonstrators and the mainland is ensured by a 15 km power cable. Due to the strong currents in the area and a seabed dominated by hard substrates, a section measuring 11 km is not buried but simply laid on the bottom. This section of the cable is protected by cast iron shells and stabilised by 120 concrete mattresses installed in 2013.

Commissioning:
- OpenHydro: no power connections were made during the various tests of the 2 MW demonstrator farm.
- HydroQuest: the 1 MW demonstrator has been connected to the grid since June 2019.

Tasks conducted:
- Monitoring of the benthic colonisation of the artificial structures.
- Monitoring of the great scallop population (growth reference state).

Fromveur tidal energy test site cable

Power:
500 kW (max)

Voltage:
7.5 kV

Type:
Alternating current

Date laid:
2015, with the cable laid in May, installation of the D10 tidal turbine in June, connection and start of production in September, and connection to the grid in November.

Description:
The Fromveur test site, designed to test SABELLA's tidal turbines, is located in the Fromveur Passage between the island of Ushant and the Molène archipelago (Brittany, France). The D10 tidal turbine demonstrator is connected to the island of Ushant by an unburied cable measuring 2 km. This cable is unprotected except for a 200 m section covered by cast iron shells. Initial energising of the cable took place between mid-October and the end of December 2018 on a continuous basis, and then on an as-needed basis until April 2019.

Commissioning:
September 2015. Production over several months on a non-continuous basis until April 2016. Raising of the turbine in July 2016 and re-installation in October 2018. Continuous production until end of December 2018 and then on an as-needed basis until March 2019. Raising of the turbine in April 2019 followed by re-installation for a week in October 2019 with little production, then raising again.

Tasks conducted:
- Monitoring of the benthic colonisation of the unprotected cable.
- Temperature measurement.

SEM-REV test site cable

Power:
8 MVA

Voltage:
20 kV

Type:
Alternating current

Date laid:
2012

Description:

The SEM-REV offshore test site is located off the coast of Le Croisic, to the west of the Guérande bank, and is connected to the shore at Le Croisic (Pays de la Loire department, France). The SEM-REV site is owned by Centrale Nantes. It is operated by the Research Laboratory in Hydrodynamics, Energetics and Atmospheric Environment (LHEEA, UMR 6598) of the French National Centre for Scientific Research (CNRS). Centrale Nantes is the project manager for the setting up of the test site, and holds all the necessary administrative authorisations for the testing of multi-technology prototypes (wave energy and floating offshore wind). A 23 km export cable connects the prototypes to the high voltage delivery station on land via a subsea connection hub. The cable is buried along its entire length at a depth of around 1.5 m below the sediment, except in front of a rocky headland to the north-west of the Four plateau. At this point, it is protected by 60 concrete mattresses along a 350 m-long section. These protection mattresses were installed in 2013.

Commissioning:
The Floatgen floating wind turbine (2 MW) has been connected to the grid since September 2018.

Tasks conducted:
- Measurement of electromagnetic fields.
- Temperature monitoring.
- Monitoring of the colonisation of artificial structures.

2.2 Power connection cables other than for ORE

Jersey-Cotentin connections

Power:
50 MW (Normandie 1)
90 MW (Normandie 2)
100 MW (Normandie 3)

Voltage:
90 kV (Normandie 1-2-3)

Type:
Alternating current

Dates laid:
1982, replaced in 2016 (Normandie 1)
2000 (Normandie 2)
2013 (Normandie 3)

Description:
Jersey's electricity supply is ensured by three power cables located in the Normand-Breton Gulf between the island and the Cotentin Peninsula (Normandy, France). The most recent cable, Normandie 3, was laid to the south and is buried, unlike Normandie 1 and 2, located further north, which are simply laid on the seabed at a distance of 500 m from each other and with no associated protection.

Tasks conducted:
- Measurement of electromagnetic fields.
- Studying of the reserve effect.
- Temperature measurement.

HVDC Cross-Channel interconnector

Power:
2 GW

Voltage:
270 kV

Type:
Direct current

Date laid:
1981

Description:
The HVDC Cross-Channel interconnector refers to the very high voltage connection between the French and British electricity grids. This link consists of four cables that cross the Strait of Dover over a distance of 46 km. These cables were buried in the sediment, with a target depth of about 1.5 m during the cable laying work. Maintenance operations were performed on a few hundred metres of this cable in 2017, this section now being laid on the bottom and protected by riprap.

Tasks conducted:
- Measurement of electromagnetic fields.

3 - Project results

Thirteen fact sheets, each addressing a specific scientific focus, present the methods developed and implemented as well as the main results of the project.

3.1 Measurement of physical effects

- **Fact Sheet 1**
  Tools for measuring electromagnetic fields
- **Fact Sheet 2**
  Dynamic measurements of electromagnetic fields
- **Fact Sheet 3**
  Static measurements of electromagnetic fields
- **Fact Sheet 4**
  Effects of subsea power cables on temperature

3.2 *In situ* assessment of potential impacts on benthos

- **Fact Sheet 5**
  Methods for monitoring sub-tidal benthic communities in the vicinity of cables
- **Fact Sheet 6**
  Monitoring of epibenthic communities associated with cable protection structures
- **Fact Sheet 7**
  Monitoring of benthic megafauna associated with cable protection structures
- **Fact Sheet 8**
  Monitoring of benthic megafauna associated with floating wind turbine connection structures
- **Fact Sheet 9**
  Assessment of the reserve effect associated with the presence of a protection corridor
- **Fact Sheet 10**
  Assessment of the impact of power cables on adjacent benthic communities

3.3 Laboratory assessment of potential impacts on benthos

- Fact Sheet 11
  Methods for the experimental study of the responses of benthic organisms to artificial magnetic fields
- Fact Sheet 12
  Study of the impact of artificial magnetic fields on European lobsters
- Fact Sheet 13
  Study of the impact of artificial magnetic fields on great scallops

Objective: **To develop tools for the dynamic or static measurement of electromagnetic fields at sea.**

Dynamic measurement of electromagnetic fields: the PASSEM tool

Description

The PASSEM tool is a system for measuring electromagnetic fields developed by MAPPEM Geophysics. Towed by a surface vessel, it consists of a main "fish" where the acquisition electronics and certain sensors are located, followed by a cable with electrodes forming several dipoles and measuring potential differences between two electrodes (Fig. 5).

Fig. 5: View of the PASSEM tool on deck prior to deployment.

The main "fish" comprises the acquisition system, the navigation sensors (altimeter, pressure sensor, inclinometers), and a highly sensitive, three-axis fluxgate-type magnetic sensor for magnetic field measurements. The electronic fields are measured by four independent dipoles of different lengths (Fig. 6).

Acquisition

The dipoles are distributed along a cable towed by the system. The electric fields are measured using AgCl electrodes and high-gain preamplifiers. The four measurement dipoles have different lengths (19 m, 17 m, and two 4 m dipoles) and provide data redundancy. Acquisition is carried out with a resolution of 24 bits and a frequency of 2 kHz for all sensors. The noise level for the electric sensors is 10^{-10} nV/m/√Hz, and less than 10 pT/√Hz for the magnetic sensor. These noise levels are well below the ambient signal levels.

Advantages

The PASSEM tool enables electromagnetic fields to be assessed quickly and over a wide area. It also allows the main sources of the fields to be identified. This system is easy to deploy. With its dimensions (length of 1.5 m and diameter of 20 cm), the "fish" can be easily handled by two people on the deck of a vessel, and the detection cables can be deployed manually. The lengths of the dipoles enable the precise measurement of the electric fields present in the area.

Disadvantages

The PASSEM tool is only capable of measuring electromagnetic fields at a given moment. As the system is towed, the magnetic data are disturbed by the movements of the measuring device and require correction.

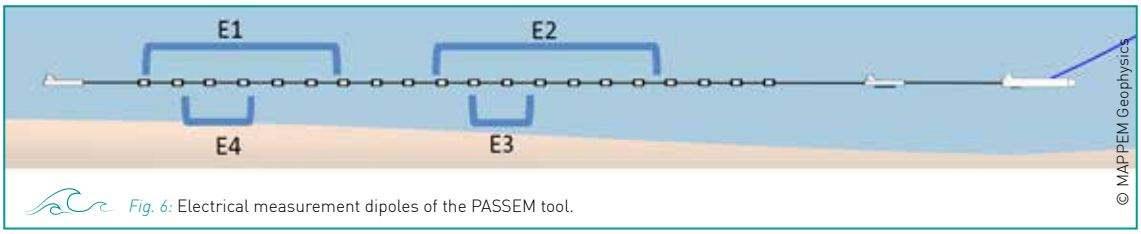

Fig. 6: Electrical measurement dipoles of the PASSEM tool.

Static measurement of electromagnetic fields: the STATEM tool

Description

This stationary device is used to measure electromagnetic fields with a very high degree of accuracy, and consequently to precisely assess variations near the signal sources (Fig. 7). The data are not disturbed by the movements of the measuring device, and the measurements can be made in close proximity to the source of the electromagnetic signal (such as cables or wind turbines). This station has a three-component, fluxgate-type magnetic sensor and two perpendicular electric dipoles. It is capable of performing data acquisition for a period of two weeks (or more if required), thereby allowing observation of the evolution of the electric and magnetic fields over time. The high-frequency acquisition (512 Hz) also allows the recording of alternating field signals.

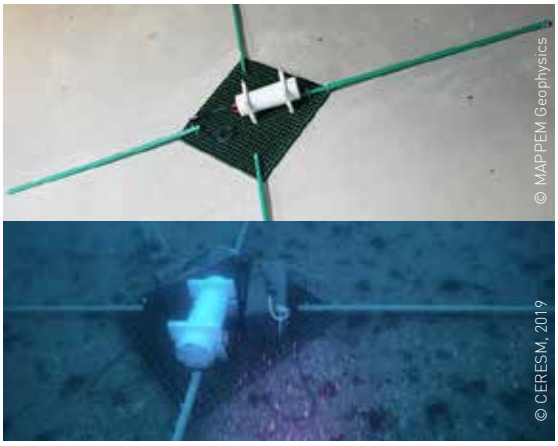

Fig. 7: View of the STATEM tool prior to deployment (top) and placed on the seabed (bottom).

Specifications

- Fibreglass frame: 1 m x 1 m.
  Total span: 5 m maximum
  with the arms of the electric dipoles.
- Immersion depth: up to 50 m.
- Weight on land: approximately 35 kg
  (without ballast weights).
  Concrete ballast weights are added
  to increase stability on the seabed,
  depending on the implementation conditions.
  They are retrieved at the same time as the station.
- Autonomy: 2 weeks.
- Magnetic sensor: three-axis fluxgate
  (noise less than 20 pT/√Hz).
- Electric sensors: AgCl type, dipole length up
  to 5 m (noise < 0.2 µV/√Hz).
- Acquisition: 512 Hz, 32 bits.

Deployment

Deployment is performed by a ship on the surface, with or without the assistance of divers depending on the launching conditions. The ship holds position directly above the selected measurement point. The STATEM tool is then activated on board (synchronisation of the GPS, initialisation and self-tests). It can be deployed either using only a crane (with a mooring block if the need for localisation accuracy is not very high), or with the help of divers for exact positioning on the seabed (notably near the infrastructures by precisely measuring the distance to the source).

Advantages

The STATEM tool enables field measurements to be made more accurately than with a towed system as the data are not affected by the movements of the measuring device. Recording is done much closer to the source of the electromagnetic disturbance. In addition, the tool is capable of measuring electric and magnetic field variations over time.

Disadvantages

This system can require divers to install and retrieve the equipment. It can also be difficult to implement at sites where objects (fishing gear) are present on the seabed and/or in the water column.

LEARN MORE

The µV/√Hz for the electrical measurements or pT/√Hz for the magnetic sensors are conventional units of measurement calculated from the frequency spectra of noise (power spectral density). For the electric sensors, the electric fields are often also specified in µV/m as the levels depend on the length of the dipole used to perform the measurement.

Objective: **To characterise the electric and magnetic fields in the vicinity of several types of subsea power cables.**

Context:

To date, and considering the vast number of subsea power cables already deployed throughout the world's oceans, surprisingly few *in situ* measurements have been made of the resulting electromagnetic fields. Indeed, the field strength values generated are often provided on the basis of models and are rarely validated by *in situ* measurements. Within this context, the objective of this study was to measure the electromagnetic fields emitted by subsea power cables already in operation and presenting contrasting characteristics (power rating, burying depth, etc.). The two study sites selected feature very different power transmission technologies: DC power transmission for the cables of the HVDC Cross-Channel interconnector between France and the United Kingdom, and AC power for the cables linking the island of Jersey to the Cotentin Peninsula in France. The signals measured were therefore expected to be different.

Method:

The electromagnetic fields were measured using the PASSEM tool (Fact Sheet 1) during two different missions.

- For the HVDC Cross-Channel interconnector, 13 transects were performed on 27 September 2018 at a distance of between 4 and 20 m above the four HVDC cables and at a speed of approximately 3 knots (Fig. 8).
- For the Jersey interconnector, 11 transects were performed above the three cables from 25 to 26 June 2019: five transects on Day 1 above the Normandie 1 (N1) and Normandie 2 (N2) cables in the vicinity of the P1 zone, and six transects on Day 2 above the Normandie 3 (N3) cable in the vicinity of the P4 zone (Fig. 9). Due to unfavourable weather conditions, only the zones of the profiles P1 and P4 could be inspected.

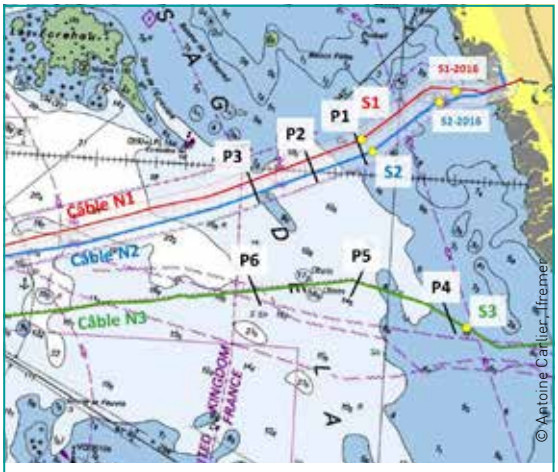

Fig. 9: Positions of the profiles (P1 to P6) and stations (S1 to S3) initially planned for measuring the electromagnetic fields along the Jersey-Cotentin connection comprising the N1, N2 and N3 cables, using the PASSEM tool.

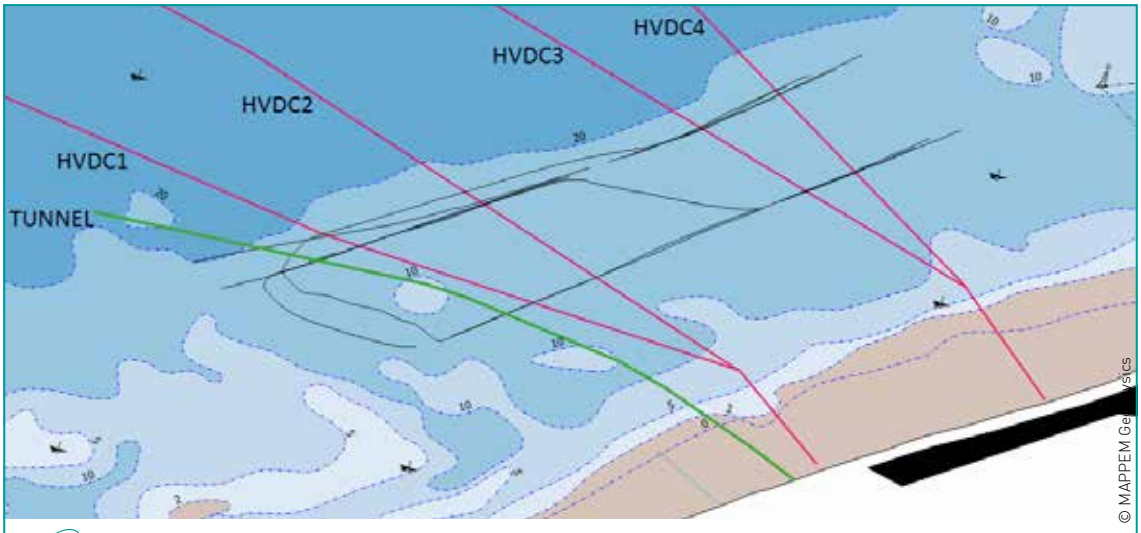

Fig. 8: Positions of the transects defined using the PASSEM tool (black lines) to measure the electromagnetic fields emitted by the cables of the HVDC Cross-Channel interconnector (red lines).

Results:

The electromagnetic signals of the cables were clearly identifiable in the measured data, notably in the spectrograms used to measure the various detectable harmonics.

The HVDC Cross-Channel cables showed a magnetic field of a few hundred nanoteslas at a distance of 10 m, and an electric field that was solely due to the disturbance frequencies present, themselves related to the devices used to rectify the electric current (Fig. 10). The signals were different at the Jersey site. The magnetic fields were of the same order of magnitude, but presented mainly frequency components due to the nature of the current flowing through the cables. The frequency content was therefore much stronger with decreasing harmonic components. The 50 Hz signals were obviously the highest (Fig. 11). The electric signals were more easily exploited due to the length of the dipoles of the PASSEM tool. The main magnetic signals could, however, also be identified.

Measurements taken above the HVDC Cross-Channel cables unexpectedly identified a significant electric signal above the Channel Tunnel, and therefore likely to come from this underground structure. In this area, the measuring device showed a saturated signal over a few tens of metres on the "west" side of the transects. As the recording range of the electric signal had been previously configured for the characterisation of the cable signals, this indicates that the Channel Tunnel potentially generates an electric field higher than those associated with the HVDC Cross-Channel power cables. A new measurement campaign, with a recording range tailored to the signal that can be expected for this type of structure, would help to more precisely characterise the electromagnetic effect experienced by the benthic ecosystem at this location.

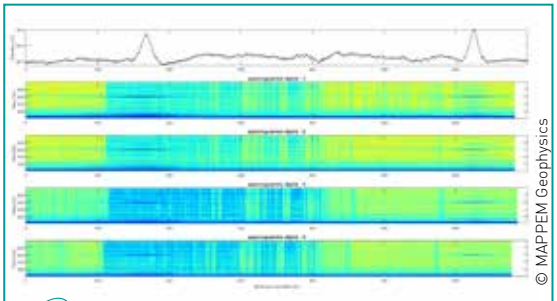

Fig. 10: Magnetic fields observed at the HVDC Cross-Channel site (top graph) showing the magnetic signals of the two cables, and spectrograms of the electric signals measured by the four dipoles of the PASSEM tool (bottom graphs). The presence of both cables is visible, particularly thanks to a 600 Hz signal resulting from the power conversion to direct current.

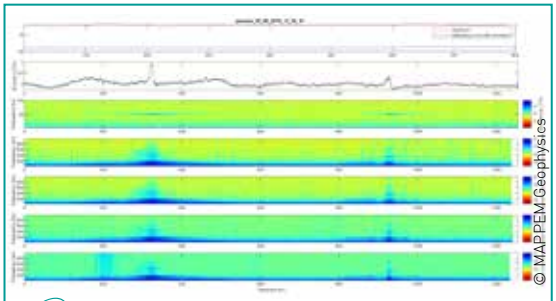

Fig. 11: Magnetic fields observed at the Jersey site (top graph) showing the magnetic signals of the two cables, and spectrograms of the electric signals measured by the four dipoles of the PASSEM tool (bottom graphs).

Conclusion:

At the scale of an area where several cables are present, the PASSEM system made it possible to characterise the electromagnetic signals and to obtain an assessment of the amplitude of the electric and magnetic fields depending on the power of the electric current in the cables. The electric fields were measured with high accuracy. The magnetic fields were often noisier because of the distance to the cables (generally several metres) and movements due to the system being towed by the ship.

