Guide to the environmental impact evaluation of tidal stream technologies at sea :

GHYDRO

FRANCE ENERGIES MARINES

DCNS EDF Ifremer

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Acronyms

ACCOBAMS:	Agreement on the conservation of cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area
ADCP:	Acoustic doppler current profiler
ADEME:	Agence de l'environnement et de la maîtrise de l'energie
ADV:	Acoustic Doppler velocimeter
CEI:	Calls for Expression of Interest
ASCOBANS:	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
EC:	Environmental Code
EMF:	Electromagnetic field
CETMEF:	Centre d'études techniques maritimes et fluviales
CITES:	Convention on international trade in endangered species of fauna and flora
CMS:	Convention on migratory species
CTD:	Conductivity temperature depth
MSFD:	Marine strategy framework directive
DDTM:	Direction départementale des territoires et de la mer
DIRM:	Direction interrégionales de la mer
DML:	Délégation à la mer et au littoral
DREAL:	Direction régionale de l'environnement, de l'aménagement et du logement
HF Radar:	High frequency radar
IGN:	Institut national de l'information géographique et forestière
IUCN:	International union for conservation of nature
MBS	Multibeam sounder
MEDDE:	Ministère de l'écologie, du développement durable et de l'énergie
OSPAR:	Oslo Paris convention
PACOMM:	Programme d'acquisition de connaissances sur les oiseaux et mammifères marins
PTS:	Permanent threshold shift
SEENEOH:	Site expérimental estuarien national pour l'essai et l'optimisation hydrolienne
SEL:	Sound exposure level
SHOM:	Service hydrographique et océanographique de la marine
S.M.:	Suspended matter
SPL:	Sound pressure level
TTS:	Temporary threshold shift
ZNIEFF:	Natural Zone of Interest for Ecology, Fauna and Flora

Introduction

0.1. Context

The development of marine renewable energy[1] in France has become increasingly important since the EU adopted an action plan called the "climate and energy package" in December 2008. The objective of the action plan is to achieve by 2020[2]:

- 20% reduction of greenhouse gas emissions in the European Union compared to the 1990 levels.
- 20% contribution of renewable energy to energy consumption.
- An increase in energy efficiency of 20%.

In the framework of this objective, and the 2009/28/CE Directive, France aims to achieve 23% renewable energies in its energy mix.
The exploitation of renewable marine energy in France could attain 3% of this objective by 2020[3].

In this context, after bottom-mounted offshore wind turbines, tidal stream turbines will be the next technology to mature, with test sites and pilot projects currently under development. Indeed, France has the second largest potential for current resources in Europe, behind the United Kingdom. The principal identified national sources are found in highly localised zones of the country's northwest coast: Raz Blanchard, Raz de Barfleur, Paimpol-Bréhat, Fromveur or Raz de Sein.

Three Calls for Expressions of Interest (CEI) organised by the ADEME in the framework of the 'Investments for the future' funding programme concern these technologies.
The scope of the first CEI included demonstrators tested at sea, and two tidal stream projects were selected in 2009.
The second CEI, closed on 31 October 2013, covers the technological building blocks designed especially for the marine tidal power sector, such as systems facilitating the connection or the injection of the electricity produced onto the grid. Selected projects should be demonstrated at sea, primarily and when appropriate, on the test sites managed by "*France Energies Marines*" (ADEME, 2013).
The third CEI, concerning projects for tidal stream pilot farms, opened 1 October 2013 and will close 24 April 2014. The farms should include between 3 and 10 machines with a minimum raw capacity of 2,500 MWh / year / machine.
Two specific sites, in which 7 zones are planned, have been identified at Raz Blanchard and Fromveur (Fig. 1 and 2).

0.2. *"France Energies Marines"* tidal stream turbine sites

The "*France Energies Marines*" test sites are made available to technology developers for the complete process, up to technology qualification.

- The SEENEOH test site (Fig. 1)
The "*Site Expérimental Estuarien National pour l'Essai et l'Optimisation d'Hydroliennes*" (SEENEOH) is located in the heart of Bordeaux in the fluvial section of the Gironde estuary. The closeness of the site to the city significant reduces the financial constraints related to machine deployment in the natural environment. The three available locations can accommodate floating, bottom-mounted or variable support technologies, and can be used to test tidal stream turbines at full scale (fluvial and estuarine environments) and at intermediate scale (oceanic environment).

[1] The term marine renewable energy is used in France to refer to all forms of exploitation of renewable resources from the marine environment: wind, currents, waves, tides, temperature, salinity, biomass (http://www.connaissancedesenergies.org/fiche-pedagogique/energies-marines).
[2] http://europa.eu/legislation_summaries/environment/tackling_climate_change/index_fr.htm
[3] http://www.developpement-durable.gouv.fr/IMG/pdf/Livre_bleu.pdf

- The Paimpol-Bréhat observation and testing site (Fig.1)

The Paimpol-Bréhat site is relatively representative of a tidal power zone in terms of hydrodynamics, the nature of the seabed, etc. At the same time it offers more benign conditions than other tidal power sites, thus facilitating operations at sea. For "*France Energies Marines*", it is the primary location for observation of the physical and biological environment and for validation of subsystems that will be developed within the framework of R&D projects.

0.3. Tidal stream pilot sites

- Raz Blanchard: The tidal power reserve covering the raz Blanchard and the raz de Barfleur, on the Normandy coast, is the largest at the national level, with a potential of more than 50% of the French reserve estimated to be between 2 and 2.5 GW (DIRM Eastern Channel – North Sea 2013). The zone selected for the CEI covers a surface of 7.3km².

- Fromveur: The tidal power reserve of the Fromveur passageway, between the Molène archipelago and the island of Ouessant, is the second most important French tidal power site, with an estimated 300 to 500 MW (Boyé *et al.*, 2013). Concerning the Brittany region, this site has been selected as a suitable zone for the development of a pilot farm. A zone of 4km² has been defined in consultation with the zone's actors (fishermen, PNMI, industrialists, state services (DREAL, DIRM, pDML), Prefectures, regional council) in the 'Regional conference of the sea and the coastline'.

- Paimpol-Bréhat: EDF is developing an experimental tidal stream turbine site off Paimpol-Bréhat (Côtes d'Armor), which will include 4 turbines of 500KW each, using the technology of the Open Hydro company (DCNS).

Figure 1. Map of the main French R&D sites, test sites and pilot sites for tidal stream turbine technologies

In their report, the study mission on renewable energies (Boyé *et al.,* 2013) proposed a timetable, designated as proactive, for which the tidal stream component is shown in table 1.

Tests and demonstrators	Pilot farm development	Pilot farm deployment	Farms or industrial installations 100-300 MW	Farms or industrial installations > 300 MW
2011-2013	2011-2013 Call for proposals 2013	2014-2016 possibly 2014-2015	2017-2018, possible deployment from 2016	2020

Table 1. Timetable for development of French tidal stream projects (Boyé et al., 2013)

0.4. Objectives of the guide

The main objective of this guide is to promote the environmental integration of a new type of construction at sea, for which there is very little feedback about the potential ecological impacts.
Due to the lack of French feedback (some exists at the international level) and the continued lack of knowledge concerning the marine environments targeted by tidal stream turbine technologies, the structural context in which environmental monitoring of the tidal stream projects will be developed is still in draft form. In terms of the environmental knowledge (physical and biological), as well as the regulatory and technological aspects (machines, installation, maintenance...), the assessment of the environmental impacts of tidal stream projects is still in its infancy. This guide proposes recommendations and methods that allow, for the first time, these different aspects to be taken into account.

The GHYDRO project thus aimed to create this methodological guide, which is intended to provide the means to analyse the main potential environmental impacts linked to the different tidal stream turbine technologies at sea. It makes recommendations on the choice of location, the description of the initial state and the ecological monitoring of tidal stream projects.

The methodological guide currently represents a summary of the recommendations concerning the diverse physical parameters and biological compartments of the ecosystems that are potentially affected. The guide in no way represents a regulatory document for impact studies of tidal stream projects.

0.5. Perimeters of the study

Spatial perimeter
The spatial perimeter of the study consists of the maritime domain from foreshore to offshore. Only impacts on the marine environment will be addressed. The impacts of the onshore cable (above the high tide limit) for example, will not be presented in this guide. Fluvial technologies will be presented, but their impacts will not be discussed in this guide.

Thematic perimeter
The guide mainly concerns:
- Environmental aspects (i.e., the potential impacts on the marine ecosystems concerned by this type of construction). The potential impacts on the usages and more specifically, on professional fishing activities will be mentioned briefly.
- Ecosystem parameters and compartments: physical (substrate, hydrodynamics, water quality, acoustics...) and biological (benthos, fish, birds, mammals...).

Technical perimeter

- From test sites to industrial parks[4].
- The different phases of a project (installation, operation, decommissioning).
- Tidal stream turbine technologies under development (especially in Europe) that might be installed in France.
- Different construction components of the tidal stream projects (foundations, turbines, converters, cables).

0.6. Intended readership of the guide

The guide responds to a strong demand from developers of tidal stream projects and the associated research departments, but also the state services (and state operators such as the Agency for the protection of the marine environment) and the local authorities who will examine the applications.
This document may also be useful reading for those parties involved in the consultations that will accompany the installation of future tidal stream projects.

0.7. Contents of the guide

The guide is organised according to the different compartments of the affected ecosystems (Table 2). The physical and biological compartments of the marine ecosystems have been addressed separately in order to propose methodologies adapted to each one, in relation to the establishment of the initial state, the characterisation of the potential impacts and the environmental monitoring.

Table 2 (below) provides help for the reader on using this guide according to two criteria: the pressures[5] or the ecosystem compartments and usages.

First, the guide presents the regulatory context of tidal stream projects, the main tidal stream technologies and the consideration of usages of the maritime domain.

Second, for each ecosystem parameter or compartment, the guide describes:

- Methods for the definition of the initial state: spatial perimeter of the study, description of the ecological context, identification of relevant indicators and methodology for acquiring information.
- Methods for the identification and analysis of potential ecological changes.
- Methods for identification of cumulative impacts.
- Description of a typical environmental monitoring program.
- Suggestions for impact mitigation measures (removal / reduction / compensation / remediation).
- Deficiencies and research programmes to be developed.

[4] Test sites (prototype tests), pilot parks (several machines) are distinguished from pre-industrial (≈10 machines) to industrial (several tens to around a hundred machines) parks.

[5] Pressure: corresponds to the impact of pressure sources in the environment, possibly resulting in a change of state, in space or time, of the physical, chemical or biological characteristics of the environment. Order of 17 December 2012 concerning the definition of the good environmental state of marine waters (http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000026864150&dateTexte=&categorieLien=id).

	Pressures							
	Presence of structures on the seabed	Presence of structures on the seabed	Operation of the tidal stream turbines					
			Energy reduction	Chemical contamination	Turbidity increase	Acoustic perturbations	Electromagnetic perturbations	Thermal perturbations
Topography	§ 4.2							
Nature of the seabed	§ 4.2							
Sedimentary dynamics	§ 5.2.1	§ 5.2.1, 5.1.1						
Current		§ 5.1.1						
Swell		§ 5.1.1						
Environmental noise		§ 6.2.2				§ 6.2		
Benthos	§7.2.1, 7.2.2	§ 7.2.2	§ 7.2.2	§ 7.2.2	§ 7.1.2.4		§ 7.2.2	§ 7.2.2
Pelagic compartment	§ 8.2.1, 8.2.2	§ 8.2.1, 8.2.2	§ 8.2.2	§ 8.2.2	§ 8.2.1	§ 8.2.1, 8.2.2	§ 8.2.2	
Marine mammals	§ 9.2.3.2	§ 9.2.2, 9.2.3.3		§ 9.2.3.1, 9.2.5.2	§ 9.2.3.1	§ 9.2.4	§ 9.2.5.1	
Marine avifauna		§ 10.2		§ 10.2		§ 10.2		
Usages	§ 3	§ 3						

Table 2. Navigation table for the methodological guide on the environmental impacts of tidal stream turbine technologies.

The environmental effects (or pressures) correspond to modifications of a large range of environmental parameters generated by the presence and the operation of a tidal stream project. These effects interact with the physical and biological components of the marine environment. Each possible interaction can potentially give rise to an environmental impact, which can attain a significant level of ecological nuisance or benefit (Polagye *et al.*, 2011).
The effects to be addressed are therefore linked to:

- The presence of the machines:
  * static effects,
  * dynamic effects.
- Chemical effects.
- Acoustic effects.
- Electromagnetic effects.
- Energy extraction.
- Cumulative effects (each of these effects can be augmented by the deployment scale of tidal stream projects, the presence of other MRE projects and other usages that impact the marine environment).

1. Tidal stream energy

1.1. Context

The energy from tidal currents is the kinetic energy contained in the currents associated with the movement of water masses that accompanies the tidal phenomenon. A tidal stream turbine is thus a device that converts this tidal current energy into electrical energy.
Marine currents are in theory exploitable throughout the world, but tidal currents are presently the preferred domain for this type of technology because they have particularly favourable characteristics compared with regular currents (such as the Gulf Stream):

- Strong intensity: in certain zones, tidal currents can reach 10 knots or more[6], or 5 metres per second (m/s), while regular currents rarely exceed 2 knots.
- Proximity to the coast: streams of strong current appear in shallow areas located near the shore, or at topographical constrictions (capes, straits...), which facilitates the exploitation.
- Stability of flow directions: the alternating currents of the rising (flood) and falling (ebb) tides means that the flow directions are generally bidirectional, which simplifies the capture system.
- Predictability: the tidal currents are perfectly predictable since they depend only on the relative positions of the celestial bodies that generate them (moon and sun) and the local topography.

After the United Kingdom, France has the second most largest tidal power reserve in Europe, with a theoretically exploitable potential estimated at around 2 to 3 GW (source: EDF). The tidal stream resource in French territorial waters is concentrated off the tip of Brittany, between Ouessant and the continent, and around Cotentin, in the Raz Blanchard and the Raz de Barfleur (Fig. 2). Other zones like the Gironde Estuary and Paimpol-Bréhat have been identified as having a certain amount of tidal stream resources.

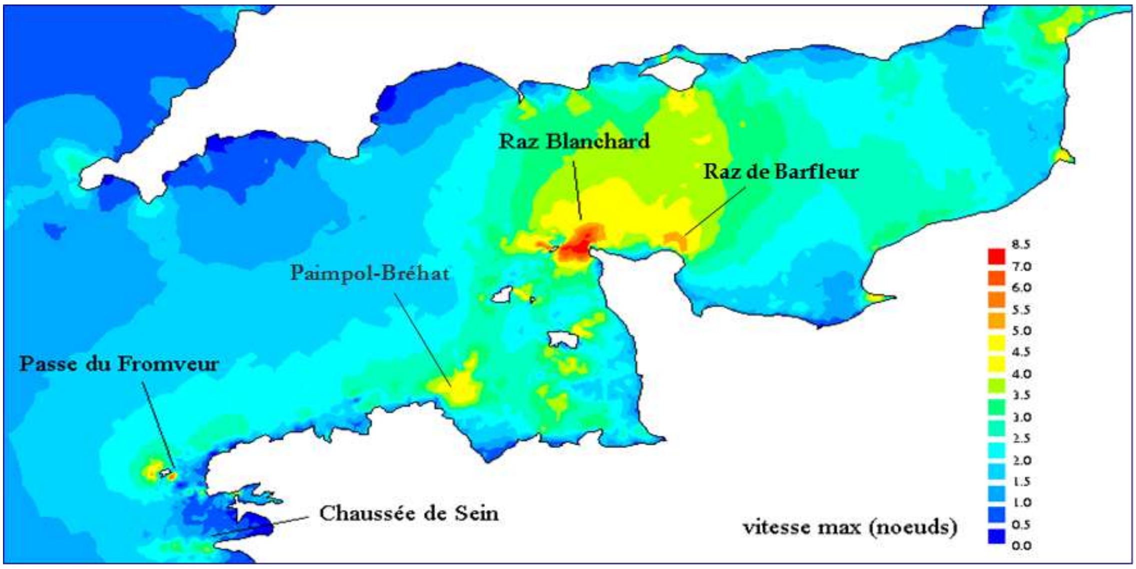


Figure 2. Ocean hydrokinetic resources off Brittany and Normandy coasts (source EDF)

[6] 1 knot = 0.51 m/s

1.2. Operating principle of a tidal stream park

The tidal current turns the turbine of a tidal stream station, for which several operating principles exist (see §1.3.). This rotation drives an alternator that produces a variable electric current. Depending on the technologies and the configuration of the tidal stream park (*a priori* consisting of similar turbines), different electricity conversion configurations can be foreseen (on land or at sea) in order to obtain electricity that is compatible with the electricity network (V, fixed).

In the case of pilot and industrial farms, and depending on the distance from the shore, the tidal stream turbines can be connected to an underwater junction box (or a converter station if necessary) via an underwater cable known as an umbilical (Fig. 3).

Even though the connection configurations vary depending on the technologies, the umbilical cables are not generally stabilized and are designed specifically to absorb the various movements linked to the swell and to the marine currents. The underwater junction box is mounted or fixed directly on the seabed or on a supporting structure.

The energy produced by the tidal stream turbines is then transmitted to the shore by means of one or more export cables connected to the public electricity network, via a delivery station.

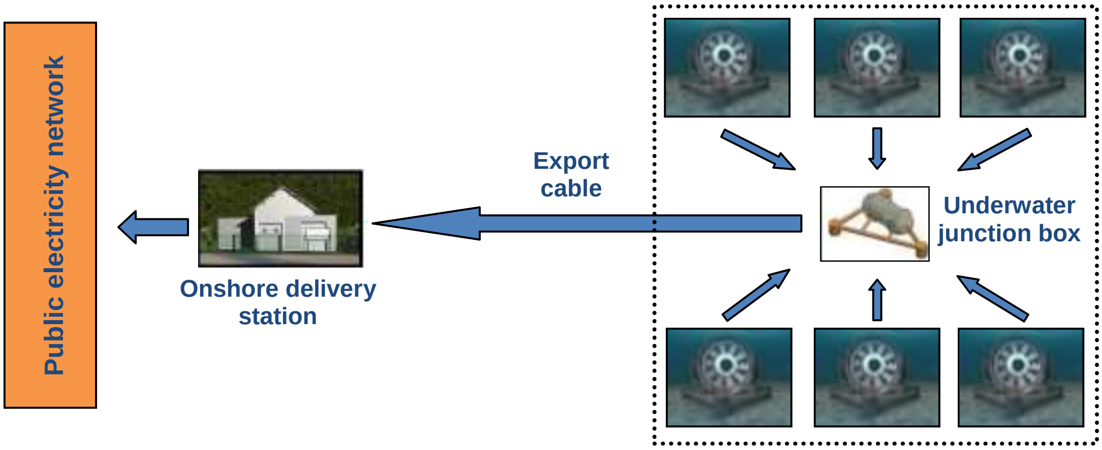


Figure 3 Diagram of the principle of a tidal stream park and the connection system (source: EDF – Openhydro example)

1.3. Tidal stream technologies

1.3.1. Overview

A tidal stream turbine is an underwater device that takes the kinetic energy of marine currents and converts it to electrical energy. The blades of the tidal stream turbine transform kinetic energy to mechanical energy. An alternator then transforms this mechanical energy to electrical energy. These technologies, designed specifically for the marine domain, are also exploitable in the fluvial or estuarial domains provided that the installation space is adequate. Tidal stream turbines can be distinguished from classic hydraulic turbines (Pelton, Francis, Kaplan…), which use the potential energy corresponding to the difference in levels between two reservoirs as the energy source.
A tidal stream station consists of several elements:

- **A turbine**: it collects the kinetic energy of the current and converts it to mechanical energy. Despite the large range of tidal stream technologies, two main types of turbines can be distinguished (Fig. 4):

  - Axial or transverse flow systems: these devices work in a similar way to an underwater wind turbine since the blades of a rotor convert the linear current to a rotation, then to electricity via a generator. The devices can be either horizontal flux or transverse flux turbines.

    These two types of devices can be associated with a special casing used to accelerate the fluid ("Venturi effect"). This is referred to as a channelled flux system.

  - Hydrofoil systems: this type of device consists of underwater "paddles" (also known as "flapping wings") operating a hydraulic system. The paddles oscillate as a result of the currents, thus compressing a hydraulic fluid. The pressure is then converted to electricity.

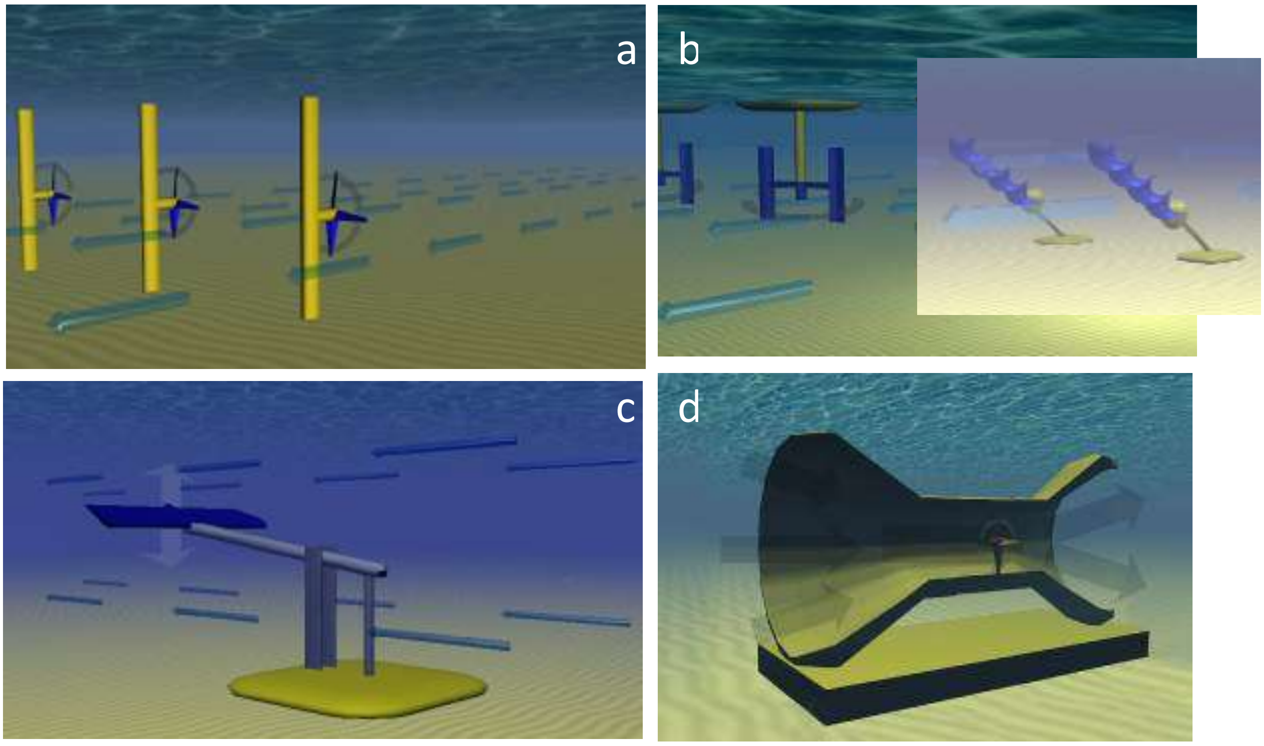


Figure 4 Different types of turbines: axial flux (a), transverse flux (b), flapping wings (c) and channelled flux (d) (source: www.aquaret.com)

- **A supporting structure** to maintain the turbine under the water, whose foundations can take several forms (Fig. 5):
  - Structure resting directly on the seabed (gravity foundation).
  - Pylon driven into the ground (mono- or multi-pile foundation, with or without jackets).
  - System floating in midwater or on the surface, fixed to the seabed by conventional (for soft sediments) or gravitational anchors.

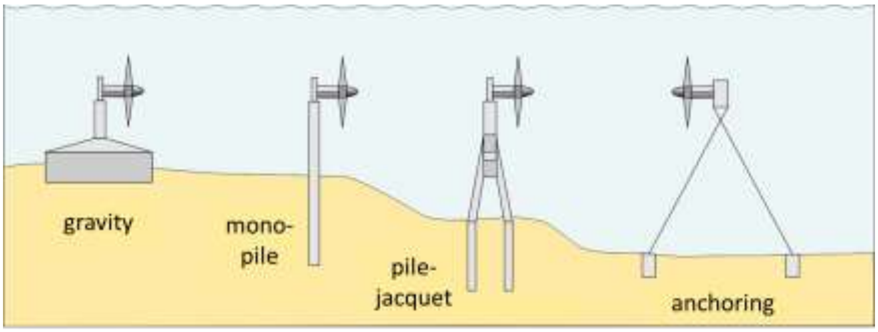


Figure 5 Different types of foundation

- **A mechanical transmission** (can include a multiplicator) and an **electricity generator** (Fig. 6).
- **Auxiliary elements** (potentially) to optimize the operation of the tidal stream turbine: control-command system, brake, electronic systems…

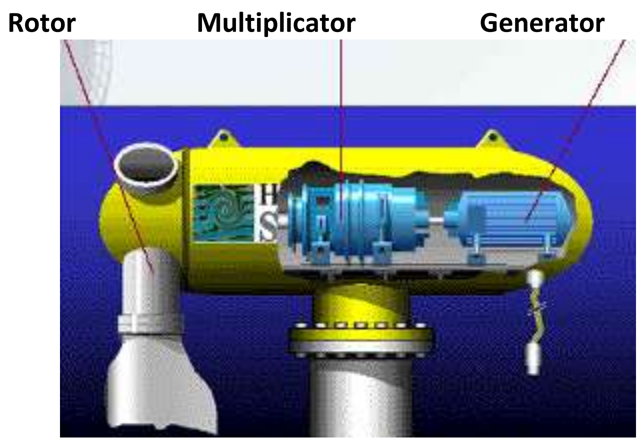


Figure 6 Example showing the elements of a tidal stream turbine

1.3.2. Tidal stream turbine designs

Like other types of marine energy, the development of tidal stream turbine technologies has accelerated rapidly in the last few years. Almost a hundred tidal stream turbine designs are currently in the development phase around the world. By varying the dimensions of the turbine, these tidal stream designs are aimed at both the marine domain and the fluvial and estuarial domains. For the sake of clarity, only European technologies that are adapted to the marine environment and that are at an advanced design stage are presented in this section (Tables 3 and 4).

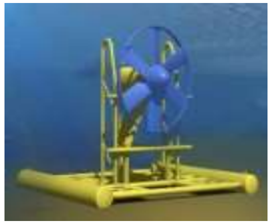
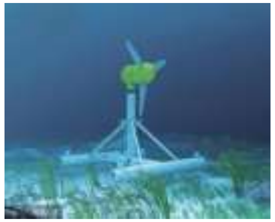
	GRAVITY FOUNDATION				
Constructor	**Andritz**	**Sabella**	**Voith Siemens**	**Openhydro**	**Atlantis Resources**
Technology name	**Hammerfest Strom**	**D03, D10 et D15**	**HyTide**		**AK 1000**
Illustration (*sources: develop-er web sites* or *energiesdelamer. blogspot.fr*)					
Power (MW)	1	0.2 to 2 MW	1	0.5 to 2	1
Ext. Diameter (m)	23	3 to 15	16	6 to 16	18
Height (m)	30	5.5 (D03) to 16 (D10)	30	21 (for the ϕ16m)	22.5
Foundation	Gravity tripod with ballasts	Gravity platform	Gravity platform (or mono pile)	Gravity tripod	Gravity tripod with ballast
Total weight (tons)	300	290 (D10)	200	850 (ϕ16)	1300
Rotation speed (r/min)	10	10 to 15		3 to 7	
Maintenance principles	Lowering and raising of the nacelle independently from the tripod	Lowering and raising of the turbine independently from the platform	Lowering and raising of the turbine independently from the platform	Raising of the complete turbine + tripod	Lowering and raising of the nacelle independently from the tripod
Feedback	Prototype of 0.3MW tested in Norway (2003 to 2009) Prototype of 1MW tested at the EMEC (2011/2012)	D03 prototype tested in the Bénodet estuary (2008/2009) Demonstration project in Fromveur	Prototype of 0.1MW tested in Korea (2007) Prototype of 2MW tested at the EMEC (since 2011) Pilot park project in the Raz Blanchard (2015)	OT6 prototype tested at the EMEC (2008) OT10 prototype tested in the Bay of Fundy (2009) OT16 prototype (0.5MW) tested at Bréhat (2011) Pilot park project in the Raz Blanchard (2015)	HS 1000 0.5MW prototype tested at the EMEC (2010)

Table 3. Examples of different tidal stream turbine technologies (source: EDF)

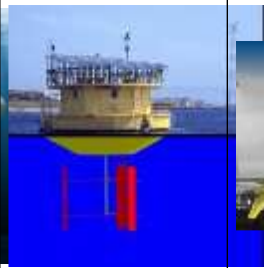
	GRAVITY FOUNDATION		MONO- AND MULTI-PILE FOUNDATION			FLOATING STRUCTURES	
Constructor	**Lunar Energy / Rotech**	**Flumill**	**Alstom**	**Marine Current Turbines / Siemens**	**Verdant Power**	**Ponte di Archimede**	**Scotrenewables Tidal Power Limited**
Name of the technology	***(projet à l'arrêt)***		**TGL**	**SeaGen**		**Kobold turbine**	**SR250**
Illustration (*sources: developer web sites* or *energiesdelamer.blogspot.fr*)							
Power (MW)	1	2	1	1.2	1.2	0.03 to 0.05	0.25
Ext. Diameter (m)	15	≈8	18 to 20	2 x 16	16	5	8
Height (m)	20	≈45	23	21	21	5	Length: 33 m
Foundation	Gravity tripod	Gravity	Tripod fixed by piles	Quadripod fixed by 4 micropiles	Mono-pile	Floating platform	Anchored floating structure
Total weight (tons)	2 500	160 – 200	150				100
Rotation speed (r/min)				14			
Maintenance principles	Lowering and raising of the turbine independently from the tripod	Possibility to raise the turbine to the surface	Raising of the nacelle to the surface by floatation	Tower-hoist to lift the turbines out of the water			Possibility to raise the turbines to the surface
Feedback	Prototype of 1MW tested in Korea (2009) Project of 300MW in Korea (2015/2016)	Prototype tested at the EMEC between sept 2011 and january 2012	Prototype of 0.5MW tested at the EMEC (2010) Test of a prototype of 1MW at the EMEC in progress (2013) Project of pre-commercial farm of 4-10MW (2014/2016)	Seaflow prototype of 0.3MW tested off Bristol (2003 / 2009) SeaGen prototype tested in Northern Ireland (since 2008)	Prototype tested in New York (2002-2006): Installation of 6 turbines connected to the network (2008-2012)	Enermar pilot project in Sicily (since 2004) Test of a prototype of 0.07MW in China (since 2006)	Prototype tested at the EMEC (2011/2012) Development project for a prototype of 2MW

Table 4. Examples of different tidal stream turbine technologies (source: EDF) - continued

1.3.3. Summary of the potential impacts of tidal stream technologies

Tidal stream technology is still in the development phase, giving rise to various types of turbines or installation modes. The different designs will have very different environmental impacts: the main impacts of a floating tidal stream turbine and one with a mono or multi-pile foundation, will not concern the same environmental compartments.