Limitations:

The movements of the PASSEM tool increased the level of noise in the data. The quantification of the electromagnetic fields was approximate as the electric currents flowing through the cables were often not precisely known at the exact moment when the system passed over the cables. This is because the power data were averaged. Furthermore, it is difficult at this stage to normalise the electromagnetic field values with respect to the distance to the cable due to the non-linear and complex nature of the emitted fields.

Objective: **To measure the variations over time in the electric and magnetic fields in the vicinity of several types of subsea power cables.**

Context:

To date, considering the vast number of subsea power cables already deployed throughout the world's oceans, relatively few *in situ* measurements have been made of the resulting electromagnetic fields. Indeed, the field strength values generated are often provided on the basis of models and are rarely validated by *in situ* measurements. Among these measurements, a limited body of research is concerned with the evolution of the fields over time. Within this context, the objective of this study was to measure the fluctuations over time of the electromagnetic fields emitted by two subsea power cables in operation.

Method:

The electromagnetic fields were measured using the STATEM tool (Fact Sheet 1) in the immediate vicinity of the Normandie 1 cable connecting Jersey to the French grid and of the connection hub for the SEM-REV test site. For the "Normandie 1" cable, the system was deployed from 25 to 29 June 2019 on the seabed at the S1 station, at a distance of 4 m from the cable (Fig. 12). For the SEM-REV site cable, the system was positioned 2 m from the connection hub (Fig. 13) on 22 October 2019. The exact geographical position of the device was less important than the distance and orientation of the station with respect to the cable.

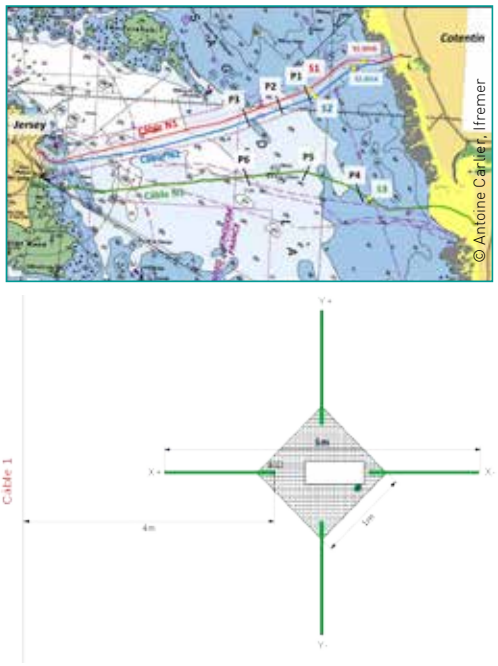

Fig. 12: Location of the S1 station on the Jersey-Cotentin connection comprising the N1, N2 and N3 cables (top), and positioning of the STATEM tool in relation to the N1 cable (bottom).

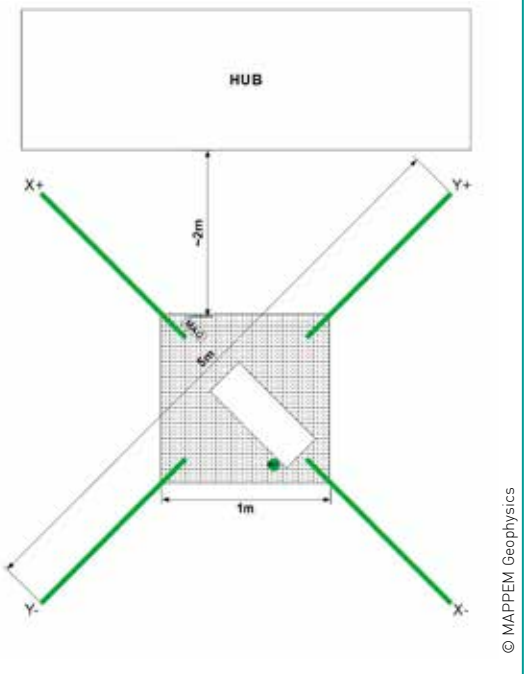

Fig. 13: Diagram showing the position of the STATEM tool in relation to the connection hub of the SEM-REV test site. Dipole 1 corresponds to dipole X+X-, and dipole 2 to dipole Y+Y-.

Results:

For the "Normandie 1" cable, the variations in the magnetic field, measured and filtered on the main harmonics, followed the variations in the power of the current in the cable throughout the measurement period (Fig. 14). These variations were in the range of **a few nanoteslas 4 m from the cable**. The same was true for the electric fields (Fig. 15), with variations of a few hundred nanovolts per metre for approximately 30 MW of power present in the cable (approximately 200 A).

At the connection hub of the SEM-REV test site, the electromagnetic field data were obtained over a short period of time (a few hours), which corresponded to a phase of increasing power generation by the Floatgen floating wind turbine, including maximum generation at the end of the recording period. The strength of the magnetic field emitted by the hub followed the same oscillations as the intensity of the electric current. **This magnetic signal varied from 0.5 to 6 nT at a distance of 2 m from the hub, with saturation at 6 nT during the maximum power generation phase** (Fig. 16).

The electric field increased progressively over the same period, reaching a maximum value of 16 µV/m. This signal was less well correlated with the intensity of the electric current produced at the beginning of the recording period (Fig. 17).

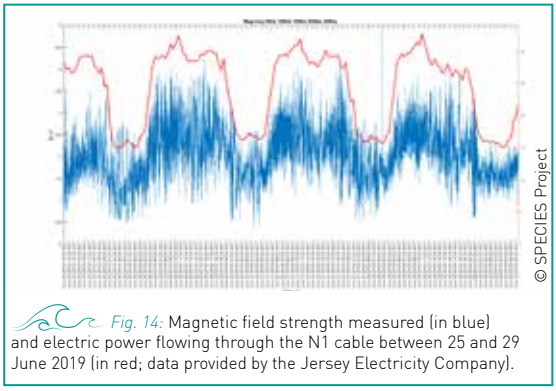

Fig. 14: Magnetic field strength measured (in blue) and electric power flowing through the N1 cable between 25 and 29 June 2019 (in red; data provided by the Jersey Electricity Company).

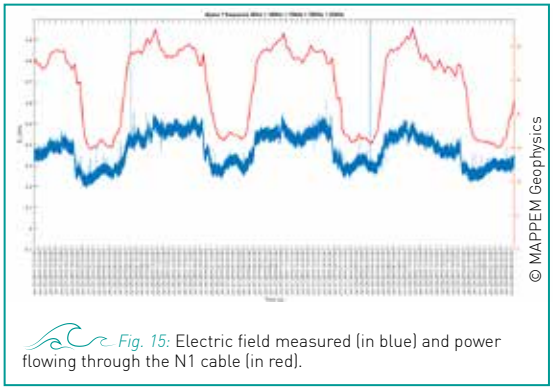

Fig. 15: Electric field measured (in blue) and power flowing through the N1 cable (in red).

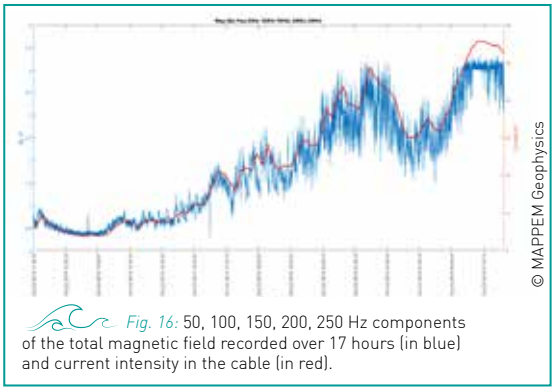

Fig. 16: 50, 100, 150, 200, 250 Hz components of the total magnetic field recorded over 17 hours (in blue) and current intensity in the cable (in red).

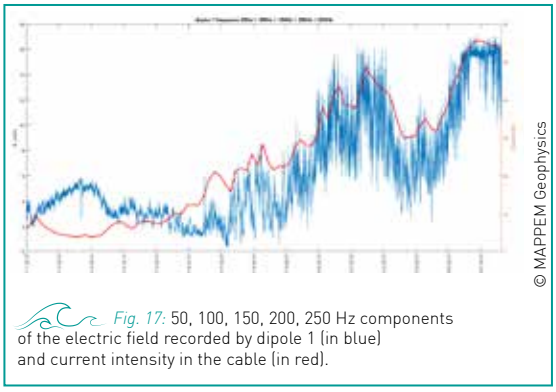

Fig. 17: 50, 100, 150, 200, 250 Hz components of the electric field recorded by dipole 1 (in blue) and current intensity in the cable (in red).

Conclusion:

The STATEM station made it possible to very accurately measure the electric and magnetic fields in the vicinity of a laid cable and a subsea electric connection infrastructure. The correlation between the electromagnetic fields recorded and the intensity of the electric current flowing through the cable and the hub was very good. The recorded electromagnetic fields even reflected the phase of maximum power generation at the SEM-REV test site. The STATEM tool is thus able to correctly assess the electromagnetic signal emitted during the different phases of operation of ORE systems.

Limitations:

It was necessary to know the characteristics of the injected electric current and the relative positions of the cable and the station in order to extrapolate the amplitudes of the signals emitted by the cables. Given the non-linear nature of the electromagnetic fields and the complexity of the cable structures, it is difficult at this stage to accurately standardise the magnetic fields emitted in relation to the distance from the cable and the current on the basis of the measurements made.

Effects of subsea power cables on temperature

Objective: **To characterise the potential heat produced by the passage of electric current through cables.**

Context:

In general, the passage of an electric current through a conductor produces heat. This is known in physics as Joule heating. Although the conductive part of the cables, also known as the core, is protected by various metallic and plastic materials, thermal radiation exists, and is usually dissipated by the movements of the water mass. In the case of subsea power cables, the aim was to determine whether their operation can lead to an increase in temperature both at their surface, which is colonised by benthic organisms, and in their immediate environment. Although the electric power cables of offshore wind farms and marine interconnectors can transmit high levels of electric power, there is very little data in the literature on the potential temperature increase on and around the cables, whether or not they are buried.

Method:

Surface temperature recordings of various power cables were made at several study sites with cables in operation: the Jersey-Cotentin connection and the Ushant, Paimpol-Bréhat and SEM-REV test sites. At each of these sites, the strategy consisted in taking *in situ* temperature measurements using autonomous probes attached to the surface of the cables as well as on an inert support nearby to obtain the natural seawater temperature (control temperature). The potential disturbance was characterised by measuring the difference in temperature between the cable probes and the control probes. The probes used were iButton-type probes (Fig. 18). They were configured to record the temperature every 1 to 3 hours depending on the sites, with a sensitivity of 0.06°C and an accuracy of 0.5°C. A sealant was used to seal the probes. The cable probes were attached to the surface of the cables using Colson™ clamps.

The intermittent power generation and the fluctuation in consumption resulted in a variation in the power and intensity of the electric current flowing through the cables.

The recordings were therefore made over a sufficient period of time to capture these variations in electric power and therefore potential heating.

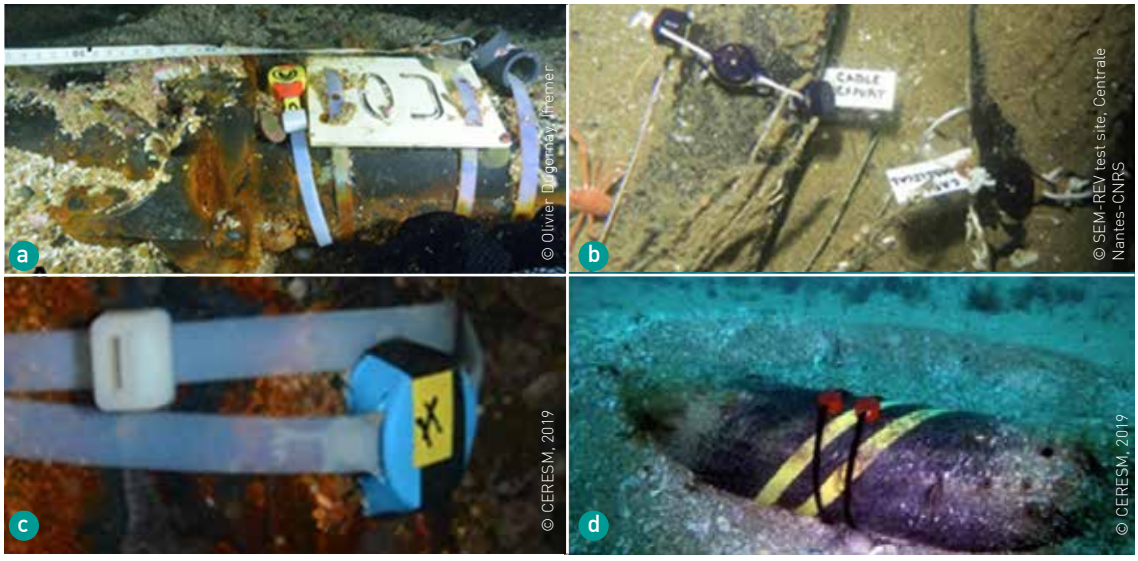

Fig. 18: Examples of the temperature probes installed on cast iron protection shells (a: Paimpol-Bréhat site) or directly on the surface of an unprotected cable (b: SEM-REV site; c and d: Jersey-Cotentin connection).

Results:

Temperature data were obtained during the operational phase on the cables of the Jersey-Cotentin connection and the Ushant and SEM-REV test sites. Reference temperature data were acquired for the Paimpol-Bréhat cable.

The measurements carried out on the Ushant cable showed no difference in temperature between the probes attached to the cable (n=3) and the probes attached to a section of control cable without electric current (n=3), located approximately 5 m from the main cable. The data concerning the power passing through the cable during this period are currently still unavailable, and therefore cannot be compared with the measured temperatures. Despite this, the absence of any temperature difference between the cable probes and the control probes tends to indicate that no heating occurred.

At the Jersey-Cotentin connection, the temperature fluctuations observed on the two cables exactly followed those measured on the control probes and were entirely uncorrelated to the power variations measured in the cables (Fig. 19). The very small temperature differences obtained between the cables and the control probes were within the accuracy range of the probes. Thus, the measured temperature difference (0.2°C) between the two probes attached to the cables of the Jersey-Cotentin connection (N1 and N2) was greater than the difference obtained between each of these probes and the control probes. Six sensors were installed at the SEM-REV site: two sensors on the umbilical of the Floatgen wind turbine, one on the export cable of the test site, and three on a control station located approximately 5 m from the power cables. The mean deviations were obtained by averaging all of the absolute deviations for each condition. For example, the calculation formula for umbilical sensor no. 1 (UM1) was:

UM1-C = Mean (Σ |UM1-Control no. 1|; Σ |UM1-Control no. 2|; Σ |UM1-Control no. 3|).

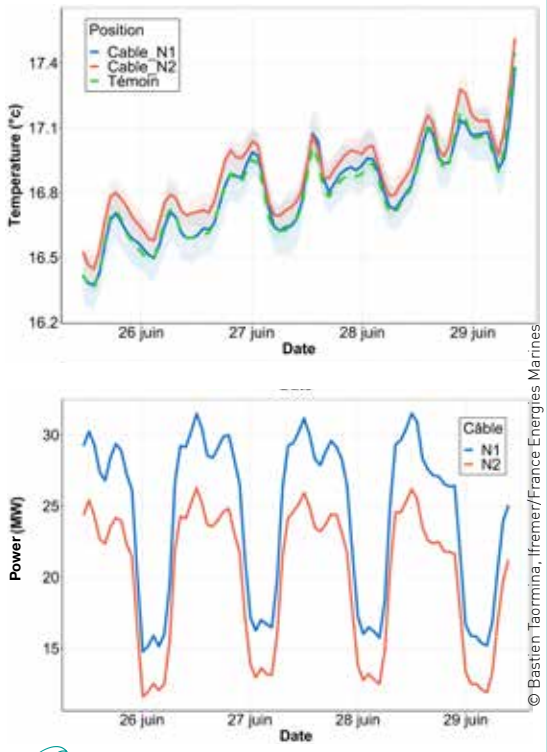

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Fig. 19: Temperature measured every hour from 25 to 29 June 2019 at the surface of the N1 and N2 cables and at a control station near the two cables (top), and power flowing through the N1 and N2 cables on the same dates (bottom).

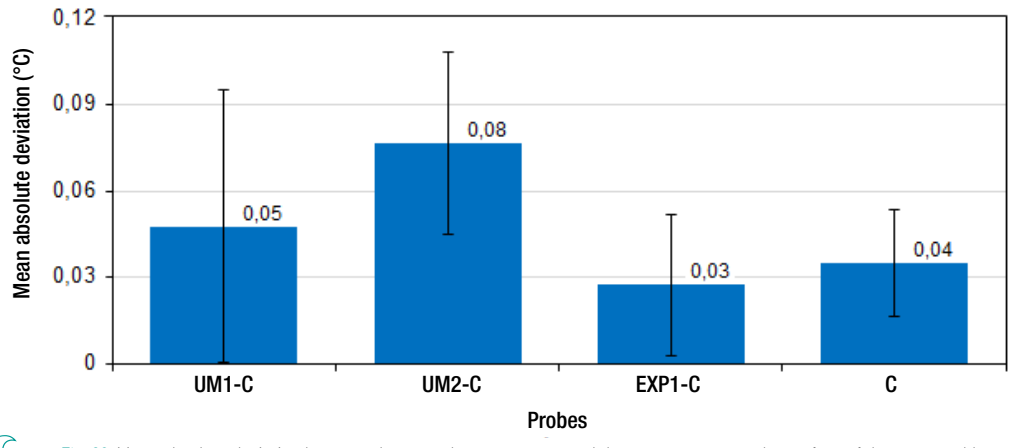

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Fig. 20: Mean absolute deviation between the control temperatures and the temperatures at the surface of the power cables measured every hour from 12 September 2019 to 7 February 2020 (n=3,097 measurements): probe 1 on the Floatgen umbilical (UM1), probe 2 on the Floatgen umbilical (UM2), probe on the site export cable (EXP1), probes on the control station (C). The error bars correspond to the standard deviations.

The mean absolute deviations observed between the control temperatures and the temperatures of the sensors positioned on the surface of the power cables were 0.05°C (± 0.05°C) and 0.08°C (± 0.03°C) for the Floatgen umbilical sensors, and 0.03°C (± 0.02°C) for the sensor on the site's export cable. The mean absolute deviation in temperature from the control sensors was 0.04°C (± 0.02°C) (Fig. 20). These deviations were calculated only during the wind turbine's production periods. These values were very small and were within the resolution and accuracy ranges of the temperature sensors used. Consequently, the variations observed could be due to intrinsic variations on the sensors. If they had really corresponded to heat emissions from the power cables, the temperature increase would not have exceeded 0.11°C for a 2 MW power cable.

In the same way as for the Jersey-Cotentin connection, the temperature fluctuations observed on the two cables exactly followed those noted with the control sensors. These variations were independent of power generation. They can be explained by such hydrodynamic factors as the tide and/or waves. Indeed, from 28 to 31 October 2019, the wave height was between 1.07 m and 2.02 m, while from 2 to 3 November 2019, it was between 3.10 m and 4.14 m (measurements taken from the SEM-REV wave sensor). This resulted in a homogenisation of the water column and a smoothing of the oscillations of the temperature curves (Fig. 21).

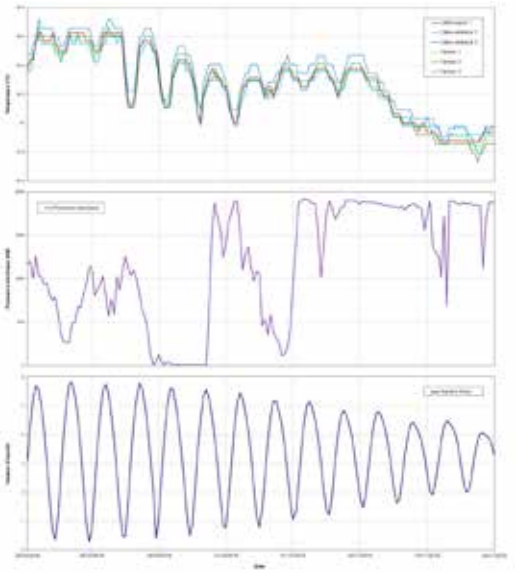

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Fig. 21: Temperature measured every hour from 28 October to 4 November 2019 (top) at the surface of the export cable (one sensor), at the surface of the Floatgen umbilical (two sensors), and at a control station near the two cables (three sensors), power flowing through the two cables on the same dates (centre), and water depth on the same dates (bottom).

Conclusion:

The data acquired at the Jersey-Cotentin connection and at the Ushant and SEM-REV test sites showed no heating of the surface of the cables – and therefore of their immediate environment – at a sensitivity level of 0.06°C. The temperature monitoring of the cables could not be carried out or finalised at all of the study sites. However, considering that the cables in the Jersey-Cotentin connection had a higher power rating than the cables at the other test sites considered in the study, it would appear that the ecological impact related to the temperature of the cables laid on the seabed during operation was negligible.

Limitations:

The temperature could not be measured on the buried part of the SEM-REV site power cable. It was therefore not possible to characterise the potential heating around a cable buried 1.5 m below the seabed. Thermal radiation from buried cables can heat the sediment in the immediate vicinity as it is not exposed to much water movement. This constitutes a knowledge gap that would be worth addressing in a future study.

Methods for monitoring sub-tidal benthic communities in the vicinity of cables

Objective: **To identify the *in situ* monitoring strategies in order to assess the potential impact of power cables on benthic communities located in close proximity to cables.**

Context:

The monitoring of benthic communities consists in making an inventory of the target communities, i.e., a list of taxa and a count of each taxon per unit of area. This inventory can be carried out using **destructive** protocols whereby organisms are collected directly on site and then analysed in the laboratory. **Non-destructive** protocols also exist and involve inventories carried out *in situ* via direct observations or using underwater imaging techniques. The method selected depends on the initial scientific question and the characteristics of the study site, in particular the nature of the substrate (hard or soft) and the depth.

Destructive monitoring:

In situ sampling

Benthic communities can be sampled directly *in situ* by a team of trained divers or, in some cases, using remotely operated devices. These techniques have the advantage of being able to take samples at very precise positions, which is useful for assessing impacts that are in theory very localised, such as those of a subsea power cable (see Fact Sheet 6). However, they are complicated to set up. For **soft substrates**, hand-held sample-taking apparatus can be used to collect sediment and the associated endofauna from a given area. In the case of **hard substrates**, it is possible to use a suction sampler, i.e., a type of underwater compressed air vacuum cleaner (Fig. 22), after scraping a given surface to collect the whole of the community attached there.

Fig. 22: Sampling of the benthic macrofauna using an underwater suction sampler after scraping.

Fig. 23: Open Van-Veen grab sampler on deck.

Remote sampling

Certain sampling tools can be used from the deck of a vessel to collect samples of benthic communities. These techniques are not able to accurately locate samples but do not require the intervention of divers. They can be adapted to assess the reserve effect, which can concern a wider area on either side of the cables (see Fact Sheet 9). Different tools can be used depending on the target benthic compartment. Samples of endofauna can be taken using different types of **grab samplers** including Van-Veen, Smith-McIntyre or Hamon (Fig. 23). Epifauna can be collected using beam or bottom **trawlers**. The **dredges** *Rallier du Baty* and *Charcot-Picard* can take samples of both compartments. However, these techniques cannot be used to collect samples from hard substrates and therefore only concern communities of soft substrates.

Advantages and limitations

Whatever the type of destructive sampling used, the samples collected are then sieved and preserved before being processed in the laboratory. The advantage of these types of destructive monitoring techniques is that organisms can be determined with a high degree of taxonomic accuracy since this is done in the laboratory using determination keys, binocular magnifiers and microscopes. In addition, the data collected are quantitative in nature, resulting in more robust analyses. The associated laboratory work (sample sorting and determination) is nevertheless time-consuming and destructive approaches mean that monitoring cannot be performed over time at specific locations.

Non-destructive monitoring:

In situ inventories

Sub-tidal benthic communities can be inventoried visually directly on site by teams of divers. Since 2008, these inventories have been standardised thanks to the delimitation of surface areas using quadrats (Derrien-Courtel, 2008; Derrien-Courtel *et al.*, 2013; Le Gal and Derrien-Courtel, 2015). The inventory can either be exhaustive or focus on certain compartments (such as algae, crustaceans or macrofauna), depending on the scope of the study. The disadvantage of this type of monitoring is that it often requires long dives and divers with good taxonomic skills, but it does have the advantage of allowing the monitoring over time of specific locations.

Underwater imaging

Underwater images can be taken directly by **divers** (photoquadrats or video transects) (Fig. 24), or by using **remote devices**, which may be **mobile** (suspended camera, video sled, ROV, AUV, etc.) or **stationary** (fixed video system with or without bait). By using underwater images, large quantities of data with high spatial resolution can be collected quickly. It is easy to refer back to the raw data to verify an identification, a count, or to search for a new parameter. However, this approach requires laboratory processing, which is time-consuming and tedious given that reliable automatic object recognition tools are not available. As the identification of organisms has been carried out by an observer, an analysis protocol by sub-sampling of the image is then often necessary.

Fig. 24: Diver taking photographs at the Paimpol-Bréhat site.

Advantages and limitations

These non-destructive monitoring protocols have been regularly used along the Channel-Atlantic coastline since 2004 to characterise epibenthic communities as well as hard substrate communities, but are not suitable for cryptic communities of endofauna. Contrary to destructive methods, these protocols do not cause any disturbance to the communities, which is key to ensuring long-term monitoring on the same site. However, they offer a slightly lower taxonomic resolution than destructive methods because even experienced scientists can sometimes miss some extremely small species (< 5 mm).

In situ assessment of potential impacts on benthos

Monitoring of epibenthic communities associated with cable protection structures

Objective: **To study the succession of epibenthic communities colonising artificial structures associated with a subsea power cable in a highly hydrodynamic environment.**

Context:

For the requirements of connecting ORE systems or ensuring connections between islands and continents or riparian countries, subsea power cables can be buried, simply laid on the seabed, and/or protected with artificial structures. The latter constitute available substrates for plant and animal species that are fond of hard bottoms. One of the objectives of the study was to characterise the colonisation and succession of these communities on the different artificial structures of the Paimpol-Bréhat tidal energy test site. Indeed, the colonisation by epibenthic communities (a phenomenon known as biofouling) of artificial structures installed in highly hydrodynamic environments remains poorly known.

Method:

Two types of artificial structures (cast iron protection shells and stabilising concrete mattresses) associated with the export cable of the Paimpol-Bréhat tidal energy test site were monitored over a period of five years at a frequency of every six months (Fig. 25). The monitoring was carried out by underwater images taken by divers at three different sites along the cable route. At each site, photographs were taken of both the artificial substrates and the surrounding natural substrate. The photographs were then analysed in the laboratory in order to describe the epibenthic communities using a method optimised for this study.

Fig. 25: Photograph of one of the monitored sites showing the cable protected by a cast iron shell and a stabilising concrete mattress.

Results:

This study revealed a generally similar ecological succession (barnacles, different types of ascidians and red algae) for the communities of the two artificial habitats. These communities tended, however, to differentiate after four years of monitoring, with the appearance of kelp on the mattresses and hydrozoans on the shells (Fig. 26 and 27). Nevertheless, these ecological succession processes did not seem to be complete. In other words, the state of equilibrium, known as the climax, had not been reached since the communities showed no stability over time at the end of the monitoring period. Indeed, the surrounding natural substrate, dominated by pebbles and boulders, presented benthic communities that were stable over time, with a majority of encrusting taxa, and therefore structurally less complex than the communities observed on the artificial substrate at the end of the monitoring period.

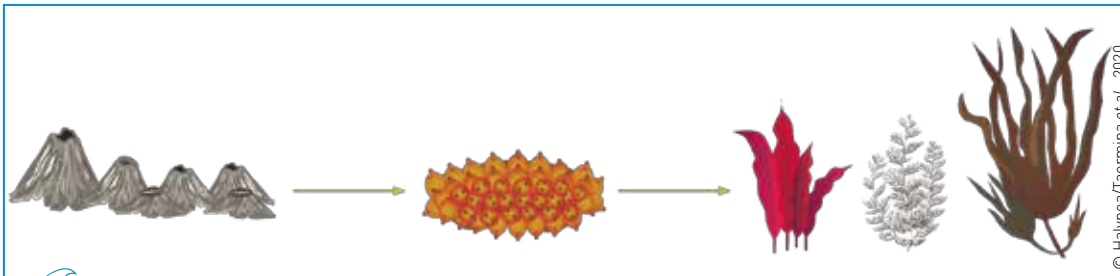

Fig. 26: Conceptual diagram of the ecological succession observed on the artificial structures at the Paimpol-Bréhat site. Barnacles were the first taxa to dominate the community, followed by a wide variety of ascidians and then by various erect algae and hydrozoans.

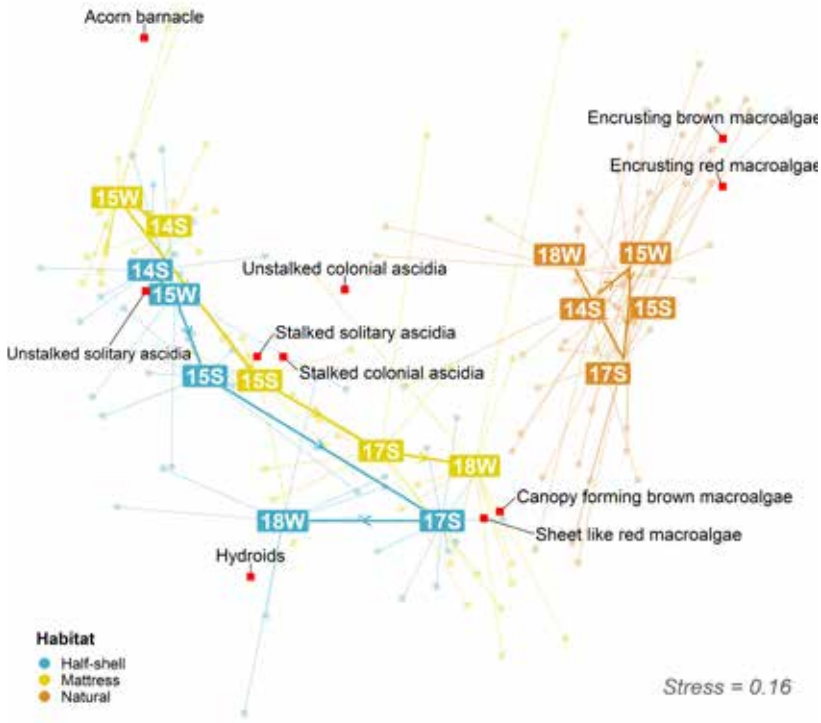

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Fig. 27: Non-metric multidimensional composition of the epibenthic communities based on the Bray-Curtis similarity index of the images. Each point represents an image and the lines connect all of the images from the same measurement campaign and habitat to its centroid. The arrows show the evolution over time (S = summer, W = winter).

Conclusion:

The deployment of artificial structures has created new habitats described as stable in an environment where the nearby natural habitat is highly mobile and strongly exposed to sediment abrasion. Epibenthic succession has thus reached more complex ecological stages within the artificial habitats. Although these epibenthic communities colonising the artificial substrates did not appear to have reached a climax at the end of the monitoring period, these artificial substrates already provided a habitat for structurally complex communities that could potentially generate a local increase in diversity.

Limitations:

As the surrounding natural substrate is not rock in the strict sense of the term but rather a mix of pebbles and boulders of different sizes, it is difficult to really decide on the question of the difference in colonisation between the artificial and natural substrates in this study. In order to answer this question, it would be necessary to study a site where the artificial structures are directly installed on rocky reefs or in the immediate vicinity thereof. A better characterisation of the different monitoring sites, for example by installing current metres to characterise the hydrodynamics, would have allowed a better understanding of the spatial variability of the environmental conditions within the present study.

LEARN MORE

Taormina B., Marzloff M., Desroy N., Caisey X., Dugornay O., Metral-Thiesse E., Tancray A., Carlier A. (2020b) **Optimizing image-based protocol to monitor macroepibenthic communities colonizing artificial structures.** *ICES Journal of marine science,* Vol 77, 835-845 https://doi.org/10.1093/icesjms/fsz249

Taormina B., Percheron A., Marzloff M., Quillien N. Lejart M., Caisey X., Desroy N., Dugornay O., Carlier A. (2020c) **Succession of epibenthic communities on artificial reefs associated with offshore renewable energy facilities within a tide-swept environment.** *ICES Journal of marine science,* Vol 77, 2656–2668 https://doi.org/10.1093/icesjms/fsaa129

In situ assessment of potential impacts on benthos

Monitoring of benthic megafauna associated with cable protection structures

Objective: **To characterise the habitat potential for benthic megafauna provided by the artificial stabilisation structures of subsea power cables.**

Context:

The deployment of artificial structures to protect and stabilise subsea power cables, whether for offshore renewable energy projects or to connect riparian countries, leads to the creation of a new potential habitat for fish and crustaceans, two groups of organisms that form part of the megafauna. This potential direct impact is often considered to be beneficial. However, knowledge concerning the actual impact of this type of structure on the ecosystem and the long-term dynamics of colonisation is still very limited. This study therefore aimed to better characterise the habitat potential for benthic megafauna provided by the concrete mattresses used to stabilise the Paimpol-Bréhat tidal energy test site export cable. Indeed, 120 concrete mattresses were installed in August 2013 on a section of the unburied cable of approximately 10 km, at depths of between 18 and 20 m. One of the specificities of this study site is the existence, since 1966, of a shellfish reserve near these concrete mattresses.

Method:

Of the 120 concrete mattresses installed, 45 were monitored from 2015 to 2019 over several sectors of the cable route. This *in situ* monitoring was based both on counts made during the dives and on the analysis of the videos taken by the divers. It enabled the inventory of five target taxa: two crustaceans (the edible crab *Cancer pagurus* and the European lobster *Homarus gammarus*), and three fish (the conger eel *Conger conger*, the ballan wrasse *Labrus bergylta*, as well as the poor cod and pouting grouped under the term *Trisopterus* spp.). This monitoring also provided the opportunity to describe the dominant substrate and the number of cavities present for each mattress, distinguishing between "holes" (triangular cavities between two concrete blocks making up the mattress) and "caves" (larger cavities formed under the mattress when it is not in direct contact with the seabed) (Fig. 28).

Fig. 28: Main mobile megafauna species finding refuge in the cavities of the concrete mattresses: *Homarus gammarus* in a "hole" (top left), *Cancer pagurus* in a "cave" (top right), *Trisopterus* spp. in a "cave" (bottom left), and *Conger conger* in a "hole" (bottom right).

Results:

Considering only the target species, it was noted that species diversity and density did not vary significantly between 2015 and 2019 (with the exception of *Trisopterus* spp.) (Fig. 29). The maximum densities observed concerned 0.28 individuals/m² for lobsters and 0.22 individuals/m² for conger eels. The settlement of these species thus seems to have taken place very quickly following the installation of the concrete mattresses, and the maximum occupation rate had in all likelihood already been reached at the start of the monitoring period (i.e., within two years or less). The number and nature (cave or hole) of the shelters available for each mattress significantly determine the composition of the benthic megafauna community present. The presence of lobsters is largely associated with the number of holes. Moreover, the nature and number of shelters depend on local physical conditions such as substrate type, topography, or exposure to the tidal current (Fig. 30). The study thus found:

- mattresses with numerous cave-like cavities in areas dominated by boulders and subject to strong currents, and that were heavily colonised, especially by *Trisopterus* spp. which are gregarious fish;
- mattresses with numerous hole-type cavities associated with pebble zones, and moderately colonised by all the solitary species of the megafauna;
- mattresses with a very small number of available cavities, and sparsely colonised by the benthic megafauna.

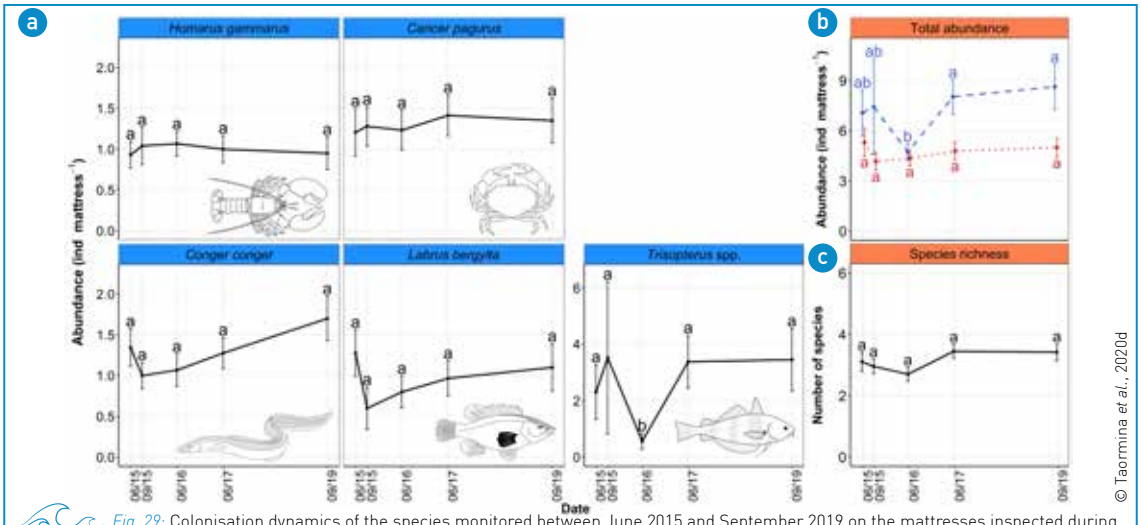

Fig. 29: Colonisation dynamics of the species monitored between June 2015 and September 2019 on the mattresses inspected during each measurement campaign (average number of individuals per mattress and standard error) (a), total abundance per mattress (in red: without *Trisopterus* spp.; in blue: with *Trisopterus* spp.) (b), and species diversity per mattress (c).

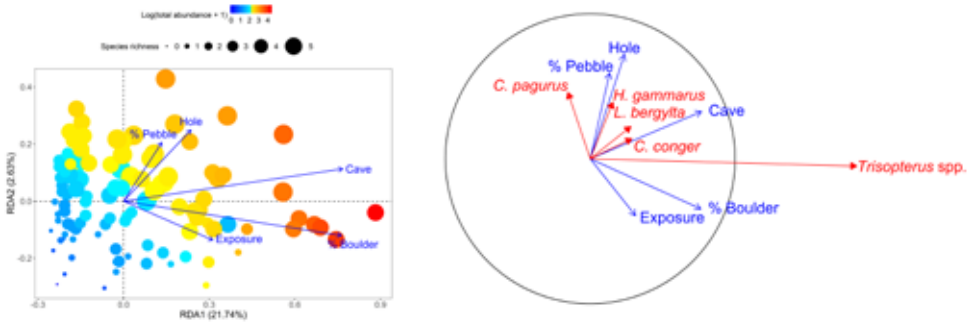

Fig. 30: Ordering diagrams for the redundancy analysis. Each point represents a mattress at a given measurement campaign. The blue arrows represent the relationships of the environmental variables with the axes.

Conclusion:

This study showed that stabilising concrete mattresses provide a suitable and sustainable habitat for the five taxa of fish and crustaceans monitored. In particular, and in order to accurately characterise the habitat potential of an artificial structure, the study highlights the importance of considering both the design of the structure itself (which determines the specificity of the habitat) and the way in which this structure interacts with the local natural substrate and tidal current (these conditions determining habitat availability).