Before their development on an industrial scale, the designs can be evaluated at test sites, then at pilot sites, with the goal of verifying the relevance (feasibility, suitability for the site, energy efficiency…) and the environmental impact. As a result, it is likely that the current designs will evolve, or even that "types" will emerge that are adapted to a specific site configuration (depending on the depth, the distance from the shore, the nature of the seabed, the strength of the currents, local environmental issues…).

Finally, the environmental impacts of the project, in addition to being dependent on the local characteristics, will vary not only with the type of turbines, but also with the size of the park and the electric connections.

1.4. Electric connections

1.4.1. Context

This guide addresses the environmental and socio-economic implications of a production park itself, but it is also important to integrate the system for energy transport to the landing point because, although it is not specific to the tidal stream technology used, the electric connection can be critical in terms of potential impact.

The production capacities of a tidal stream park can be very different depending on whether it is experimental, pre-commercial or industrial. The power involved, as well as the location of the production installations, has an effect on the strategies for connection to the electricity network.

According to a study by the "*Réseau de Transport d'Electricité*" (RTE) company[7], the experimental or pre-commercial farms with an installed power between 17 and 100MW can be connected to the public transport network[8] via a delivery station situated onshore[9]. This installation schema is shown in figure 3. Certain stations can be underwater.

For industrial parks with a greater power level (over 100MW), it is probably unfeasible to individually connect the farms to a ground station, given the large number of medium voltage cables that would be needed and the associated number of landing points. The installation of transformation platforms at sea, similar to those used for offshore wind parks, should be forseen (Fig. 7). This solution avoids multiplying the connections between the farms and the land, but has a certain visual impact in the case of above-water solutions. Given the current status of the technologies, underwater cables of 225kV will be installed by RTE between the platforms and the onshore delivery station. R&D work is in progress to develop high power underwater stations.

[7] "*Accueil de la production hydrolienne*", Prospective study by the RTE, january 2013

[8] To the public distribution network, for farms with power less than 17MW.

[9] The delivery station can contain a transformer, protection and breaking equipment, and a control-command and communication interface.

Figure 7 Examples of electric current transformation platforms at sea

1.4.2. The export cable

Currently, the connection problems concern tidal stream parks of low to medium power, whose main goal is to allow technology developers to test and validate the performance of demonstrators under real conditions. The tidal stream parks are therefore connected by an export cable to a delivery station located onshore. Total cable diameter is generally less than 20 cm. It is installed conventionally by a cable ship. Since it is, at least partly, located in zones of strong current, the cable may require stabilisation in sectors with rocky seabeds where it cannot be embedded, even if it already has a weighted protective sleeve. The environmental impacts are then potentially different, depending on the means employed, which themselves depend on the environmental context and the local possibilities (available resources and materials).

1.4.2.1. Anchoring or weighting of cables on a hard substrate

❖ Anchoring

Two types of anchoring can be envisaged. Sealed anchoring is performed using threaded stainless steel rods that are screwed into a pre-drilled hole. The seal is chemically secured by injection of an epoxy resin. Mechanical anchoring involves screwing a threaded screw in a clean, pre-drilled hole.

In both cases, rotary-percussion drilling is performed by divers using a hydraulic drill. The underwater cable is then fixed to the anchoring system by means of an anchoring ring (Fig. 8).

Potentially, the environmental implications will mainly concern the sound environment and local pollution risks.

Figure 8 Hydraulic drill - Example of an anchoring ring

❖ <u>Concrete mattress</u>

The (pre-assembled) concrete mattresses consist of a mesh of concrete blocks connected by a polypropylene rope. They are generally placed discontinuously along the cable. The standard dimensions of a concrete mattress are 6m in length by 3m in width. They are installed from a barge equipped with a crane and a hoist (Fig. 9). The negative impact caused during installation on benthic habitats could be offset by the new habitat offered by this type of structure.

Figure 9 Concrete mattress (source: BERR 2008)

❖ <u>Shells</u>

Customized metallic shells can also be installed around the cable, when it is laid, in order to protect it from abrasion and to increase its weight and stability (Fig. 10).
This system does not generate *a priori* any significant additional impact compared with the cable itself.

Figure10 Installation of shells (source: EDF)

❖ <u>Rockfills (Rock Dumping)</u>

This technique involves covering the underwater cable to a varying height with blocks of stone (Fig. 11), using a barge equipped with a crane fitted with a grapple (for small volumes) or by piling or "directional" injection (for large volumes).
The environmental impact is then linked to the implementation of the technique (temporary degradation of the water quality, increase in noise levels…) and the increased footprint. In the longer term, the rockfills represent new habitats for the biocenoses.

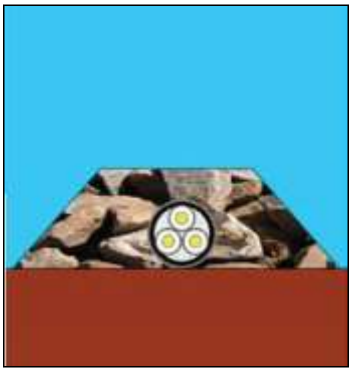


Figure 11. Example of rock dumping (source: RTE)

❖ Concrete blocks or weights

The installation of concrete blocks or weight structures is generally used to weight and fix the conduits, thus securing them on the seabed (Fig. 12).

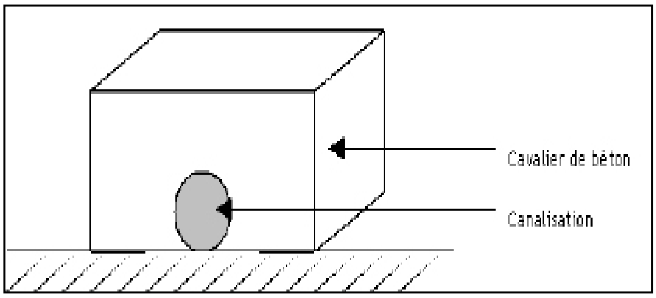


Figure 12. Concrete weight (Source: CETMEF)

This technique can however be used to locally stabilise an underwater cable at a certain number of points in the structure that have been identified as particularly critical. The concrete structures are then placed over the cable using a crane and divers who guide the installation underwater. As for the concrete mattresses, the environmental impacts will concern the footprints (benthic biocenoses, see paragraph 7.2).

1.4.2.2. Embedding in soft substrates

Embedding involves digging a channel in the seabed to lay the cable in (Fig. 13).

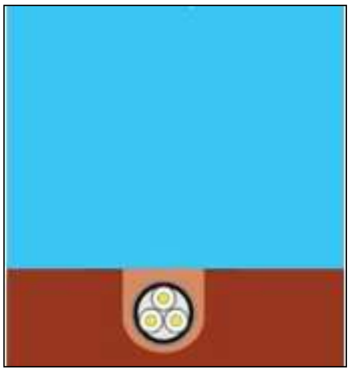


Figure 13. Example of cable embedding (source: RTE)

In a seabed composed of fine or sandy sediments, the "jetting" technique, using a high-pressure water or air jet, is used to loosen the sandy or muddy material and to continuously open up a trench in which the cable is laid (Fig. 14). For coarser materials or more difficult terrain, a plough is a better tool. The principle of embedding and laying is then identical to that of jetting (Fig. 15). These techniques allow the continuous laying and burying of the cable and require a cable ship. Depending on the nature of the seabed, they can be used to bury the cable to a maximum depth of 2 to 3m.
In addition to the disturbance of the materials caused by the embedding and refilling, these operations generate a resuspension of materials, whose sedimentation is most often localised within a zone of 10 to 20m around the laying axis (Knudsen *et al.,* 2006, Wilhelmson *et al.,* 2010).

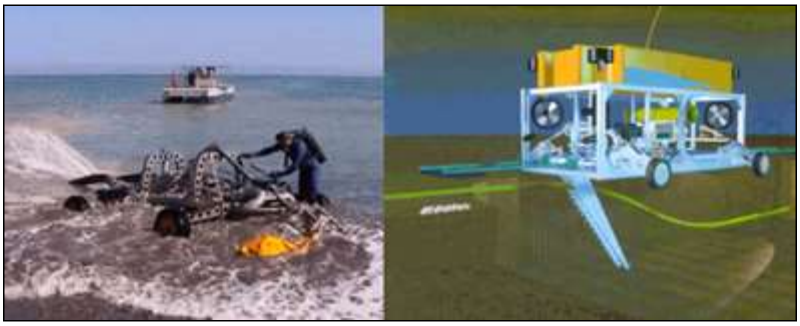


Figure 14 Jetting technique (source: RTE)

Figure 15 Embedding plough

Figure 16 HRB

Figure 17 Splitter (source: RTE)

For hard substrates, a hydraulic rock breaker (HRB) or a splitter can be used to open a trench and lay the cable, before covering it again with debris (Fig. 16 and 17). In this case, the sonic environment is also significantly affected during the operations.

1.4.3. Landing

The landing zone is the point where the underwater cable is connected to the ground network. In general, suitable zones are rare and represent the critical factor in the strategy for the connection of the tidal stream power.
The choice of operating method for the laying of the terminal part of the underwater link depends on the physical characteristics of the coastline, on the statutory protection status and the ecological sensitivity of the environments and their usages.

❖ Landing by trench

The operation of cable laying and embedding on the beach can be achieved using onshore mechanical equipment (Fig. 18). The trench is usually dug using a mechanical shovel with a narrow bucket. The embedding depth should be adjusted to avoid all risk of exposure in case of strong storms. At the end of the operation, the site is restored to its former physical state. The operations thus generate the "classical" effects of excavation sites (noise, disturbance of the fauna and usages…).

Figure 18 Laying work on the beach (source: EDF)

❖ Landing by directional drilling

At some sensitive coastal sites or in the presence of a dune ridge, directional drilling can be used to reduce the impacts, by passing directly under the foreshore or the dune environments without making trenches (Fig. 19).

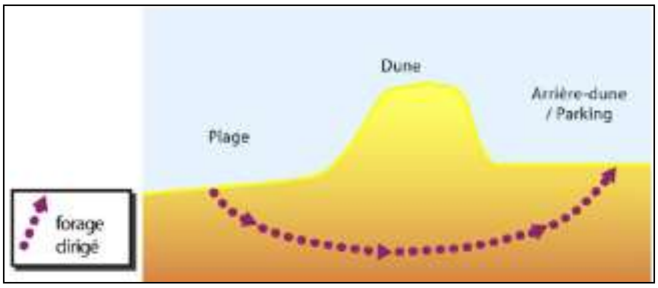


Figure 19 Schematic diagram of directional drilling

The underwater and onshore parts of the cable are connected in an underground walled space called the junction box (Fig. 20). This is generally positioned inland from the beach.

Figure 20 Junction box (source: RTE)

1.4.4. Delivery station

The purpose of the delivery station is to ensure the interface between the production park situated at sea and the public electricity network. The station is needed to provide an easy-access means of shutdown and to house the distribution network protection systems. It also contains the energy meters and ensures that telemonitoring information is relayed from the tidal stream park.
The connection to the electricity network can be made at an existing delivery station or may require the construction of a new building. Taking into account the sensitivity of the coastline and the regulations related to urban planning, careful landscaping and architectural integration of the building is needed.
It is important to note that the potential impacts specifically linked to the onshore delivery station are not addressed in this guide.

1.4.5. Summary of potential impacts of the electric connection

The installation and operation of the electric connection cables can impact different environmental components, and are therefore to be considered, in the same way as the tidal stream park itself, in the assessment of the environmental implications of the project. The environmental components that are potentially concerned (and the "intensity" of the potential impacts) are not the same in the installation / decommissioning phases as in the operation phase. They also vary according to the stabilisation techniques potentially employed.
Each case is therefore unique. Nevertheless, the main compartments potentially impacted by the connection cables are the local usages of the area (navigation, etc.), the noise, the water quality and the benthic compartment during the installation operations; and mostly the benthic biocenoses during the exploitation phase (linked to the modification of the habitat and the local currents and/or the possible effects on the temperature or the electromagnetic fields).

1.5. Conclusions: specific needs for impact assessment

The assessment of the environmental implications of a tidal stream park at sea should thus be based on the "interference" between the different components of the park and the different environmental components, including functional components, in which it is integrated.
The technical information that should be provided in the impact study is summarized in table 5 (excluding decommissioning, because it is difficult to identify the precise procedures that will be implemented; the principles that are envisaged for the decommissioning of a park are only briefly covered).

1.6. Recommendations

For project design, the recommendations are:

- Integrate the sequence of actions Avoid – Reduce – Offset (MEDDE, 2012), at a very early stage and throughout the project.
- Take into account the environmental sensitivities and the activities of sea users at each stage of the project. To achieve this, regular consultations are necessary as the project progresses.

When drafting the "project description" part of the impact study, it is recommended to include as many illustrations, diagrams, maps, photographs as possible, to help reader understanding.

		Installation
Park	General planning (administrative, technical, work stages), project costs	Location (map), geographic coordinates, surface, depths, number and arrangement of machines, unitary and total power, demarcation (navigation), maintenance (frequency, duration, nautical resources)
Turbines	Resources (type of ship, duration and period of installation), means of stabilisation	Type of machine, dimensions, type of foundation / structure, operation (rotation speed and axis, duration of operation), blade tip speed, specific products (antifouling, lubricants, anti-corrosion protection…), emitted noise (intensities, frequencies)
Underwater electric converters	Resources (type of ship, duration and period of installation), means of stabilisation	Dimensions, cooling system, specific products
Transformation platform	Resources (type of ship, duration and period of installation)	Location (geographic coordinates), dimension (underwater / above water), means of access
Umbilicals	Resources (type of ship, duration and period of installation)	Number, length, type of connection, underwater junction box
Export cable	Resources (type of ship, duration and period of installation), type of protection and stabilisation (embedding and/or laying) (technical characteristics, quantities); work methods at the landing point.	Landing corridor (geographic coordinates, length, width), distance from the shore, maps, characteristics of the transported current (power, frequency, voltage…), expected electromagnetic field
Delivery station	Implementation plans	Location, surface area, plans, emitted noise

Table 5. Technical informations to be provided in the environmental impact study for a tidal stream park project (excluding decommissioning)

2. Legal framework

2.1. Regulatory procedures applicable to tidal stream projects

Depending on the project, the construction of a tidal stream park at sea is subject to different regulatory procedures summarized in table 6. Some of these procedures require an impact study (and a public enquiry[10]) under the Environmental Code.

Prior to their establishment, electricity production installations using tidal stream energy are subject to an authorisation for exploitation under the Energy Code (article L311-1 of the Energy Code).

Regulatory framework applicable to tidal stream parks at sea
Declaration or authorisation for the exploitation of an electricity production installation
Temporary occupation permit or a concession for use of the public maritime domain *Impact study and public enquiry*
Authorisation under the Water Act *Incident study (or impact study constituting the incident study) and public enquiry*
Advance declaration or authorisation under the town planning Code (for the onshore parts) ***Potentially Coastlines Act procedure*** *(public enquiry, if crossing an outstanding area or in the 100m strip)*

Table 6. Regulatory framework applicable to tidal stream parks at sea – additional procedures may be required depending on sites (Natura 2000, derogation for damage to protected species, etc).

[10] A public enquiry may be compulsory depending on the size of the project investment.

The project developer must also obtain a temporary occupation permit or a concession for use of the public maritime domain (articles L-2122-1 and L. 2124-3 of the general code on public property – CG3P)[11]. These authorisations take the form of a prefectural order and grant the petitioner a title of occupancy of the public maritime domain for the duration of the works and their future exploitation.

In the context of a concession for use of the public maritime domain (whose duration cannot exceed 30 years), an agreement, negotiated between the regulatory authorities and the developer, and annexed to the prefectural order, specifies notably the subject of the concession and the technical requirements that must be respected by the developer, including those concerning the rehabilitation of the site at the end of the exploitation. It fixes the modalities for use of the granted state dependencies and establishes the amount of the fee to be paid to the State.

When the works have a direct impact on the marine environment and represent a sum greater than 1.9 million euros, the developer must obtain an authorisation under the Water Act (articles L 214-1 and the following of the Environmental Code), delivered by prefectural order. The installation works of a tidal stream park at sea depend more specifically on the section 4.1.2.0 of the nomenclature annexed to article R.214-1 of the Environmental Code regarding "port planning and other works made in contact with the marine environment and having a direct impact on the environment". The prefectural order of authorisation fixes the specific requirements related to the conditions for construction, development and operation of the project. Furthermore, at the end of the construction and operation period and according to the provisions of article L 214-3-1 of the Environmental Code, the operator or otherwise the owner, must rehabilitate the site so that the objective of balanced management of water resources is in no way undermined.

The town planning code (art. L421-5 and R 421-8-1) exempts certain installations from any town planning authorisation due to "their nature and their installation at sea, in the public maritime domain and submerged beyond the low tide mark". As a consequence, tidal stream parks and the export cables at sea are exonerated.

Onshore, the laying of an underground cable is exempt from town planning formalities according to article R421-4 of the Environmental Code. *A contrario*, the establishment of an onshore electrical station does not fall within the scope of this Article and must be the subject of an advance declaration or a building permit application depending on the floor area and the footprint. These requirements can be reinforced if the station is located in a protected site (listed or classified site, parks or reserves…).

The instruction procedure for these different authorisations includes:

- An administrative consultation with the state services (DDTM, DREAL, Maritime prefectures…), the local authorities concerned by the project and, when necessary, the management bodies of the Marine Protected Areas.
- A public enquiry to be conducted under the Environmental Code (Water Act), concerning the occupation of the public maritime domain if the concession regime is chosen, and possibly under the Coastlines Act (for example, such an enquiry is compulsory if the cable passes in the 100 metre strip or in an outstanding area) which can be conjoint with the different regulatory procedures if the authorisation applications are deposited concurrently.

[11] A concession is only granted for the use of PMD for use by the public, a public service or an activity of general interest (art. R 2124-2 of CGPPP), while the TOP can be requested by / granted to any developer.

2.2. The environmental assessment

Under the Environmental Code and the General Code on Public Property, applications for concession of use of the public maritime domain and for authorisation under the Water Act must be accompanied by an impact study (Fig. 21) and, if applicable, by a Natura 2000 impact assessment.
Tidal stream turbine projects are directly concerned by section 27 (energy production at sea – compulsory impact study) and possibly by sections 10 (recovery of the area of the public maritime domain - compulsory impact study or on a case-by-case basis, depending on the surface area involved) and 11 (shoreline work – impact study on a case-by-case basis) of the table annexed to article R 122-2 of the Environmental Code.

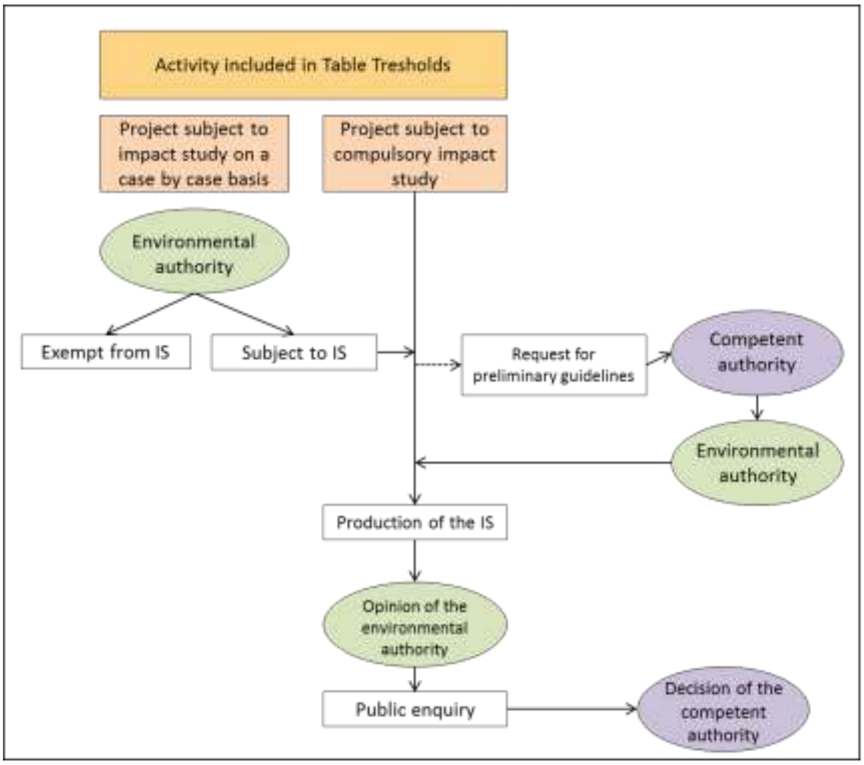


Figure 21. Flowchart showing the environmental assessment procedure

2.2.1. Preliminary guidelines

Before writing the impact study, the developer can request preliminary guidelines from the competent Authority making the authorisation decision for the project, who then consults the Environmental Authority.
The guidelines (defined by L122-1-2 and R122-4 of the Environmental Code) aim to inform the developer about:

- Degree of precision required in the information to be provided in the impact study.
- Zonings, schemas, inventories related to the zone liable to be affected.
- Other known projects with which the cumulative effects need to be studied.
- The possible need to study the important effects of the project on the environment of another State (Espoo Convention).
- The organisations likely to provide the developer with useful information for the establishment of the impact study.

The guidelines can also give details about the appropriate perimeter for the study of each impact of the project.
The developer can also ask the competent Authority to organise a consultation meeting with the local stakeholders, again before writing the impact study.

The whole procedure does not presuppose in any way the decision that will be taken at the end of the administrative investigation procedure. In addition, the opinion expressed does not engage the administration on the content of the impact study.

In their request for preliminary guidelines, the developer must provide a minimum of elements concerning the main characteristics of the project and the zone it is likely to affect (main environmental issues, major impacts) and where appropriate, any possible interactions with other projects, works or developments for which they are the manager.

Note that the Environmental Code does not define a deadline for rendering this opinion.

2.2.2. Principle and content of the impact study

The content of the impact study should be **proportional to the environmental sensitivity** of the zone likely to be affected by the project, **to the importance and the nature of the works and developments** proposed and **to their foreseen effects** on the environment or human health.

The content is defined by article R122-5 of the Environmental Code (EC). It includes, amongst other things and typically:

- A description of the project, with its different components (turbines, cables, converters/transformers; works at sea and onshore), and its different phases (installation, operation and maintenance, decommissioning).

- A description of the initial state of the project zone likely to be affected.

- An analysis of the consequences of the project for the environmental components and human health within its zone of influence (taking into account the principles of proportionality).

- A presentation of measures foreseen to avoid and reduce the substantial negative effects and offset, whenever possible, the important residual negative effects, which could not be avoided or sufficiently reduced.

- An analysis of the project accounting with the different management and guidance documents in the domain of the protection of aquatic environments (SDAGE, Action Plan for the marine environment provided for by article L. 219-9 of the Environmental Code…), natural environments (Natura 2000 network, etc.), landscapes (Classified sites, outstanding coastal areas), and with the "*Schéma de Mise en Valeur de la Mer*" (when one exists)…. These plans and programmes are defined in R122-17 of the Environmental Code.

The reform of December 2011, resulting from the Grenelle Environment Acts, introduced new thematic areas to be analysed (such as **cumulative effects**) and reinforced the consideration of the **ARO doctrine (**Avoid – Reduce – Offset). The new additional key points of this environmental assessment thus concern:

- An analysis of the **cumulative effects** of the project with other known projects (see art. R122-4-6° of the EC): projects for which the opinion of the environmental authority has been rendered public or, for projects subject to the Water Act not requiring an impact study, which have been the subject of an impact assessment report and a public enquiry.

- The presentation of an outline of the **main alternative solutions** examined by the petitioner or the project developer and the reasons for which, in view of the effects on the environment or human health, the presented project was selected (Avoid – Reduce).

- The presentation of the main methods for **monitoring the ARO measures** and their effects, an estimation of the costs related to these measures, as well as a statement of the expected effects of these measures.

The impact study can replace the impact assessment report required under the Water Act (Act n° 2006-1772 of 30/12/2006), if it contains the necessary information. Similarly, it can replace the Natura 2000 impact assessment study, if it contains the information required by this regulation.

2.2.3. Opinion of the Environmental Authority

Finally, note that the project impact study is subject to the opinion of the environmental authority (art. L122-1 III of the Environmental Code). The authority is different depending on the nature of the project in question. In this case, for projects under prefectural orders, it is the Prefect of the Region. This opinion, an indispensable part of the procedure, together with the public enquiry if it is available, should be rendered within two months of the referral to the Environmental Authority by the authority competent to authorize the project.

2.3. Specificities and difficulties of the environmental assessment of a tidal stream project

Marine tidal stream projects have the particularity of being, even more than others, geographically constrained by the available resource (the tidal current), which favours the comparison of impact assessments and the collection of feedback. Indeed, the potential geographic areas in which they occur are well defined and their marine components generally have common characteristics (e.g., hard seabeds, strong hydrodynamics with specific biocenoses, high noise levels, reduced usage, etc.).

These characteristics also mean that the environments are also not well known in terms of biodiversity, noise and, more generally, their ecological functionalities. Collecting data can indeed be quite difficult in these environments (marine conditions, currents), and they have been little studied as yet.

Another important challenge for the environmental assessment of the marine tidal stream turbines lies in the fact that the technologies are currently being developed, and there is to yet any real *in situ* feedback of their impacts.

To date, the assessment can only be done based mainly on an analysis of "**potential functional interference**" between the different components of the tidal stream park and the components of the marine environment. The implementation of demonstrator parks and test sites represent important steps to better understand these interactions, and to improve the environmental assessment of future industrial parks.

As a corollary to these difficulties, there still exist few or no compensatory measures so far identified related to the offset of important residual effects on the ecological functionalities or the marine biocenoses (at least in high energy environments).

2.4. Recommendations

For all types of industrial tidal stream project at sea, the main recommendations are:

- To conduct surveys and studies of the environment and usages at a very early stage of the project, typically several years before the projected date of entry into service. These studies and local consultation processes serve the project design, the identification of possible technical alternatives, the progressive assessment of potential implications of the project for the environment, etc.

- To apply the Avoid-Reduce sequence at all stages of the project design. This process reduces or gradually restricts the "range of possibilities", but permits the best techno-economic and environmental compromise, and facilitates societal acceptability.

- To integrate the feedback from the test sites.

3. Consideration of usages

3.1. The different potential usages, affected or not

There are numerous usages of the sea that operate in the three dimensions, occupying the surface, the water column or the seabed. All these usages can be potentially affected, to a greater or lesser extent, at the different stages of a tidal stream project.
The project developer should therefore establish, as early as possible, an overview of the usages on the project site and in the surrounding environment, which are potentially concerned by the works.
These usages can be:

- Commercial navigation (of people or goods).
- Professional fishing, including shore fishing (for the landing zone).
- Marine cultures (shellfish aquaculture, algae culture…) and marine livestock (fish farms…).
- Recreational: fishing (leisure fishermen, onshore fishermen…), bathing, boating, scuba diving, hiking, nature observations, etc.
- Dragging of sediments.

Other usages related to the extraction of mineral resources such as marine aggregates, for example, are *a priori* relatively unconcerned by potential tidal stream projects, since favourable sites for one usage are not generally favourable for another. However, the presence of a tidal stream turbine site that is closed to shipping forces shipping to be diverted, which can induce extra operating costs for extractors.

3.2. Characterising the usages and assessing the impacts

It is essential to properly characterize the different maritime usages, both spatially (perimeters concerned) and temporally (variability of usages depending on the season), but also from the point of view of their importance in the local or regional economy, or relative to the well-being and quality of life of residents.
This characterisation should be quantified as far as possible (especially for the usages with local economic benefits), via the exploited resources, the number of direct or indirect jobs, or the direct or indirect revenue generated. Possible information sources include the administrations in charge of the Public Maritime Domain (DDTM, Maritime prefecture, Departmental prefecture), the Marine Protected Areas Agency and the MPA management bodies (such as the Marine Natural Parks who produce "vocation maps" localizing the most favourable zones for each usage), the chambers of commerce and industry, the ports, committees of maritime fisheries and marine fish farming, professional organisations, tourist offices, town councils, INSEE or other statistics…
Concerning the recreational usages, it is often difficult to quantify the importance of the usage itself, in the absence of commercial structures overseeing them. In this case, it is then useful to survey the administrations (DDTM), associations (recreational boat users, environment, sport or culture) and the municipalities concerned.

This cartography of the usages can be used to identify or prioritize the potential temporary or permanent interference with the project. The interference can lead to:

- A disturbance to the usage (with or without modification of the modalities of the usage). This disturbance can be temporary or permanent, and it is generally localized in the area of the park or the cables.
- A halt in the usage for the duration of the works and/or the operation of the park.
- In some cases, the disturbance or total ceasing of a usage can lead to a transfer of the activity to another area. This may be the case for maritime navigation and fishing (draught insufficient to cross the park), and activities carried out on the coast (landing of the cable).

This cartography can also be used to identify possible ways to avoid or reduce the most significant impacts. Depending on the techno-economic feasibility for the project promoter and the compatibility with environmental sensitivities, this may concern:

- Choice of implantation site and repartition of the turbines (as well as the choice of their technology).
- Choice of the periods for work at sea (offshore and on the coast) for the park and cable installation works, or maintenance.
- Choice of the cable routing (only to a certain extent). Note that a collaborative framework is currently being drafted between RTE and the professional Fisheries Committees to define the main principles and means of consultation concerning cable routes.