LEARN MORE

Taormina B., Laurans M., Marzloff M., Dufournaud N., Lejart M., Desroy N., Leroy D., Martin S., Carlier A. (2020d) **Renewable energy homes for marine life: habitat potential of a tidal energy project for benthic megafauna.** *Marine Environmental Research*, Vol 161, 105131 https://doi.org/10.1016/j.marenvres.2020.105131

Limitations:

The various cavities present have been described here very briefly, differentiating only between two types: caves and holes. It would have been interesting to give more precise descriptions of these cavities, especially caves, for example by providing quantitative criteria such as their depth, their size, and the shape of their opening. This would have led to a better understanding of the properties of the artificial reef.

The occupation of artificial reef habitats by benthic megafauna can vary according to nycthemeral and tidal cycles, depending on the ecology and the behaviour of the different species. To integrate this parameter, it would be interesting to use a fixed, autonomous video recording system over a sufficiently long period to cover several daily cycles and different tidal coefficients.

Monitoring of benthic megafauna associated with floating wind turbine connection structures

Objective: **To study the colonisation by benthic megafauna of the connection structures (hub and umbilical) of the floating wind turbine at the SEM-REV test site.**

Context:

In a similar way to the study of the megafauna conducted on the Paimpol-Bréhat tidal energy test site (see Fact Sheet 7), this research aimed to characterise the habitat potential for benthic megafauna provided by two structures associated with the connection of the Floatgen floating wind turbine installed on the SEM-REV test site. These structures were the connection hub (Fig. 31) and the section of the umbilical laid on the seabed and held in place with attachment brackets. The ecological context of this site is very different from that of the Paimpol-Bréhat site due to the type of seabed, the depth, the oceanographic conditions, and the proximity of the Loire estuary. It was therefore interesting to describe the community of species of the mobile megafauna in this environment.

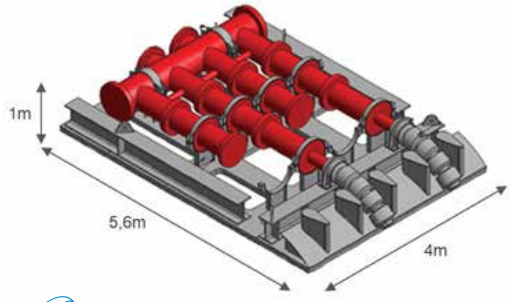

Fig. 31: 3D view of the connection hub installed at the SEM-REV test site.

© SEM-REV test site, Centrale Nantes-CNRS

Method:

This monitoring of the megafauna on the hub and umbilical of the Floatgen floating wind turbine was performed by divers. This operation required almost ideal sea conditions with no swell for launching and good visibility to be able to work at a depth of 40 metres. On two occasions, the water visibility was very low and did not allow the monitoring work to be carried out. During these dives, the two divers were equipped with cameras to film the entire area monitored. In the same way as for the Paimpol-Bréhat site, the counting of megafauna individuals was based on both *in situ* counts and the analysis of the videos taken by the divers.

Species observed	Connection hub	Floatgen umbilical	
		(Dive 1, 10 minutes, 165 m)	(Dive 2, 14 minutes, 230 m)
Conger eel *(Conger conger)*	10	0	0
Lobster *(Homarus gammarus)*	3	1[a]	1[b]
Edible crab *(Cancer pagurus)*	6	5	16
Velvet crab *(Necora puber)*	4	1	1
Pollock *(Pollachius* sp.*)*	1	0	0
European spider crab *(Maja brachydactyla)*	0	0	1
Pouting *(Trisopterus* spp.*)*	Several dozen	Few	Several dozen[c]
Tub gurnard *(Chelidonichthys lucerna)*	0	1	2
Common sole *(Solea solea)*	0	0	2
Common dragonet *(Callionymus lyra)*	0	0	2

(a) at the umbilical, approximately 20 m from the hub; (b) at a stabilisation bracket; (c) concentrated mainly at the stabilisation brackets.

Tab. 1: Abundance of the different species of megafauna recorded around the connection hub at the SEM-REV test site and on two transects along the Floatgen umbilical.

A complete survey of the hub and part of the umbilical was performed during three dives on 24 May 2018. The first dive allowed for surveying the entire structure of the connection hub, which meant that the count was exhaustive. As for the Floatgen umbilical, the length monitored depended on the dive time, which was limited by the great depth. Thus, in order to characterise the two transects on the umbilical, the effective time of monitoring was specified and the distance travelled was estimated thanks to the precise localisation of the site's infrastructures.

The majority of the megafauna taxa were identified at the specific level and counted during the dive (Tab. 1).

Results:

The monitoring of the two connection structures made it possible to identify the species that were mainly present in a preliminary and exploratory manner (Tab. 1). Crustaceans were found in common, although lobsters and velvet crabs were present in greater numbers at the hub. Regarding edible crab, it would seem that both habitats were suitable for this species. The conger eel, on the other hand, was only found on the hub. While the hub was barely covered by sediment, several sections of the umbilical were no longer visible and therefore offered no potential habitat. The presence of pouting on this cable was concentrated near the stabilisation brackets (Fig. 32).

The regulatory impact study carried out for the location of the SEM-REV test site indicated that pouting, tub gurnard, common dragonet and sole were present in the nearby sandy bottom habitats (fine sand). We can therefore assert that they were not influenced by the habitat formed by the hub and umbilical. The same is probably true for edible crab, European spider crab and velvet crab, which are classified as having no affinity for a particular substrate. In contrast, the conger eel, lobster and pollock were never mentioned in this impact study, which is logically due to their affinity for rocky substrates. These species were therefore certainly attracted to the artificial structures studied.

Fig. 32: ROV image of an attachment bracket used for the laid section of the Floatgen umbilical, around which a school of pouting is concentrated.

Conclusion:

The two connection structures – the hub and the umbilical – represent two different artificial habitats giving rise to the presence of distinct groups of species. Thus, the holes and cavities offered by the hub were largely colonised by conger eels and lobsters, in a similar way to what was observed under the concrete mattresses at the Paimpol-Bréhat tidal energy test site. On the umbilical, the only notable artificial habitat was provided by the stabilising brackets. The movements of sand generated around the cable by the swell and the current lead to very variable levels of burying and sometimes to depressions. These represent potential habitats for edible crabs, which can bury themselves there.

The simplicity of the umbilical structure and the limited size of the hub allowed for quality monitoring by divers. However, intervention difficulties remained due to the distance from the coast and the sometimes very poor visibility. For the umbilical, an alternative to diving would be to deploy a ROV to acquire good quality data over a short period of time. The complex three-dimensional structure of the hub would make monitoring by a ROV and the obtaining of reliable quantitative data more difficult, but it would provide a good idea of the species present.

This monitoring work carried out before the passage of electric current through the umbilical provided preliminary data on the level of colonisation of these structures. While this research lacks replication over time, it could nonetheless serve as a reference for subsequent monitoring that will be carried out during the periods of operation of the floating wind turbine.

Assessment of the reserve effect associated with the presence of a protection corridor

Objective: **To assess the potential reserve effect on benthic communities associated with fishing restrictions along the corridor formed by the subsea power cables between the island of Jersey and the Cotentin Peninsula in France.**

Context:

In most cases, the corridors formed by subsea power cables are excluded from certain anthropogenic activities, such as fishing with towed gear, in order to avoid damage. Areas where trawling, dredging and mooring are prohibited can thus become "reserves" for benthic communities, which are protected in these areas against modification of the sedimentary bed and against abrasion. This is an indirect impact of the presence of subsea cables, and is sometimes considered as a "positive" impact. Yet, this potential reserve effect associated with the presence of power cables has been the focus of very few studies, and mainly in relation to areas where the cables are not buried. Between the island of Jersey and the Cotentin Peninsula, two power cables laid on the seabed run along the same corridor, with fishing with towed gear being prohibited here since the 1980s. This corridor represents an area of 60 km² where benthic communities can potentially benefit from the reserve effect.

Methods:

Here, the study specifically targeted the endofauna in the samples taken (Fig. 33):

- on the French side, in October 2017 using a Van Veen grab (0.1 m²) at 12 sites in a sandy-muddy habitat (four within the cable protection zone and eight outside of it);
- on the English side, in March 2018 using a Hamon grab (0.1 m²) at nine sites in a gravelly habitat (three within the cable protection zone and six outside of it).

The samples were sieved on board using a mesh of 2 mm. The organisms were then sorted, determined and counted in the laboratory. The strategy adopted consisted in comparing the benthic biodiversity analysed at taxonomic and functional levels, both inside and outside the corridor. To this end, a statistical study was carried out on the relationship between community diversity, position with respect to the exclusion area, and the fishing effort estimated from VMS data obtained for the years 2014 to 2016 (Fig. 33).

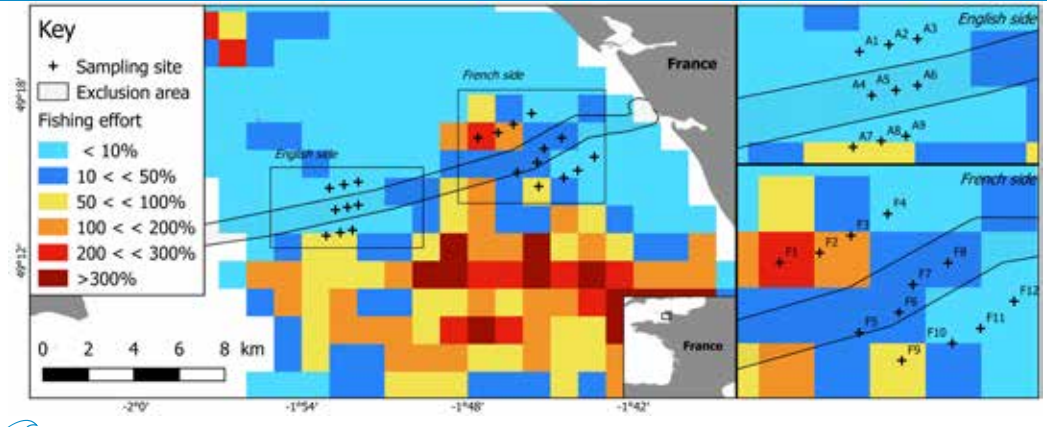

Fig. 33: Map of the study area between the island of Jersey and France showing the location of the 21 study sites on both the French and English sides. Fishing pressure is represented on a grid as a percentage of the area modified per year (a value greater than 100% for a cell indicates that its entire area was modified more than once during the year).

Results:

On the English side, no difference between the communities inside and outside the exclusion area was observed, whatever the functional and taxonomic diversity indices tested (Fig. 34 and 35). In contrast, on the French side, the communities within the exclusion area were slightly more diverse from a taxonomic perspective than those of the sites located outside of the area (significant difference for species diversity and Shannon index) and to a lesser extent from a functional perspective (significant difference for functional diversity) (Figs. 34 and 35).

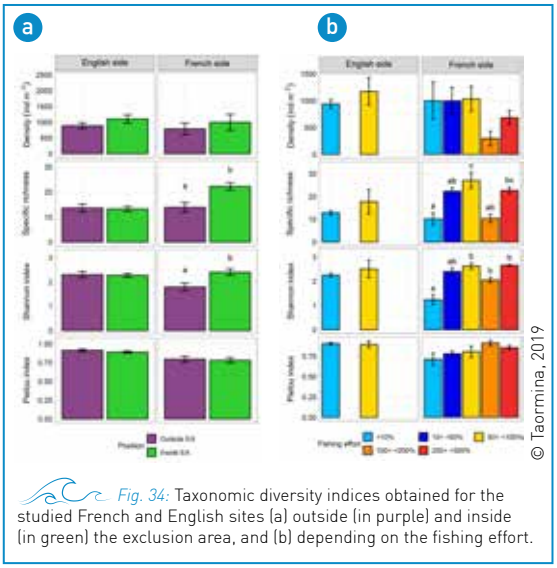

Fig. 34: Taxonomic diversity indices obtained for the studied French and English sites (a) outside (in purple) and inside (in green) the exclusion area, and (b) depending on the fishing effort.

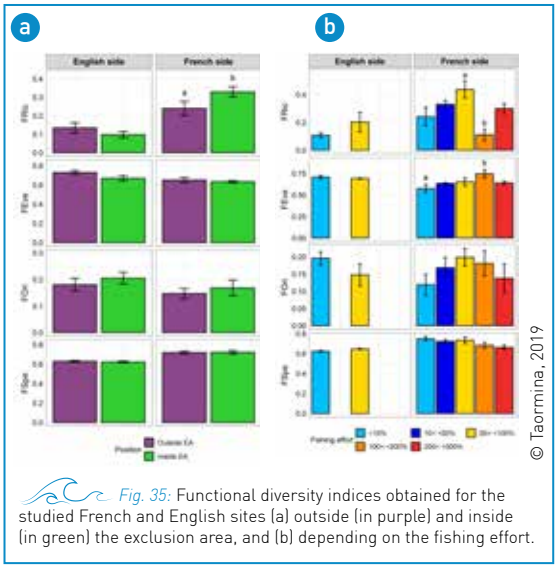

Fig. 35: Functional diversity indices obtained for the studied French and English sites (a) outside (in purple) and inside (in green) the exclusion area, and (b) depending on the fishing effort.

Conclusion:

On the French side, the differences highlighted suggest a slight but nevertheless real reserve effect, with more diverse communities inside the exclusion area.

On the English side, the lack of difference noted can be explained by low fishing pressure, even outside the exclusion area.

LEARN MORE

Taormina B (2019) **Potential impacts of submarine power cables from marine renewable energy projects on benthic communities.** *Doctoral thesis: University of Western Brittany. 274 p.*

Limitations:

Pressure from fishing with towed gear is generally low in the study area compared with elsewhere in the Normand-Breton Gulf. The spatial distribution of this fishing pressure seems to be heterogeneous in the vicinity of the exclusion area. Consequently, it was difficult to apply a sampling protocol that included a clear gradient of fishing pressure from the centre of the exclusion area to the outer areas, and thus to relate the differences in diversity to fishing pressure.

The results concern only the endofauna fraction of the target benthic communities. Studies have shown, however, that epifauna, which include larger and often more fragile species, are generally more sensitive to pressure from fishing with towed gear than endofauna. However, epifauna are not very present in the study area due to strong tidal currents and sediment movements. This explains why epifauna were not investigated as part of this study.

Assessment of the impact of power cables on adjacent benthic communities

Objective: **To study the potential impact of the subsea electric power cable of a tidal turbine on the biocenoses of sub-tidal rocky seabeds.**

Context:

The aim of this study was to better characterise the potential impacts of the presence of a cable on the associated benthic communities, within the framework of an extremely limited number of existing *in situ* studies. Bedrock communities were thus studied in the vicinity of a cable and in a control area to assess the influence of the energised cable on their composition.

Method:

The study was carried out along the export cable of the Fromveur tidal energy test site, located off the south coast of the island of Ushant. The area of bedrock studied here is crossed by the cable at a depth of 13 m. In accordance with the national WFD protocol (Derrien-Courtel, 2008; Derrien-Courtel *et al.*, 2013; Le Gal and Derrien-Courtel, 2015), a complete inventory (fauna, flora and shrub layer) of 20 non-destructive quadrats of 0.25 m² was taken *in situ* by divers during each measurement campaign. Of these 20 quadrats, 10 were positioned in immediate proximity to the cable (cable area), and another 10 at a distance of five metres from the cable (control area) (Fig. 36). Within each quadrat, each species was counted: as a number of individuals (or colonies), as percentage cover (non-individualisable encrusting fauna), or as percentage cover class (for encrusting algae only). Two measurement campaigns were conducted, the first in July 2018 and the second in June 2019. The cable was energised continuously between mid-October and the end of December 2018, and then discontinuously until April 2019.

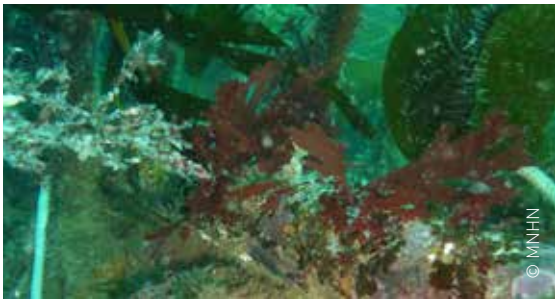

Fig. 36: Photograph of the monitored power cable (foreground) in a kelp forest. The quadrat used to monitor the epibenthic communities is visible in the bottom left corner.

Results:

Shrub layer

In both the control and cable areas, the shrub layer was found to be dominated by the kelp *Laminaria hyperborea*. After statistical analysis of the data acquired, no significant difference between the two measurement campaigns was noted, either in the total density of the shrub layer or in the densities of the species making up this layer.

Sub-stratum

At the sub-stratum level, 39 and 49 taxa were inventoried in the control area and 45 and 49 taxa in the cable area in 2018 and 2019 respectively. Within the control area, several taxa showed significant variations in abundance between 2018 and 2019 (Fig. 37). These differences were most certainly related to the natural variation over time of these communities. For the cable zone, there was a significant decrease in the numbers of the annelid *Spirobranchus* spp. (the most abundant species in 2018 and no longer observed in 2019) and of encrusting brown algae.

In parallel, the density of the rhodophycea *Polysiphonia stricta* increased significantly between the two sampling years. With regard to the comparison between the control area and the cable area in 2019, statistical tests showed a significant difference for 12 of the taxa. Of these, three were significantly more abundant in the cable area: the rhodophyceae *Callophyllis laciniata, Kallymenia reniformis* and *Polysiphonia stricta*. While the latter was not observed in 2018, the other two were already more abundant in this area. The species that were the most abundant in the control area were the phaeophyceae *Dictyota dichotoma* and *Dictyopteris polypodioides*, the rhodophytae *Symphyocladia parasitica* and *Phyllophora crispa*, the echinoderm *Marthasterias glacialis*, the cnidarian *Corynactis viridis*, the annelid *Sabella discifera*, the ascidian *Polyclinum aurantium*, and the bryozoan *Crisia aculeata*.

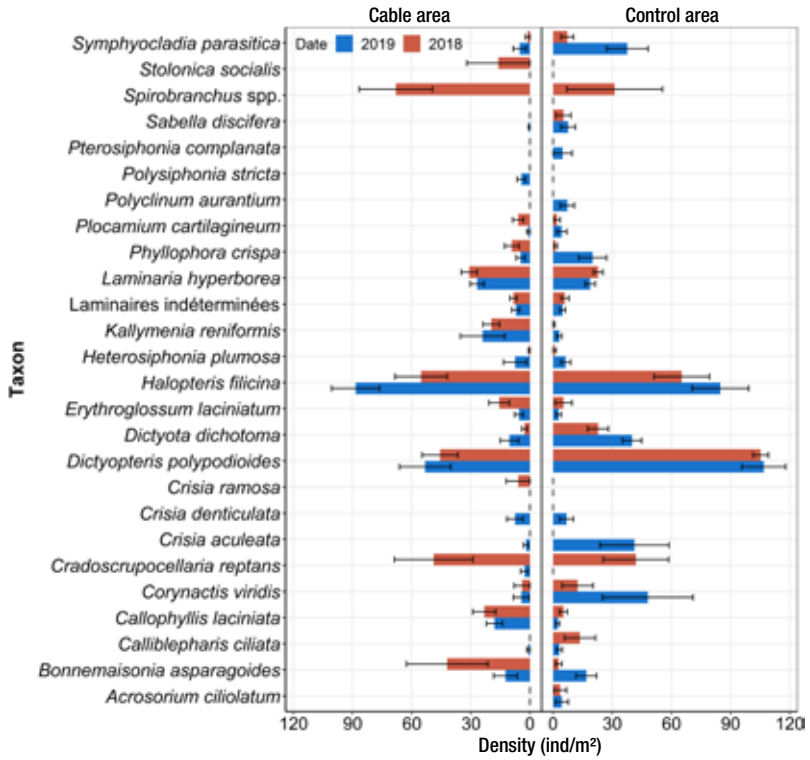

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Fig. 37: Densities of the different taxa recorded in the control density and cable areas during the 2018 and 2019 measurement campaigns (with an average density > 2 individuals/m² for at least one of the campaigns).

Conclusion:

This study revealed significant differences in the numbers of certain species (12) in the communities of attached organisms (flora and fauna) in the control area compared to the cable area, based on Welch's *t*-tests for comparing the mean per mutation (n=100) calculated for each taxon. The greater abundance of certain species in the control area can most likely be explained by the less uneven topography, which allows slight deposits of sediment, thus favouring the development of certain species such as the phaeophyceae *Dictyopteris polypodioides* and *Dictyota dichotoma*, the annelid *Sabella discifera*, and the ascidian *Polyclinum aurantium*. It is therefore difficult to link this difference to the presence of the cable. The changes to the kelp biocenosis caused by the laying of the cable took place in several stages. Initially, the laid cable created a new substrate that was progressively colonised by pioneer species, such as encrusting brown algae and *Spirobranchus* spp. The disappearance of *Spirobranchus* spp. after the cable was in service was probably the result of the natural ecological succession of colonisation of a new substrate rather than due to the effect of the electromagnetic field.

Limitations:

The initial aim of this study was to observe the effect on benthic colonisation of the passage of current through the cable and therefore the generation of electromagnetic fields. Due to technical problems, the tidal turbine only operated for a short time between 2018 and 2019, which therefore limits the scope of the results obtained in view of the initial objectives.

Methods for the experimental study of the responses of benthic organisms to artificial magnetic fields

Objective: To develop laboratory tools and protocols adapted to the analysis of the response of model benthic organisms to artificial magnetic fields.

Context:

The *in situ* study of the response of benthic organisms to the emission of magnetic fields generated by power cables offers the advantage of analysing a realistic ecological context. This is often complicated by the logistics of conducting the study on site as well as the multitude of uncontrolled factors that can potentially influence the response of these organisms. Laboratory approaches are highly complementary to *in situ* approaches as they allow only the factor under study to be varied while controlling the other factors. Nevertheless, the organisms studied are not in a very realistic context. The experimental approaches adopted in this study consisted in creating magnetic fields of selected strengths in the laboratory and then studying the behavioural or physiological response of model species when exposed to these fields.

General description:

Helmholtz coils were designed and manufactured for the project in order to create experimental areas where the desired magnetic field was relatively uniform, i.e., as constant as possible in strength. The device consisted of two coils of the same dimensions positioned in two parallel planes, one opposite the other, at a controlled distance. Injecting electric current into these coils allowed for creating a uniform magnetic field at the centre of the device. The power supply could be **direct** or **alternating current** to simulate the magnetic fields produced by different types of subsea power cables. By changing the intensity of the electric current injected into the coils, it was possible to adjust the strength of the magnetic field produced to create values close to those found in the vicinity of subsea power cables. Within the framework of the study, two different "Helmholtz coil" devices were used: one for juvenile European lobsters and one for great scallops.

Device for studying juvenile European lobsters

The first device was used to study the response of juvenile European lobsters (see Fact Sheet 12). It consisted of two Helmholtz coils with 600 m of cable (cross-section of 2.5 mm² with copper conductor). The coils were wound around two 1.5 m square wooden frames (representing 100 cable windings) positioned vertically 1 m apart (Fig. 38). To create a constant magnetic field, the two coils were connected to a laboratory DC power supply (BK Precision BK-1745A model). To create an alternating magnetic field, the power supply was provided by a single-phase autotransformer (RS CMV 15E-1 model).

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Fig. 38: Helmholtz coils used for the experiments on juvenile European lobsters.

Device for studying great scallops

The second device was used to study the response of great scallops (see Fact Sheet 13). It consisted of two coils with 1,200 m of cable (cross-section of 2.5 mm² with copper conductor). The coils were wound around two 1.5 m square PVC frames (representing 200 cable windings) positioned 1 m apart (Fig. 39a). This configuration created the magnetic field that can be expected within one metre of a subsea power cable, and which was homogeneous in the experimental area. Developed by TBM Environnement and MAPPEM Geophysics, this mobile system is designed for regular use and various experimental requirements (homogeneous fields, barrier effects, DC/AC currents, etc.). In addition, all of the electrical parameters (voltage, turning on/off, coil temperature) were controlled, recorded and programmed using specially designed software developed by MAPPEM Geophysics.

Fig. 39a: Helmholtz coils used for the experiments on great scallops.

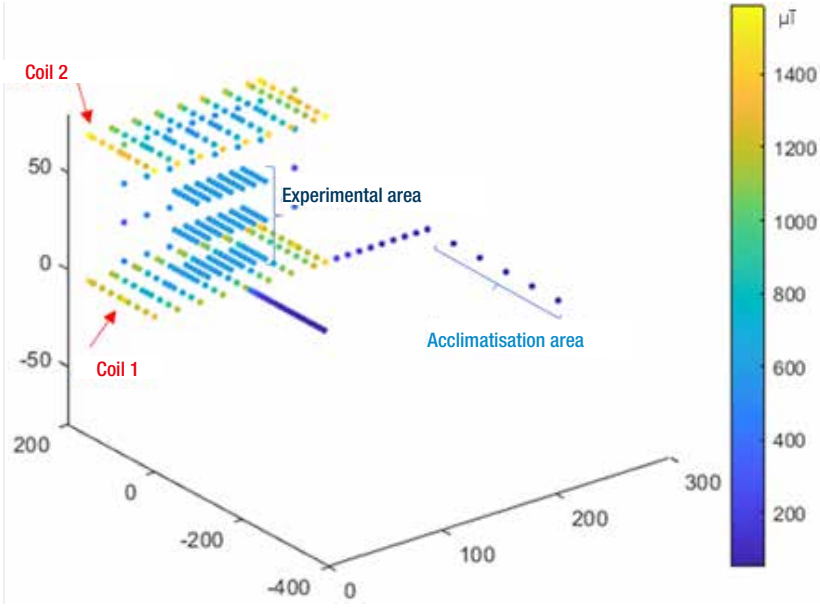


Fig. 39b: Mapping of the 600 µT magnetic field produced in the experimental area.

Study of the impact of artificial magnetic fields on European lobsters

Objective: **To experimentally study the impacts of artificial magnetic fields on the behaviour of juvenile European lobsters.**

Context:

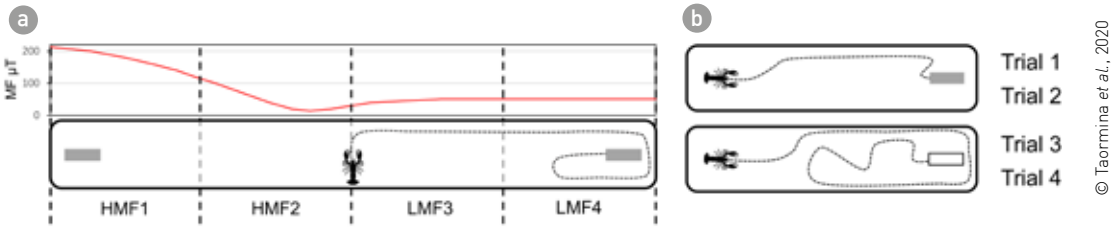
The European lobster *(Homarus gammarus)* is an emblematic species of great commercial importance found in French coastal waters. It is regularly observed in various artificial reefs, including installations associated with offshore renewable energy projects. This colonisation can lead to the lobsters being exposed over long periods of time to the magnetic fields emitted by subsea power cables. It is therefore necessary, through controlled laboratory studies, to determine what the potential impact of artificial magnetic fields produced by DC cables (static magnetic field) or AC cables (time-varying magnetic field) may be on species that are known or suspected to be sensitive to these fields. Furthermore, most of the work to date focuses on the adult phase of biomodels, whereas the early stages of development of organisms are critical for maintaining populations. The study therefore focused on the behaviour of juvenile European lobsters.

General protocol:

Two different tests were developed to analyse the potential influence of an artificial magnetic field on the behaviour of juvenile lobsters (Fig. 40):

- a shelter choice test to demonstrate the phenomena of attraction, repulsion or indifference to two types of artificial magnetic fields;
- a test of their exploration behaviour and ability to find a shelter after a week's exposure to artificial magnetic fields.

The artificial magnetic fields, both DC and AC, were generated in the laboratory using Helmholtz coils. This device is described in detail in Fact Sheet 11.



a **Repulsion/attraction tests:**
Use of a corridor (125 x 14 x 7 cm) comprising a shelter at each end. Four different zones were identified according to the magnetic field strengths: high magnetic fields (HMF) 1 and 2 and low magnetic fields (LMF) 3 and 4. The gradient of the magnetic fields produced by the AC and DC tests is shown above.

b **Post-exposure test:**
Use of a corridor (66 x 14 x 7 cm) comprising a shelter positioned at one end. Four consecutive trials were carried out: the first two with a grey shelter and the last two with a white shelter.

Fig. 40: Experimental set-up used to study the juvenile lobsters.

Repulsion/attraction tests:

Method

The test to investigate the attraction or repulsion potential of the artificial magnetic fields consisted in releasing a lobster into the centre of a corridor (125 x 14 x 7 cm) comprising a semi-cylindrical shelter at each end. The experiment included three different conditions:

- The corridor was subjected to a zone of **static** artificial **magnetic field** gradient (created using direct current), meaning that one side of the corridor was subjected to an artificial magnetic field of up to 200 µT, while the other side was in the ambient natural magnetic field (test with 31 lobsters).
- The corridor was subjected to a similar gradient zone, but the artificial **magnetic field** was **time-varying** because it was created using alternating current (test with 30 lobsters).
- The corridor was not subjected to any artificial magnetic field, only to the ambient natural terrestrial magnetic field. This represented the **control condition** (test with 31 lobsters).

The behaviour of each lobster was monitored by video recording in order to avoid any disturbance caused by the presence of the investigator. Subsequent analysis of the videos made it possible to determine the trajectory of each lobster, and in particular its average speed, the total distance travelled, and the percentage of time spent in the different zones of the corridor.

Results

The percentage of time spent in each zone of the corridor was essentially the same, regardless of the test condition. No significant difference was noted between the three test conditions in the exploratory behaviour of the lobsters, including their average speed and the distance travelled in each zone of the corridor (Fig. 41).

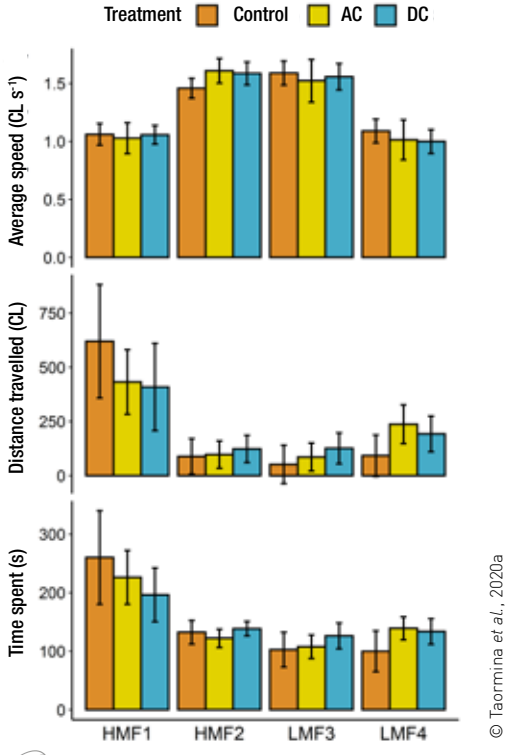


Fig. 41: Average speed (top), distance travelled (centre), and time spent (bottom) by the juvenile lobsters in the four zones of the corridor (HMF 1 and 2 and LMF 3 and 4) depending on the test condition applied (control condition in orange, time-varying magnetic field in green, static magnetic field in blue). CL: Carapace length of lobster.

Exposure test:

Method

In order to study the exploratory behaviour of lobsters and their ability to find a shelter after exposure to an artificial magnetic field, 111 juvenile lobsters were exposed to three different conditions over the course of one week:

- Exposure to a **static** artificial **magnetic field** of 225 µT (test with 35 lobsters).
- Exposure to a **time-varying** artificial **magnetic field** of 225 µT (test with 38 lobsters).
- Exposure to the ambient natural magnetic field, representing the **control** condition (test with 38 lobsters).

Following this exposure period, the ability to find a shelter was assessed as follows: the lobster was released at the end of a corridor (66 x 14 cm) that comprised a shelter at the opposite end. Each lobster was subjected to four consecutive trials. These four trials were similar except for the colour of the shelter used: grey half-cylinders for the first two trials and white half-cylinders for the last two. The behaviour of the lobsters was monitored by video recording. Based on analysis of the videos, it was possible to determine the time it took each lobster to enter the shelter, the total distance travelled, and the average speed of its movements.

Results

No mortality was observed during the week of exposure in any of the test conditions. The exploratory behaviour was similar for all three conditions. Indeed, no significant differences were noted in the time taken to find the shelters, the average speed of movement, or the distance travelled. However, the lobsters took longer on average to find the white shelters than the grey shelters (Fig. 42). As the edges of the corridor were white, this result is not surprising as the white shelters were less visible to the lobsters and therefore more difficult to find.

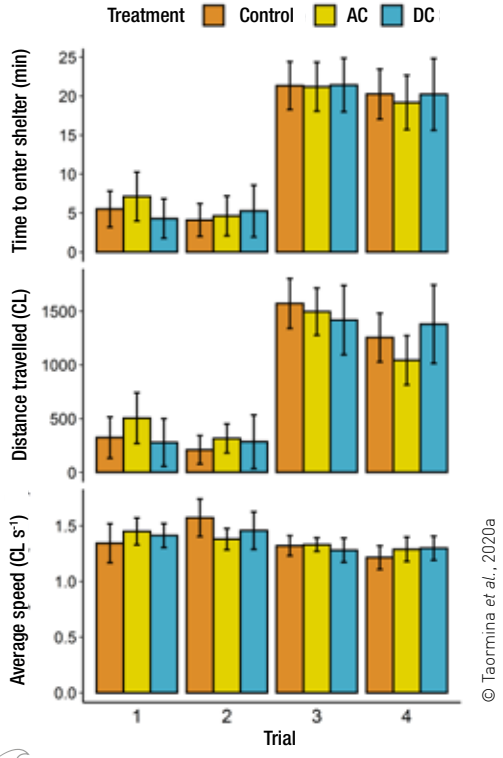


Fig. 42: Time to find shelter (top), distance travelled (centre), and average speed (bottom) of the juvenile lobsters for the four consecutive trials (grey shelters: 1 and 2; white shelters: 3 and 4), depending on the test condition applied (control condition in orange, time-varying magnetic field in green, static magnetic field in blue). CL: Carapace length of lobster.

Conclusion:

This study demonstrated that artificial magnetic fields, whether static or time-varying, did not impact the behaviour of juvenile European lobsters in the laboratory at the strengths tested (around 200 µT). The ability of the lobsters to find shelter after a one-week exposure period remained unchanged, and no phenomenon of attraction or repulsion to the artificial magnetic fields was observed.

Limitations:

- It cannot be excluded that higher magnetic field strengths could have an impact on the lobsters. By replicating this experiment using different strengths above 200 µT, it could be possible to identify threshold values beyond which a change in behaviour would be detected.
- Individuals of this species at different life stages (eggs, larvae, adults) could respond differently to this type of disturbance, as was recently shown for the spiny lobster (Ernst and Lohmann, 2018).
- To date, the ability of the European lobster to sense the Earth's natural magnetic field has not been demonstrated and no specific receptor has been identified. Basic anatomical and physiological studies, such as those carried out by Boles and Lohmann in 2003 on the Caribbean spiny lobster (*Panulirus argus*), would provide a better understanding of the risk of impact of magnetic fields on lobsters.

LEARN MORE

Taormina B., Di Poi C., Agnalt A.-L., Carlier A., Desroy N., Escobar-Lux R. H., D'eu J.-F., Freytet F., Durif C. M. F. (2020a) **Impact of magnetic fields generated by AC/DC submarine power cables on the behavior of juvenile European lobster *(Homarus gammarus)*** *Aquatic Toxicology, Vol. 220, 105401* https://doi.org/10.1016/j.aquatox.2019.105401

Study of the impact of artificial magnetic fields on great scallops

Objective: **To experimentally study the impacts of artificial magnetic fields on the behaviour of adult great scallops.**

Context:

The great scallop (*Pecten maximus*) is a species of great commercial importance. According to the CNPMEM (French National Committee for Maritime Fisheries and Marine Aquaculture), great scallop fishing involves some 600 boats and 2,400 fishermen in France. Its distribution area, which covers the Atlantic coast and the Channel (with major concentrations in the Baie de Saint-Brieuc and the Baie de Seine), will be affected by the installation of the future wind farms and their numerous interconnection cables. Great scallops may therefore find themselves in the vicinity of and exposed to sources of artificial magnetic fields over a long period of time. Basic knowledge of magneto-sensitivity in molluscs is very limited and few studies have assessed the impact of artificial magnetic fields on this group. Experiments in a controlled environment were necessary to define how these organisms perceived variations in magnetic fields and whether these variations induced stress. This impact was assessed in a controlled environment by measuring and interpreting the behaviour of great scallops exposed to artificial electromagnetic fields.

Method:

Origin of the great scallops

The great scallops were all caught by diving at Roscanvel, in the roadstead of Brest, and acclimatised in aquariums for one month prior to the experiments. At the end of this period, many great scallops were buried in the sediment, a sign of good acclimatisation to the experimental conditions.

Monitoring of their behaviour

Thirty great scallops were each fitted with an accelerometer attached with Velcro to their shells to track their movements at a frequency of 25 Hz (Fig. 43). The accelerometer data were extracted and processed according to the protocol detailed by Coquereau *et al.* in 2016. The behaviour was described according to four parameters: the number of movements made, the duration of valve closure (in s), the acceleration in valve closure (in g), and the amplitude of valve closure (in °).

Fig. 43: Accelerometers attached to the great scallops.

Generation of the magnetic fields

Artificial magnetic fields, both DC and AC, were generated in the laboratory using Helmholtz coils, as per the device described in detail in Fact Sheet 11. Two magnetic field strengths were selected: 80 µT and 600 µT. Mapping of the field between the coils was carried out for each test condition, as well as in the acclimatisation aquariums and towards the coil control station, to verify that both zones remained at terrestrial magnetic field values.

Tests

The great scallops were divided into three groups and monitored over a period of three weeks (schedules in Table 2). Control periods preceded and followed the magnetic field exposure phases for all of the groups. In the behavioural study, each great scallop acted as its own control. Thus, the response of each individual corresponded to any deviation from the observations made during the previous control period at the same times.

For Group 1 and Group 2, each day of exposure consisted of an impulse sequence between 10 a.m. and 10:30 a.m. comprising five exposure periods of one minute each separated by five-minute rest periods, followed by an intermittent sequence between 11 a.m. and 4 p.m. comprising three exposure periods of one hour each separated by one-hour rest periods. Throughout the monitoring, the great scallops were fed daily at 3 p.m. with a T-iso microalgal culture. During the last exposure, the great scallops were also fed to assess the effects of the magnetic field on food intake. The rest periods between each exposure were monitored and marked with the letter "R" in order to assess a recovery time or long-term effect.

For Group 3, the great scallops were exposed each day for two hours before being placed individually in the presence of a spiny starfish, *Marthasterias glacialis* (Fig. 44). One third of the great scallops in this group came from Group 1, one third from Group 2, and one third comprised treatment-naive individuals.

The differences between the test conditions were analysed by comparison of means using the ANOVA method.