3.3. Fishing activities (professional and recreational)

Data related to the volumes and values of landed products, as well as the associated fishing effort can be estimated through the declarations of fishing professionals, via the administration in charge of maritime affairs (fishing monographs published by the DDTM and DML), DPMA, PMA Agency, auctions and professional structures for product commercialisation. The summaries produced by the Ifremer Fisheries Information System can also provide information.
However, some deficiencies have been identified concerning the interactions between the fisheries and the other users (SGWTE, 2012), which may lead to an undervaluation of the activities and consequences induced by a tidal stream turbine site:

- Transfer of the fishing effort.
- Spatial knowledge of the activity of small ships in coastal areas[12].
- Lack of information on the other usages (in the absence of spatial planning).

[12] Potential sources: professional structures (via their fishery observatories when they exist)

During the construction phase: the effects on fishing are due to navigational restrictions and the temporary removal of fish due to the construction work (e.g. noise, see chapter 8).
During the operation phase, two hypotheses can be envisaged depending on whether the site will be open or prohibited to any form of navigation.

<u>1: Case of prohibition</u> (all forms of activity are therefore impossible):

- ➢ Existing activity such as professional fishing (all types of sector): the loss of one or more fishing zones can lead to a cessation of activity (in the case of a ship entirely dependent on a zone) or more likely transfer of the fishing effort to adjacent zones and thus the risk of exacerbating any existing space and usage conflicts between sectors and fleets.
- ➢ However, this suppression of pre-existing human activity, accompanied by a new activity (MRE), is liable to induce a modification in the local biological equilibria.

<u>2: Case of restricted access for certain types of activities:</u>

Although the zones suitable for tidal stream turbines are generally not favourable for certain fishing activities (presence of hard seabeds and strong currents), due to the presence of artificial structures in the water column and on the seabed, the site can be made inaccessible to certain fishing sectors, notably trawling. However, passive methods could potentially be practiced (notably depending on the arrangement of the turbines within the park). In the absence of official restrictions on access to the site and/or on the route of the cable, it is possible that fishermen, fearing a potential risk of collision or damage, themselves decide to no longer use the site. There would then be avoidance *de facto*.
In the USA, a "gentlemen's agreement" has been signed between an underwater telecommunications cable operator and fishing representatives in order to give priority to safeguarding the cable in case of collision, by abandoning trawling in the sea, with financial compensation measures for the fishermen.

Note also that, due to their characteristics (hydrodynamics, spatial distribution and configuration of submerged structures), tidal stream turbine sites are likely to interact more strongly with fishing activities than would a wind farm.
During the decommissioning phase, the effects are identical as during the construction phase (Bald *et al.,* 2010).

3.4. Recommendations

In conclusion, it is strongly recommended that project developers identify very early, in addition to the ecological sensitivities, all usages that may be impacted by the project. Spatial planning, implemented by the PMA Agency in the framework of the MSFD is then useful. The developers should work with representatives of the usages in place to identify and integrate impact avoidance and mitigation measures as soon as possible and throughout the development. For example, the data available on fishing activity can be optimized with the collaboration of professional structures.

Physical environment

A precise characterisation of the physical environment is necessary and vital in order to assess the potential interactions between the structure(s) and the marine environment.

This "Physical environment" chapter deals only with the parameters that should be taken into account from the point of view of environmental impacts and does not consider dimensioning, which is inherently dependent on each technology and not the subject of this guide.

The physical data that must be taken into account to estimate the potential impacts of a tidal stream project on its environment concern:

- **Morphology of the seabed:** the analysis of the bathymetry can be used to assess the reliefs on which the structures will be installed and to guide the design towards a particular type of foundation. The bathymetric monitoring can be used to measure the impact of the structures on the morphology of the seabed (scouring, silting).

- **Nature of the substrate:** the precise definition of the nature of the seabed that will hold the foundations can be used to estimate a possible modification of the substrate (and therefore of the associated aquatic biocenoses), but also the scour or silt phenomena around the structures.

- **Sedimentary dynamics:** the estimation of the capacity of the sediments to move in the study zone can be used to adapt the design of the foundations to the site, in order to limit the interactions between the structures and their environment, but also to limit potential impacts on the biocenoses.

- **Currents:** a detailed study of the currents is designed to contribute to the estimation of the sediment transit speed. The study of the currents is also used to evaluate the issues concerning benthic and pelagic species. The resource assessment and the effects of turbulence are not discussed here.

- **Swell:** the swell models also contribute to the estimation of the sedimentary transit, and thus their potential impacts on any living species. The swell is used primarily to design the structure, but this aspect is not discussed here.

- **Underwater noise:** the characterisation of the sound environment during the different stages of a tidal stream farm project is designed to evaluate the impacts that modifications of this sound state can have on ecosystems.

- **Electromagnetism:** the measurement or estimation of the initial electromagnetic environment can then be used to correctly determine the modifications of the electromagnetic field induced by the operation of a tidal stream turbine and to assess their potential impacts on marine fauna.

Each of the listed physical parameters can be influenced by the presence of a perennial, noise-generating structure at sea. Figure 22 summarises the interactions between the different parameters of the physical environment presented in this guide and the chapters in which each parameter will be discussed.

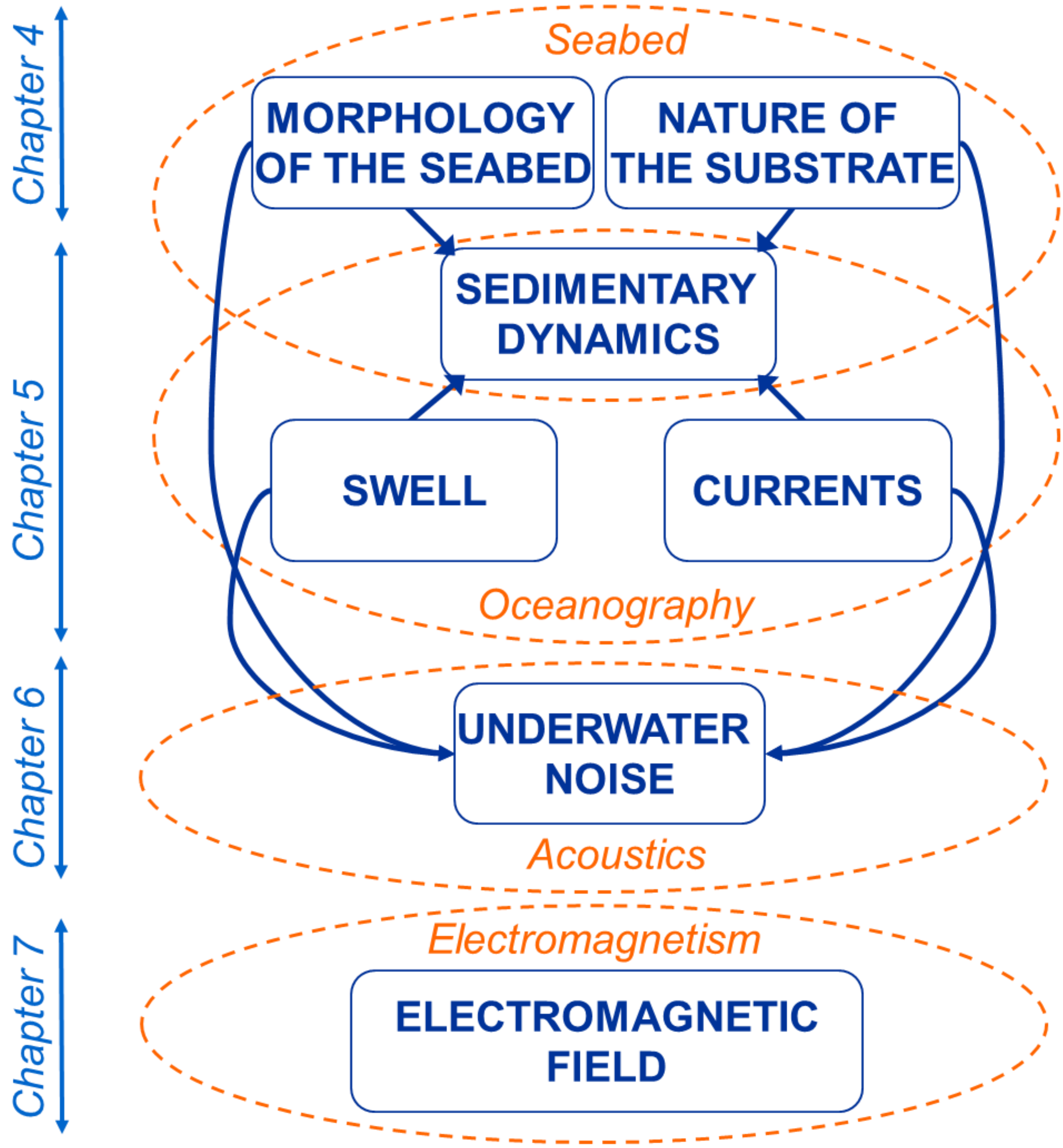


Figure 22 Parameters of the physical environment studied (dark blue), their interactions (blue arrows) and their field of study (orange)

4. Seabed

4.1. Description of the initial state

Different parameters should be measured to characterize the seabed where a tidal stream farm will be built:

- **Bathymetry:** bathymetric maps are used to define the water depth at each point of a study sector, but also to assess the morphology of the seabed for the complete zone.
- **Nature of the seabed:** this is determined based on geophysical surveys correlated with superficial sedimentary samples; it is used to characterize the sedimentary cover in the study sector. The interpretation of the seabed nature maps can also provide indications about the mobility of the sediments.
- **Thickness of the soft sediments:** in the case where soft sediments cover the exploration zone, different geophysical methods are used to define the thickness of this sediment layer along parallel and transverse profiles.

The other parameters that allow a detailed characterisation of the geological substrate (notably geotechnical parameters, geophysical methods adapted to coarse or rocky sedimentary environments) can be crucial to the dimensioning of the foundations. They are, however, not part of the objectives of this document.

4.1.1. Definition of the study zone

During the development of a tidal stream project, the initial stage of the project development includes the definition of a sector of interest – on the scale of a regional zone of strong currents for example – on which a first study is conducted.
The regulatory, environmental, usage constraints and a general bibliographic study of the physical and biological parameters allow the definition of a restricted zone, which will be studied in detail.
It is in this restricted sector, which is the subject of the concession application, that the potential environmental impacts will be primarily studied.
The nature and the morphology of the seabed should be defined precisely for the complete study sector, but also for a wide corridor (500m minimum) connecting the installation and landing zones, to allow laying of the connection cable.
In the case where perturbations of the hydrodynamic conditions would be expected beyond the zone of the concession application, it may be pertinent to plan a survey of the theoretical zone of influence of these perturbations.
Thus, the study zone includes the:

- Machine installation zone.
- Cable installation zone.
- Landing zone.

If necessary, the zone of potential influence, outside the concession zone.

4.1.2. Study objectives

> ***Note:*** *the bathymetric data acquired in the case of tidal stream turbine installation projects are not only intended to estimate the environmental impacts. The data are crucial for foundation design, machinery installation, underwater cable routing and oceanographic model parameterisation (chapter 5). Recommendations on the quality and accuracy of the results are therefore specified for all the needs of a tidal stream park development project.*

The objective of the morpho-bathymetric and morpho-sedimentary surveys is to precisely characterize the seabed that will bear the tidal stream farm. These surveys are used to:

- Provide a reference state in the context of the site monitoring.
- Provide the input data used to estimate the impacts on the seabed, but also on living organisms, in order to propose preventive measures wherever possible.
- Monitor impacts observed during the project lifetime, to potentially adjust the planned measurements or to propose new measures to limit or offset these impacts.

The objectives of the initial state surveys and the different monitoring surveys require specific levels of detail and resolution, which are described in sections 4.1.4. and 4.4.2.

4.1.3. Potential information acquisition methodologies: bibliography

- **<u>Morphology of the seabed</u>**

The main bibliographic source for general knowledge about the bathymetry of the French coast comes from SHOM (*Service Hydrographique et Océanographique de la Marine*) (Fig. 23). The main objective of these probe records, acquired at varying resolutions, is to provide the necessary information for maritime navigation. They thus provide a valuable database for the selection of study zones and the preparation of the specific bathymetric survey.

SHOM, in partnership with IGN, is also in the process of making a numeric altimetry model at the land-sea interface on the coastal fringe. This program, called Litto 3D, is currently in press for the coasts of the mainland and the overseas territories.

Since the beginning of 2013, the SHOM interactive data catalogue of has been accessible on the site: http://data.shom.fr/

Since the beginning of 2013, the SHOM interactive data catalogue of has been accessible on the site: http://data.shom.fr/

Other bibliographic sources of bathymetric data exist notably include Ifremer. Specific local sectors of the French coastline have been surveyed using a multibeam sounder and have sometimes benefited from very detailed studies, which would appear to provide essential information. The different publications are accessible via:

- Sextant, a server for georeferenced marine data (www.ifremer.fr/sextant).
- Ifremer Publications Service, Quae (www.quae.com, section Atlas & Cartes).
- Marine Geosciences department website at Ifremer (http://wwz.ifremer.fr/drogm/cartographie/produits/atlas_bathymetrique).

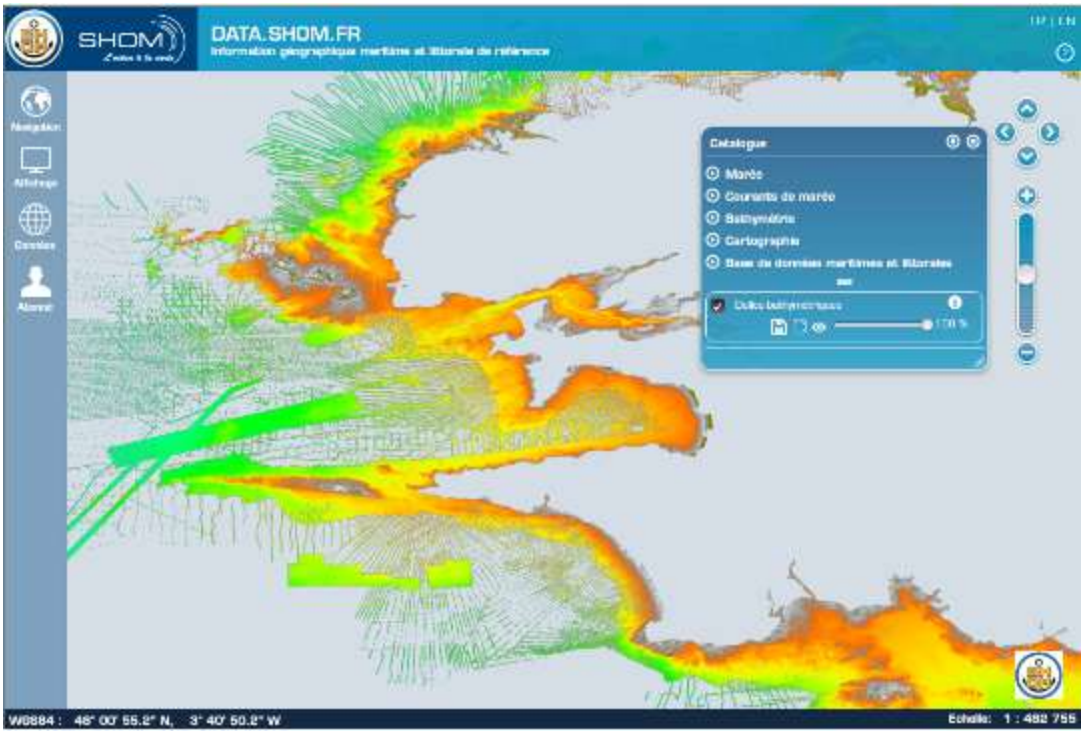


Figure 23 Part of the SHOM bathymetric grids, in the Pointe de Bretagne area

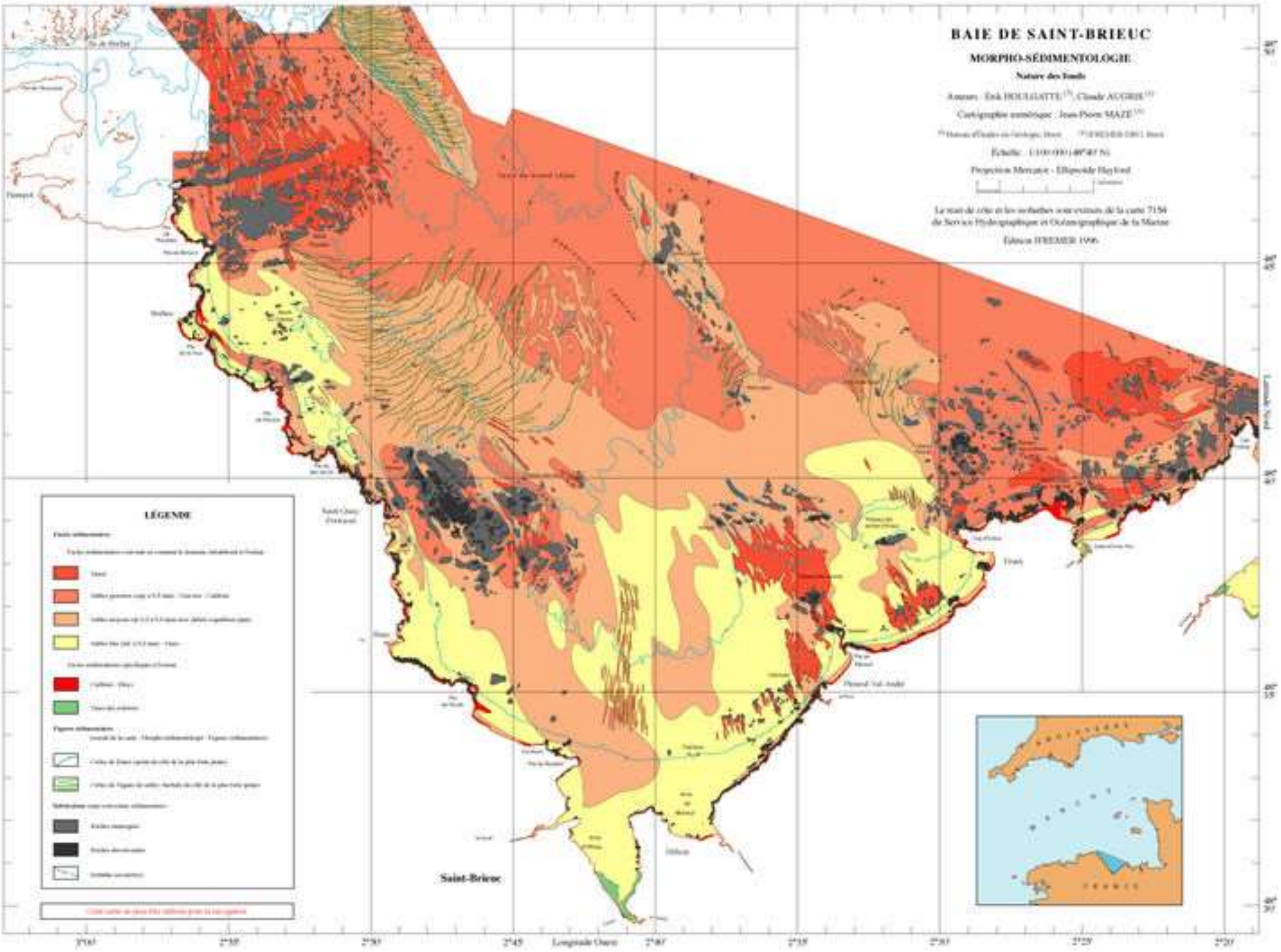


Figure 24 Ifremer map showing the nature of the seabed in the Bay of Saint-Brieuc (Atlas thématique de l'environnement marin en baie de Saint-Brieuc, Augris et al., 1996)

- **Nature of the seabed**

The G maps from SHOM are the most comprehensive bibliographic source for the whole of the French coast. They provide a first indication of the nature of the seabed, and are based on different bibliographical sources, with a wide range of resolutions. The information obtained from these maps should therefore be treated with caution, but nevertheless represent very interesting first indications about the nature of the seabeds encountered in a study sector. The data catalogue is accessible on the website*:* http://data.shom.fr/

Ifremer also produces numerous thematic maps, concentrating on precise coastal sectors in France (www.quae.com, section Atlas & Cartes). These very detailed data sets represent very precise information sources, but so far only cover a few areas in France (Fig. 24).

Ifremer has also produced a bibliographical summary of the available coastal data relevant to the exploitation of marine aggregates, at the request of the Ministry of ecology, sustainable development and energy (MEDDE: *Ministère de l'Ecologie, du Développement Durable et de l'Energie*). The data can be visualized on the site: www.ifremer.fr/sextant/fr/web/granulats-marins.

The geomatics portal of the Marine Protected Areas Agency is a free database that notably includes the results of the CARTHAM program, in the form of data, maps and reports. This program has been used to identify the heritage marine habitats for 40% of the surface area of the territorial waters of metropolitan France, covering most of the Natura 2000 sites.
http://cartographie.aires-marines.fr

Other bibliographic sources can also provide interesting information, such as the cartographies of benthic habitats, based notably on the nature of the seabed (EUNIS type classification). The French network REBENT takes part in this process and provides interesting information on localized coastal sectors (www.rebent.org).

4.1.1. Potential information acquisition methodologies: geophysical surveys

- **Bathymetric acquisition tools**

The acquisition of bathymetric data is performed using an oceanographic or other appropriate ship. The vessel should have the following equipment:

- **An accurate positioning system**

The surface positioning system should allow the ship to be positioned in x, y and z. It is recommended to use a differential or kinematic (RTK) GPS, whose specificity is to apply a correction to the classical GPS receiver, thanks to a reception relay onshore. The installation of this device allows a positioning with an uncertainty of the order of a few centimetres (CETMEF, 2008). The accuracy of z (altitude) furnished by the RTK GPS can be used to compensate for tidal movements. Even if, in these circumstances, the deployment of a tide gauge seems superfluous, it can nevertheless allows to correct for tidal model mispredictions, in the case of perturbations in RTK GPS reception.

- **An attitude reference system**

The objective of the attitude reference system is to correct the movements of the boat (heading, pitch, roll and heave). This tool is an essential link in any bathymetric multibeam chain. It is crucial to guarantee the accuracy and quality of the data. However, beyond certain sea conditions (most often between 1 and 1.5m swell), the attitude reference system can no longer compensate for the movements of the boat. Data acquisition should then be stopped.

- **A bathymetric multibeam sounder**

The multibeam sounder allows the acquisition of bathymetric data on a wide swath (about 6-7 times the water height) perpendicular to the axis of the ship. The simultaneous acquisition of numerous beams in a wide corridor, allows a complete insonification of a sector, with a very high resolution (Fig. 25-a).

The number of beams of the sounder, its angular aperture, the acquisition speed and the water depth are the main parameters that can be used to modify the resolution of the bathymetric survey (from a few tens of centimetres in shallow waters, to several tens of metres in deep ocean waters). The choice of the survey resolution depends primarily on the requirements related to the foundation dimensions. However, a survey at the 1m scale may be adapted to the estimation of the main impacts on morphology.
The precise functioning of a multibeam sounder is described on the Ifremer site (http://flotte.ifremer.fr/Presentation-de-la-flotte/Equipements/Equipements-acoustiques/Sondeurs-multifaisceaux). It is nevertheless important to specify that the water depth is defined based on the time between emission and reception of an acoustic wave being reflected on the bottom. It is therefore essential to perform measurements of the sound velocity in water (as a function of the water temperature and salinity) several times per day, in order to ensure the measurement of water height. Particular attention should be paid in the estuarine sectors, where strong variations in temperature and salinity are observed.

- **Image acquisition tools**

In parallel to the bathymetric acquisition, an acoustic imaging survey should be done. Two different systems can be used:

- Side scan sonar

Towed behind a ship using an electro-mechanical cable, this transceiver system uses the acoustic backscatter properties of the seabed (reflectivity) to reconstitute an acoustic image of the bottom. Two transducers placed on either side of the sonar towfish are used to acquire the data on a strip perpendicular to the direction of travel of the boat, which then produces a succession of parallel and perpendicular profiles. The images thus reconstituted – called sonograms – are then processed, clustered into mosaics and interpret-

ed by correlating them with sedimentary samples (Fig. 25-b).
The survey quality and resolution are determined by the emission frequencies and reduction of the range.

(http://www.rebent.org//medias/documents/www/contenu/documents/FT09-FO02-2003-01.pdf)

This acquisition tool, which is relatively easy to implement, nevertheless has limitations specific to the context of tidal stream turbines. Indeed, since the system is towed behind a boat, its positioning remains somewhat approximate (several metres), and surveys in zones with strong currents make the positioning of the tool very imprecise. The use of a positioning beacon on the fish is therefore necessary to limit this approximation (which will be of the order of a meter).

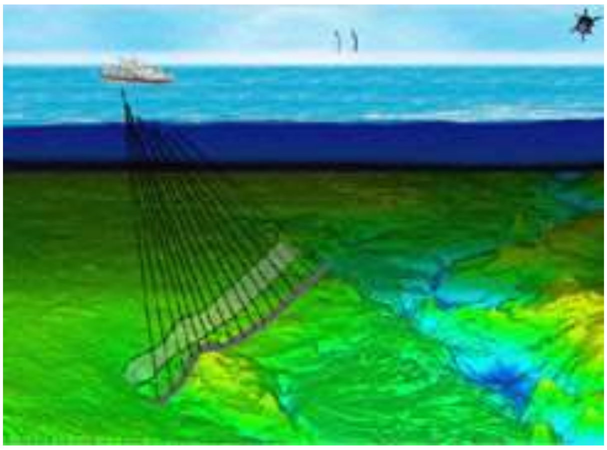
The side scan sonar, by its immersion depth (commonly of the order of 10m), can nevertheless prove to be very effective for the cartography of localized structures, at high-resolution.

- Multibeam sounder reflectivity

The use of the reflectivity from the multibeam sounder is particularly suitable for acquisition in an energetic environment and allows an acquisition simultaneously with the bathymetry (Fig. 25 a). Indeed, since the MBS is fixed on the hull of the acquisition ship and the attitude reference system compensates for the movements of the boat, the reflectivity from the sounder is in fact as accurate for positioning as the bathymetry (of the order of a few centimetres).

The use of high-resolution multibeam sounders allows the extraction of the reflectivity from the bathymetric sonar beams, so the final acoustic images will have the same resolution as the bathymetry. The acquired parallel profiles (and some perpendicular profiles) are processed and then clustered into mosaics to be interpreted by correlating them with the sedimentary samples.

a.



b.

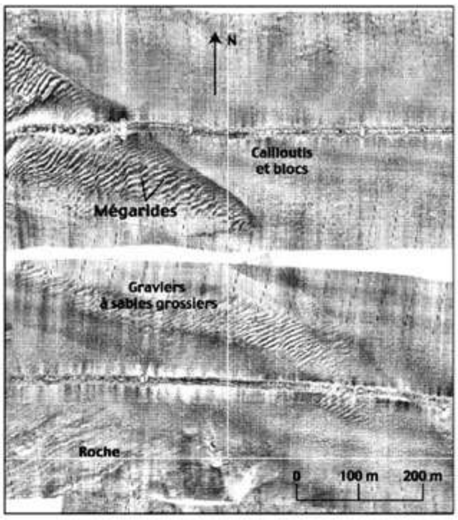


Figure 25 (a) Schematic diagram of the acquisition with a multibeam sounder, (b) part of a sonogram with the associated sedimentary facies and features (source: Ifremer)

- **Data representation**

A clear representation of the acquired data is crucial to highlight the quality of the work done, but also to then allow the presentation or re-use of the data (Fig. 26).

The different maps and data that should be produced are:

- A map of the work performed (positioning of the sedimentary samples, surveyed profiles, any video points…).
- Bathymetry data:
  - DFM (digital field model) at a scale of 1m or better.

- Map of the bathymetry showing the isolines.
- Imaging:
  - Map of the acoustic mosaics (similar resolution to the bathymetry, or better if possible).
  - Morphosedimentary map (interpretation of the nature of the seabed + sedimentary features).
  - Granulometric description and analysis of the sedimentary samples.

The maps produced in paper format, should be presented at an appropriate scale (1/5000th or 1/10000th according to the size of the zone).
The presence of specific structures should be presented on a zoom of the map at an appropriate scale.

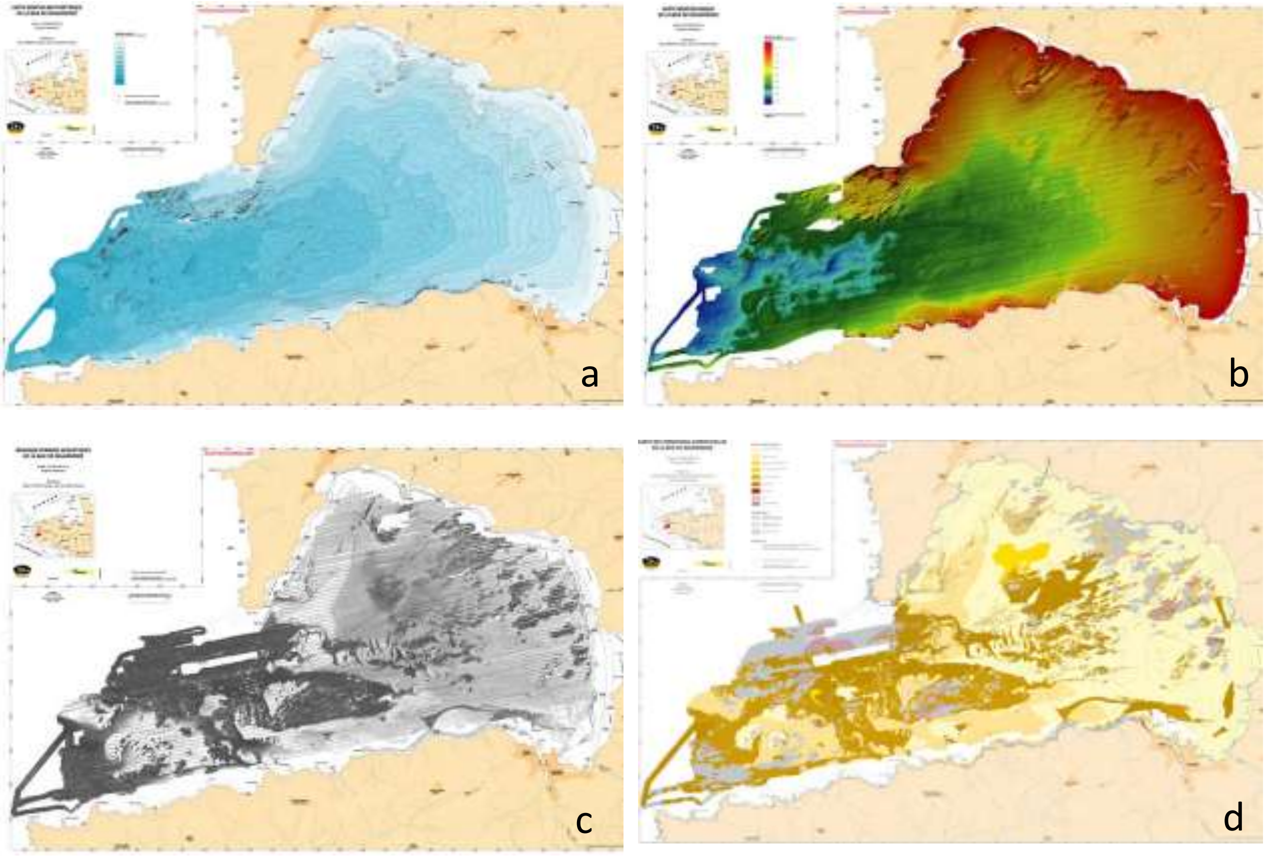


Figure 26 Maps from the "Atlas thématique de l'environnement marin de la baie de Douarnenez": (a) morpho-bathymetric map of the Bay of Douarnenez, (b) morphological map of the Bay of Douarnenez, (c) mosaic of acoustic images of the Bay of Douarnenez, (d) map of the surface formations of the Bay of Douarnenez (Augris et al., 2005)

4.2. Methods for the identification and analysis of potential ecological changes

Impacts on the seabed are directly linked to the technical choices made about:
- ○ Foundation type.
- ○ Cable laying method.
- ○ Landing technique for the underwater cable.

The different possibilities are:
- For the foundations types:
  - Gravity (resting on the seabed), with or without preparation of the ground.
  - Mono or multi pile (pylon(s) driven into the ground, jackets), installation by driving or drilling.
  - Anchors (conventional or suction anchors) placed in the soft seabed (gravity anchors will be treated like gravity foundations).

- For the underwater cables:
  - Laid on the seabed, protected or fixed if necessary.
  - Buried, where the seabed allows it.
  - Laid in trenchs, in the case of rocky substrates.

- For the landing techniques:
  - Laid, protected or fixed if necessary.
  - Buried or laid in a trench.
  - Directional drilling.

These different technical options are described in section 1.3. Note that the electrical substation, if present, can be designed with a different foundation from the machines.

The rest of this chapter describes the envisaged impacts, for each of the above-mentioned technical choices. Potential changes are taken into account during the three phases of a project:
- ○ Construction phase.
- ○ Operational phase.
- ○ Decommissioning phase.

In this guide, it was considered necessary to make hypotheses about different envisaged impacts, this being the most pragmatic way to propose methods for the identification and analysis of the changes. It is clear that the technical options related to the technologies, at the scale of the projects and the study sectors, will necessitate specific expertise to adapt these recommendations to the real contexts of the projects.

4.2.1. Potential changes during the construction phase

The construction work phase runs from the possible preparation of the ground, until the commissioning of the farm.

Gravity type foundation

During the construction phase, and in the case of a gravity foundation installation, three situations can arise:
- The foundation is adapted to the seabed, without ground preparation.
- Ground preparation may be required by the addition of materials (sediments, rocks).
- Ground preparation may be required by substrate ablation (excavation of a soft substrate, levelling of an uneven rocky substrate).

Table 7 presents, for each case, the envisaged impacts on the studied compartment (here, the morphology and nature of the seabed) that can be used to propose a method to identify and analyse possible changes in the seabed, on the one hand by forward-planning, and on the other hand, by assessing effects when it is done.

Technical hypothesis		Impact envisaged during the works phase	Type of impact		Method of identification of change	
			Duration	Intensity and range	Precautions	Monitoring
GRAVITY	Without preparation	Sinking of the foundation into the ground	Definitive	Low and localised	Preliminary geo-technical studies	Visual checks (ROV…)
	With ground prepara-tion	Re-suspension of the sedi-ments	Temporary	High and localised	Estimation of volumes re-suspended	-
		Change of bathymetry and nature of the seabed around the foundations	Definitive		Estimation of volumes deposited / removed	Assessment of volumes after operation

Table 7 Potential changes during the construction phase for a gravity foundation

In the case of where gravity foundations are cho-sen, the seabed is highly sensitivity if ground preparation is needed. The scale of preparation for the works is therefore crucial to estimate the impacts they will have on the physical environ-ment. The environmental impact study should thus describe the precise course of the phasing of the works. The knowledge of the impacts also involves the deployment of specific tools in the works phase, which are used to assess the im-pacts of the structure on its environment.

Pile type foundation

This section covers various types of foundations, that penetrate the seabed, such as monopiles, mesh structures (jackets), or the multipodes de-scribed in part 2.

These technologies can be installed:

- either by driving, into soft seabeds or softer rocky substrates (such as lime-stone);
- or by drilling, in the case of rocky sub-strates.

Taking into account the two installation tech-niques, table 8 proposes a method for predicting and measuring the possible changes in the sea-bed.

Technical Hypothesis		Impact envisaged during the works phase	Type of impact		Method of identification of change	
			Duration	Intensity and range	Precautions	Monitoring
PILE	Driving	Re-suspension of sedi-ments	Temporary	Weak and diffused	Estimation of vol-umes re-suspended	-
	Forage					

Table 8 Potential changes during the construction phase for a pile type foundation

There are many types of anchoring, adapted to different types of seabed:

- Conventional anchors, which can take numerous forms adapted to different types of soft substrates.
- Suction anchors, in the form of closed tubes, which are buried in cohesive seabeds.
- Gravity anchors, deposited on the seabed.

Gravity anchors are not included in table 9, because their installation, as well as their interactions with the environment, is similar to the gravity foundations mentioned previously.

The installation of a conventional anchor is simple: the anchor is deposited on the seabed then put under traction, allowing it to penetrate a few metres into the sediments, thus giving it its resistance.

The installation of a suction anchor takes place in two stages: the anchor is first deposited on the seabed and sinks under its own weight; then, the water contained in the unburied part is pumped in order to achieve the maximum embedding.

Technical Hypothesis		Impact envisaged	Type of impact		Method of identification of change	
			Duration	Intensity and range	Precautions	Monitoring
ANCHORS	Conventional	Temporary soiling during the installation of the anchor	Temporary	Weak and localized	-	Monitoring survey
	Suction	No impact				

Table 9 Potential changes during the construction phase for an anchored structure

Underwater cables

The soil conditions and the environment usages define the type of posing to be used for the underwater cable, and the appropriate protections.

- On a rocky substrate, the cables will normally be laid on the bottom and fixed or protected if necessary (mattress, rock dumping, grout bags), a trench may also be dug to install the cables.
- On a soft seabed, embedding appears to be the simplest way to protect the cable.

Table 10 shows the different predicted impacts on the morphology and the nature of the seabed, during the laying of the underwater cables, as well as the means of identifying these impacts and their degree of intensity with regard to the seabed.

Landing

The technical solutions used to bring the cable ashore are:

- Laying, with protection of the cable.
- Installation by trenching or by embedding, on the ground section, the foreshore and in the shallow waters.
- Directional drilling, where this technique is possible, allowing the cable to be passed completely underground, from a point at sea to an available space onshore.

The potential impacts for each of the implementations define the sensitivity of the studied compartment (here the nature of the seabed) with regard to the landing technique (Table 11).

Technical hypothesis		Impact envisaged during the works phase	Type of impact		Method for identifying the change	
			Duration	Intensity	Precautions	Monitoring
CABLES	Laid	Chafing	Permanent	Moderate	Calculation of cable stability	Visual checks
	Laid in a trench	Re-suspension of the sediments	Temporary	Weak	Estimation of volumes re-suspended Hydro-sedimentary model-ling	-
		Modification of the morphology	Definitive	Definitive but localised	-	Visual checks
	Embedded	Remixing of sedi-ments	Temporary	Moderate	Estimation of volumes re-mixed	Visual checks
		Re-suspension of sediments	Temporary	Weak	-	
		Creation of a pit	Temporary		Sedimentary study to esti-mate behaviour of the pit	-

Table 10 Potential changes during the construction phase, related to cable laying

Technical hypothesis		Impact envisaged	Type of impact		Method for identifying the change	
			Duration	Intensity	Precautions	Monitoring
LANDING	Laid	No impact				
	Passed in trenchs or embedded	Remixing of sediments	Temporary	Moderate	Sedimentary study to esti-mate the behaviour of the pit	Visual checks
		Creation of a pit	Temporary			
	Directional drilling	No impact				

Table 11 Changements potentiels en phase de construction liés à l'atterrage

4.2.2. Potential changes in the operational phase

The operational phase for a tidal stream farm is estimated to be 20 years. The specific hydrodynamic conditions will inevitably lead to interactions between the structures and the seabed. The following paragraphs and tables propose, for each technical orientation, different predicted impacts, the different methods to diagnose and characterize these impacts, and finally, the general sensitivity of the studied compartment with regard to the structures.

Foundations :

For each of the foundations mentioned in section 4.2.1., table 12 shows the predicted impacts, the means of identifying them and in a general way, their potential pressure on the seabed.

Technical hypothesis		Type of impact		Method for identifying the change	
		Duration	**Intensity and range**	**Precautions**	**Monitoring**
FOUNDATIONS	**Gravity**	Modification of the nature and the thickness of the sediments, close to the foundations and potentially in the influence zone Silting / Scouring around the foundations	strong	- Study of the sedimentary dynamics (sedimentary features, modelling, sediment traps…)	- Regular geophysical surveys *(See 4.4 Monitoring surveys)*, - Photos, videos
	Piles				
	Anchors				

Table 12 Potential changes during the operation phase, related to the foundations

Table 12 highlights the fact that, regardless of the type of foundations, a change may occur in the substrate (nature, thickness). The hydrodynamics, especially important on the studied sites, cause potentially significant impacts depending on the local context, not only on the physical environment, but also in this specific case on the structure itself. Indeed, scouring or substrate change phenomena can influence the behaviour of the foundations.

The study of these phenomena and regular surveys are therefore critical to prevent any risks for the foundations (see chapter 5).

Underwater cables

Table 13 shows the predicted impacts of the cable on the seabed during the operating time of the park, the methods for identifying and assessing these impacts the different degrees of their potential pressure.

Technical Hypothesis		Type of impact		Method for identifying the change	
		Duration	**Intensity and range**	**Precautions**	**Monitoring**
CABLES	**Laid**	Restriction of the sedimentary transit → sediment trapping	Weak to moderate	Adapted to the architecture of the farm	Monitoring surveys needed *(see 4.4)*
	Laid in a trench	Filling of the pit with sediments of a different nature	Weak	-	Monitoring surveys needed *(see 4.4)*
	Embedded	Sedimentary dynamics lead to movement of the cable Sedimentary dynamics lead to disembedding of the cable	Moderate	Adapted to the architecture of the park Embeded sufficiently deep to avoid the sedimentary dynamics	Monitoring surveys needed *(see 4.4)*

Table 13 Potential changes during the operation phase, related to the cables

The envisaged modifications of the substrate related to the presence of underwater cables are all caused by sedimentary dynamics. Particular attention should be paid to the study of this phenomenon (see chapter 5).
It should be noted that the cable itself (or its protective structures) changes the nature of the substrate.

Landing
At the landing zone, the potential impacts identified have made it possible to define the sensitivity of the studied compartment (morphology and nature of the seabed) with regard to the landing techniques. Table 14 presents the potential impacts the cable may induce in the landing zone.

Technical Hypothesis		Type of impact		Method for identifying the change	
		Duration	**Intensity and range**	**Precautions**	**Monitoring**
LANDING	**Laid**	Restriction of the sedimentary transit → sediment trapping	moderate	-	Monitoring surveys needed *(see 4.4)*
LANDING	**Laid in a trench**	The permanent embedding of the cable can be jeopardized by a variation in the thickness of the sediments.	strong	Study of the coastline Trench sufficiently deep to overcome the sedimentary dynamics	Monitoring surveys *(see 4.4)*
LANDING	**Embedded**	No impacts			

Table 14 Potential changes during the operation phase, related to landing

4.2.3. Potential changes during the decommissioning phase

Note: *The hypotheses proposed in this chapter in no way constitute technical recommendations. They are the result of observations of what is most often done in other sectors. If other decommissioning methods are projected, the same exercise of assessment of the impacts and the methods for their identification should be performed.*

In the decommissioning phase, the predicted impacts and the methods for their identification are presented for each part of the farm that interacts with the seabed.

It should be noted that it is difficult to predict impacts precisely, since the fate of the foundations and cables is unknown. Several predicted scenarios are therefore given below.

Foundations
The expected impacts of the decommissioning of the foundations and the sensitivity linked to the works involved are presented in table 15.
In the case of gravity foundations, it is assumed that each of the foundations will be totally removed. If ground preparation had occurred during the installation phase, it is assumed that no excavation or addition of substrate will take place in the decommissioning phase.
In the case of pile type foundations, the decommissioning hypothesis chosen was the cutting of the piles as close as possible to the seabed, or potentially deeper in the case of soft sedimentary bottoms.
Anchored systems, meanwhile, would be removed in their entirety.
The fate of the recovered materials should be specified (recovery, recycling…).

Technical hypothesis		Predicted impact	Type of impact		Method for identifying the change	
			Duration	Intensity and range	Precautions	Monitoring
FOUNDATIONS	Gravity	Re-suspension of sediments Creation of a pit	Temporary	Weak	Estimation of the volumes moved	Monitoring survey (geophysical, Video…)
	Piles	Structures exposed on the seabed	Definitive	Definitive	-	
	Anchors	Creation of a pit Re-suspension of sediments	Temporary	Weak	-	

Table 15 Potential changes in the decommissioning phase, related to the foundations

Underwater cables
Decommissioning hypotheses have been made in order to propose the cable impacts on the seabed and the means to identify them. Here, it is assumed that the laid cables will be removed. Concerning the cables installed in trenches or embedded, two cases will be studied (Table 16):

- Cables to be left at the bottom.
- Cables to be removed.

The option chosen for the decommissioning will need to be justified as the solution having the least environmental impact.

Technical hypothesis		Envisaged impact	Type of impact		Method for identifying the change	
			Duration	Intensity and range	Precautions	Monitoring
CABLES	Laid	Re-suspension of sediments	Temporary	Weak	Estimation of the volumes re-suspended	Monotring survey (geophysical, Video…)
	Embedded/ entrenched → Ablation of cables	Re-suspension of sediments Remixing of sediments	Temporary	Moderate to strong	Estimation of the volumes re-suspended / remixed	Monitoring survey (geophysical, Video…)
	Embedded/ entrenched → Left at the bottom	Movement of the cables Definitive embedding of the given cable	Definitive	Moderate to strong	Use feedback from the operation to estimate the movement and define the decommissioning plan	Monitoring surveys after decommissioning *(see 4.4)*

Table 16 Potential changes in the decommissioning phase, related to the cables

Landing

Decommissioning hypotheses have been made for each landing technique:

- Cable laid on the foreshore: ablation of the cable.
- Cable laid in a trench: ablation of the cable on the one hand, and maintenance in the environment on the other hand.
- Directional drilling: maintenance of the cable underground.

The formulated hypotheses were used to predict the potential impacts on the seabed, to provide indicators for identifying and analysing these changes, and to deduce a potential stress on the environment (Table 17).

<table>
<tr><th colspan="2" rowspan="2">Technical hypothesis</th><th rowspan="2">Envisaged impact</th><th colspan="2">Type of impact</th><th colspan="2">Method for identifying the change</th></tr>
<tr><th>Duration</th><th>Intensity and range</th><th>Precautions</th><th>Monitoring</th></tr>
<tr><td rowspan="5">LANDING</td><td>Laid</td><td>Re-suspension of sediments</td><td>Temporary</td><td>Weak</td><td>Estimation of the volumes re-suspended</td><td>Monitoring survey</td></tr>
<tr><td rowspan="2">Laid in a trench or embedded
→ ablation</td><td>Re-suspension of sediments</td><td rowspan="2">Temporary</td><td rowspan="2">Moderate to strong</td><td rowspan="2">Sedimentary study to estimate the behaviour of the pit</td><td rowspan="2">Visual checks</td></tr>
<tr><td>Remixing of sediments</td></tr>
<tr><td>Laid in a trench or embedded
→ maintenance</td><td>Definitive embedding of the given cable</td><td>Definitive</td><td>Moderate to strong</td><td>Monitoring of the behaviour of the cables for the duration of the operation</td><td>Monitoring surveys after decommissioning (see 4.4)</td></tr>
<tr><td>Directional drilling</td><td colspan="5">No impact</td></tr>
</table>

Table 17 Potential changes in the decommissioning phase, related to landing

4.3. Identification of cumulative impacts

In the case of the study of the morphology and nature of the seabed, the expected impacts are linked to the presence of the machines, foundations and cables.

The scale of the expected impacts is linked to the scale of the projects: the more machines a project has, the more it will impact the seabed.

The envisaged impacts on the seabed can have indirect effects on benthic species. Indeed, the modifications of substrates, of morphology and/or an increase in turbidity lead to a modification of benthic habitats (see chapter 7).

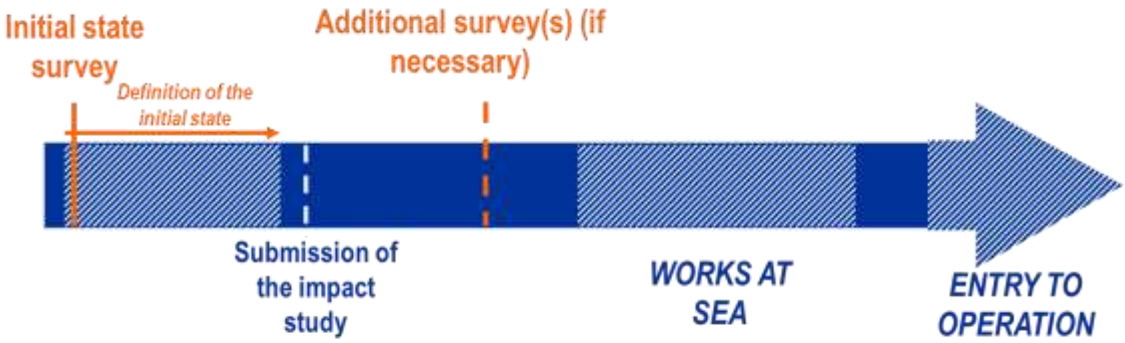
4.4. Description of the environmental monitoring programme

The bibliography, recommendations of the state services, and predicted impacts given the tables in section 4.2 and the methods for their identification and analysis can be used to draft an indicative environmental monitoring programme.

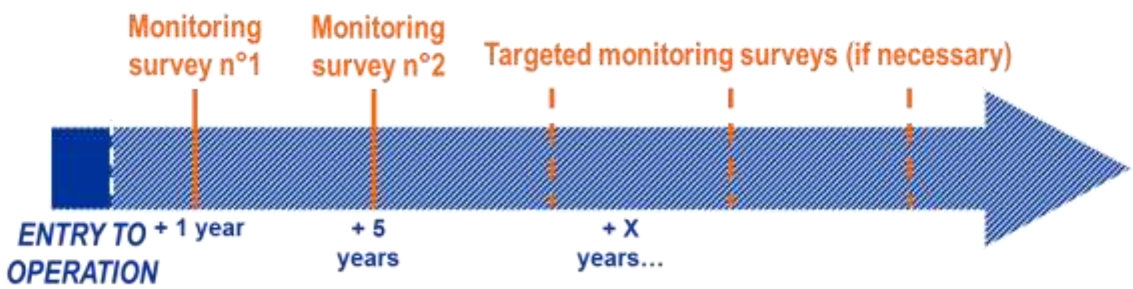
4.4.1. Environmental monitoring plan

The proposed monitoring schedule is as follows :

- From the preliminary phase of the project to the entry into operation of the park:



- In the operation phase:



- In the decommissioning phase :

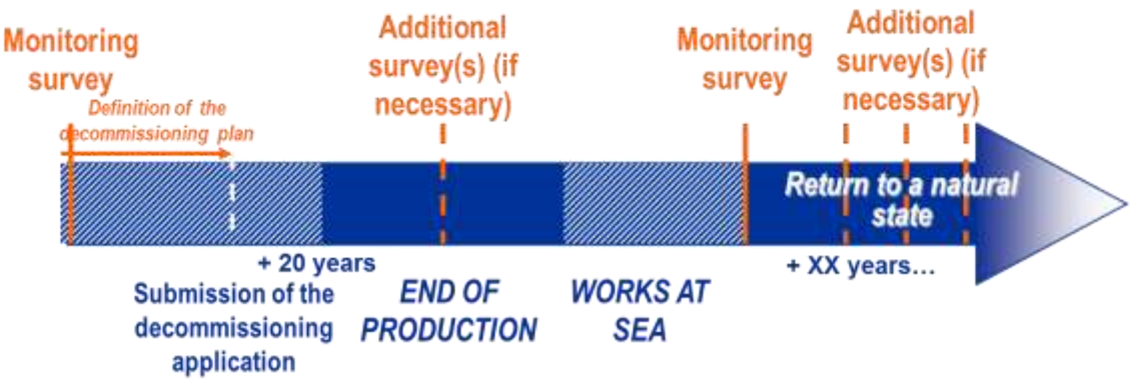


Figure 27 Theoretical schema of the strategy for the implementation of seabed monitoring, for the duration of the tidal stream project

The maintenance phases, when the turbines are removed from the water, do not require any specific surveys before / after each maintenance operation, concerning the impacts on the physical environment.

Figure 27 presents the three types of survey:

- Initial State survey.
- Complementary surveys.
- Monitoring surveys.

- The **monitoring surveys** mentioned in the tables in section 4.2 are not mentioned in figure 27, because they correspond to specific and localised studies, linked to the works phase: their programmes are the responsibility of the works operators.

The contents of the Initial Status survey are described in section 4.1.
The complementary surveys mentioned are the result of administrative obligations, from the choice of the operator, or from specific points where a particular sensitivity / an impact on the physical environment has been identified. The details of these surveys depend on the phenomenon to be studied and are specific to the problem to be addressed.

It is important to note that all the surveys should be made at the same season each year, in order to allow the comparison of the possible variations of the sedimentary covers in nearly identical conditions (one can imagine that winter storms would sweep away any silting of sediments deposited during the summer seasons).

4.4.2. Monitoring survey programme

These surveys are conducted for the complete study sector and for the reference zone, with similar tools to those used to establish the Initial State.

The programme for classic monitoring surveys includes:

- A multibeam bathymetric survey for the complete zone, with the same resolution as for the initial state survey, which is used to produce:
    - A detailed bathymetry map (*see section 4.1.4 – data representation*).
    - A differential bathymetry map.
- A high resolution bathymetric survey around the foundations, if an impact is expected.
- An imaging survey and samples for the complete zone, with the same resolution as for the initial state, which is used to produce:
    - A sedimentary facies map.
    - An analysis of facies variations.
- A high resolution imaging survey around the foundations, if an impact is anticipated.
- Potentially, video checks (by divers, ROV) around the foundations.
- Other relevant tools can also be deployed for the assessment of the impacts that the project may have on the substrate (e.g., magnetometric surveys to study the lateral displacement of an embedded cable).

Complete monitoring programmes should be performed in the first years after implantation of a farm, and just after the decommissioning. If no impact on the seabed has been identified after the first surveys are completed (after 5 years, for example), the need for continued detailed surveys may be reconsidered.

Targeted monitoring surveys may be used to study a specific and/or localized impact observed during the first years of operation of a farm or persisting after decommissioning. The programme and schedule of these surveys will then be defined depending on the problem to be addressed, based on the protocols proposed above and for example, in consultation with a monitoring committee (including scientific bodies and the project promoter).
When the monitoring programs are completed, the results and analyses in terms of impacts will be submitted to the state services for assessment. These detailed studies of the physical environment also contribute to studies on the natural environment.

4.5. Measures for impact mitigation

As mentioned in section 1.6, it is necessary to take into account the potential impacts linked to the technical choices from the start of the project design and to apply the principles: Avoid – Reduce – Offset.
These mitigation measures will be proposed after a precise definition of the initial environmental state of the site, and the study of the impacts specific to the technology deployed in the sector.

Among the different possible mitigation measures, some may lead to modifications in the design or the architecture of a project (for example, a modification in the design of the foundations to limit their footprint). It is therefore critical to take the environment into account very early in the design of the project.

In generic terms, it is difficult to propose precise measures to avoid, reduce or offset impacts. However, a few suggestions may indicate potential measures (Fig. 28):

- Increasing the embedding depth (to limit the movement of the cables due to the sedimentary dynamics).
- Rock dumping (to prevent the disembedding or chafing of the cables, to prepare the seabed for the reception of the foundations).
- A concrete mattress (to prevent the disembedding of the cables or to limit their chafing).
- Plastic or live algae (to limit the scouring around the foundations).
- Anchoring rings (to fix the cables to the rocky seabed in order to limit their movement and chafing).
- Grout bags (to weight and fix the cables to the bottom, in order to limit their movement and chafing).

It is important to note that these measures can also generate an impact, which should therefore be taken into account in the project.

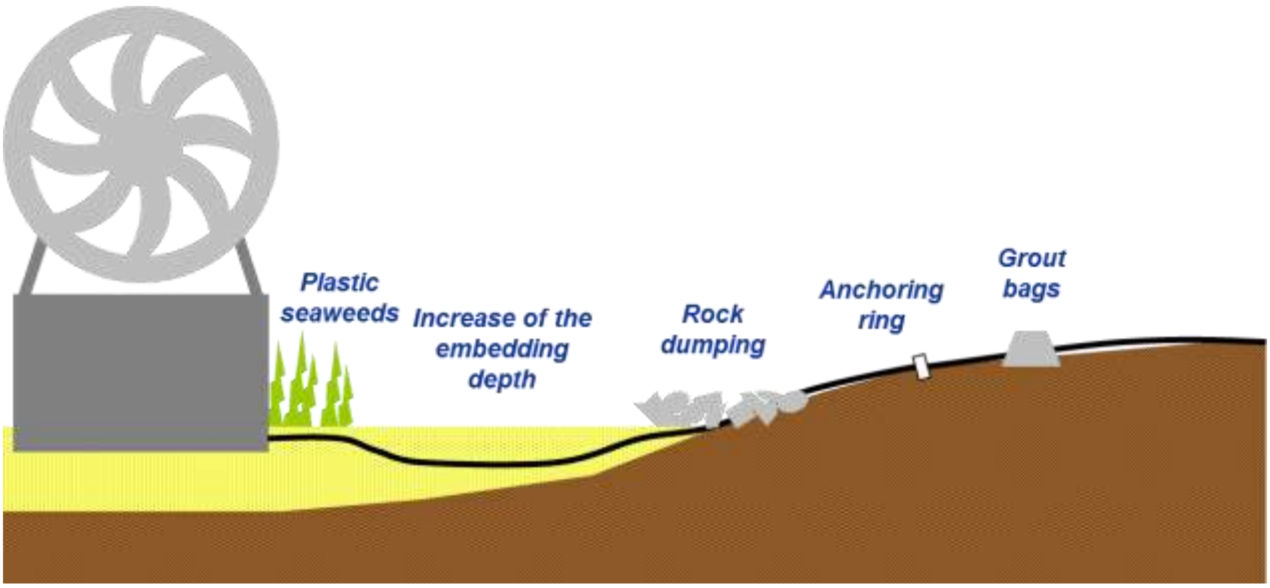


Figure 28 Diagram of the different technical solutions aimed at mitigating the impacts of a project on a potential modification of the seabed

4.6. Deficiencies and research programme

As a benefit of the continuing evolution of the multibeam sounders, data of better quality and resolution can now be acquired, notably in the imaging mode. For this type of environment, these tools might usefully replace the side-scan sonars (easier implementation and more accurate positioning). These developments will thus allow the identification of highly localized impacts, or their earlier diagnosis, at the time of the first substrate modifications.

The modifications of the nature of the seabed estimated in the project study phase are sometimes linked to the sediment dynamics (see chapter 5). The impacts of such structures on the sediment dynamics and associated sediment deposits are still relatively unknown at the scale of the hydrosedimentary cell (or sub-cell).

The costs and deployment difficulties related to the geotechnical campaigns in an energy environment raise questions about the capacity of the geophysical methods to characterize the physical and mechanical properties of the sub-seabed. More powerful geophysical imaging tools would indeed allow a better characterization of the structure and nature of the sub-seabed and would help project promoters to better understand their study zones during the development phases of farms.

Currently two approaches are being developed, which may be complementary because they image the sub-seabed using different parameters of propagation properties: acoustic methods (i.e., seismic) and the electrical and electromagnetic methods.

Key references

IFREMER - Présentation des caractéristiques de fonctionnement des équipements acoustiques utilisés en géophysique marine. http://flotte.ifremer.fr/Presentation-de-la-flotte/Equipements/Equipements-acoustiques.

IHO Standards for Hydrographic Surveys - 5 th. Edition, February 2008. Special Publication No. 44 published by the. International Hydrographic Bureau.(http://www.iho.int/iho_pubs/standard/S-44_5E.pdf)

5. Oceanography

5.1. Description of the initial state

5.1.1. Definition of the study zone

The definition of the study zone varies according to location. It should be noted that the oceanographic measurements will generally be done at the scale of the concession (several km²), with one or several measurement points depending on the case, while numerical models and standard meteoceanic statistics will be done on a regional scale. The monitoring zone for impacts in operation should be determined on a case-by-case basis (probably between the concession and regional scales).