		Group 1	Group 2	Group 3
Placed in tank		18 April	3 May	17 May
Control 1		21 - 23 April	3 - 5 May	17 - 19 May
1st exposure	Level	80 µT DC	600 µT DC	600 µT DC
	Date	24, 25, 26 April	6, 7, 8 May	20, 21, 22 May
Control 2		27 - 28 April	9 - 12 May	23 - 26 May
2nd exposure	Level	600 µT DC	80 µT DC	600 µT AC
	Date	29, 30 April and 1 May	13, 14, 15 May	27, 28, 29 May
Control 3		2 - 3 May	16 - 17 May	30 May - 2 June
Removed from tank		3 May	17 May	3 June
Objective		Monitoring of behaviour	Monitoring of behaviour	Behaviour + response to predator

Tab. 2. Experimental protocol for the three groups of great scallops.

Fig. 44: Example of the response of a great scallop to the approach of a predator, the spiny starfish *Marthasterias glacialis*.

Results:

Impact on the activity of the great scallops

The number of movements per hour was quite high during the first control phase and decreased immediately upon exposure to a magnetic field, whether at 80 µT or at 600 µT. This decrease in activity was primarily measured during the day, but not at night. It was also reversible as it could increase again at the end of the monitoring period.

For Group 1, the first control period showed significantly different activity from the second control period and the exposure period at 600 µT (Fig. 45, top).

For Group 2, three distinct phases appeared: a first phase corresponding to the first control period where the activity was high and significantly different from all the other periods; a second phase consisting of exposure to 600 µT and the second control period with average activity; and finally, a third phase with exposure to 80 µT and the control period at the end of the experiment with low activity, significantly different from the other two periods (Fig. 45, bottom). This decrease in activity was mainly found during the periods when the great scallops were exposed to an electromagnetic field, whether pulsed or intermittent (Fig. 46).

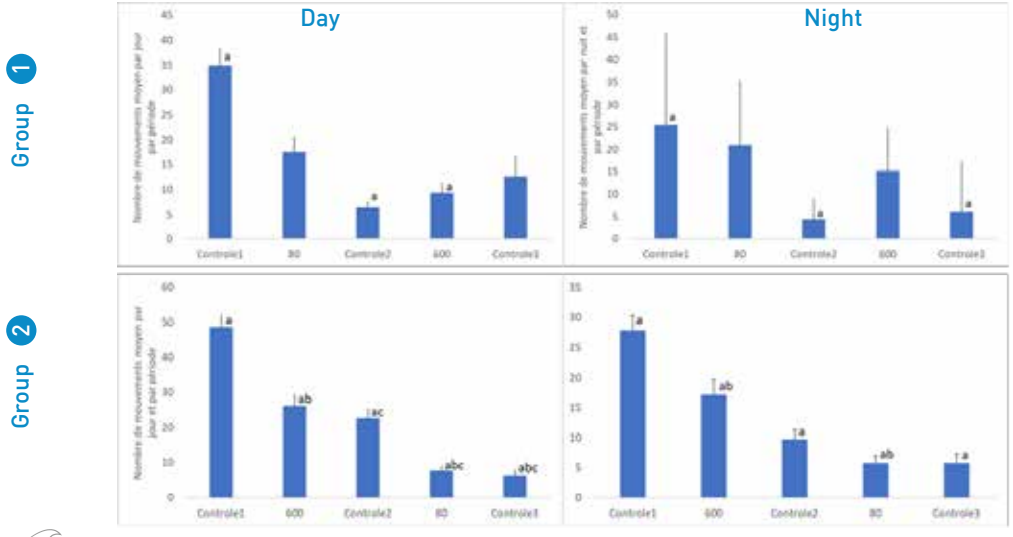


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Fig. 45: Average number of movements made during the day and at night by the great scallops in Group 1 and Group 2 for each monitoring period. Different letters indicate significantly different periods.

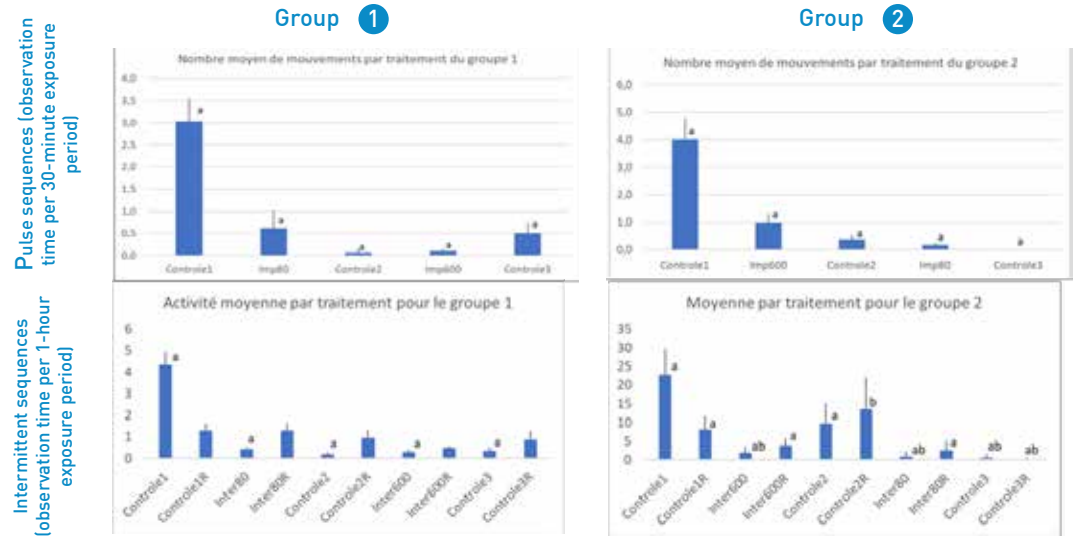

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Fig. 46: Average number of movements made by Group 1 and Group 2 in the presence of impulse sequences and intermittent sequences for each test condition. The letters indicate significantly different test conditions.
The periods marked "R" correspond to rest periods following the exposure periods.

Impact on the response of great scallops to a predator

Regardless of the test condition applied or the group to which the individual great scallops had initially belonged, no difference was noted in the acceleration, duration or amplitude of the movements of the Group 3 great scallops in response to the approach of a starfish (two-factor ANOVA, $P > 0.05$). Only the number of movements showed significant changes: on the one hand between the control group and the 600 µT AC test condition (two-factor ANOVA, $P = 0.006$), and on the other hand between the treatment-naive great scallops (never previously handled) and the Group 2 great scallops (having just undergone three weeks of experimentation) (two-factor ANOVA, $P = 0.045$) (Fig. 47). However, the properties of the movements performed (acceleration of the first valve closure, average acceleration and amplitude of the movements) did not differ between the test conditions ($P < 0.05$).

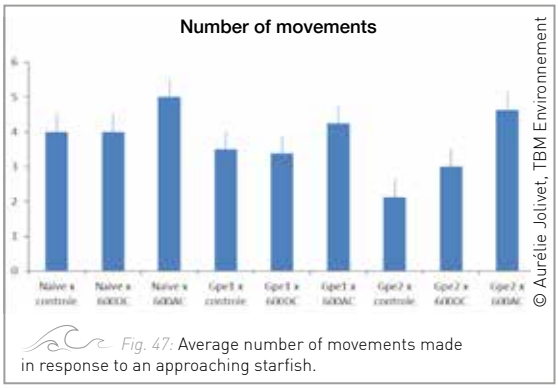

Fig. 47: Average number of movements made in response to an approaching starfish.

Conclusion:

Two types of experiments were carried out. For the first two groups, short exposure times of one minute (pulsed) or one hour (intermittent) were applied several times a day at two different values: 80 µT and 600 µT. From the second day of exposure, a very clear decrease in activity was observed, whatever the value of the field applied (80 µT or 600 µT). This minimum activity then continued throughout the experiment. Night-time activity was less affected. Activity during the exposure periods could be reactivated when food was distributed. Great scallops are not very mobile and are not likely to encounter strong changes in the surrounding magnetic field. Moreover, magnetoreception has not been demonstrated in scallops in general. It would seem, rather, that they use variations in light for their orientation. Great scallops have an extensive and complex visual system composed of two retinas (distal and proximal), each containing a different structural type of photoreceptor with a different physiological response. To date, the mechanisms involved in magneto-sensitivity are not clearly defined and two main hypotheses are discussed. One of these hypotheses attributes a dual function to the photoreceptors of the visual system, which possibly also act as magnetoreceptors (Lohmann and Ernst, 2014).

Limitations:

The results obtained must be interpreted with caution as they may stem from interactions between the exposure to artificial magnetic fields and the experimental conditions, which may have had an effect on the activity of the great scallops. Despite the precautions taken during these experiments (isolation of the experimental area, acclimatisation for one month in aquariums), one group showed that the responses can be influenced by both the conditions in their previous groups and the duration of the experiments. Observations in the natural environment would therefore be necessary to validate or invalidate the hypothesis of a perception of magnetic fields by great scallops and to evaluate the potential impact on the activity of this species.

4 - Project feedback

4.1 Constraints related to industrial schedules

Several *in situ* measurement campaigns designed to determine the impact of the operation of subsea power cables were initially planned, with the ambition of employing a Before-After-Control-Impact (BACI) approach at the Ushant and Paimpol-Bréhat tidal test sites. The objective was to describe possible changes in benthic communities in the assumed area of influence of the cables before and after their power connection. This included fauna located in the immediate vicinity or directly attached to the cables or associated artificial structures. Theoretically, this approach should have allowed for differentiating between the potential impacts generated by the passage of the electric current (electromagnetic field, heat) and those associated with the mere physical presence of the cable. However, setbacks in the schedule of the industrial groups planning to deploy tidal turbines at these two test sites prevented the connection of their electric power cable during the three years of the study and the implementation of monitoring using a BACI approach (see Fact Sheets 6 7 and 10).

At the Paimpol-Bréhat site, it was nevertheless demonstrated that the epibenthic communities associated with the artificial structures of the cable (see Fact Sheet 6) had not reached the climax from the point of view of their composition and were continuing their process of ecological succession six years after the cable was laid. This feedback is interesting, because if the test site's cable had been operational, it would have been impossible to dissociate changes in the community due to the natural phenomenon of ecological succession from those possibly due to the passage of electric current. This ecological restoration period for communities is in line with the ten-year period observed during major disturbances such as large-scale development projects. This result shows that it is very important for the community to be in a state of equilibrium in order to implement a BACI approach. To overcome this problem, the use of "control" cables without electric current could be considered. This approach was tested at the Ushant tidal site, where two 3 m sections of control cable were installed at two stations close to the tidal turbine power cable. This strategy had also been envisaged at the Paimpol-Bréhat site, with the installation of sections of control cable protected by cast iron shells on either side of the main cable. However, as the logistical challenge was much greater here than at the Ushant site, where the cable is unprotected, this protocol could not be implemented.

Fig. 48: Launching of the HydroQuest Ocean tidal turbine at the Paimpol-Bréhat site.

4.2 Regulatory standards

The regulations also impose certain methodological constraints. In accordance with French standard NF C18-510 of January 2012, which governs work carried out on subsea power cables, the installation of sensors or coupons for monitoring biofouling on cables is an activity that poses no risk to the cable, but that requires coming into contact with it without moving it (paragraph 9.7.2.3). This standard stipulates that such activities must be carried out under the supervision of a site manager holding B0 authorisation (non-electrical work in low-voltage installations) or H0 authorisation (non-electrical work in high-voltage installations), compatible with the conditions of the electrical environment. In addition, the standard specifies three safety levels for carrying out activities:

- priority must be given to the lockout of the cable;
- where lockout is not possible, the cable must be de-energised, or kept energised only as a last resort;
- in all cases, the general condition of the cable must be examined with a view to taking all appropriate additional precautionary measures.

It should be noted that the cleaning of a cable is excluded from this section and is dealt with in paragraph 9.7.2.4.4 of the standard.

First and foremost, it is necessary to have a site manager with H0 or B0 authorisation for accessing high-voltage areas. On the SEM-REV test site, for example, the personnel from Centrale Nantes have this authorisation in order to cover this type of intervention. The difficulty also lies in determining and justifying the necessary safety level depending on the work to be performed. For instance, during the diving operations to install and retrieve the temperature sensors on the SEM-REV site, a procedure to stop and de-energise the wind turbine and the electrical substation was implemented in order to de-energise the subsea cable as the divers were working in direct contact with it.

Fig. 49: Intervention at the SEM-REV test site.

4.3 Complex biological samples

ORE installation environments present certain specificities depending on the type of target energy. By definition, tidal sites are subject to intense tidal currents, and wind sites to strong and rather regular winds. The conditions in these environments make scientific intervention difficult. In the case of tidal sites, only slack tide periods during neap tides are conducive to conducting studies, which greatly limits the possibilities for *in situ* measurements. These are further limited by the more unpredictable weather conditions (mainly wind and waves), which can prevent any type of intervention and postpone the measurement campaign to the next neap tide. Throughout the study, numerous measurement campaigns were thus either cancelled at the last minute or only partially carried out (particularly at the Paimpol-Bréhat site). It should therefore be borne in mind that it is particularly difficult to obtain regular, multi-year data series on benthic biodiversity on ORE sites based solely on diving operations.

The effects generated by subsea power cables have the specificity of being extremely localised. These effects, such as habitat modification or emissions of heat and electromagnetic fields, only affect a few metres, or even a few tens of centimetres, on either side of the cables. Studying the response of benthic communities to these effects therefore constitutes a methodological challenge, as sampling must be accurate and precludes the use of commonly implemented blind sampling methods such as grab samplers or video systems deployed from the deck of a vessel. For such sampling, one of the only relevant solutions for obtaining images (see Fact Sheets 6 and 7), conducting inventories (see Fact Sheet 10), or taking *in situ* samples with handheld sample-taking apparatus, is scuba diving. However, this has certain limitations as

the working time and depth of intervention are generally limited. The use of rebreathers and professional divers capable of working at greater depths can extend the amount of time spent on the seabed, but this complicates the logistics and significantly increases the cost. These limitations are exacerbated when the objective is to study endogenous benthic communities, as in the case of buried power cables. For these communities, underwater imaging by divers, which has the advantage of being quick and simple to set up, cannot replace *in situ* sampling (Fig. 50). This sampling procedure, which can be performed using manual sample-taking apparatus, must comply with particularly complex protocols that are difficult to implement. Indeed, the number of replicates per station must be sufficiently high to attempt to measure an impact that is believed to be low. It should be noted that the use of remotely operated underwater vehicles such as ROVs can also be envisaged. However, this requires considerable nautical and economic resources to be implemented, particularly in areas with strong tidal currents.

Fig. 50: Diver taking macrophotography of an invertebrate attached to the Paimpol-Bréhat test site power cable.

During the study, the difficulties related to sampling the benthic communities mentioned above had a significant impact on the work planned for the SEM-REV test site. This site's power cable was selected in order to study the colonisation of the stabilising concrete mattresses by vagile benthic megafauna (see Fact Sheet 6) and the influence on the endogenous benthic communities of the cable being buried. These different scientific objectives nevertheless encountered numerous complications related to two main factors:

- Depth: the target sampling stations were located at depths that were too great (around 40 m) for safe diving operations over long periods of time;
- Turbidity: as this site is subject to turbid inflows from the Loire and Vilaine rivers, visibility, which is difficult to predict, can be almost zero. These conditions pose major problems for the safety of divers and make it very difficult, if not impossible, to locate the structures to be studied. Consequently, the use of underwater imaging tools was of limited interest. Thus, the study of the endofauna near the cable, initially planned to be carried out using handheld sample-taking apparatus, could not be conducted, despite numerous attempts with teams of experienced divers.

Notwithstanding all these specificities, certain optimised protocols were developed during the project to study the effects of subsea power cables. The feedback from the project thus makes it possible to propose a few methodological recommendations to overcome certain difficulties in the study of benthic communities potentially exposed to the influence of these cables. It would logically appear to be more reasonable to target shallow cable sections located in clear waters, which would enable the divers' working time to be increased and improve diver safety. Endofauna studies could focused on intertidal habitats where a buried or protected cable is located and that are accessible by foot, in order to avoid the need for divers, and to increase the number of possible working periods, and potentially the frequency of monitoring regardless of the weather conditions. However, this would require the power cables studied to be buried at shallow depths (< 2 m deep), which is now rarely the case in intertidal zones where the use of horizontal directional drilling is preferred.

Protocol for monitoring benthic megafauna on the concrete mattresses at the Paimpol-Bréhat test site.

The monitoring of the mattresses at the Paimpol-Bréhat tidal test site (see Fact Sheet 7) led to the development of a very precise operational monitoring protocol summarised below:

- The mattresses that could be monitored regularly were selected in advance according to their depth and the average spacing between two mattresses in order to optimise the time of each dive in terms of the number of mattresses monitored.
- Each mattress monitored was numbered to ensure accurate identification. The numbered plate was installed in the same place on each mattress during the first field operation (Fig. 51).
- As the position of the mattresses was very precise, the first mattress monitored was marked so that the divers could immediately find their bearings.
- During each mission, two teams of divers followed each other at each slack tide: the first team intervened about 45 minutes before the slack tide and the second team just after. This ensured that the work could be carried out in low current conditions. Each dive lasted between 35 and 45 minutes depending on the duration of decompression stops.
- In order to optimise the time spent working on the seabed, the first team used a diver's buoy to mark the last mattress inspected. This operation allowed the first team to return to the surface in complete safety while making their decompression stops, and the second team to immediately find their bearings and continue the work under optimal conditions.
- At the end of the operation, the divers set off a diver's buoy from the seabed and drifted upwards along it. As the current very often picked up at the end of the operation, this system allowed the ship to follow the divers' ascent in complete safety.

Fig. 51: Marking of the concrete mattresses inspected and the lobster shelters identified.

4.4 Choice of the best tool for measuring electromagnetic fields

Two different tools were used to measure the electromagnetic fields produced by the subsea cables: the STATEM and PASSEM systems (Tab. 3). The PASSEM system characterises electromagnetic fields over a large area in a few hours, but only at a given moment. In contrast, the STATEM device, a fixed system deployed on the seabed, measures variations in electromagnetic fields over several days or even weeks. However, like any autonomous sensor installed at sea, there is a risk that it could be lost or damaged, for example by trawling. In the case of ORE projects, as power generation varies over time (depending on tidal or wind conditions),

System	STATEM	PASSEM
Deployment	Stationary, installed by divers	Towed by a boat
Spatial extent of the measurement	Limited	Equal to that of the transect performed
Time extent of the measurement	Equal to that of deployment and autonomy	Limited

Tab. 3. Characteristics of the devices for measuring electromagnetic fields.

the use of the STATEM system makes it possible to measure the influence of these variations on the electromagnetic fields produced by the cables. It is thus possible to obtain average and maximum *in situ* values for these fields. This tool gives a more global view of the electromagnetic disturbances than the PASSEM system because the fields produced vary more over time than they do spatially.

Fig. 52: Photographs of the STATEM (left) and PASSEM (right) systems prior to deployment at sea.

4.5 Use of an approach combining *in situ* studies and laboratory experiments

The project aimed to combine ***in situ*** studies to investigate the potential impact of different power cables under natural conditions with **laboratory** experiments to determine the response of target organisms to the emission of electromagnetic fields. Each of the two approaches has its advantages and limitations. They can be very complementary in addressing the same issue when they are conducted in parallel.

In situ approach

Many external parameters, such as the energising of the cables or weather and tidal conditions, affect the feasibility of implementing *in situ* operations. All of the study sites are also subject to unpredictable events that can influence the results and make them difficult to interpret. This is particularly true when seeking to assess the impact of electromagnetic fields, which are in theory weak, according to the current scientific knowledge on this subject. As they do not cause drastic changes in the composition of benthic communities or in their functioning, the potential impacts can easily be masked by larger changes related to other factors, whether natural or anthropogenic. *In situ* studies, however, where they can be maintained over time, can reveal medium- or long-term changes that are otherwise difficult to detect.