Note: *All the hydrosedimentary and oceanographic phenomena are studied for several applications: the assessment of the environmental impacts, but especially the dimensioning of the structures and the generation potential of these machines.*
The aspects related to project design are not the subject of this guide and will therefore only be mentioned briefly in this chapter. Nevertheless, during the lifetime of the project, there may of course be opportunities to consider possible shared approaches (example: using the same models for the study of the impact of the park on the current, which may influence the sedimentary dynamics, and for the study of swell-current interactions that may influence the generation potential) and on the definition of a pertinent study zone.
The details of how the turbulence and swell-current interactions are taken into account are therefore not provided here, as they are currently the subject of a research programme (see section 5.6). These points are nevertheless mentioned in the text whenever necessary.

5.1.2. Description of the oceanographic and hydrosedimentary context

Different processes should be studied and measured to characterize the meteoceanic conditions of a tidal stream turbine site. In addition to their consideration as technical criteria, the analysis of these phenomena is crucial for the assessment of the local hydrosedimentary context and therefore the possible impacts on biological populations (see relevant chapter).
The main forcings concerned are:

- **The tide:** the tide of course affects water levels and is a forcing for the currents. On the French coasts, the tide follows a cycle of 12h25 (high tide / low tide) superimposed on a 14-day cycle (spring / neap cycle).
- **The wind:** the wind is a forcing for the sea states and the currants.
- **The currents:** the current of course can be used to estimate the available resource, but it is also a constraint on the choice of machine dimensions and their wear. Except in specific cases, the currents of a tidal stream turbine site will be dominated by the tidal cycle. On a tidal stream turbine site, the currents will generally be alternating (in one direction then in the other, for each half tidal cycle). However, the tidal currents are not the only processes to be studied on a tidal stream turbine site, which can be influenced by the wind, swell, turbulence, or other very specific regional effects.
- **The sea states:** the swell and/or the wind sea (waves created in the exact place where the wind blows) influence the dimensioning and the wear of the machines, directly by wave effects or indirectly by current modifications. By interaction with the currents, these factors they can influence the production.

On a tidal stream turbine site, by definition highly energetic, these different forcings cause strong sedimentary dynamics, which will be a critical process in the project:

- **Sedimentary dynamics:** the sedimentary movements may be important, notably for the study of the silting on the site after installation of the machines (and thus possible substrate modification).

Rocky sites are not free of sedimentary movements. On the contrary, a tidal stream turbine site is highly energetic, and will usually not allow deposition and sedimentation, but may be the site of important transits, of sands, or even pebbles or blocks, on the bottom (bedload) or in the water column (in suspension). The introduction of machines can block part of this transit, and, in addition to the potential damage to the tidal stream turbines, can cause significant hydrosedimentary impacts if the problem is not foreseen.

5.1.3. Characterisation of the natural variability of the installation site

The parameters related to the current and sea states fluctuate widely in time and are spatially highly variable. The project data, even after technical and scientific expertise, will thus remain flawed by the natural variability and measurement or study uncertainties that should be reduced as much as possible. The standard statistics used for the preliminary studies are carried out on series reconstituted over 20 years in order to obtain a better representation of the temporal variability of the processes (normal approach).
For the detailed study of a site, the spatio-temporal variability of the current should be studied in greater detail:

- The time step of 5 to 10 minutes normally used for the study of tidal currents is not sufficient for a detailed study of the site. An approximation of the turbulence will be necessary, with a time step that is not yet well defined (a few tens of seconds);
- Spatially, the current can vary very significantly over a few tens of metres on the sites with the greatest energy potential, hence the need to produce detailed models, associated with measures at several points on the park.

The spatial variability of the swell is also important, and a model approach associated with measures at several points is also necessary.
The variability of the wind can be estimated by standard statistics.

5.1.4. Identification of relevant parameters and indicators

In a first approach, preliminary studies can be used to select the potentially interesting site(s) in a given maritime sector, before launching more detailed studies on this site. These initial investigations rely on bibliographical data (standard statistics), principally:

- Map of the vertical mean current fields for different coefficients (e.g., for coefficients of 20, 45, 70, 95, 120) with a time step of 1 hour for each of these tides (AM, PM-6h, PM-5h, PM+6h).
- Offshore swell statistics[13], (monthly correlograms: Hs / Tp and Hs / Direction, as well as swell for centennial projects).
- Wind statistics (wind rose).

Once a site has been selected, the objective is to specify the site conditions using the complementary approaches of numerical models and measurements, as are described below. The models allow an approximation of the spatial variability of the phenomena (cartography), while the main goal of the measurements is to obtain accurate time series at a given point.

The following data can be measured / calculated at this stage of the study:

- Time series of the current from the surface to the seabed (direction and intensity), with a time step of 5 to 10 minutes (+ spectral analyses), in order to study the variability of the current over the tidal cycle.
- Likewise, with a time step of a few tens of seconds (depending on the feasibility and the chosen filtering, which will depend on the quality of the ADCP[14] output signal), in order to study the processes with a shorter time period, such as the turbulence.

The swell time series is useful for looking for correlation of the significant heights and the periods with the turbulent intensities, or lack thereof. **However, it is important not to use this relatively short time series (example: 3 months of measures) to produce the statistics. A swell series should be multiannual to make statistical sense.**
In addition to the previously mentioned parameters, other parameters are studied on more precise scales (turbulence, current-swell interac-

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[13] Hs = Significant wave height; Tp = peak period
[14] ADCP = Acoustic Doppler Currentmeter Profiler (see paragraph 5.1.5**Erreur ! Source du renvoi introuvable.** on oceanographic measures)

tions...), particularly for the study of the tidal power resource (energy production) or dimensioning the structures.
Since these phenomena are linked to a machine design or concern the resource, they will not be discussed in their entirety here.

Concerning the turbulence, on the one hand, it can have an impact on the resource and on the other hand, the machines can affect the turbulence of the environment. These considerations are taken into account in the 'wake studies' and the 'park effect' study where the effect of the machines on the physical environment is also mentioned.
The turbulence may also have an influence on the re-suspension and the deposit of fine sediments, when they are present (depending on the site).
These issues are currently topics for research, notably concerning the sedimentary dynamics of rocky sites with strong tidal currents.

5.1.5. Possible methods for the acquisition of information

By definition, a tidal stream turbine site has high energy, making on-site measures difficult (restricted weather windows, maintenance at sea of the measurement moorings...), and requiring specific numerical modelling (swell-current interactions).
The major types of methods are listed below, in chronological order of appearance in the project:

Bibliography and existing data
Standard statistics can be produced using existing databases. Numerous sources exist (non exhaustive list of some accessible databases):

- **For tide and current**
  - Operational oceanography sites (http://www.previmer.org).
  - Estimation of astronomic tide levels by the SHOM for different tidal coefficients, available on the web (and extreme levels: positive and negative storm surge).
  - Current atlas of the SHOM: regional cartography of the directions and vertical mean tidal currents every hour for the coefficients 45 and 95 (indicative).
  - Tidal prediction software and operational oceanography sites (PREVIMER or similar).
- **For sea states**
  - Operational oceanography sites (http://www.previmer.org).
  - ECMWF (operational numerical model): total sea state (swell + wind sea), every 6 hours, with a resolution of 1.5° × 1.5° in multiannual series.
  - WW3 (operational numerical model): total sea state, every 3 hours, with a resolution of 0.5° × 0.5° in multiannual series
  - Satellite data (for example CERSAT site of IFREMER)
  - CANDHIS buoys (in France): CETMEF site measures
  - ANEMOC (numerical model with reanalysis of past *in situ* data): total sea state, over 23 years, on the French coasts (provided by the CETMEF)
- **For wind**
  - Operational oceanography sites (http://www.previmer.org) (Fig. 29)
  - Météo-France data in the "climatological files": standard wind statistics at onshore stations (indicative)
  - Purchase of Aladin or Arome data (model with assimilation and replay)
  - ECMWF: wind at 10m, every 6 hours, with a resolution of 1.5° × 1.5° in multiannual series
  - CFSR (NCEP): wind at 10m, every hour, with a resolution of 1/3° in 30 year series
  - Other global or regional models: WRF, GFS, NAM…

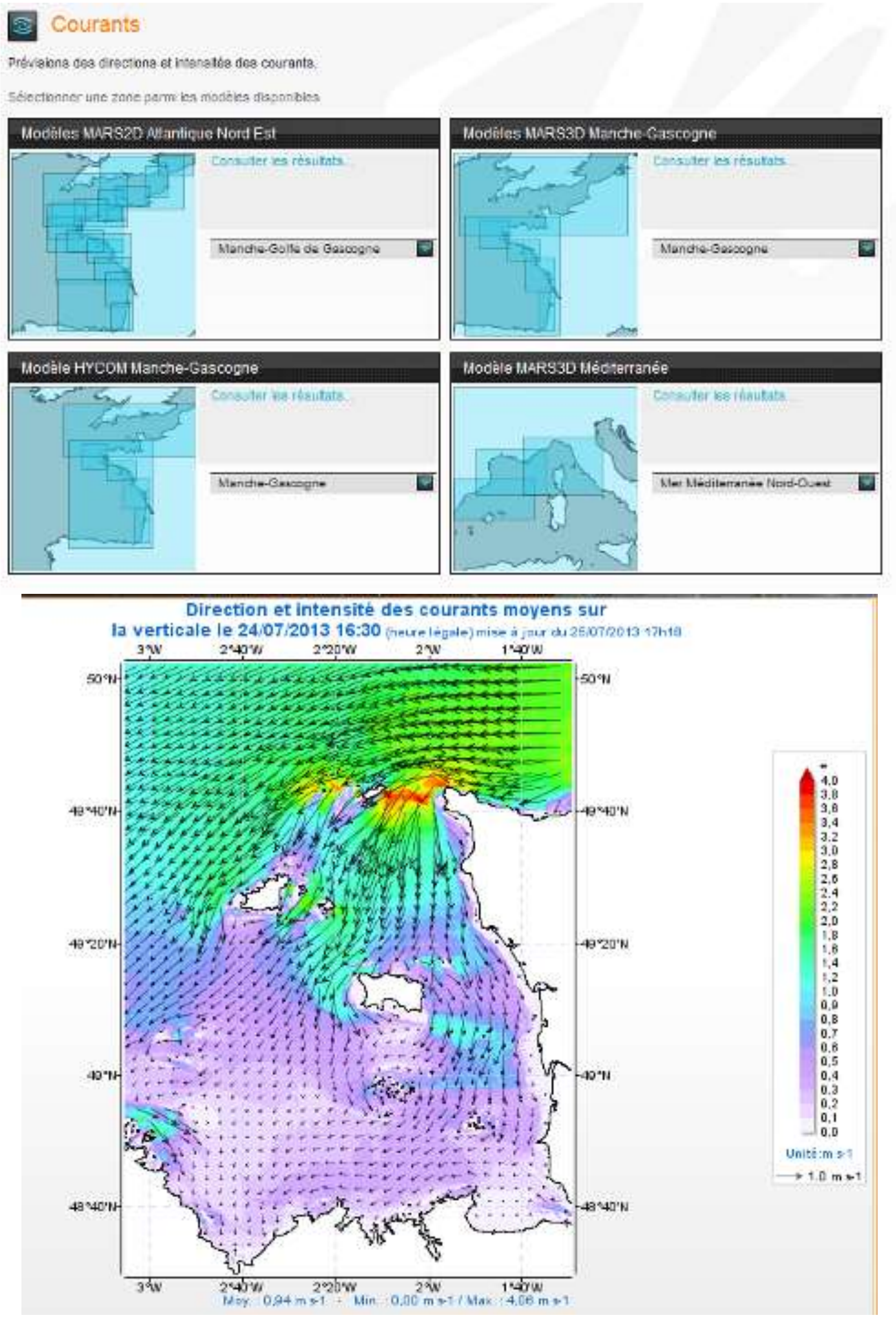

Figure 29 Available models and example output on the PREVIMER site, here for the current fields of 24/07/2013 at 16h30 on MARS2D (source: http://www.previmer.org)

<u>Onsite measures</u>

Current measurements are generally made using ADCP (Acoustic Doppler Currentmeter Profiler) deployed on the seabed and sufficiently weighted (several hundred kilos) to withstand the currents at the site. These devices, equipped with 4 transducers, are used to measure the currents in the water column above them, by sampling the water column vertically, and with a time step that it is possible to choose (generally an average current value every 5 to 10mn, but acquisition frequency can be up to 1 to 2Hz (or even 4Hz on some models) to study the temporal variability in detail (Fig. 30).

An ADV (Acoustic Doppler Velocimeter) can also be used, for infrequent current measurements (the ADV measures at 1 point rather than on the water column) using 3 transducers, with an acquisition frequency greater than the ADCP (measures that can be used as a complement).

Level measurements are made using the ADCP pressure sensors.

Sea state measurements can also be carried out using an ADCP, which has the advantage of using a single device at the same measure point. At regular intervals, the device will measure the orbital speeds to estimate the swell**.**

Note: *For current and sea state measurements, it is interesting to take advantage of the deployment of the devices to measure the temperatures and salinities.*

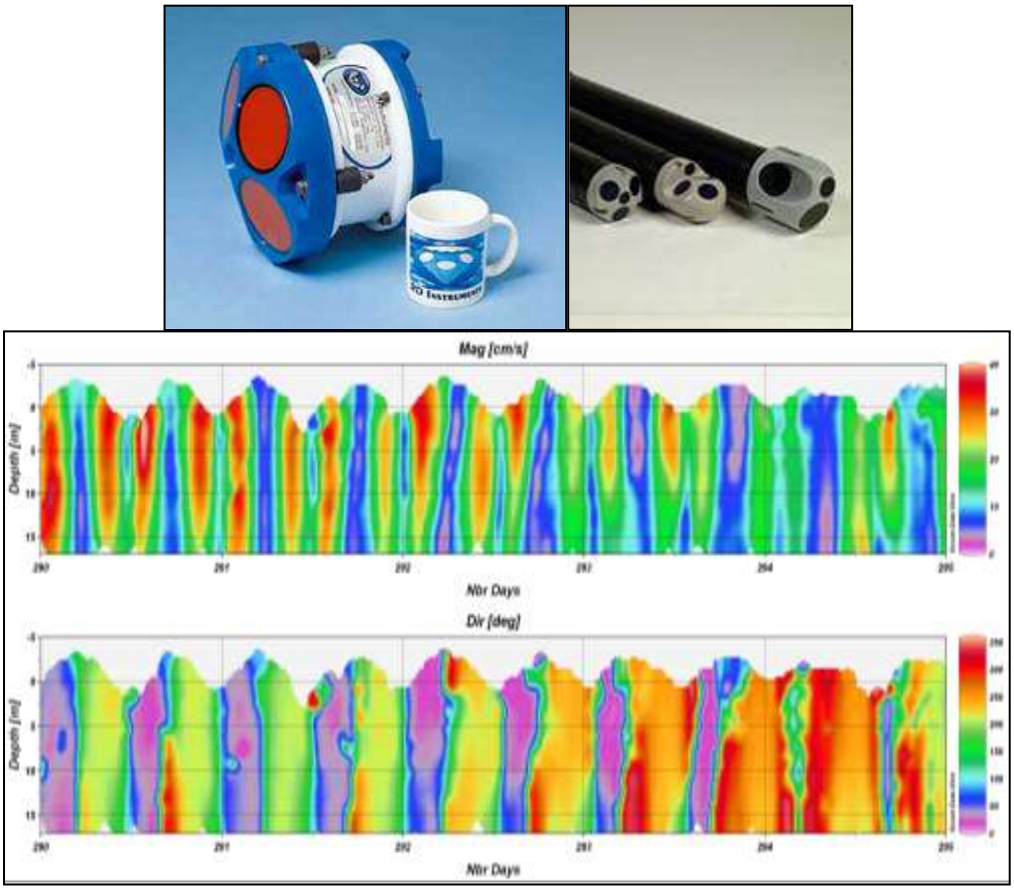

Figure 30 Examples of current profilers and data representation (source: SHOM) – from left to right: RDI Workhorse 300 kHz; NORTEK Aquapro 1 MHz; current time series for 5 days in intensity and in direction

Granulometry measurements (if there is sediment or sedimentary transit), **turbidity and/or S.M.** (suspended matter) may also prove necessary in order to understand the hydrosedimentary processes governing the site, but this point should be addressed on a case-by-case basis and remains very difficult on a site subject to strong currents (example: it can be difficult to place the turbidity chains in the water column...). These measures should be compared to the measures taken with the side-scan sonar or equivalent for the study of the seabed morphology.

Note : *The turbidity can be used to characterize the opacity of the seawater and is expressed in NTU (Nephelometric Turbidity Unit), or NFU (Nephelometric Formazine Unit), while the TSS is used to characterize the concentration of particles in the water column (in mg/L). The NTU / NFU units are sometimes difficult to relate to the S.M., because they depend on the measurement device and the environment (requiring calibration)..*

The turbidity measurement is usually done by optical means (transmissiometers, OBS[15], or combinations of both, Fig. 31) but can be made acoustically (by studying the backscatter from an ADCP). SM measurements are generally made by analysis of water samples. Indirect measures are also possible, by tracer monitoring or remote sensing, for example (surface turbidity). Other types of measuring devices exist, notably precision altimeters (ALTUS-type) or in situ laser granulometers (LISST[16]).
The difficulty of the tidal stream turbine sites will be to identify the sedimentary processes that are not apparent on the site itself (a rocky site for example). Also, only devices laid on the seabed (and heavily weighted) can be deployed.

Figure 31 Exemples de dispositifs de mesures de turbidité et de M.E.S. De gauche à droite : transmissiomètre (source : NEOTEK) ; OBS (source : ZEBRA TECH Ltd.)

[15] OBS = Optical Backscatter Sensor (also known as nephelometer or scatterometer)
[16] LISST = Laser In Situ Scattering and Transmissivity

Numerical modelling

The meteoceanic phenomena to be studied are very complex and highly variable: individual measures and studies are therefore not sufficient to understand them. This is why modelling tools have been developed. The objective of these models is first, to obtain a global vision of the study sector (current field map for example), and second, to simulate long-term phenomena in a much shorter time. They are also used to test different installation configurations in order to estimate the hydrosedimentary impacts for different configurations of a tidal stream park. The disadvantage is obviously the simplification that must be made of the processes to be studied, since a model can never reproduce natural complexity in its entirety. In particular, it is clear that the numerical models can only simulate processes for which the physical laws are known, which is not necessarily the case for a high energy site. These tools are thus highly complementary to on-site measurements.

Two types of model exist: numerical models (software) and physical models (mock-ups). Note that so-called "hybrid" models are also used, which are a combination of the two. Only numerical models will be discussed here, because this is the type mainly used for the hydrosedimentary studies of tidal stream turbine sites. However, the physical model can be used to estimate the hydrodynamic parameters of the machine, particularly for wake effects.

The numerical models used for the study of a tidal stream turbine site will mainly concern the generation / propagation of sea states and currents. Hydrosedimentary models are also implemented.

- **Models of swell generation / propagation:** these models use the nonlinear theory of swell and generally take into account the refraction, but also the effects of camber and diffraction (3rd order swell). In this regard, it is important to note that:
    - These models can be used to correctly represent the propagation of swell on rugged bathymetries and shoals, as may be the case at a tidal stream turbine site, with a rocky seabed and very high roughness (sometimes metres).
    - A numerical model can only be used if an offshore Hs / Tp / Direction time series is available, over a long period (20 years). These time series are however generally extracted from databases of larger scale (and low resolution), themselves derived from reconstructions of numerical models, which serve to determine the conditions at the limits of the regional models used for the projects. Specific measures performed on site can also be used to verify / calibrate the propagation matrix over the period of measures.

- **Current models:** these models use the Navier-Stokes equation to simulate the spatio-temporal variation of currents. Simplifying hypotheses are often needed, for example by simulating only the tidal currents, but not the turbulence or the general currents. In recent years, 3D models have become very powerful and are increasingly used. In a tidal stream turbine context, where the vertical profiles and the swell interactions will be high, this type of model is therefore preferred (the 2D models work on vertical averaged speeds).
    - It should be noted that the implementation of these models requires detailed knowledge of the water level variation at each moment, as well as the bathymetry, which will modify the currents in the zone.
    - In the case of a tidal stream turbine site, given the strong currents, and very frequent heavy swells, the swell-current interactions should be studied in detail:
        - **Effect of currents on the swell:** these effects are complex and poorly represented most of the time, because of the multiple interactions possible (current refraction, frequency modulation, vertical currents, camber...). The limitation of these models is often that "wave blocking" (breaking of the wave due to an opposite current) is not taken into account, sometimes necessitating numerical "tricks" (work of a modelling expert).
        - **Effect of swell on the currents** (to a lesser extent): to represent the currents induced by the swell, the calculation is based on a 3D model.

- **Hydrosedimentary models:** the objective here is to study the potential sedimentary movements and the evolution of the seabed under the action of the currents and the swell, before or after the installation of a tidal stream farm for example.

This type of modelling, in addition to the expertise needed to use it correctly, notably requires precise information about the sedimentary cover and the calibration of the deposition / erosion from measurements. There are two main types of modelling: for cohesive (mud type) and non-cohesive (sand type) sediments. The main objective in all cases is to study the potential impact of the machines on the sedimentary dynamics and morphology of the seabed.

Note that so-called "hybrid" models are also used, which are a combination of two types of models:

- Large size numerical models providing forcings (input data) for a smaller scale model.
- Near field scale models providing input data for a more global numerical model (for example for a scale model wake study; and integration in a numerical model to calculate the park effect).

5.2. Methods for identification and analysis of potential ecological changes

Like the potential impacts on the seabed, the potential impacts on the meteoceanic and hydrosedimentary conditions will be dependent on the technique used:

- The main effects will be due to the presence of an obstacle in the water column (the tidal stream turbine) and to the presence of a structure on the seabed (base and foundations of the tidal stream turbine or electric substation). The geometry of these two systems will therefore influence the physical processes downstream with regard to the direction of the current. When there are structures floating on the surface or subsurface, they are also likely to have a local impact on the waves.
- The potential hydrosedimentary impacts also depend on the landing cable (maritime portion).

Only the potential impacts on the swell, the currents and the sediment dynamics are addressed here. Evidently, other potential impacts could be studied on a case-by-case basis. The aspects directly related to the meteoceanic conditions are presented here.

The distinction will be made here mainly for:

- For the tidal stream turbines and the electric substation: between the floating structures or laid on the bottom.
- For the landing cable (for its maritime and terrestrial part): on the works method (laid, embedded in a trench or directional drilling).

5.2.1. Potential impacts in the installation phase

During installation, no impact is expected on the waves or the currents.

Hydrosedimentary impacts will be linked to the possible re-suspension of soft sediments during the installation of the foundations and the underwater cables (Table 18). This point was addressed in the previous chapter. As a reminder, the potential pressures on the seabed were estimated to be weak for the installation of the foundations, except in the case of prior ground preparation (dredging, for example) for which the perturbation was found to be moderate.

- These potential impacts should be studied on a case-by-case basis, depending on the sensitivity of the ecosystem and the usages. For example, the proximity of an oyster farm or a seagrass bed will be addressed by modelling the turbid plumes of these re-suspended sediments, in order to study the evolution of the concentrations with the currents and the potential impact on the organisations in terms of TSS (filtering organisms) or turbidity (need for light for photosynthesis). This chapter does not however address the biological aspects, which will be considered later, but only the physical aspects.

- In this context, modelling of the evolution of TSS concentrations can therefore be performed, on the basis of the meteoceanic models developed for the study of the initial state. Different scenarios can thus be simulated, that are representative of the processes in the zone. For example, different scenarios with tidal current only (coefficients 45, 70, 95), then cases with more or less unfavourable wind or swell conditions. Different installation scenarios or different technical options for the foundations and the cables can also be modelled.
    - These models will be conditioned by the working hypotheses provided as input data, i.e., the initial concentration and volumes re-suspended. Note that this data is not easy to obtain reliably, and is highly dependent on the works method and machinery.
    - The results of these models may lead to a restriction in the prefectural order for the works: work only for certain tidal coefficients or certain hours (which may in any case be necessary for the manoeuvrability of ships), compliance with threshold levels of turbidity or TSS, to be regularly checked during the installation. This is especially true in the case of dredging on a site with a covering of soft sediments.

Technical hypothesis		Impact envisaged during the works phase	Type of impact		Method of identification of change	
			Duration	Intensity and range	Precautions	Monitoring
FOUNDATION	Without ground preparation	Re-suspension of sediments	Temporary	Weak	Modelling of turbid plumes if necessary	Turbidity measures
FOUNDATION	With ground preparation	Re-suspension of sediments	Temporary	Moderate	Modelling of plumes	Turbidity measures
CABLES	Laid	No potential impacts				
CABLES	Embedded	Re-suspension of sediments by trench digging	Temporary	Moderate	Modelling of plumes	Turbidity measures
CABLES	Directional drilling	No potential impact				

Table 18 Summary of the potential impacts as a function of the type of works

5.2.2. Potential impacts in the operation phase

The presence of obstacles (e.g., turbines, substation or the underwater cable) modifies the local hydrodynamic conditions, by:

- An increase of the turbulent energy of the flow, due to the generation of eddies.

- An acceleration of the flow near the obstacle, by convergence of the lines of the current.

- By reflection of the swell on the obstacle.

In the operation phase, the impacts on the local swell and current conditions can be decisive, because the 'mask' effect and the 'wake' effect can impact the generation potential from the tidal stream turbine located downstream and can have repercussions for the sediment dynamics (Table 19). These processes generally occur on a limited spatial scale (a few tens of metres around the foundations), but may have serious technical or environmental consequences:

- In the sedimentary zones: scours at the foot of the pile or gravity foundation (the well-known "horseshoe vortex" phenomenon at the bottom of the bridge piles, for example, where the current may accelerate locally by 30-40%). Different states of the art concluded for piles for example that large pits can form, with 4 times the diameter of the pile upstream and 6 times downstream (Bijker *et al.*, 1988, in Whitehouse, 1998).

- In rocky zones: capture of part of the sedimentary transport? The potential modification of the substrate of the tidal stream park can have an influence on the hydrosedimentary processes.

In any case, these processes should therefore be studied in as much detail as possible, because they may influence the technico-economic feasibility of the project, but also lead to substrate changes, either because of the works (installation of anti-scouring rocks on a sandy seabed) or by indirect impact of the machines (capture of sand or pebbles in an initially rocky zone).

To study these impacts, physical modelling can be performed (scale model in a tank or channel for example, to determine the influence of the tidal stream turbine on the downstream current), associated with numerical modelling (park effect, with tidal stream turbine and natural ambient current parameters as input data), and of course measures on a full-scale prototype in the natural environment, which will probably be the most informative.

These effects should be studied in 3D and will be measured by well placed and well oriented ADCP and/or ADV, on a prototype or the operating park. Turbulence measures may also be necessary, with the uncertainties that they may bring (see above).

We assume here that the tidal stream turbines do not interfere with the whole water column, i.e., they occupy either a part between the seabed and the subsurface (tidal stream turbine laid on the seabed), or an area between the surface and the subsurface (floating or surface fixed tidal stream turbine). If the tidal stream turbines sometimes touch the surface for some coefficients (i.e., no draught above the machine), it is clear that other very problematic processes may appear and increase the sensitivity (breaking above the tidal stream turbine, acceleration of currents, etc.)..

Technical hypothesis		Impact envisaged during the operation phase	Impact intensity	Method of identification of change	
				Precautions	Monitoring
TURBINE	Fixed on the seabed	Silting effect (current)	moderate	Physical modelling Numerical modelling Prototype?	ADCP and ADV measures
	Fixed at the surface	Silting effect (current) Masking effect (swell)	Moderate to strong	ditto	ditto
	Floating	Silting effect (current) Masking effect (swell)	Moderate to strong	ditto	ditto
FOUNDATION	Gravity	Hydrosedimentary impacts	strong	ditto	ditto+ turbidity + morpho-dynamic moni-toring
	On piles	Hydrosedimentary impacts	strong	ditto	ditto+ turbidity + morpho-dynamic moni-toring
	Anchored	Hydrosedimentary impacts	weak	Mainly numerical modelling	ditto+ turbidity + morpho-dynamic moni-toring
CABLE	Laid	Hydrosedimentary impacts	moderate	ditto	ditto+ turbidity + morpho-dynamic moni-toring
	Embedded	No expected impact of the cable itself, but should be monitored in case of erosion (cable exposed?) – not addressed here in the context of the environmental impacts			
	Directional drilling	No potential impact			

Table 19 Summary of the potential impacts in the operation phase

5.2.3. Potential impacts in the decommissioning phase

The potential impacts during decommissioning are roughly the same as in the installation phase, i.e., mainly the re-suspension, more or less signif icant depending on the works methods and the type of foundation / cable (Table 20).

Technical hypothesis		Impact envisaged during the decommissioning phase	Type of impact		Method of identification of change	
			Duration	Intensity and range	Precautions	Monitoring
FONDATION	Gravity	Re-suspension of sediment when raising	Temporary	weak	Modelling of turbid plumes if necessary (according to the sensitivity of the environment)	Turbidity measures
	On piles	Depends on the works techniques? (*a priori* little sedimentary impact)	Temporary	Weak or null	Modelling of turbid plumes if necessary (according to the sensitivity of the environment)	Turbidity measures
	Anchored	Re-suspension of sediment when raising	Temporary	weak	Modelling of turbid plumes if necessary (according to the sensitivity of the environment)	Turbidity measures
CABLE	Laid	Re-suspension of sediment when raising	Temporary	weak	Modelling of turbid plumes if necessary (according to the sensitivity of the environment)	Turbidity measures
	Embedded	Re-suspension of sediment		moderate	Modelling of turbid plumes	Turbidity measures
	Directional drilling	No potential impact if the cable is left in place				

Table 20 Summary of potential impacts of decommissioning

5.3. Identification of cumulative impacts

The potential impacts presented above (wake effect, change of substrate) remain local and without major issues in the case of a single tidal stream turbine (except in specific situations). In the case of a tidal stream park with dozens of machines, park effects will influence a larger zone though:

- Wake effect, which conditions the installation of the machines, and thus the extent of the park (space occupation),
- Hydrosedimentary impacts on the whole of the sector (also to be studied outside the concession). They can influence benthic populations (change of substrate) or hydro-sedimentary processes.