Fig. 53. In situ monitoring of the Paimpol-Bréhat cable.

Laboratory approach

Laboratory experiments make it possible to precisely study the short-term impact of one or more factors while rigorously controlling most of the other parameters likely to influence the study model. In particular, they can measure the sensitivity of the receptor organism and be used to describe in detail its responses to the factor under study by applying a range of strengths that may exceed those encountered in the natural environment. However, the laboratory approach has its limitations, which are mainly of a technical nature. Indeed, it is complex to produce high and homogeneous magnetic field strengths over large areas (several square metres) and to maintain them over a long period (several days). This constraint imposes methodological choices such as the use of short exposure times with high magnetic field strengths or vice versa, or again working on restricted areas and therefore appropriately sized biomodels. Moreover, transposing the results obtained in the laboratory

to the natural environment is often complicated and subject to debate. Although laboratory experiments can reveal behavioural effects and threshold electromagnetic field values, they cannot replace *in situ* studies to measure effects in the natural environment or to establish whether the effects observed in the laboratory have a real impact on the scale of a population, a community, or even a food web. It is therefore important to remember that *in situ* studies and laboratory experiments are complementary.

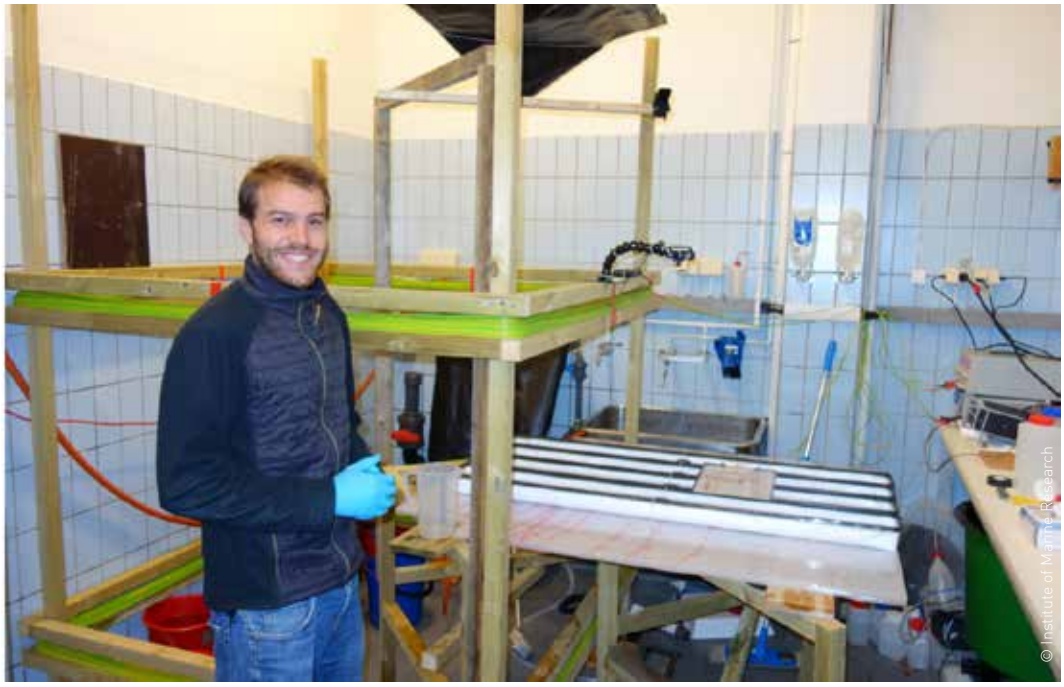

Fig. 54. Laboratory experimental set-up used to study the impact of electromagnetic fields on juvenile European lobsters.

5 - Project review

5.1 The reef effect of power cables

With regard to the reef effect associated with subsea power cables, a distinction must be made between the **cable itself**, whether unprotected or with a protection shell, and the **associated structures** put in place for its protection and stabilisation (such as mattresses and riprap) or for power connections (such as hubs). The cable, unprotected or with its protections close together, represents a long, thin, cylindrical artificial reef with a diameter of less than 20 cm. The associated structures, however, are far larger, with a volume of several cubic metres, and can be very varied and complex in shape.

As the cables and associated structures constitute hard substrates, they are subject to colonisation by sessile epibenthic invertebrates (Fig. 55a). However, they can host taxonomically distinct communities, even when located in the same environment, due to differences in the materials used (plastic, metal, concrete, etc.), in height or in shape complexity. At the Paimpol-Bréhat test site, the study showed that the concrete mattresses and cast iron half-shells associated with the cable, although deployed in the same environment, supported different sessile epibenthic communities (see Fact Sheet 6). For megafauna such as fish or decapods, the associated structures, which are larger and more complex, offer greater potential for shelter. They therefore constitute more attractive artificial reefs than the cables alone (Figs. 55b and 55c). The concrete mattresses deployed on the Paimpol-Bréhat test site, as well as the connection hub of the SEM-REV site, are thus colonised by a large community of mobile megafauna (see Fact Sheets 7 and 8).

While subsea power cables and their associated structures constitute artificial reefs that can be colonised by a wide range of sessile and mobile species, the real question is whether the magnitude of the reef effect is significant, particularly in terms of sheltered biodiversity and community production. Compared to artificial reefs for which significant impacts are well established, such as shipwrecks (Krone and Schröder, 2011), wind farm foundations (Reubens *et al.*, 2010), or systems designed for ecosystem conservation (Jensen, 2002), the cables alone can be considered to have a minor effect, if only

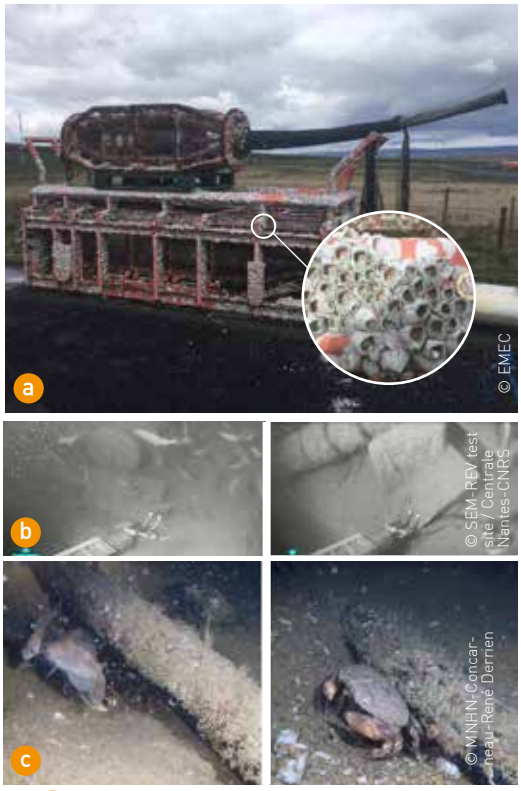

Fig. 55: Benthic colonisation on different types of cables and associated structures.

a Power connection hub at the EMEC wave energy test site (Orkney Islands, Scotland) and close-up view of barnacles after three years of deployment at sea.

b Heavy colonisation by *Trisopterus* spp. (left) and by *Conger conger* and *Homarus gammarus* (right) of the connection hub of the SEM-REV test site on soft sediment.

c Occasional colonisation by *Trisopterus minutus* and *Homarus gammarus* (left) and by *Cancer pagurus* (right) of the umbilical of the Floatgen wind turbine installed at the SEM-REV test site.

because of their low spatial coverage. Indeed, even though the cables can be deployed over several tens of kilometres (or even hundreds of kilometres for interconnectors), their limited width tends to reduce the associated reef effect. **The cables alone will therefore support an epibenthic community and potentially act as a periodic staging point for several species of mobile megafauna, but should not lead to a drastic change in the receiving ecosystem.**

In contrast, the **structures associated** with the cables could play a more important role. Due to their greater structural complexity, they present similarities with the other types of artificial

reefs mentioned above, and therefore allow for the sustainable development of a diverse and self-sustaining reef community that can have a significant influence on the surrounding habitats. Although a single structure may play an anecdotal role, **the deployment of several units (such as mattresses or hubs) within the same geographical area can have a significant influence on the surrounding environment through the creation of a network of artificial reefs.**

In the context of ORE development, it should be noted that the specific structures of the power cables will interact with other artificial structures such as wind turbine foundations or protections against scour, and will thus contribute to the constitution of a vast network of artificial reefs.

5.2 The potential of cable corridors to act as marine reserves

The study carried out on the exclusion area associated with the cables connecting the island of Jersey to France showed only a minor effect on the composition of the benthic communities (see Fact Sheet 9). This was primarily due to the relatively low level of the main anthropogenic pressure in the study area, i.e., fishing with towed gear, both within and outside the exclusion area. The area is also subject to strong hydrodynamics, which can have the effect of masking the impacts of fishing given the natural instability of the environment. The fact that no data on the environmental status of the area were available prior to the establishment of the exclusion area means that the conclusion regarding its effect on the benthic community is incomplete.

Protected areas associated with subsea cables have certain specificities, including their geometry. As they are designed to encompass the cable route, they are usually linear and particularly narrow (a few hundred metres in width) (Taormina, 2019). This configuration has a high perimeter to area ratio and a high proportion of edges. This is not at all optimal from the perspective of conservation ecology, which seeks to minimise edge effects while maximising the protected internal surface area (McLeod *et al.*, 2009). This is because the high proportion of edges makes the protected areas associated with the cables more likely to be subject to fishing or other banned human activities. In addition, when the perimeter to area ratio is high, mobile species are more likely to disperse across boundaries to unprotected areas (Buechner, 1987). For conservation purposes, marine protected areas generally focus on critical habitats that are important for biological conservation or ecological functionality, such as nursery areas, spawning grounds, and areas with high species diversity (McLeod *et al.*, 2009). As cable routes are generally constrained by law to avoid damaging sensitive areas during the laying phase, it is quite rare for a protected area associated with one or more cables to include a critical habitat. A few cases nevertheless exist, such as at Belle-Île-en-Mer in Brittany, where the presence of a subsea cable is at the origin of the only protected area that partly encompasses a maerl bed, which constitutes a biogenic habitat of high ecological value (Dubreuil *et al.*, 2017) (Fig. 56).

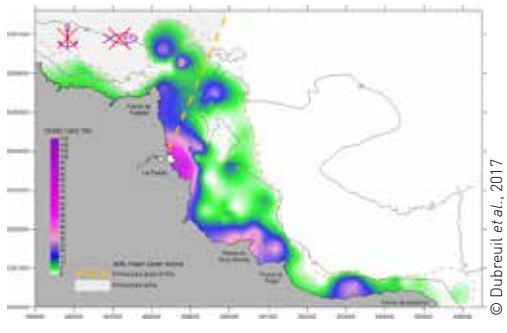

Fig. 56: Distribution of maerl cover in the Belle-Île sector (coordinates in WGS 84, UTM zone 30 - 1,000 metres in two grids).

Protected areas associated with subsea power cables are not designed and demarcated with ecosystem conservation considerations in mind. As such, they are not as effective as true marine protected areas. However, even though they are not optimised, **they can have a positive impact on the marine ecosystem from a conservation point of view if the area has not been disturbed by human activities prior to cable-laying, or from a restoration perspective if the ecosystem was in a poor environmental state prior to the application of the regulation.** It should be noted that within the framework of ORE projects, the restrictions may not be confined to the cable routes but extend across the whole farm, thus creating more extensive and effective reserve areas, particularly thanks to a much smaller perimeter to area ratio. In this context, a study using trophic models highlighted an increase in

the biomass of a large number of trophic groups (mainly fished species) and average trophic levels of predators within an offshore wind farm, which can be explained by the total closure of this area to fishing activities (Halouani *et al.*, 2020). **The ecological benefits of these protected areas can also act in synergy with the reef effect created by the artificial structures,** as in the case of the Dutch offshore wind farm *Egmond aan Zee* where habitat heterogeneity and the biodiversity of benthos, fish, marine mammals and birds have increased (Lindeboom *et al.*, 2011).

Fig. 57: Cable-laying ship.

5.3 Thermal radiation

The issue of the heating of the surrounding environment due to the passage of electric current through the cables sometimes raises questions concerning its potential ecological impact. **The measurements carried out within the framework of the project did not show any increase in temperature due to contact with the cables laid and in operation** (see Fact Sheet 4), thus supporting the hypothesis that, in the case of laid cables, **the heat is immediately dissipated by convection with the water mass** (Taormina *et al.*, 2018; Carlier *et al.*, 2019). However, uncertainty remains concerning the potential role of thermal insulation played by the epibenthic fauna having colonised the cables. The ongoing collaborative R&D project ABIOP+, which aims to better account for biofouling through engineering-relevant quantification protocols, is currently investigating this issue for the case of dynamic power cables.

During the project, no measurements could be made on buried cables, which are most likely to propagate the temperature increase above the cable into the more permeable sediments. Due to the low number of *in situ* temperature measurements for this type of cable, scientific uncertainty still remains regarding the consequences for the endofauna living nearby. It is therefore essential to better characterise this effect by targeting buried cables with higher power ratings (Carlier *et al.*, 2019).

5.4 The potential ecological impact of electromagnetic fields

5.4.1 New in situ data

The characteristics of artificial electromagnetic fields and their potential impacts on marine life are still poorly understood today. Within the framework of feedback on ecological impacts, it is important to distinguish between results obtained in the laboratory and those obtained in the field. Most experimental studies on the impact of magnetic fields on aquatic life use strengths greater than or equal to 1,000 µT (Taormina, 2019). The use of such very high strengths is often justified by data from modelling, but they are not necessarily representative of the values measured *in situ*. The few field studies that have measured magnetic fields emitted by cables have indeed shown much lower ranges of strengths.

The literature review conducted for the project indicates that a maximum of 116.8 µT was measured by Love *et al.* in 2017 for a 35 kV AC cable. Although the strengths of the fields produced by a power cable depend strongly on its characteristics and the distance to the cable, a discrepancy seems to exist between the strengths measured *in situ* and those used in the laboratory (Snoek *et al.*, 2016; Taormina, 2019). Very high strengths greater than 1,000 µT can exist, but these are confined to contact with very high power cables. As the latter are most often buried or protected by other structures, it is highly unlikely that benthic species would encounter magnetic field strengths of this magnitude (Fig. 58) (Albert *et al.*, 2020). It would therefore seem that most of the magnetic field strengths applied in the experimental studies are not very representative of reality. Even though these studies provide useful data, the transposition of the experimentally obtained results to the field thus remains difficult. In a context where the number of connections and the individual power of subsea cables are increasing rapidly, more *in situ* measurements of the strength of the magnetic fields produced are needed in order to better understand and assess the potential impact of this disturbance on marine life.

With this in mind, **the project has contributed to demonstrating the relevance and potential accuracy of the tools and methods developed to characterise electromagnetic fields in proximity to these cables and infrastructures.** They are available for other studies and can be integrated for a better *in situ* characterisation of the fields and their potential impacts, notably with regard to theoretical calculations for each type of cable and observations of fauna in the vicinity of the cables.

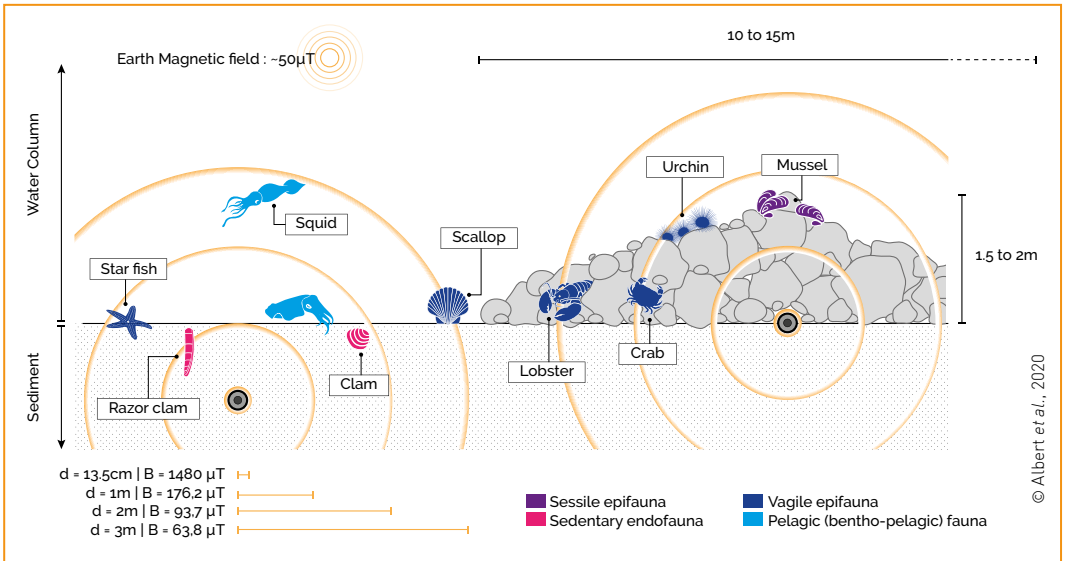

Fig. 58: General distribution of certain invertebrate species on the seabed, and theoretical magnetic field strengths emitted by 225 kV cables (buried 1 m deep and unburied) with an electric current of 1,000 A (diameter: 27 cm).

5.4.2 Standardisation of the value of electromagnetic fields

In situ measurements of electromagnetic fields produced by subsea power cables are not only rare, they also lack standardisation. These measurements are seldom carried out at the same **distance from the cable**, with this distance often not even being indicated. They are therefore difficult to compare. Furthermore, the electric **power** flowing through the cables at the exact moment of the measurements is rarely indicated or cannot be precisely given since this data is often averaged over a variable period of time. Consequently, it is not possible to know whether or not the measured field strength values are representative. **Homogenisation of the data obtained is therefore necessary in order to compare different cables.** With regard to distance, harmonising the field strength values obtained one metre from the core of the cable would appear to be a sensible choice as this distance is often used. In order to standardise the field produced in relation to the power involved, the **field strength to power ratio** can be used, while specifying the maximum power that can flow through the cable. Thus, for a given cable, taking the example of the magnetic field, the strength produced could be given in **µT/MW at a distance of one metre.**

5.4.3 Electromagnetic fields and marine life

Although in recent years the issue of the impact of magnetic fields on marine life has attracted increasing attention from the scientific community, a significant knowledge gap still exists. Experimental studies on the impact of magnetic fields on juvenile European lobsters and on great scallops were thus carried out within the framework of the project (see Fact Sheets 12 and 13). As far as European lobsters are concerned, however, uncertainties remain for adult individuals, on which no studies have been carried out to date. Another perspective for this target species would be to study the potential impact of magnetic fields on embryonic and larval development, as mated females can sometimes be found in very close proximity to power cables when occupying artificial reefs (Fig. 59).