5.4. Description of the environmental monitoring programme

A monitoring programme that could be adopted for a tidal stream project is summarized below. We use the same terminology as defined in the previous chapter concerning the seabed. The initial state survey was described previously.

The control surveys and the monitoring surveys will be merged here, because it is recommended to install a platform for operational oceanography that will function throughout the life of the project:

- Measuring devices (current, swell, turbidity) at the different monitoring points within and outside the tidal stream park.
- Continuous numerical modelling by real time data assimilation (swell gauge, ADCP, CTD, HF radars, etc.).

The operational oceanography monitoring performed for the needs of park operation (real-time estimation of the meteoceanic constraints and the resource) may also be used to estimate the environmental impacts on the current and the sea states. The environmental component of this monitoring will thus be performed almost continuously for the duration of the operation (therefore, no survey frequency is suggested here).
The turbidity or TSS measurements are also an integrative parameter of the oceanographic conditions (current, sea state, turbulence) and can be used to calibrate the hydro-sedimentary models.

Monitoring of the hydrosedimentary impacts will be performed based on the geophysical surveys described in the previous chapter, but can also be performed continuously for certain parameters (turbidity, seabed altimetry...) with the use of measuring devices that transmit the data. This type of time series can facilitate the interpretation of the differences between successive geophysical surveys.

5.5. Measures for impact mitigation

The reduction of the wake impacts of the turbines and their hydrosedimentary impact depends on their geometric optimisation, to be studied on a case-by-case basis by the industrialists. This depends on the site, the machines, and the requirements of the authorities. In addition, the lack of feedback prevents a comprehensive and comparative list of possible solutions from being established. Finally, this point may be confidential when it affects the calculation of the generation potential.
Similarly, no "generic" compensatory measure is proposed here to offset the impact of the park on the sea states and the currents (to be considered on a case-by-case basis according to the issues and the identified impacts).

The measures involving cessation, reduction and compensation for this type of project, in addition to the impact on the generation potential, will mainly concern the hydrosedimentary impacts. The two main types of measures, mentioned in the methodological guidelines of the DGEC (2012), are choice of a different installation zone, adaptation of works techniques.
Other measures include the adaptation of the design and the installation of anti-scouring devices around the piles and the gravity foundations, which themselves have an impact on the substrate and thus on benthic habitats (see Chapter 7).

5.6. Deficiencies and research programmes

The park effect remains difficult to quantify, given the current degree of maturity of the projects (prototypes and pilot farms). The spatialization of the information is one of the expectations of industry, i.e., the search for solutions to precisely quantify the meteoceanic conditions for the complete park, and the complete water column. This requires the optimisation of the joint use of numerical models, *in situ* measures (ADCP) and remote sensing to better spatialize the information.

Effects of turbulence and wave-current interactions are also difficult to study. Notably, recent work has been conducted to measure the turbulence using ADCP (Thomson *et al*., 2010). Working groups are on-going among industrialists and scientists to continue to improve the reliability of tidal stream turbine resources (effect of turbulence on the generation potential) and to estimate the hydrodynamic impacts (wake of a machine).

The study of the sedimentary dynamics in the energy environment is also part of the concerns of the industrialists: quantification of the transport of sediments or pebbles on a rocky site; prediction of the risk of abrasion of the machines by materials in suspension; prediction and monitoring of scouring or deposit zones; quantification of the TSS re-mobilized during the works phase; effect of the park on the hydrosedimentary processes on a larger scale than the park itself, etc.

In general, **the optimisation of measures for sites with strong currents** is a baseline for tidal stream projects. Some systems are deployed on sectors such that the dimensions must be adapted to the current and swell. Other systems are placed on the seabed, but should allow measurements in the complete water column (a typical example being the ADCP).

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6. Underwater noise

No place in the ocean is completely silent. However, the noise may be very different in nature depending on the location, the seasons, the climatic conditions, between day and night, etc. As such, the underwater noise represents a physical component that should be assessed and whose modifications potentially have consequences for the ecosystem.

Overview of underwater noise

In water, sound is a combination of progressive waves in which water particles are alternately compressed and decompressed. It can be measured as the variation in pressure within the environment around an equilibrium point corresponding to the hydrostatic pressure[17]. Known as the acoustic pressure, this pressure variation acts in all directions and normally with very small amplitudes compared with hydrostatic pressure. The international system unit of pressure is the Pascal (Pa, newton per square metre). An additional sound measure is the particle motion component, indicating the displacement (m), speed (m/s) and acceleration (m/s^2) of water particles in the medium.

Research work over the past 30 years has clearly shown that marine mammals are sensitive to acoustic pressure, but also that many fish and invertebrates respond to the particle motion generated by the acoustic wave, which can cause different degrees of perturbation of the underwater life (Sand and Karlsen, 2000; Ona *et al.*, 2007; Sand *et al.*, 2008; Anon, 2008; Sigray and Andersson, 2011).

Some marine organisms are sensitive to the pressure, the particle motion or both. Only a description on a logarithmic scale, the decibel scale[18] (abbreviated dB) can correctly describe, on the one hand, the physiological mechanisms linked to sound reception and, on the other hand, the very high dynamics of the underwater sound amplitudes. This scale is, by definition, a unit relative to a reference acoustic pressure level. In underwater acoustics; this reference level is 1µPa (one millionth of a Pascal). Thus, a decibel level only makes sense if it includes the reference.

Underwater noise levels are not comparable with airborne noise levels. Indeed, the reference level is 1µPa in underwater acoustics, compared to 20 µPa in air. In addition, with a density about 1000 times higher than air, the ocean environment is considered to be an incompressible propagation medium, in contrast to air. Thus, any comparison is unfounded. As an illustration, a qualitative scale of underwater noise levels emitted at one meter in a low-frequency band of a few kHz is proposed (Fig. 32).

Acoustic waves in water propagate very rapidly (typically 1500m/s) and over distances that can be very large. The noise level distribution in the water column and in the sediments is mainly a function of the sources present (natural, animal or human origin), bathymetry conditions, temperature and salinity conditions, the nature of the seabed, and the sea state. Thus, the disparities in propagation are often very high at the local scale (at one position but for two different immersions for example) or at the scale of an ocean basin.

[17] The hydrostatic pressure is the pressure exerted by a liquid in equilibrium due to the force of gravity. It corresponds to the pressure exerted by the water on the surface of a submerged body. It increases by about one atmosphere for a depth of 10 metres.

[18] The decibel is a logarithmic scale measurement in acoustics. The definition of the decibel is $P_{dB} = 20 \log10 (P/P_{ref})$, where P_{ref} is the reference acoustic pressure in µPa.

Pressure can be measured using a pressure sensitive device such as a hydrophone (an underwater microphone) that renders the rapid fluctuations of pressure as a function of time. The oscillation of the acoustic signal defines its frequency, expressed in Hertz (Hz). When the frequency is low (slow oscillations) the sounds are also low; when the frequency is high, the sound is high. Signal processing techniques exist to analyse sound signals as a function of their frequency, which may give rise to divisions in normalized frequency bands called octaves[19] or third octaves. To quantify the amplitude of the acoustic oscillations, we use the RMS value of the wave defined as the square root of the mean square of the signal over a time interval. Other quantities can be used to account for the amplitude of the sound waves (Sound Pressure Level, SPL), such as the maximum levels or peak-to-peak levels. The RMS amplitudes are generally dedicated to long sounds, while the maximum and peak-to-peak levels are dedicated to short (transitory) signals. To quantify the impact of the sound waves on marine fauna, these quantities for the wave amplitude can be supplemented by an assessment of the acoustic energy received during a given period, the cumulative sound exposure level (SEL) is then evaluated.

The perceived sound field depends on the sensitivity of each species. This sensitivity depends on the noise frequency or species hearing function. For comparison purposes, the acoustic sensitivity of the human species covers the frequency range from a few tens of Hz (the lowest perceptible sound frequency) to about 20 kHz (the highest perceptible sound frequency). The range of sensitivity decreases with age.

[19] An octave is the interval between two sounds where the fundamental frequency of one sound is twice the frequency of the other one. A third octave is a fraction of an octave. The ANSI S1.11 (2004) standard defines the central frequencies and the characteristics of the filters used to distinguish them.

The defined physical quantity for the translation of the acoustic sensitivity of each species is the Sound Exposure Level. It is the integral of the acoustic energy received on the biological sensitivity frequency band (frequency band actually perceived by a species) over a given period (Table 21). If this sound exposure lasts longer than one second, one can speak of Cumulative Sound Exposure, which makes sense in terms of effect.

The criteria recently proposed for underwater animals were formulated by Hastings and Popper (2005) and Southall *et al.* (2007) and are of a dual nature, providing both the limits of the acoustic peak-to-peak pressure and the specific sound exposure levels for a species.

Finally, the resulting the ambient noise that can be measured by a hydrophone, particularly if it has an anthropogenic component[20], is often stochastic in nature[21]. This is related to the fact that the occurrence of anthropogenic noise sources and, to a much lesser extent, the detailed environmental conditions, are difficult to predict. Indeed, it is particularly difficult to predict when the next fishing vessel will pass by a given point. The concept of percentiles can be used to translate and to quantify this randomness. A percentile[22] corresponds to the proportion of time and space for which the noise exceeds or is less than a given level.

[20] Linked to human activity.

[21] A stochastic phenomenon is a phenomenon that can only be analysed statistically, as opposed to a deterministic phenomenon.

[22] This concept is widespread, even in everyday life: the health records of each individual have curves showing the weight distribution of the child population as a function of age in percentiles: for example for each age, "the average weight of the top percentile" can be seen, i.e., the average weight of the heaviest 10% of children, or again, the average weight of the lightest 5% of children. The 50th percentile represents the median weight, i.e., the weight of 50% of children of the same age.

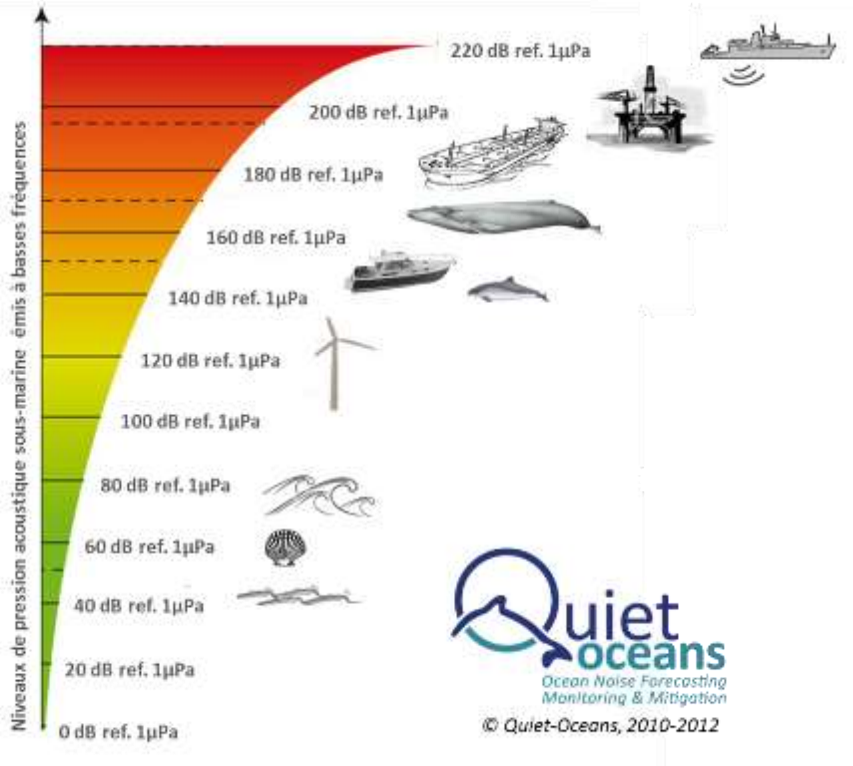

Figure 32 Qualitative scale of the average underwater noise levels emitted at one metre in a low frequency band of several kHz. Source: Quiet-Oceans.

Name	Definition	Unit
Acoustic pressure emitted	The emitted acoustic pressure is the amplitude of the signal that would be generated at one metre from a source of noise if it were transitory. This pressure can be expressed as an instantaneous value, average value, RMS value[23], or maximum value.	dB re 1µPa @1m
Acoustic pressure received	The received acoustic pressure is the amplitude of the signal as it can be measured by a hydrophone at a given distance from any sound source. This pressure can be expressed as an instantaneous value, RMS value, or maximum value.	dB re 1µPa
Sound exposure level	The sound exposure level is the acoustic energy received on a frequency band of biological sensitivity (frequency band actually perceived by a species) over a given period.	dB re 1µPa ^{2}s

Table 21 Definitions and measurement units

[23] The RMS (Root Mean Square) value corresponds to the square root of the mean squares of the signal over a fixed period of time.

6.1. Description of the initial state

6.1.1. Definition of the study zone: the noise footprint concept

The noise study zone should encompass the geographical zone for which the tidal stream turbine development project is likely to modify the initial sound conditions. This concept is called the "noise footprint". The noise footprint of the project is the zone for which the statistical noise of the project exceeds the existing statistical noise. As noise is propagated in the volume of water bounded by the surface and the bottom of the ocean, this noise footprint is three-dimensional in nature. Thus, the choice of study zone is based on:

- ✓ The characteristics of the initial noise.
- ✓ The nature of the noise introduced by the tidal stream project;
- ✓ The propagation characteristics of the noise introduced by the project.
- ✓

Thus, the geometry of the noise footprint can be highly variable depending on the life cycle of the project, the technical choices for the construction, the design of the machines, the climatic and oceanographic conditions, the bathymetric conditions, the nature of the seabed, and the levels of the existing noise. All of these parameters should therefore be considered in any prediction of the noise footprint of a project and, consequently, in the definition of the study zone.

6.1.2. Description and variability of the underwater sound chorus

Ambient oceanic noise is composed of a large number of sounds of different nature and characteristics (Fig. 33). The origins of the noise can be classified into three categories (Table 22):

✓ Noise of a physical nature: noise related to the breaking of waves on the surface, to the breaking of waves on the coastal strip, to the sediment transport, etc.

✓ Noise of biological origin: noise emitted by living organisms such as, for example, shrimps, scallops, marine mammals, etc.

✓ Noise of anthropogenic origin: noise of human origin, such as shipping, yachting, construction noise, fishing gear, seismic sonars, sounders, etc.

Each of the noises has different time, frequency and energy characteristics. Therefore, masking or interference effects may exist between the different sounds that make up the measured ambient noise. In the case of tidal stream turbine sites, it has been observed that the sedimentary transport (Willis *et al.,* 2013) contributes significantly to the environmental noise and can generate a specific noise by physical interaction with the machines.

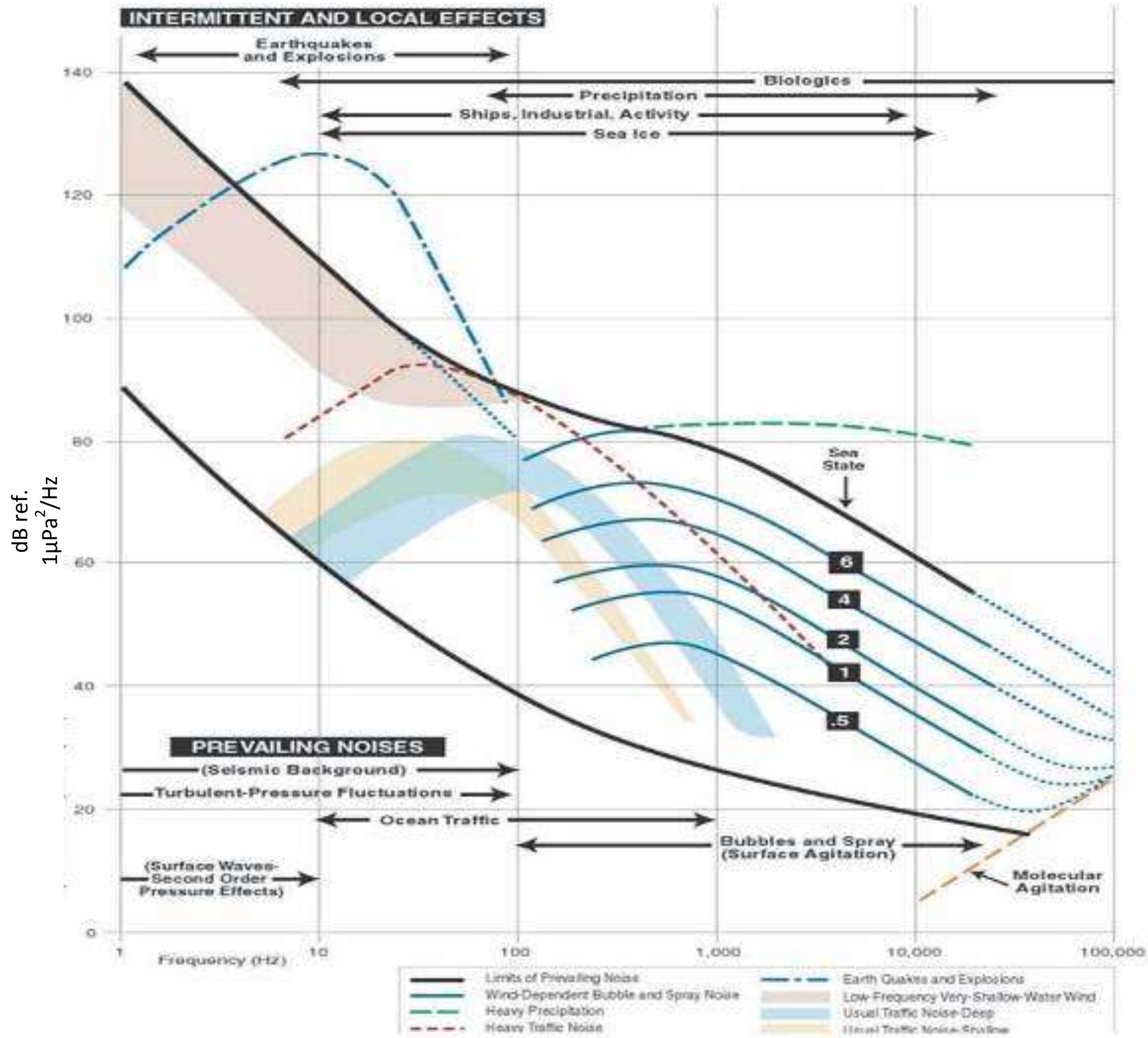

Figure 33 Evaluation of the acoustic spectrum as a function of the frequency and the nature of the noise. Unit used: dB re 1µPa²/Hz [24]. From Wenz (1962)

[24] The unit in dB re 1µPa²/Hz indicates that the noise is estimated on a band of 1 Hz.

Nature		Example	Location of the noise sources	Range of most energetic frequencies	Type of noise	A priori range (highly dependent on the environmental conditions)
Physical	Sea state (surface noise)	Agitation on the surface of the oceans	Foreshore zone Large zone	100Hz - 10kHz	Continuous	Scale of a basin
	Sediment transport	Movement of sediments	Surf zone Strong current zone	Several tens of kHz	Temporary	Several metres
	Wave breaking	Surf Rough sea or worse	Surf zone Coastal zone Large zone	10Hz – 1kHz	Temporary	Several hundreds of metres
Organic	Cetaceans	Common dolphin, Bottleneck dolphin, Porpoise, etc.	Coastal zone Large zone	Several Hz to several hundreds of kHz	Temporary or impulsive	Several hundreds of kilometres (mysticetes) to several hundreds of metres (ondotocetes)
	Macrobenthos	Bivalve molluscs and larger crustaceans including crabs, lobsters, shrimps, etc.	Coastal zone	Several Hz to several tens of kHz	Impulsive	Several metres
	Pinnipeds	Grey seal, Harbour seal, etc.	Foreshore zone Large zone	100Hz - 10kHz	Impulsive	Several hundreds of metres to several kilometres
Anthropogenic	Commercial traffic	Cargo, ferry, etc.	Foreshore zone Large zone	1Hz – 10kHz	Continuous	Several tens of kilometres
	Fishing activities	Ship, trawler, etc.	Foreshore zone Large zone	1Hz – 10kHz	Continuous and impulsive	Several tens of kilometres
	Yachting and diving activities	Zodiac, jet-skis, etc.	Foreshore zone Large zone	1Hz – 10kHz	Continuous	Several tens of kilometres
	Maritime works	Pile driving, drilling, dredging, etc.	Foreshore zone Large zone	1Hz – 10kHz	Continuous or impulsive	Several tens of kilometres

Table 22 Main contributions to the ambient noise in the context of a tidal stream turbine site

6.1.3. Characterisation of sound variability

The characterisation of the sound chorus and its variability can be obtained by:

- ✓ Passive measurement for noise of physical and biological origin.
- ✓ Measurement and numerical modelling for noise of anthropogenic origin.

6.1.3.1. Characterisation by passive measurement with mono-sensors

A statistical analysis of the acoustic events recorded by a passive acoustic system (Fig. 34) involves the extraction of the individual sources from the measured sound signal, followed by their characterisation. The distinctive properties of the different events in the time-frequency representation space make it possible to identify the constituent sound events of the chorus though the use of specialised instruments. Indeed, the transcription of the data in this space, for example by constructing the data spectrogram, can be used to:

- ✓ Filter the noise and provide better processing, facilitating the detection of natural, biological or anthropogenic sound events.
- ✓ Present the data in a space highlighting the intrinsic properties of the signals, which facilitates their classification.

This type of processing can be used to detect and characterize all types of noise: transient noises (limited duration), broadband noises, continuous noises, spectral lines, etc. (Gervaise *et al.*, 2010; Gervaise, 2011; Gervaise *et al.*, 2012; Di Lorio *et al.*, 2010).

The expected results can be used to characterize the sound chorus at different time scales, and include:

- ✓ Quantification of the events classified by the nature of the noise.
- ✓ Time series of the noise natures, their statistical distributions, and their respective contribution to the chorus. For biological noise, these series are an indicator of the ecological use in the range of the hydrophone.
- ✓ The percentile values of the different noise natures as a function of the time of day, monthly, seasonal or annual averages.

Marine species are only sensitive to a limited frequency band (sensitivity band of the species). However, the ambient noise levels can vary greatly depending on the frequency. Therefore, it is important to characterize the variability of the sound chorus in frequency sub-bands, the standard being in octaves or third octaves. This characterisation by frequency bands can be used to understand the potential effects as a function of the sensitivity range of the species potentially present.

The results of the measurements are valid only for a three-dimensional zone around the hydrophone considered. The validity zone of the measure is dependent on the range (or detection distance) of the instrument and is estimated with acoustic propagation models.

The use of a multi-sensor measuring system (network of synchronized hydrophones and/or antennas) would allow a detailed characterisation of the spatial variability of the sound chorus. However, it adds a strong operational constraint (system cost, deployment difficulties, etc.) and is probably unsuitable in the context of an impact study. In the remainder of this document, it is assumed that the sound measurement is performed with a single hydrophone (or a few unsynchronized hydrophones).

Figure 34 Examples of autonomous underwater recorders for acoustic listening: Aural, DSG Ocean, SM2M and RTSYS.

6.1.3.2.Characterisation by measurement and modelling

The acoustic measurement is, by nature, local and occasional. Thus, the ambient noise measurement is only valid for the position (latitude, longitude, depth) of the hydrophone and at the moment of the measurement.

Thus, extrapolation methods that take into account the physics of the acoustic phenomena pave the way towards a spatial characterisation of the anthropogenic ambient noise and the noise footprints of the energy projects, in predictive or monitoring mode. The methods based on the propagation models also allow the statistical characterisation of the noise, in a similar and complementary way to the statistical analyses of the *in situ* measures. This consistency of approach, analysis and presentation means that the local measure can be used to set (or calibrate) the acoustic models.

Thus, the ambient noise maps, which should represent the statistical variability of the noise in the same way as the *in situ* measurements are presented in the form of percentiles that represent, at each location of the study zone, the noise level estimated along the water column for the proportion of time defined by the percentile value (Fig. 35). Only the assimilation of the acoustic signals analysed in third octaves in the acoustic propagation models developed by military experts allows the presentation of an overall view of the statistical noise at the project scale.

6.1.4. Implementation of *in situ* measurements

6.1.4.1. Problem of acoustic measurement at a tidal stream turbine site

The main characteristic of the tidal stream turbine sites is that they are subject to strong currents. From the point of view of *in situ* acoustic measurement, this raises the following problems:

- ✓ Logistic difficulty of the operations at sea and security of the deployed equipment.
- ✓ Difficulty in the design of sensor maintenance systems to make them current resistant and silent ;

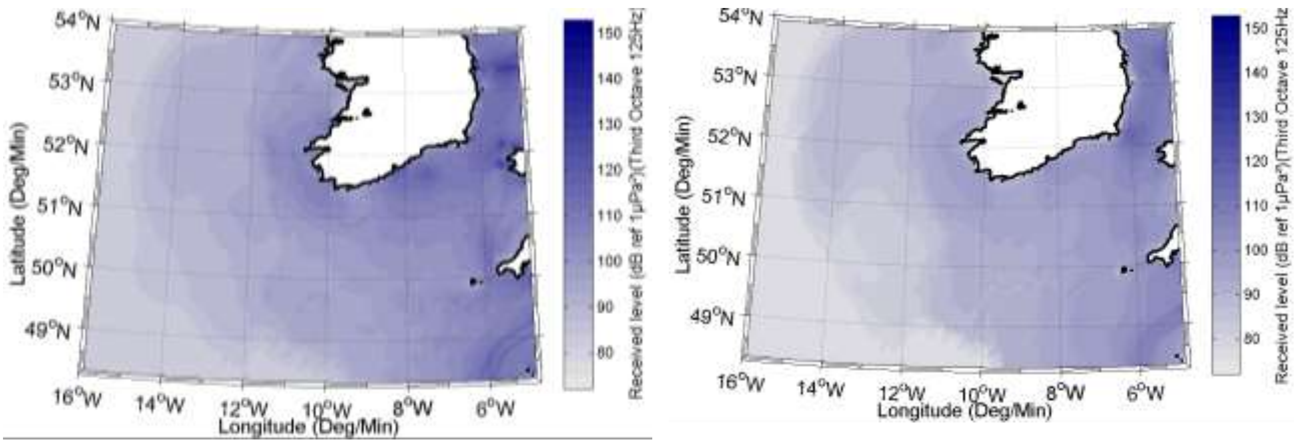

Figure 35 Example of statistical map of noise generated by maritime traffic in the third octave at 125 Hz: (left) map of noise levels for the 10th percentile in summer, e.g., 10% chance of observing a noise higher than the levels given by the colour code; (right) map of median noise levels in winter, e.g., 50% chance of observing a noise higher than the levels given by the colour code. Source: Quiet-Oceans, STRIVE Noise project funded by the Environmental Protection Agency, Ireland (Folegot et al., 2013)

✓ Pollution of the passive measurement: when the speed of the current is high, the hydrophone significantly modifies the local flow around itself. The flow is likely to become turbulent and to generate a noise of low intensity, but close enough to the hydrophone to pollute the measurement (Martin, 2012; Willis *et al.*, 2013).

✓ Reduction of the noise detection performance: the natural, biological and anthropogenic noise is detectable when it sufficiently dominates the background noise (e.g., the sum of the other noises at the location of the hydrophone). The pollution of the signal by the noise associated with the presence of the sensor and its anchorage in the current can mask the existing natural, biological or anthropogenic noises to be measured. The reduction of this performance may however be acceptable depending on the typology of the site and its biological frequentation.

The solutions to avoid or reduce these practical problems exist or are the subject of research. For example, underwater combat applications are subject to the same difficulties, especially when using towed passive acoustic sensors. The techniques developed involve "sheathing" the hydrophones in (relatively) acoustically transparent materials. The thicker the sheath, the more efficient the insulation of the flow noise, although this is at the cost of a decrease in detection performance. The solution of sheathing the cables can also significantly reduce the vibrations linked to the current. Other possible solutions include, in particular, the implementation of drifting measures whose aim is to minimize the relative speed between the hydrophone and the environment. Despite the necessity, there is no *a priori* solution. The solutions are based on real-world experience that can only be acquired through *in situ* experimentation.

6.1.4.2. Protocole spatio-temporel

The objective of the "ambient noise" protocol is to establish an initial sound state of the implantation site of the tidal stream park in order to assess, during the successive phases of a project, the acoustic footprint of the park on the underwater environment on the one hand and to define the different potential impacts on the marine fauna on the other hand (Fig. 36).

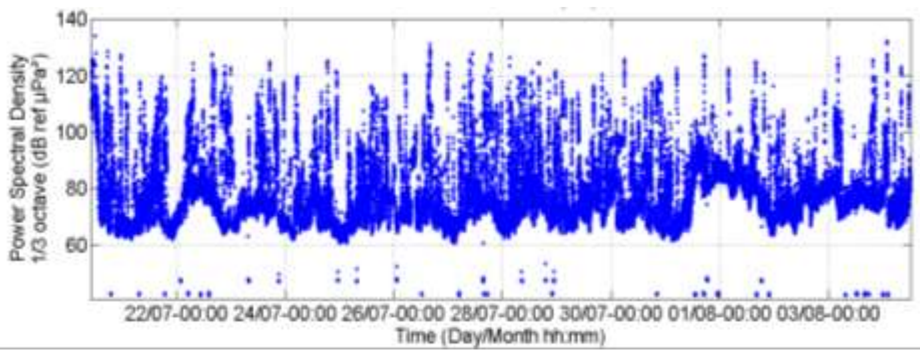

Figure36: Noise measurement after analysis in the 125Hz third octave, over a period of 15 days, showing the typical superposition of natural background noise depending on the meteorological conditions with strong anthropogenic events. Source: Quiet-Oceans, Folegot et al. (2013).

When defining a field acoustic survey protocol, it is first essential to formalize the final purpose of each hydrophone. Indeed, a purpose of characterisation of the anthropogenic and natural ambient noise is not subject to the same requirements as a measurement for the characterisation of the biological frequentation of the site. For example, for an ambient noise measurement, the system should not introduce additional noise while, if the goal is the detection of vocalisations, the instrument can introduce its own noise (turbulence noise for example) without jeopardizing the measurement. However, it is possible to tolerate intermittent measurement to characterize the ambient noise, on the condition that it covers a statistically representative diversity of environmental conditions and anthropogenic frequentation of the site.
The definition of the protocols is therefore largely dependent on the objective, the environmental conditions of the tidal stream turbine site, the existing human activities, but also the logistical conditions and the security of the material and equipment. Its precise definition therefore requires a dedicated analysis, based on:

- ✓ Analysis of the existing types of noise.
- ✓ Analysis of the types of noise linked to the project.
- ✓ Environmental conditions of noise propagation.

An element helpful in the definition of an *in situ* measurement protocol is to have an *a priori* cartographic description of the ambient noise in the zone. An initial estimate of the noise structure and its variability obtained by modelling provides preliminary information that can be used to properly set up the measurement campaign, and in particular:

- ✓ Adjust the gains of the acoustic instruments in order to adapt range of the reception amplitude to the existing noise and its dynamics, and thus ensure that it is useable.
- ✓ Quantify the dimension of the study zone and to ensure a representative survey of the entire zone and the ensemble of its diversity.
- ✓ Quantify the number of hydrophones required for the survey of the study zone as a function of the spatial variability of the noise.

6.1.4.3. Acoustic data to be collected

The positions of passive acoustic control measurement will be determined by predictive cartography of the zones exceeding the thresholds established for the species and by the habitat zones of sedentary species.
The difficulties of deployment on tidal stream turbine sites and the goal of a representative statistical characterisation require the use of a combination of configurations, fixed/drifting, short term/long term, of which each element should respond to an objective identified in the context of a given measurement. This combination involves, for each instrument:

- ✓ Deployment mode.
- ✓ Deployment duration.
- ✓ Effective duration of exploitable measurement.
- ✓ Measurement range of the instruments.

The range of the passive hydrophones, which it is essential to estimate in order to assess the observation "effort", is largely dependent on the electronic acquisition characteristics, the oceanographic conditions, the meteorology, the bathymetry conditions, the local conditions of the nature of the seabed, the ambient noise, and the

biological species that are to be identified. One solution is to model the range of the hydrophones based on these parameters.
It is vital to calibrate the hydrophones before and/or after their application.

6.1.4.4. Non-acoustic data to be collected

The random nature of the noise, combined with the complexity of the underwater acoustic propagation, means that a certain number of maritime and marine parameters need to be monitored in conjunction with the measurement. This non-acoustic monitoring is as essential as the acoustic measurement itself because it guarantees a correct interpretation. The non-acoustic measures should allow:

- ✓ Understanding of the measured acoustic events, both natural and anthropogenic.
- ✓ Characterisation of the parameters determining the acoustic propagation.

The essential non-acoustic measurements to be performed include:

- ✓ Temperature and salinity (or the speed of sound).
- ✓ Wind and / or surface roughness.
- ✓ Tide.
- ✓ Rainfall.
- ✓ Depth of each hydrophone.
- ✓ Position of each hydrophone.
- ✓ Position of the different types of vessels located in acoustic range of each hydrophone.

6.1.5. Spatialisation of the measurement by modelling

The spatialisation of the measurement by modelling involves using the predictions obtained from acoustic propagation models to extract the ambient noise information at the scale of the study area.

6.1.5.1. Acoustic modelling

There are several possible approaches to the ambient noise modelling at the scale of an ocean basin:

- ✓ The first approach involves N times 2D modelling (Nx2D): each 2D modelling is performed in a vertical plane containing the source of the anthropogenic noise. The modelling is repeated as many times as necessary according to a sufficient number of azimuths. The disadvantage of this approach lies in the fact that each propagation plane is independent of the others. In other words, the sound energy propagates necessarily in the same plane, which may be inaccurate in environments with strong bathymetric ruptures.
- ✓ The second approach involves 3D modelling. At the cost of a significant calculation time, this approach can be used to describe the exchanges of sound energy in all directions and thus takes into account the three-dimensional effects of the bathymetry and, to a lesser extent, the velocity gradients in the water column.

6.1.5.2. Selection criteria for the acoustic modelling code

The selection of the propagation model (resolution of the Helmholtz equation) should take into account a certain number of quality and performance criteria:

- ✓ The maturity of the propagation code, i.e., the use of a code that has been widely validated in many different environmental situations, and is mainly representative of the project environment.
- ✓ The computation time must be compatible with the operational requirements of the project and its deadlines.
- ✓ The pertinence and validity of the simplifying hypotheses of the Helmholtz equation (high frequency hypothesis, parabolic hypothesis, etc.) compared to the propagation conditions of the studied site.

6.1.5.3. Prediction of ambient noise

The combination of a set of environmental and anthropogenic situations representative of the study site in the acoustic propagation modelling provides a representative set of three-dimensional sound fields. Statistical analysis of this set of sound fields, which are representative of instantaneous situations, allows the extraction of seasonal statistics of ambient noise and their sensitivity in the form of percentiles, and the description of the sound state of the study zone in terms of percentiles of noise level and of spatial distribution.

6.1.5.4. Calibration of the prediction by in-situ measurement

The convergence between the measured statistics and the statistics predicted by the modelling at the measurement location allows the calibration of the obtained cartographies. Several methods are possible, but Quiet-Oceans propose a method that provides a statistical characterisation by taking into account the environmental uncertainties of the site (Folegot and Clorennec, 2013).

6.1.6. Methodological limitations and knowledge gaps

6.1.6.1. Modelling conditions

Acoustic sources are idealized as point sources or as series of point sources depending on the type of activity concerned. This is a simplification with regard to the sound sources, which are generally extended sources, and may introduce a bias very locally at the position of the noise source.
Modelling of parabolic equations (Jensen *et al.,* 2000) is based on a "slowly varying" hypothesis for the propagation medium, which is often the case at tidal stream turbine sites. The computational time required for this modelling method increases for higher frequencies and deeper environments. Thus, beyond a certain frequency, the numerical simulation scheme may need to be modified, and the modelling is therefore done using other assumptions. The conditions for continuity of results from one model to another must be evaluated carefully.
Finally, for very shallow waters (typically of the order of ten metres of water height), the influence of the interfaces (surface and bottom) is such that the modelling becomes less accurate given that the frequencies are low (cutoff frequency) and the interfaces are hard to describe.

6.1.6.2. Uncertainties in the physical data of the marine environment

The profiles of sound velocity in water, proportional to the water temperature, salinity and static pressure (or depth) are average profiles and do not take into account high resolution phenomena that may exist. These phenomena influence the sound propagation when the acoustic wavelength is smaller than the phenomenon, i.e., for the high frequencies that are in fact the most dissipative.
In the absence of *in situ* measurements, the uncertainties concerning the absolute noise levels cannot be resolved. This uncertainty decreases, however, when the prediction of the noise footprint of the project is provided at relative levels.

6.1.6.3. Uncertainties in the geo-acoustic properties of sediments and their spatial distribution

The uncertainty in the geo-acoustic properties of sediments and their spatial distribution can only be taken into account by a statistical approach that allows the parameters to be varied within a range of uncertainty and thus to take into account the sensitivity of the results to these uncertainties.
In an operational context, to resolve the uncertainties, the assimilation of *in situ* measurements (coring, seismic surveys, geo-acoustic inversion) allows the adjustment of the geo-acoustic parameters used in the models and a more accurate consideration of the effects of the seabed on the noise footprint of the project.

6.1.6.4. Uncertainties in the sound templates of existing activities

The existing activities are described, for each activity type, by sound templates. Thus, for example, individual differences between two ships with the same type of activity (commercial traffic for example) are not taken into account. However, scientific experiments (Folegot *et al.*, 2012) show that in zones liable to strong anthropogenic pressures, the effect of this uncertainty is limited by the large number of noise sources contributing to the sound chorus.

6.2. Methods for identification and analysis of potential ecological changes

6.2.1. Characterisation of the noise footprint

The noise footprint of the project is the zone of statistical emergence of the project noise, in relation to the existing sound chorus. For each homogeneous family of environmental conditions (for example, the oceanographic season) and for each type of construction, the perimeter of the noise footprint should be established based on the statistics of the perturbed acoustic fields compared to the statistics of the acoustic fields of the ambient noise that existed before the project. These maps are established after summation over the frequencies, and integration of the different oceanographic conditions representative of the site (water, surface roughness, etc.) (Fig. 37).

In order to establish a link with the noise exposure for the species potentially present in the noise footprint of the project, the project noise footprints can, in the current state of scientific knowledge:

- ✓ Be estimated for a second of activity.
- ✓ Integrate the sensitivity band of each species.
- ✓ Be expressed in dB re 1µPa^{2}s above the seasonal median of the existing ambient noise.

Their conformity will allow the subsequent assessment of the impacts with regard to marine mammals, taking into account the cumulative duration of each operation.

6.2.2. Characterisation of the noise footprint depending on the project life cycle

In addition to the initial noise, there are also noises specifically related to the construction of the project. These noises, generated by the different techniques used, can be of an impulsive or continuous nature. The accumulation of the initial noise and the noise linked to the project creates a sound state known as "perturbed". They are predicted by modelling during the risk assessment phase and before the decommissioning; by combining measurements with the models during the phases of installation, operation, maintenance and decommissioning.

6.2.2.1. Specificities of the installation phase

The installation phase of the project often requires the use of methods and tools that generate noise, including (Table 23):

- ✓ Vertical drilling, generating continuous noise.
- ✓ Directional drilling, generating continuous noise.
- ✓ Pile driving, generating impulsive noise.
- ✓ Dredging, generating continuous noise.
- ✓ Trenching, generating continuous noise.
- ✓ Mining, generating impulsive noise.
- ✓ Surface ships, generating continuous noise.
- ✓ Etc.

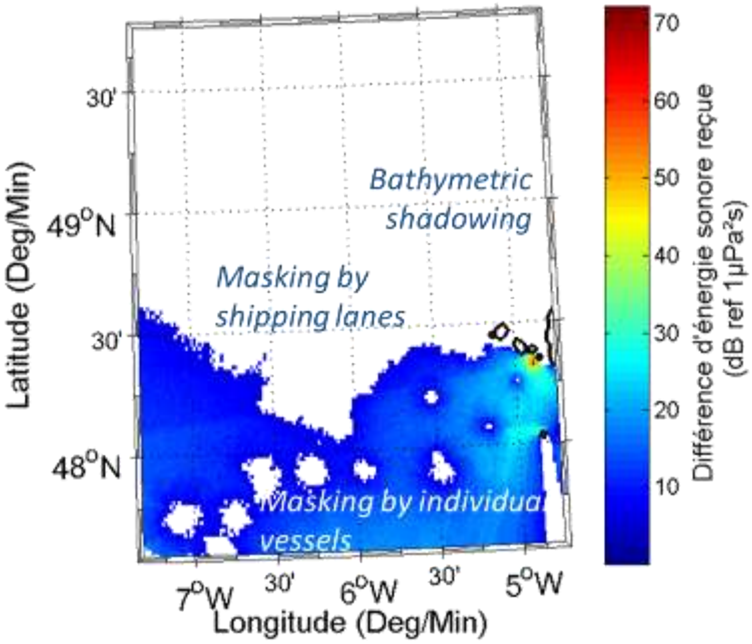

Figure 37 Example of the estimation of a noise footprint (or statistical emergence) of intensive anthropogenic noise off Molène (source: Quiet-Oceans; Folegot and Clorennec, 2013): the noise footprint is the coloured zone, the white zone corresponds to zones where the project noise is dominated by the existing sound chorus, either due to a bathymetric effect (North) or by masking from the overall maritime traffic noise (West) or by individual vessels present locally (South).

This use is limited in time. This is especially true for tidal stream projects that operate in zones with strong currents. Thus, it is essential to formalize works scenarios that are representative of each construction work, by including as a minimum:

- ✓ Nature of each operation.
- ✓ Characteristics of each tool used.
- ✓ Duration of each operation.
- ✓ Repeatability of each operation.
- ✓ Location of each operation.
- ✓ Environmental conditions allowing the operation.

6.2.2.2. Specificities of the operation/ maintenance phase

The noises associated with site operation are continuous, but intermittent with the transitions of the current. Thus, an individual characterisation over several tide cycles, including the spring tides, is sufficient to establish a template of the generated noise as a function of the current (and hence the rotational speed).

The establishment of a propagation model can be used subsequently to evaluate the noise footprint map of an individual turbine and, more importantly, of the entire park. Occasional measurements in the presence of all turbines in the park will allow the calibration of the statistical maps of the park's noise footprint.

6.2.2.3. Specificities of the decommissioning phase

The problem of noise in the decommissioning phase is probably of the same nature as in the installation phase.

Nature		Means of characterisation	A priori occurrence
Anthropogenic	Construction of the foundations	Measurement and modelling	Temporary
	Embedding of the cables	Measurement and modelling	Temporary
	Maritime traffic related to the construction	Measurement and modelling	Temporary
	Functioning of the tidal stream turbines	Measurement and modelling	Permanent
	Maritime traffic related to the maintenance	Measurement and modelling	Semi-permanent to permanent
	Maintenance	Measurement and modelling	
	Decommissioning	Measurement and modelling	Temporary

Table 23 Non-exhaustive list of the possible origins of noise linked to the tidal stream projects.

6.2.2.4. Characterisation of turbine noise

Techniques for characterizing mechanical system noises exist, which work either by finite element modelling or by modelling of linked subsystems. Modelling of linked subsystems can be used to describe the different constitutive elements of the turbines and to describe the mechanisms for the transfer of noise and vibrations to the outside, via vibration, acoustics or fluids.

The combination of the transfer functions of the constituent sub-systems and the mechanical interfaces between the subsystems allows *a priori* characterisation of the turbine noise.

The characterisation of the turbine noise by acoustic measurement is more difficult, in particular due to the presence of currents. Phenomena of measurement pollution by turbulence phenomena located around the hydrophone may limit the exploitability of such measurements.

6.2.2.5. Characterisation of the noise of particles associated with tidal stream turbines

The transport of sediments in the tidal stream turbine site may physically interfere with the turbines. The noise of the sediment transport in the zone before the installation of the park can therefore be substantially increased.

6.2.2.6. Vibrations

The construction noise and the turbine noise probably generate vibrations, which are transmitted to the seabed and are propagated in it. Currently, little knowledge exists concerning the effect of these vibrations on marine fauna.

6.2.3. From noise footprint to exposure levels

The project noise footprint is transformed into perceived sound level depending on the sensitivity of each species as a function of the frequency or their hearing function (National Research Council, 2003). This transformation, proposed by Southall *et al.* (2007), involves selecting only the frequency ranges that are actually perceived by the animals. These are calculated by weighting the spectrum of the sound wave insonifying the marine mammal by the transfer function of the ear ("M-Weighting function"), then by integrating this acoustic energy on the hearing frequency band (Fig. 38).

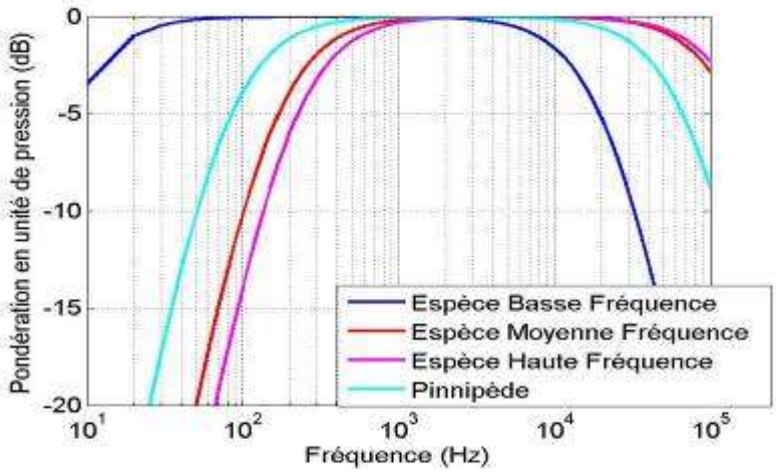

Figure 38 Weighting functions depending on the frequency and class of marine mammal species, or audiogram function, used to estimate the noise levels perceived by the biological species based on the knowledge of the noise footprint. For humans, the useful frequency band is from 20Hz-20kHz.

6.2.4. Management of uncertainties and knowledge gaps

Each descriptive characteristic of the project or description of the propagation environment should be attributed an uncertainty interval and/or a variability interval and/or an error bar. The values of these uncertainties depend on the level of knowledge of the environmental conditions of the site and the project. The impact of these uncertainties on the accuracy of the results should be evaluated by modelling. The uncertainties linked to the project are primarily:

- ✓ Noise levels of the tools.
- ✓ Nature of the seabed in the study zone;
- ✓ Oceanography in the study zone;
- ✓ Sea state.

A percentile representation can be used to represent these uncertainties.

6.2.4.1. Uncertainties in the sound templates of the project

Concerning the construction techniques, there is to date little known data regarding the noise differences as a function of the detailed specifications of the machines-tools and the site conditions (nature of the substrate, for example). However, the production of scientific literature on this subject is growing rapidly and templates can be derived from measurements made during different projects. The dispersion of the emitted noise values reported is relatively low. In the current state of knowledge, the uncertainties about the type of machine-tool and the substrate conditions, although they exist, are probably marginal.

The emergence and diversity of the technologies relating to tidal turbine technologies means that the systems may never have been deployed in real conditions. Few noise measurements have been reported so far to precisely characterize the sound signatures. Until our knowledge improves, the signatures of the tidal turbines may, however, be estimated by experts.

It is important to encourage the theoretical or experimental characterisation of the turbine noise starting from the design phases, at reduced scale and at full scale.

6.2.4.2. Uncertainties about the effects of tidal stream turbine masking

The individual turbines arranged within the park can serve as a screen for the noise of turbines located nearby. This phenomenon can exist at higher frequencies, and is probably marginal at low frequencies where diffraction phenomena have the effect of reducing the shadow of the structures.

6.3. Identification of cumulative impacts

By nature, the noise study is cumulative, in the sense that the proposed definition of the noise footprint can be used to understand the accumulation of existing noise (of various natures) with the project noise.

6.4. Description of the environmental monitoring programme

During the initial state analysis phase, the statistical seasonal characterization of the ambient noise covers statistically representative periods with seasonal *in situ* measurement campaigns (Table 24). The goal is to obtain a better representativity of the ambient noise as a function of different meteo-oceanic conditions.

During the construction phase, *in situ* passive acoustic measurements should be carried out in conjunction with the actual works phases. During the operation phase, passive acoustic control measurements are made quarterly and for the years (N), (N + 1) (N + 5), (N + 10) etc., in order to take into account the potential modifications of the noise footprint of the park (modifications of the acoustic signature of the park) after several years of operation.

During the decommissioning phase, passive acoustic measurements will be conducted in parallel with the actual works phases.

	Initial state		Monitoring during the operational phases of the tidal stream project			post-decommissioning monitoring
	Prerequisite	**Assessment**	**Construction**	**Operation**	**Decommissioning**	
Objectives		Seasonal characterisation of the ambient noise	Statistical characterisation of the sound exposition levels and the cumulative exposition levels for each construction phase	Seasonal statistical characterisation of the sound emergence of the park during the operation phase for a representative set of meteorological conditions	Statistical characterisation of the sound exposition levels and the cumulative exposition levels during the decommissioning operations	Evaluate the return to the reference state "E_0" by a seasonal statistical characterisation of the ambient noise
Perimeter of the study	Distant study area defined depending on the prediction of the noise footprint of the project and the zones statistically exceeding the thresholds of physiological damage and potential modification of the behaviour of the fauna present.					
Duration	Statistically representative duration of the site noise		Complete construction phase	Complete operation phase	Complete decommissioning phase	Quarterly
Recommended periodicity		Seasonal	In conjunction with the actual works phases	20 days/quarter during the years of partial operation and the year of full operation of the park (N), then 20 days/quarter for the years (N+1), (N+5), (N+10) etc.	In conjunction with the actual works phases	Seasonal
Method		**Means**: Physical modelling, passive acoustic measurements. The frequency range of modelling and passive measures extends from 30Hz to 80kHz. **Method**: Spatialisation of the *in situ* passive acoustic measurements in the range 30Hz to 80kHz using physical models of acoustic propagation. **Initial state**: The positions of passive acoustic measurements will be determined from a prediction of the initial ambient noise. **Construction phase**: The positions of passive acoustic measurements are determined from maps of zones at risk of exceeding the physiological thresholds and the predicted thresholds of behaviour modification. During the noisy phases of the construction works, the passive acoustic control measurements should be carried out at positions determined by the predictive cartography of the zones exceeding the thresholds and depending on the habitat zones of the marine mammals. **Operation phase:** The positions of the passive acoustic measurements are determined from predictive maps of the noise footprint in the operation phase.				
Data to be collected	Seasonal characterisation of the acoustic footprint of the project. Definition of zones statistically exceeding the thresholds of physiological damage and behavioural modification of species	Passive and active acoustic data and all data on the physical and anthropogenic environment allowing the spatialisation of the acoustic data and the analysis of the sound chorus measured by the hydrophone.				
Presentation of the results	Cartography in third octaves or octaves between 30Hz and 80kHz (minimum 90^{th}, 50^{th}, 10^{th} and first percentiles). Sensitivity intervals linked to the uncertainties of the physical environment and to their variability should be integrated into the sound maps.					

Table 24 Toolkit for acoustic monitoring

6.5. Impact avoidance and reduction measures

When the identified issues and risks require it, noise management or reduction measures can be implemented. This section first lists and analyses the different solutions to reduce, avoid and offset the sound levels and the risks to marine mammals. The offset aspect, which is currently difficult to implement, will not be addressed here. The risk management is a logical continuation of the results of Chapter 9, dealing with the impacts on marine mammals that may be found in or near the project zone. Second, in the context of this project, the techniques that could be implemented to reduce the noise nuisance are listed. The reduction and avoidance of the risks can be performed according to four main types of action (Fig. 39).

- ✓ Measures to reduce the levels of the individual noise sources.
- ✓ Measures to reduce the cumulative noise levels.
- ✓ Systems that hinder the noise propagation in the ocean.
- ✓ Measures that allow temporary removal of species from the risk zones.

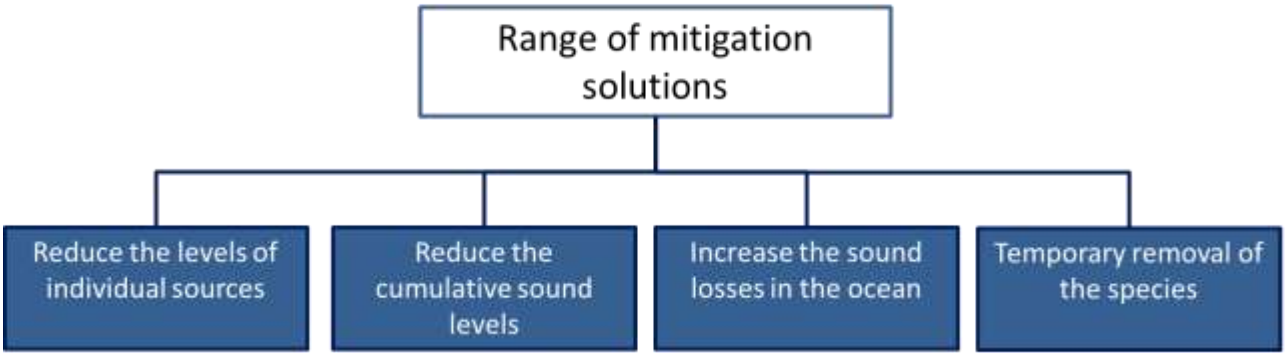

Figure 39: Axes for development of solutions for reduction and avoidance of noise risks related to marine mammals.

6.6. Deficiencies and research programmes

Research programmes concerning underwater noise specific to the context of the development of a tidal turbine sector should be able to address:

- ✓ Characterization of the noise levels emitted by the tidal stream turbines as a function of their rotational speeds. Shared databases should be established to provide models of noise sources at one metre resolution, either occasional or continuous, depending on the frequency. The measurement and analysis protocols should be able to correct the acoustic measure of the propagation effects, in particular of the waveguide effects inherent to *in situ* measurements.

✓ Characterization of the levels emitted by the new generations of tools and techniques for anchors specific to the tidal stream turbines. Shared databases should be established to provide models of noise sources at one metre resolution, either occasional or continuous, depending on the frequency. The measurement and analysis protocols should be able to correct the acoustic measure of the propagation effects, in particular of the waveguide effects inherent to *in situ* measurements.

Key references

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Southall B., Bowles A., Ellison W., Finneran J., Gentry R., Greene C., Tyack P., 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, 33: 411-521.

The potential impacts of the electromagnetic field (EMF) of the electric cables

During the operation phase of tidal stream projects, the underwater electric cables (landing cable, umbilicals, converter, etc.) can generate electromagnetic fields (EMF) that are more variable and intense than those naturally occurring in the marine environment. Many marine animal species are sensitive to EMFs and use them to navigate or locate other individuals (in predation and reproduction relationships). The cables in operation can potentially perturb the behaviour of some marine organisms.

Brief theoretical review of electromagnetic fields:

The question of the potential impact of EMFs should be considered differently depending on whether the current circulating in the cable is direct (DC) or alternating (AC, 50 Hertz), since susceptible species perceive static magnetic fields and alternating magnetic fields differently. The term 'electromagnetic field' is generic and includes the electrical field, measured in volts per metre (V/m), and the magnetic field, measured in micro-teslas (μT). Therefore, it is important to distinguish the electric fields from the magnetic fields, which, in this context, are independent of each other.

The magnetic fields that interest us here are of very low frequencies and are not comparable to the electromagnetic waves of communication equipment using radio or radar waves (mobile phones, antennas, etc.). They are of low energy and induce no ionizing effect. Their intensity decreases rapidly with the distance to the cable, regardless of the frequency (in the case of a dipole (two cables in phase opposition), the fields generated by each of the two cables compensate each other and the field then decreases by $1/R^2$). At a given distance of a cable in operation, the intensity of the magnetic field increases as the voltage increases.

The electrical field is effectively confined within the cable (insulation, metal screen). A second electrical field is nevertheless generated in the vicinity of the cables conducting an alternating current. In this case, the alternating current creates an alternating magnetic field outside the cable, which in turn generates (depending on Maxwell's laws) an induced alternating electrical field of very low amplitude, outside the cable (of the order of several μV/m). Regarding the cables conducting a direct current, the induction effect in the sea is zero. Nevertheless, the magnetic field can create an induced electrical field inside the animals moving close to the cable.

The characteristics of anthropogenic magnetic fields vary depending on the cable type (monopolar or bipolar) and, especially, on whether the cable is embedded or not (since this determines the minimum distance to the cable). The environmental context of tidal turbine projects (strong currents; dominant hard substrates) means that the landing cable is often laid on the bottom for a significant portion of the route.

The use of an alternating current (AC) is the most likely scenario in the case of the installation connections (prototype or industrial park) relatively close to shore, while a direct current (DC) is preferred for the transmission of electricity over long distances, with high voltages.

The nature of the current (alternating or direct), the voltage, the intensity and the depth of the cable embedding are important parameters to take into account, since they determine to a large extent the values of the magnetic fields emitted and potentially perceived by marine organisms around the cable.

Expected effects

The intensity of the Earth's geomagnetic field varies between different regions of the globe, between 20 and 75μT. The data currently available on the magnetic fields induced by the connecting electrical cables mainly concern offshore wind turbines. The fields modelled for the cables on offshore wind farms in operation (10 with alternating current and 9 with direct current) show that the intensities are very variable, and are between 1 and 160μT at the surface of the sediment above the cable (Fig. 40). The intensity decreases very rapidly a few metres away from the cable.

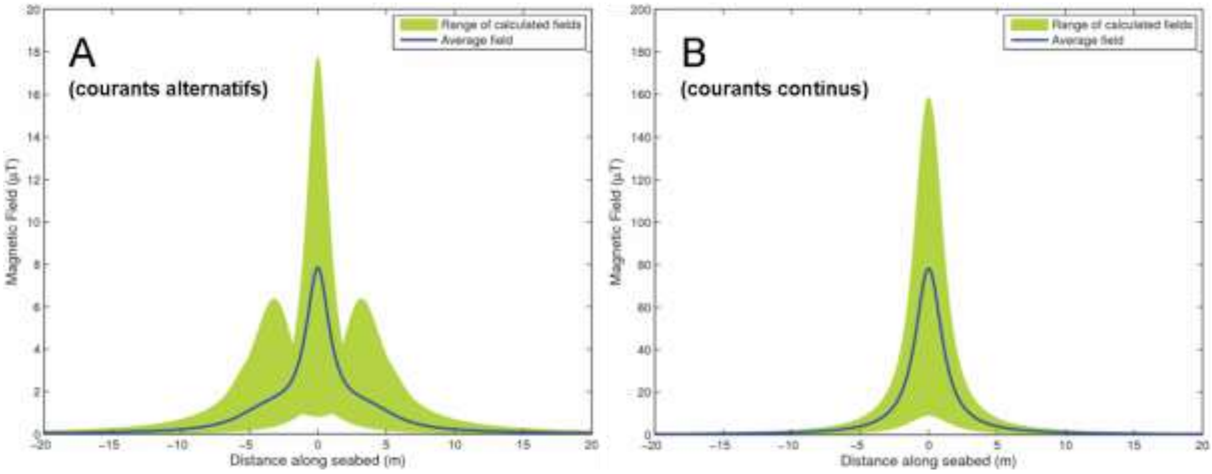


Figure 40 Modelling of the intensity of the magnetic field induced at the water-sediment interface by different connecting cables (embedded and currently in operation, as a function of the distance from the cable. The value ranges and the calculated averages for the alternating (A) and direct (B) currents are based on 10 and 9 cables, respectively (Normandeau Associates, Inc. et al., 2011).

In the context of the connection of future French tidal turbine parks, the cables used are likely to be tripolar cables with alternating current (50Hz), and a voltage of 225kV, embedded to a depth of 1.5m (except on hard substrate) (RTE, 2013).

Modelling based on these input data shows that the values for the exposure to the magnetic fields are less than 11µT above the link (at the level of the ground-water interface), and that the value of the magnetic field becomes less than 1µT at a distance of 5m from the axis of the link.