The rest of the literature on the impacts of electromagnetic fields on marine life shows rather contrasting results (Taormina *et al.*, 2018; Carlier *et al.*, 2019; Albert *et al.*, 2020). Certain species tested have indeed shown significant responses to the presence of artificial electromagnetic fields (Ernst and Lohmann, 2018; Stankevičiūtė *et al.*, 2019; Hutchison *et al.*, 2020) compared with other species tested (Bochert and Zettler, 2004; Woodruff *et al.*, 2012, 2013; Love *et al.*, 2017). These results therefore show that artificial electromagnetic fields clearly have

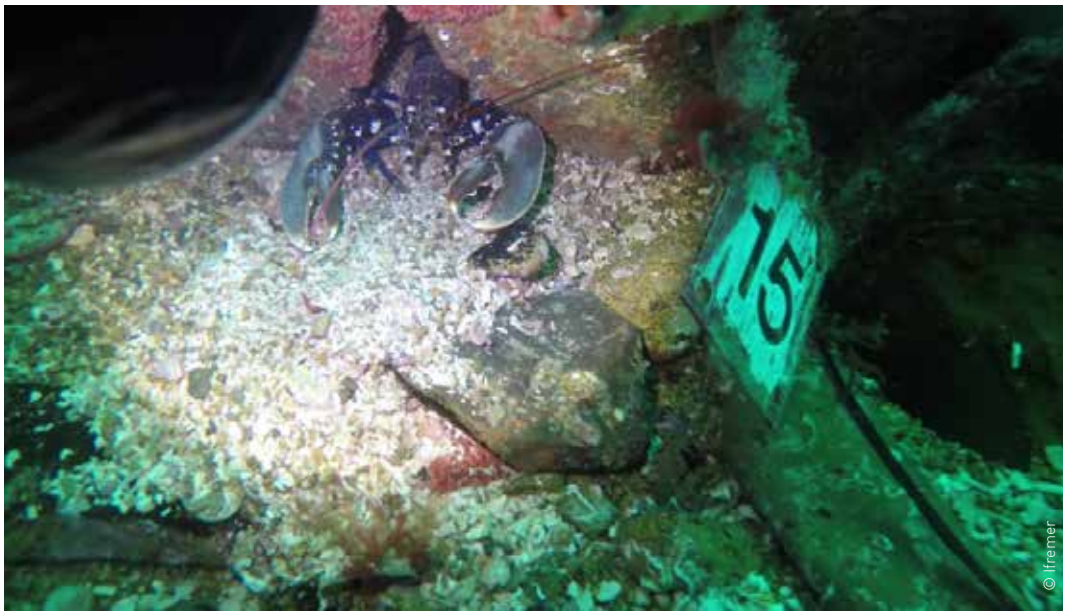

Fig. 59. Female European lobster observed under a mattress at the Paimpol-Bréhat test site.

measurable effects on certain marine organisms at the behavioural, physiological, developmental or genetic levels (Gill and Desender, 2020). Nevertheless, the extrapolation of these effects to ecological impacts proven *in situ*, such as changes in population levels manifested through changes in survival or reproductive success, remains speculative (Gill and Desender, 2020).

It should be noted that most of the studies on this subject are carried out in the laboratory. Based on a review of the literature concerning the impact of electromagnetic fields on aquatic life, it appears that the majority of studies have adopted an *ex situ* experimental approach (37 out of 47 studies), while the number of *in situ* studies remains very low (10 out of 47) (Taormina, 2019). A greater number of *in situ* studies or experiments would therefore be essential in order to reach sound conclusions. During the project, all of the fieldwork carried out at the Paimpol-Bréhat and Ushant sites was conducted without any electric current flowing through the cables, and therefore without any emission of magnetic fields. By continuing to monitor the megafauna and epibenthic communities at these sites, it would be possible to determine whether changes due to electromagnetic fields, such as the appearance or disappearance of specific species, are generated once the cables are connected.

6 - Perspectives

6.1 Current knowledge on the risks related to electromagnetic fields

Concerns about the potential impacts of subsea power cables on the marine environment are a recurrent theme in the public consultation process for the implementation of offshore renewable energy or electricity interconnection projects. Even if they do not constitute major issues, such as those posed by noise during the construction phase or collisions with seabirds, they influence the overall level of acceptance of these projects. Significant gaps in knowledge on the various environmental risks associated with these new activities at sea sometimes still exist. These gaps cause stakeholders in the regions implementing ORE projects to have a heightened perception of them. Before proceeding with a "risk withdrawal", i.e., removing from debates environmental concerns that do not constitute a significant issue for the marine environment, it is crucial to fill these knowledge gaps.

The risks associated with the emission of electromagnetic fields from power cables into the marine environment have recently been the subject of scientific debate as to whether they can be removed from the advisory and regulatory processes. As initial scientific feedback indicates negligible to low impacts on marine life (OES-Environmental, 2019), it is tempting to dismiss the associated risk and to classify it as acceptable. However, from the point of view of all the SPECIES project partners, scientific hindsight on the ecological impacts of electromagnetic fields is as yet too limited to definitively rule out this risk. As explained above, there is a lack of *in situ* physical characterisation of the fields generated, and an even greater lack of studies on the response of potentially sensitive species and the impacts on them over the long term.

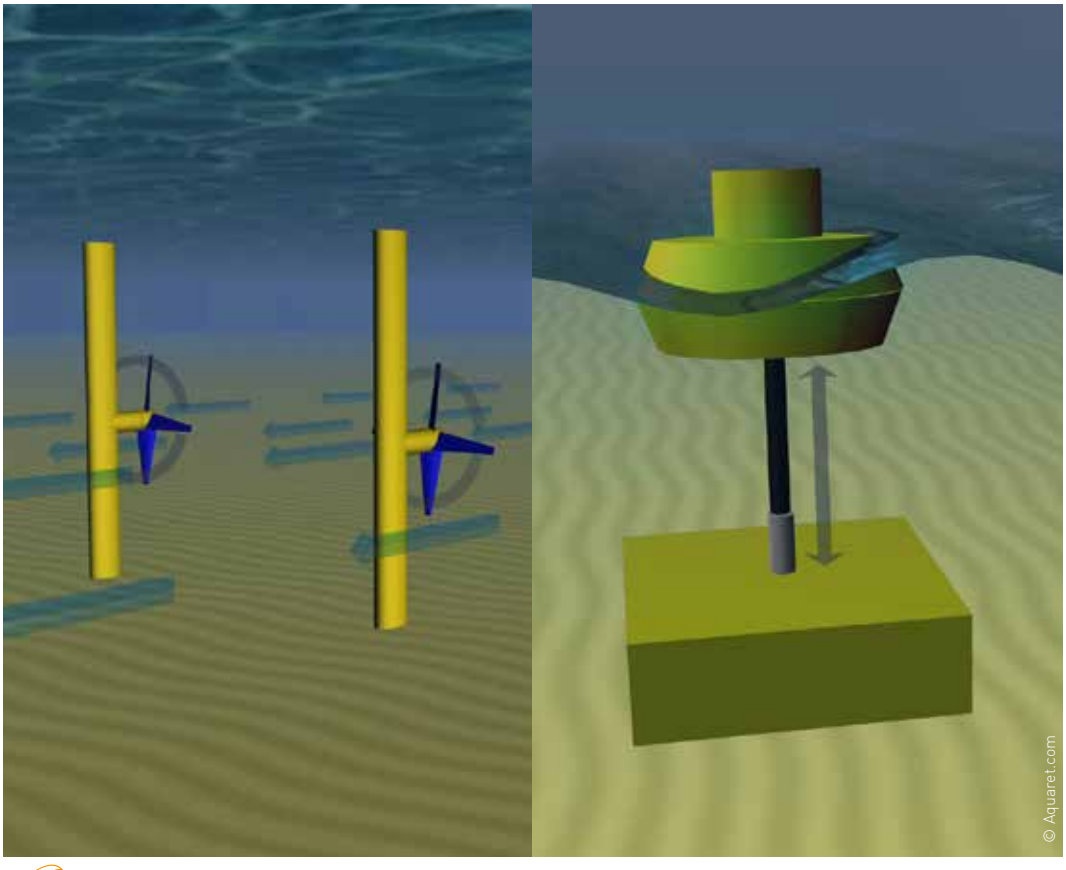

Fig. 60: Examples of ocean energy systems: horizontal axis tidal turbine (left) and wave energy system (right).

The international collaborative initiative Ocean Energy Systems - Environmental, which aims to understand the environmental impacts of devices and systems harnessing the energy of marine currents, wave power, and thermal and salinity gradients, recently developed a process for filtering out low risks (Copping *et al.*, 2020). This process aims to determine which interactions between ocean energy systems and the marine environment constitute a low risk that can be dismissed, and those which would require additional data collection or mitigation measures in order to reduce the risks to an acceptable level. The first phases of this process took place during three workshops hosted in different countries (Italy, United States and Australia) in 2019. These workshops brought together a total of 81 ocean energy experts from 11 countries (Australia, Canada, France, Germany, Italy, Netherlands, Portugal, South Korea, Sweden, United Kingdom, United States). They addressed only the case of pilot wave and tidal energy sites consisting of three or fewer converters. The focus was on the effects on marine wildlife of underwater noise produced by power generation systems and of electromagnetic fields generated by subsea power cables (Copping *et al.*, 2020). **With regard to electromagnetic fields, the workshop participants considered that connections to sites with a small number of converters posed a relatively low risk.** This conclusion was justified by the fact that the power flowing through these cables is low compared to that of commercial farm export cables or of connection cables (Copping *et al.*, 2020). Nevertheless, the participants pointed out that **this issue is still new and that it is important to continue studies on the subject, and notably to perform *in situ* measurements of electromagnetic fields.** This would be essential in guiding future scientific research and in addressing public concerns about the impact of offshore renewable energy systems.

6.2 The future of subsea power cables in France

During the project, the target cables in the various studies were either export cables at test sites (Ushant, Paimpol-Bréhat, SEM-REV) or connection cables (HVDC Cross-Channel and Jersey-Cotentin interconnectors). With the further development of French offshore wind farms in the years to come, the export cables will have characteristics that are currently not very common in French waters, i.e., a voltage of 225 kV AC for the most part (Tab. 4) (Carlier *et al.*, 2019). Moreover, over the next few years, certain connection cables will have power ratings never before achieved in France. Several projects between France, the United Kingdom and Spain are currently being studied (Carlier *et al.*, 2019). **This drastic and unprecedented increase in the number and power ratings of subsea power cables in French coastal waters calls for further characterisation of their potential impacts on benthic communities**, initiated as part of this project, with notably the characterisation of detection thresholds for electro- and magnetosensitive benthic species.

	Project name and power rating	Length of subsea link	Commissioning
ELECTRIC INTERCONNECTORS	• HVDC Cross-Channel, 2 GW (France - United Kingdom)	4 x 270 kV HVDC links, **46 km**	1986
	• BritNed, 1 GW (Great Britain - Netherlands)	450 kV HVDC, **250 km**	2011
	• ElecLink, 1 GW (France - United Kingdom)	320 kV HVDC, **51 km** of cable inside the Channel Tunnel	2019
	• Nemo Link, 1 GW (Belgium - United Kingdom)	**130 km**	2018
	• IFA-2, 1 GW (Southampton - Calvados)	HVDC, **200 km**	2020
	• FAB, 1.4 GW (France - Alderney - Great Britain)	2 HVDC links, **220 km** (30.5 km in France)	2022
	• Celtic Interconnector, 0.7 GW (France - Ireland)	HVDC, **500 km**	2025
	• Bay of Biscay, 5 GW (France - Spain)	2 HVDC links, **280 km**	2025
	• GridLink, 1.4 GW (France - United Kingdom)	AC, **140 km** (32 km in France)	2025
BOTTOM-FIXED OFFSHORE WIND	• Dieppe-Le Tréport, 496 MW (62 wind turbines)	2 x 225 kV links, AC, **24 km**	2023
	• Fécamp, 498 MW (83 wind turbines)	2 x 225 kV links, AC, **18 km**	2023
	• Courseulles-sur-Mer, 450 MW (75 wind turbines)	2 x 225 kV links, AC, **16 km**	2023
	• Saint-Brieuc, 496 MW (62 wind turbines)	2 x 225 kV links, AC, **33 km**	2023
	• Saint-Nazaire, 480 MW (80 wind turbines)	2 x 225 kV links, AC, **33 km**	2022
	• Ile d'Yeu/Noirmoutier, 496 MW (62 wind turbines)	2 x 225 kV links, AC, **27 km**	2024
	• Dunkirk, 600 MW (> 50 wind turbines)	2 x 225 kV links, AC, **10 km**	2027
FLOATING OFFSHORE WIND	• "Provence Grand Large", Faraman area, Mediterranean, 25 MW (3 wind turbines)	33 kV, AC, **30 km**	2022
	• "Les éoliennes flottantes du golfe du Lion", Leucate area, Mediterranean, 30 MW (3 wind turbines)	63 kV, AC, **18 km**	2022
	• "Les éoliennes flottantes de Groix & Belle-Île", Groix, Brittany, 28.5 MW (3 wind turbines)	63 kV, AC, **30 km**	2022
	• "Eolmed", Gruissan, Mediterranean, 30 MW (3 wind turbines)	33 kV, AC, **27 km**	2022
ORE TEST SITES	• Paimpol-Bréhat, 1 MW (1 tidal turbine)	**15 km**	2019
	• SEM-REV, 20 kV (currently the Floatgen wind turbine)	**20 km**	2018
	• Alderney Race, 12 MW (4 tidal turbines)	**3 km**	On hold
	• Fromveur, 1 MW (1 tidal turbine)	**2 km**	2015

Tab. 4. Summary of the interconnector and connection projects for ORE farms targeting metropolitan French waters (or nearby marine regions) and involving the laying of high-voltage (> 33 kV) or medium-voltage subsea power cables for the pilot projects (adapted from Carlier *et al.*, 2019).

6.3 The case of dynamic cables

The development of floating energy production systems such as wind turbines, as well as wave energy and some tidal turbine systems, requires the deployment of power cables between the surface and the seabed, known as **dynamic cables** or **umbilicals**. The presence of this type of cable is a new feature in marine ecosystems at this scale. Like power cables deployed on the seabed, they will also emit electromagnetic fields, but the potential receptor organisms are different. While static cables mainly affect benthic and benthic-demersal species, umbilicals can potentially impact pelagic species (Taormina *et al.*, 2018). Many of these are known to be magnetosensitive: sea turtles (Lohmann and Lohmann, 1996; Luschi *et al.*, 2007), marine mammals (Bauer *et al.*, 1985), teleost fish (Walker, 1984; Formicki *et al.*, 2019), and elasmobranchs (Formicki *et al.*, 2019). As this technology is still in the development phase, the response of these organisms to artificial electromagnetic fields in the water column is as yet completely unknown. With the implementation of the first pilot floating wind turbine farms, notably in France, it is essential to characterise the potential impacts generated by these dynamic cables and to adopt the necessary measures if these impacts are proven. **While mitigation measures exist for static cables, such as burying and riprap, proposing such measures for umbilicals can represent a real challenge.**

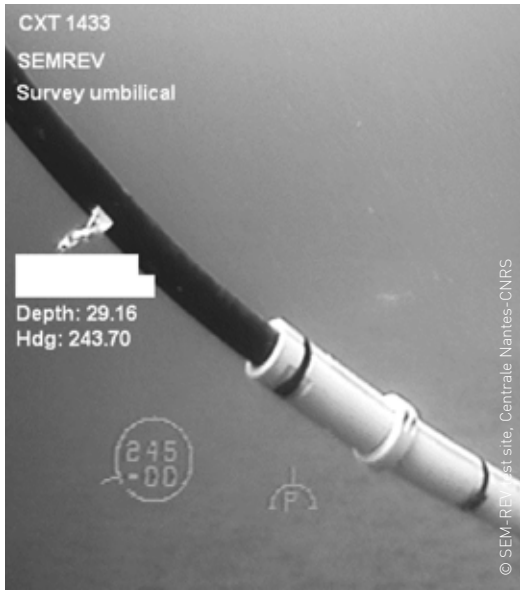

Fig. 61. Floating wind turbine and its umbilical.

6.4 Substations: priority study sites

The various effects associated with subsea power cables have the common specificity of being highly localised. With the exception of the reserve effect, they are only felt over a few metres (or even a few tens of centimetres) on either side of the cable. This is the case for habitat modification, as well as for heat and electromagnetic field emissions. Consequently, the spatial footprint of these effects for a single cable can be considered to be very low. However, where cable density is high, these effects can be cumulative and impact larger areas. This is particularly the case in the vicinity of the electrical substations of offshore renewable energy farms, where the power generated by all the converters converges before being transformed and exported to the shore grid by the export cable(s) (Fig. 62). In these sectors, mobile benthic organisms may have to cross not just one, but several differently oriented power cables, which could potentially involve different responses. It would seem that these areas of concentrated power cables have as yet never been the subject of studies on the cumulative impacts of electromagnetic fields, even in countries that already have numerous offshore renewable energy farms. In the current French context of ORE development, **these areas with a high density of cables represent priority study areas for data on the *in situ* impact of subsea power cables on benthic communities.**

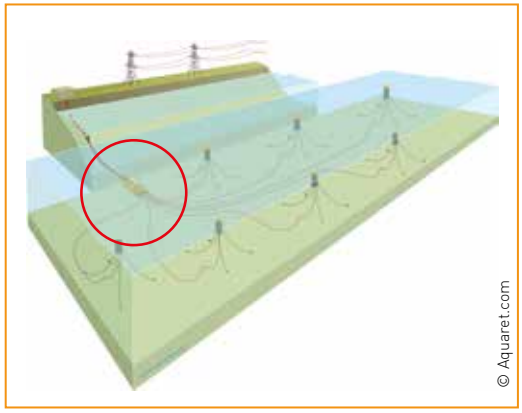

Fig. 62. Example of a power connection grid for a wave energy farm. The red circle indicates the electrical substation where the cable network is densest.

7 - Acronyms, abbreviations and definitions

A = Ampere. Base unit for measuring electric current.

AC = Alternating current. This is a periodic electric current that reverses direction twice per period and that carries alternately equal amounts of electricity in one direction and in the other.

AgCl = Silver chloride.

ANOVA = Analysis of Variance. This is a set of statistical models used to check whether the means of groups come from the same population.

AUV = Autonomous Underwater Vehicle. A robot that moves autonomously in the water.

BACI = Before-After-Control-Impact. The BACI approach consists in monitoring two sites (control and impact) before and after a disturbance, in order to measure the effect of the latter on the ecosystems.

B0 = Authorisation for non-electrical work in low-voltage installations.

DC = Direct current. This is an electric current, the intensity of which is independent of time.

GPS = Global Positioning System.

h = hour.

H0 = Authorisation for non-electrical work in high-voltage installations.

HVDC = High-Voltage Direct Current. This is a power electronics technology used for the transmission of high-voltage direct current electricity.

Hz = Hertz. Unit of measurement for frequency.

m = metre.

NF = French standard (*Norme Française*).

nT/√Hz or V/√Hz = spectral power densities.

ORE = Offshore Renewable Energy.

p = probability for a given statistical model under the null hypothesis to obtain the same or an even more extreme value than the value observed.

PASSEM = mobile measurement tool for electromagnetic fields.

ROV = Remotely Operated underwater Vehicle. A remote-controlled (usually wire-guided) underwater robot.

spp. = subspecies. Multiple unidentified species of the same genus.

STATEM = static measurement tool for electromagnetic fields.

T = Tesla. Unit of magnetic field density.

V = Volt. Unit of electromotive force and potential difference (voltage).

VA = Volt-ampere. Unit of measurement for apparent power.

W = Watt. Unit of power or energy flow.

WFD = Water Framework Directive (2000/60/EC). European Directive establishing a framework for a comprehensive EU water policy.

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The SPECIES project has significantly improved the available knowledge base concerning the potential impacts associated with subsea power cables in offshore renewable energy projects. Tools for measuring electromagnetic fields were specially developed and tested during this project. *In situ* studies of the response of benthic communities to the presence of power cables were thus carried out. In parallel, complementary laboratory experiments on the impact of artificial electromagnetic fields on the behaviour of two species of interest were conducted. This new knowledge represents a very important contribution to providing a better understanding of these impacts and to enabling the stakeholders in the sector to adopt appropriate management measures.

Although drastic negative impacts on benthic ecosystems were not highlighted, certain issues remain insufficiently documented, particularly the impact of electromagnetic fields. Indeed, in the view of all of the project partners, scientific feedback on the subject is currently insufficient to completely quash debates over the associated environmental concerns. This lack of knowledge is mainly due to the significant lack of *in situ* studies, which should therefore be given priority in the future. As the first offshore wind farms will soon be built in France, it is more necessary than ever to continue the research effort initiated within the framework of this project.

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