In some cases, the use of a direct current bipole (two cables in parallel) is planned, with a voltage of 320kV and embedding to a depth of 1.5m (except on hard substrate). The value of the emitted magnetic fields then depends on the distance between the two cables of the bipole. Above the link, the maximum values would be 20µT for the joined cables and 220µT for cables separated by 10 to 100m, since the phenomenon of mutual compensation of the magnetic fields is no longer observed.

From a practical point of view, the cables cannot be buried deep enough into the sediment to reduce the magnetic field and the induced electric field below the detection threshold of the most sensitive species (Gill *et al.*, 2009).

However, when they are laid on the bottom, the cables are often partly or totally covered with protective structures (shells or concrete mattress) that increase the distance between the actual cables and the organisms.

Some work on the potential impacts of MRE in general, or underwater electrical cables in particular, mention that the EMF associated with different MRE technologies can potentially attract, repel, or cause damage to sensitive aquatic species. A review of the available literature on the impacts of the magnetic fields generated by the cables on marine organisms shows that the acquired knowledge is contradictory and insufficient to draw any solid conclusions. For the moment, it is impossible to infer the real impact of the underwater electrical cables on these species, due to a lack of scientific evidence.

Biological environment

This "Biological environment" section discusses the possible impacts (negative or positive) of a tidal stream project on the main biological components of marine ecosystems.

This section thus deals with the potential impacts of these pressures on the four biological compartments of the ecosystem described below and whose interactions are illustrated in figure 41:

- **Benthos**: Monitoring of the benthic communities allows the observation of the impacts of an increase in the turbidity, the scouring around the elements deployed on the seabed, the reef effect of these elements or even pollutants that might be diffused by the components of tidal stream projects.

- **Fisheries resources**: In this chapter, we focus on the exploited fish and crustacean communities, but the impacts on the plankton communities are also mentioned. The potential impacts of tidal stream projects on the pelagic communities are likely to be generated by the complete range of perturbations listed above.

- **Marine mammals**: In addition to the sound perturbations that may have some points in common with offshore wind projects, there is a collision risk specific to tidal stream projects. This chapter will also deal with the impacts on the marine mammal communities of the complete range of perturbations listed above.

- **Avifauna**: The marine and coastal bird communities could be impacted by the tidal stream projects, leading to a risk of collision and direct mortality, but also to the indirect effects on the habitat of these communities.

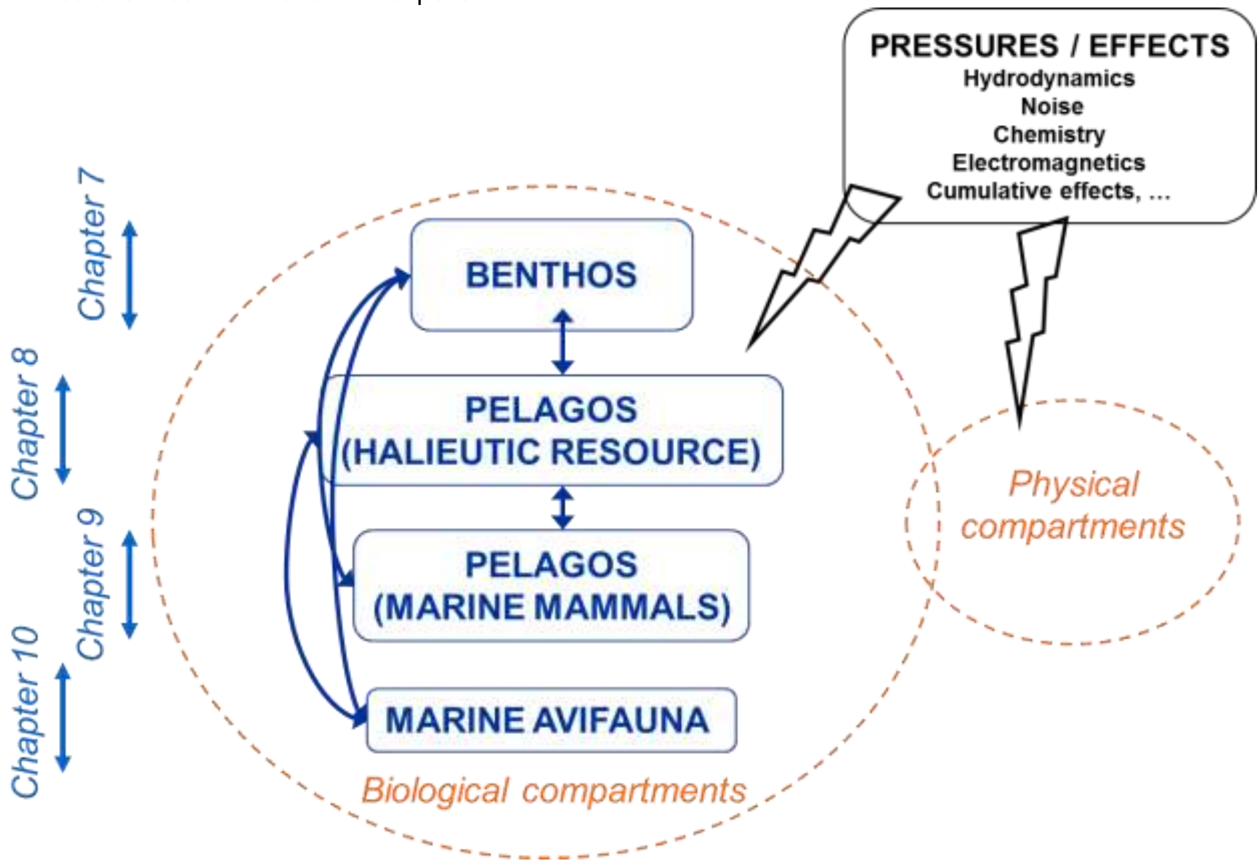


Figure 41 Biological compartments studied and their interactions (blue), under the influence of different pressures (in black)

The European project EQUIMAR (Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact, 2010) reviewed the conduct and implementation of an environmental impact study for projects harnessing currents and waves, and proposed the following methodology to establish the impact hypotheses (in three stages) for the biological domain:

- Make a list, as exhaustive as possible, of the potential influences of the development.
- Establish the most probable impact scenarios (positive or negative, anticipated or planned) in terms of modification of the environments, reaction of the species present or hindering of pre-existing activities. These scenarios will be deduced from the specificities of the development, but they should integrate the characteristics of the ecosystem, the resources and their operating procedures.
- Assign a qualitative and/or quantitative value to each impact class, which will be used to establish a hierarchy of effects according to their probability of occurrence and/or intensity.

Other authors (Polagye *et al.*, 2011) adopt a similar approach and consider that the preliminary analysis is an essential step in the assessment of environmental impacts, and aim to identify, early in project development, the key environmental issues that will require the most attention. These key environmental issues are, for example, the environmental receptors that will be significantly affected by the project, the domains that will require detailed studies, the methodologies to be implemented and the possible reduction measures.
One of the points of the preliminary analysis involves the precise description of the structures that will be put into use and the activities that will be associated with them.

7. Benthos

The benthos includes the plants and animals living in close association with the seabed. Of the benthic fauna, we only consider the invertebrates here: those living at the water-substrate interface (fixed or vagile epifauna) or in the sediments (infauna).

In comparison with the other biological compartments covered in this guide, the benthos is mostly constituted of less mobile organisms, which integrate the perturbations of their living environment, without being able to avoid them.

As for the other compartments in the coastal marine ecosystem, there is little knowledge about the potential impact of turbine technologies on the benthos (ICES, 2012; Simas *et al.*, 2010). Furthermore, the rare feedback available on this issue only concerns the deployment of demonstrators, i.e., single devices that may be connected or not (Keenan *et al.*, 2011).

Without pre-empting the nature and intensity of these potential impacts, the benthos is likely to be modified by the turbidity increase and the particle redeposition generated by the installation and decommissioning of the machines and the landing cable, the scouring around the elements deployed on the seabed, the reef effect of the submerged structures, the acoustic or electromagnetic perturbations, or even a polluting chemical environment generated by the installation phase, the materials used and/or the resuspension of polluted sediments (Shumchenia *et al.*, 2012).

In general, the tidal stream projects currently under development are (or will be) located on relatively unknown portions of the coastal domain (in particular those of the circalittoral zone), because of the extreme conditions of these sites that have strong currents. This means that special effort should be devoted to the prior knowledge of the structure and the natural functioning of the ecosystems hosting the tidal stream turbines.

7.1. Description of the initial state

The definition of the initial ecological state of the benthic compartment is an important step towards a subsequent pertinent assessment of the impacts.

It involves the description of the types of benthic communities potentially impacted by the implementation of the tidal stream project, from the machine installation site to the cable landing site on the foreshore, as well as those found in a reference zone (control). It is also essential to take into account the natural variability associated with these communities, i.e., to explain how they change in space (distribution of benthic habitats) and in time (seasonal fluctuations). In this regard, the reference zone should be monitored in parallel to the park zone.

7.1.1. Definition of the potentially affected zone and choice of a reference zone

Due to the low mobility of the benthos, the zone potentially impacted by a tidal stream project is less extensive than those considered for the other biological compartments. However, it is not limited to the zone covered by the elements deployed on the seabed (machine and converter foundations, cables, temporary anchors, etc.) and should take into account the hydrodynamic and morphosedimentary modifications that can occur around these elements. It is worth noting that the presence of mobile, or migratory (e.g., large crustaceans) benthic species, may justify a significant expansion of this area.

The potentially impacted surface around the machines depends on their technical characteristics and the scale of deployment (number of machines per farm). A demonstrator should affect the benthic compartment up to a maximum of a few tens of meters, *a priori*. On the other hand, in the presence of numerous machines, the cumulative impacts can be greater than the sum of the impacts that would be generated individually by each machine alone. For example, one cannot exclude the hypothesis that an industrial farm indirectly modifies the benthos on distant zones downstream of the currents, as a result of significant sedimentary changes (accumulations, granulometry changes).

The benthic ecosystems potentially impacted by a tidal stream project are found in a continuous area from the intertidal zone (where the tides move back and forth) to the circalittoral zone (>30m deep), passing through the infralittoral zone (from the lower intertidal zone to the lower limit of the photophilic algae), each zone being characterized by a particular type of benthic biocenosis (Dauvin, 1997).
The installation of the landing cable concerns the whole of this continuum (from 0 to 30-40m), while the installation of the converter and the machines concerns only the deepest zone (circalittoral; 30-50m).
A reference area should also be defined (Fig. 42), chosen such that it is not impacted by the project at any time during the project life cycle, but that it is nevertheless representative (in terms of structure and functioning of the benthic compartment) of the potentially impacted zone (Moura *et al.*, 2010; Sheehan *et al.*, 2013).

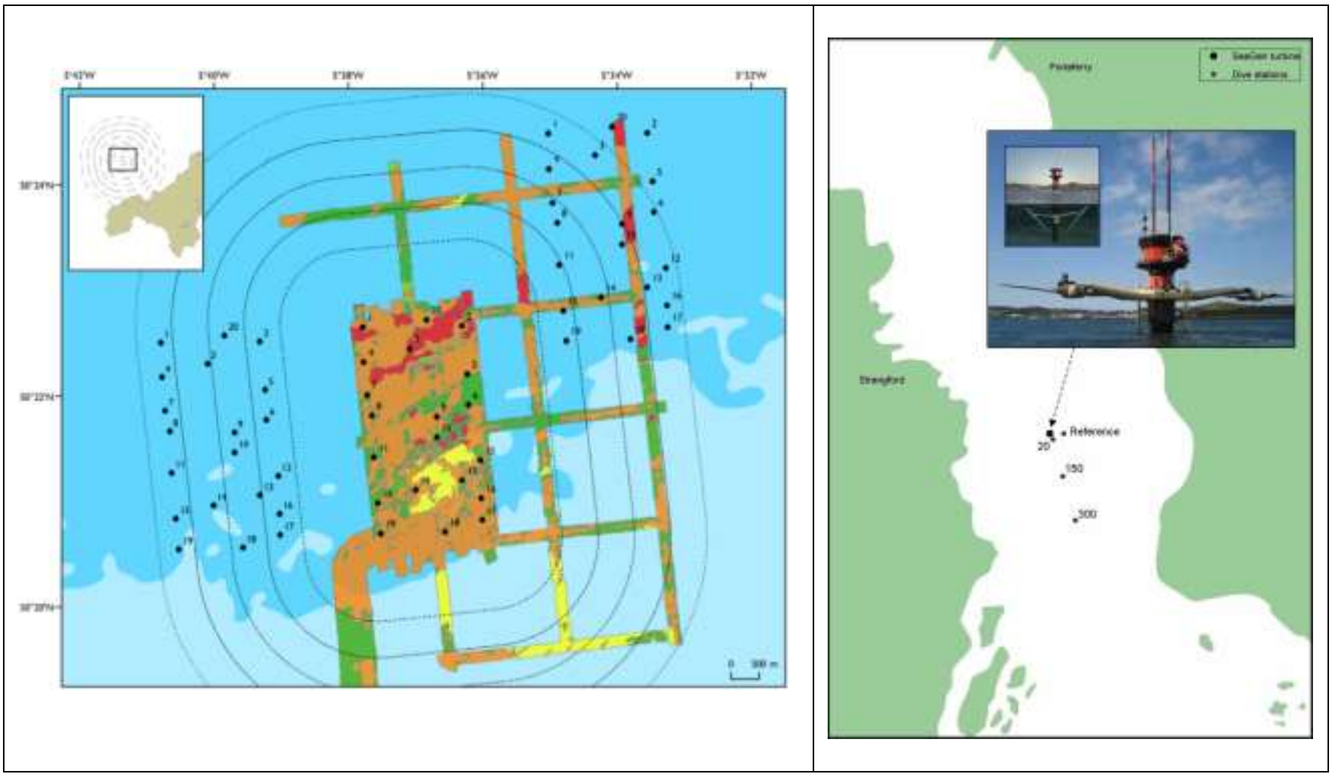


Figure 42 Map of a wave energy converter test site showing the monitoring stations in the potentially impacted zone (centre) and the reference zone (consisting of two sectors surrounding the potentially impacted zone) (Sheehan et al., 2010) (left). Map of the Seagen tidal stream turbine demonstrator site in the strait of Strangford, showing the monitoring stations in the potentially impacted zone (at 20, 150 and 300 m from the tidal stream turbine) and the reference zone (outside the wake effect of the 2 turbines) (Keenan et al., 2011) (right)

7.1.2. Description of the ecological context of the installation site (physico-chemistry, biology; ecological functions...)

In order to comprehensively describe the benthos of the tidal stream turbine site, one should provide, on the one hand, the structure (faunal composition) and the function (ecological role) of the communities concerned, and on the other hand, the different environmental factors that govern the presence of these communities at this location (natural factors and possibly other anthropogenic pressures).

These environmental parameters may be modified by the tidal stream project in proportions larger than the natural fluctuations and thus become perturbation sources (indirect impacts).
The methods available to describe all these parameters are discussed in paragraph 7.1.5.

7.1.2.3. Characterisation of key environmental factors

Taking into account the predicted potential impacts for the benthic compartment, the environmental factors to be considered are:
- Depth.
- Seabed morphology and the nature of the substrate (sediment cover) (see chapter 4).
- Amplitude of the tides, the swell and the current speed over the seabed (see chapter 5).
- Chemical environment (potential level of pollution in the water and the sediments).
- Availability of nutrition (pelagic and benthic sources).
- Sound environment (see chapter 6).
- Electromagnetic environment (see chapter 7).
- Temperature.
- Existing sources of natural and anthropogenic perturbations (other than the tidal stream project itself) for the benthos in the zone (presence of invasive benthic species, for example).

7.1.2.4. Characterisation of the structure of the benthic habitats concerned by project development

The assessment of potential impacts on the benthos should take into account the ecological specificities of the marine ecosystems concerned by the current tidal turbine installation sites (and those projected for the near future). The communities to be described depend largely on the environmental parameters mentioned above. When the complete tidal turbine project is considered (from the machines installed on the deepest sites up to the cable landing zone on the foreshore), a wide variety of benthic habitats (and associated communities) is concerned.

To date, taking into account the difficulties of access to the seabed on the sites of tidal stream turbine themselves (strong hydrodynamics and very deep waters), the range of available investigative methods is relatively small.
Another specificity comes from the fact that turbine systems are currently preferentially located on hard substrates (level bedrock, boulders) and/or very coarse bottoms (pebbles, stones), which host specific benthic communities, mainly composed of fixed and encrusting organisms (Fig. 43). This epifauna therefore occupies a predominant place relative to sediment-dwelling organisms (infauna). In most cases, the monitoring of benthic fauna on the machine installation site should therefore focus primarily on fixed and vagile epifauna (and possibly on the large mobile species found in the zone). Nevertheless, in the future, tidal stream projects could be located on soft substrate seabeds and in shallower sectors.
As mentioned previously, the context is different for the installation zone of the landing cable, as this is likely to cross very diverse benthic habitats (on both soft and rocky substrates). Monitoring of the soft substrate fauna could therefore prove to be essential in some cases.

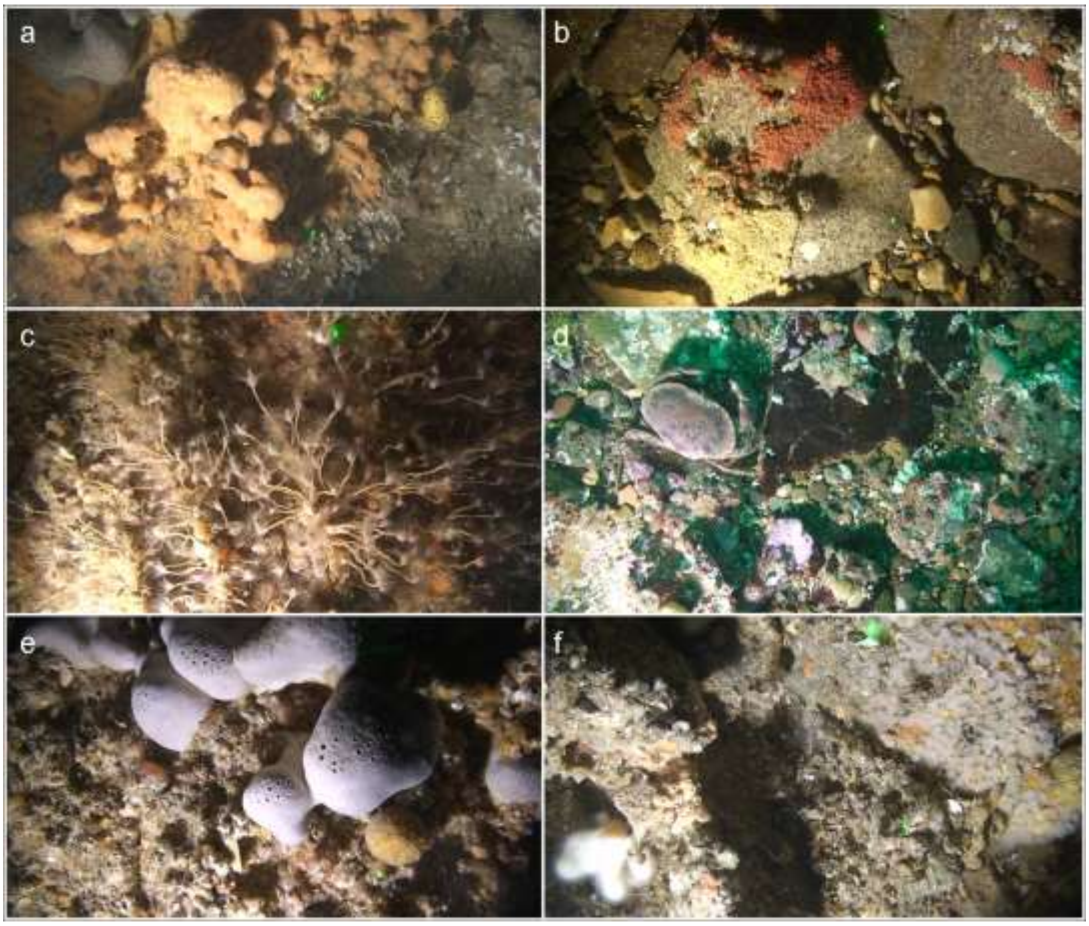


Figure 43 Overview of the diversity of hard substrate benthic populations observed on the tidal stream turbine site at Paimpol-Bréhat (© Ifremer, BREBENT-01 campaign) (a: unidentified proliferating sponge; b: unspecified social ascidians; c: Tubulariidae sp.*; d:* Cancer pagurus*; e:* Pachymatisma johnstonia*; f:* Corynactis viridis *(top right) and* Alcyonium digitatum *(bottom left))*

In terms of organism size, the monitoring should take into account all macrofauna and macroflora (size >1 mm).

In some cases, depending on the tools that can be implemented in the zone, it may be sufficient to target only the visible megafauna (epifauna of size >1 cm). This particularly concerns the areas that are the most difficult to access (very deep waters and strong currents), where only a video camera passing over the seabed can be used (without being able to record detailed images). Conversely, in other cases, and depending on the taxonomic competence available, it may be interesting to include the meiofauna (50 µm < size < 1 mm), which is likely to respond more rapidly than the macrofauna to temporary perturbations of the benthos (Albertelli *et al*., 1999). This approach will only concern highly localised zones (impact of cable embedding in a sensitive habitat, for example) that are suitable for quantitative sampling.

With regard to the benthic flora, the species to be monitored differ greatly in nature and sensitivity, depending on the zone considered. It is worth noting that little is known about the group of benthic primary producers that inhabit the deepest zones. It is important to recall here that several species of benthic flora play an essential ecological role by building remarkable habitats (maerl beds, phanerogam meadows, kelp fields) and should be paid particular attention.

The erect macroflora (macroalgae) is only found in the infralittoral zone and therefore mainly concerns the cable route monitoring; beyond this limit, encrusting benthic flora is encountered, characteristic of the circalittoral zone, which is more difficult to describe. Depending on the natural turbidity of the waters of the installation sector, the maximum depth for macroalga distribution may vary.

*** Faunal and floral composition of benthic communities**

To describe the plant and animal communities present, as a minimum the following univariate parameters should be taken into account:

- Species richness

Taxa should be identified to the lowest taxonomic level (ideally to the species). In practice, since some zoological groups are difficult to determine (sponges, hydroids...), some recognition tools (video) are indirect and sometimes biological sampling is impossible, this level of taxonomic resolution cannot be attained. It is then necessary to group species by taxonomic levels of higher order, or even according to morphological criteria (e.g., erect sponges / encrusting sponges).

- Abundance and (or) density

The organisms should be counted to determine their density as precisely as possible. A value per surface unit (number of individuals per square metre) should be determined when the individuals can be counted unambiguously.

In some cases (colonising or encrusting animals; indirect estimation methods), it is necessary to make semi-quantitative estimates, using abundance classes, or to estimate the percent coverage of the seabed.

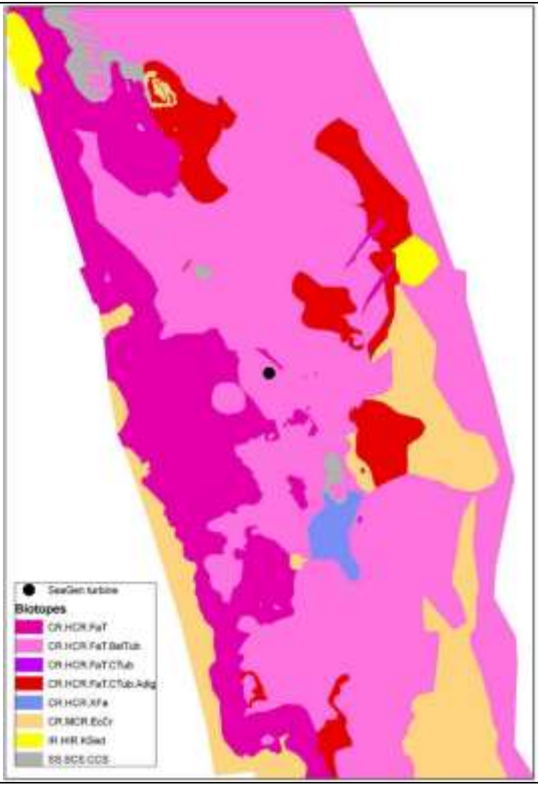
- Biomass

This parameter requires biological sampling and precise measurements in the laboratory. In addition, the lack of data on the types of ecosystems affected by the tidal stream turbine makes it difficult to use indirect methods for estimating the biomass (based on organism size for example). Nevertheless, it should be reported whenever it is technically feasible.

It may be useful to describe the communities in more detail using multivariate parameters and functional descriptors:

- Biodiversity indices (Shannon indices; Simpson index); evenness index (Pielou).
- Environmental quality indices: indices based on ecological groups. However, the quality indices generally reflect a degree of organic perturbation (sediment enrichment of organic matter). They should therefore be handled with care, since they are not necessarily relevant to the assessment of the impact of a tidal stream project. On the other hand, they may be relevant for assessing whether the installation site is already perturbed by other anthropogenic activities (see the issue of cumulative impacts presented below).
- Representativity of trophic groups (in terms of functional richness and/or biomass), within the different trophic levels (in particular at the level of primary consumers). Indeed, where changes in the nature of the substrate (granulometry modifications) and/or turbulent mixing at the water/substrate interface can occur, the alimentation strategies of a benthic community can evolve.

A synthetic map of the main biosedimentary units (Fig. 44) is expected, as well as quantitative distribution maps of the dominant benthic species or species of ecological and/or commercial interest, both for the installation zone of the machines, converter and cable, and for the reference zone. This map should respect the EUNIS (European Nature Information System) typology. Concerning rocky substrates, a list of indicator species is also expected for the different communities (or facies) encountered, based, for example, on locally implemented inventory codes (monitoring of ZNIEFF-mer for Brittany for example).



<u>Definition of biosedimentary units:</u>

- CR.HCR.FaT: very tide-swept faunal community;
- CR.HCR.FaT.BalTub: community of Balanus crenatus *and* Tubularia indivisa *Balanus crenatus and Tubularia indivisa on extremely tide-swept circalittoral rock ;*
- CR.HCR.FaT.CTub: community of Tubularia indivisa *on tide-swept circalittoral rock;*
- CR.HCR.FaT.CTub.Adig: community of Alcyonium digitatum *and dense* Tubularia indivisa *and anemones on strongly tide-swept circalittoral rock*
- CR.HCR.XFa: mixed faunal turf community;
- CR.MCR.EcCr: echinoderms and crustose community;
- IR.HIR.KSed: Sediment-affected or disturbed kelp and seaweed community;
- SS.SCS.CCS: Circalittoral coarse sediment.

Figure 44 Cartography of the main biosedimentary units obtained at the Seagen project site by sonar acoustics, video imaging (suspended frame) and diving, according to the classification system of marine habitats of Great Britain and Ireland (Keenan et al., 2011)

*** Sensitivity level of habitats and species**

Based on the census of the existing benthic biodiversity in the geographical zone concerned by a tidal stream project, the goal is then to identify the species most vulnerable to the perturbations caused by the installation and operation of the project elements (machines, cables, etc.).

The sensitivity of a habitat or a species depends on its degree of intrinsic tolerance to a perturbation and its degree of resilience (the time required to return to an ecological state close to the initial one).

A framework for analysis of species sensitivity has been proposed by the marine biodiversity information network (MARlin) in Plymouth (http://www.marlin.ac.uk/sensitivityrationale.php).

With regard to benthos, the perturbations to consider here are: firstly, the mechanical interactions with the seabed, the modification of the hydrodynamics and increase in turbidity; and secondly, the modifications of the acoustics and the electromagnetism, and the temperature increase.

The ecosystems concerned by the tidal stream turbine are, by definition, high-energy environments and are therefore subject to significant hydrodynamics and erosion phenomena.

It is therefore important to define the range of variation of the physical parameters (in particular those related to the hydrodynamics on the seabed) on the installation site. For example, the benthic communities situated at Raz Blanchard may be subject to hydrodynamics and abrasion conditions very different from those that prevail in the sector of Paimpol-Bréhat.

If the spaces, benthic communities or benthic species of high ecological and/or heritage interest are found in the area of potential influence of the tidal stream project, emphasis should be placed on the description of their biology, ecological role and degree of vulnerability.

Law no. 2006-436 of 14 April, 2006 relative to national parks, natural marine parks and regional natural parks and the Decree of 3 June, 2011 relative to the identification of categories of marine protected areas within the scope of competence of the French Marine Protected Areas Agency list the categories of marine protected areas. Particular attention should be paid to the following sites:

- Inventory zones (ZNIEFF, ZICO).
- National parks (centre of the park, adhesion area, adjacent marine area).
- Offshore Natura 2000 sites (ZPS, ZSC, SIC, pSIC);
- Natural marine parks.
- Nature reserves.
- Zones under order for protection of the biotope.
- Other categories of marine protected areas recognized by the Order of 3 June, 2011 relative to the identification of categories of marine protected areas within the scope of competence of the Agency of marine protected areas (notably international statutes).

7.1.2.5. Characterisation of the function of the concerned habitats

As mentioned above, it is necessary to signal the presence of species that play a key ecological role in the supposed area influenced by a tidal stream project (including the route of the landing cable):

- “Engineer” species (hard coral reefs, deep corals; maerl beds; eelgrass meadows; kelp fields...);
- Species or functional groups representing an essential trophic link.
- Bioturbulent species (for soft substrates).

7.1.3. Characterisation of the natural variability of an installation site

The knowledge of the natural temporal fluctuations of benthic communities (seasonal or interannual changes in the faunal composition) is essential to determine whether the impact of a tidal stream project on the benthos is significant, i.e., if it lies beyond the range of natural variation.

Therefore, it is necessary to determine an appropriate frequency for biological data acquisition. To optimize the definition of the initial state, surveys should be performed over three consecutive years, at a rate of two seasons per year (ideally in late winter and late summer). A six-month acquisition frequency has indeed been adopted in the context of the environmental monitoring of the SeaGen tidal turbine demonstrator site (Keenan *et al.*, 2011).

In practice, in the context of a regulatory impact study, it may be enough to perform two seasonal surveys (late winter and late summer) in the same year. In this case, the consideration of one or several reference sites in the impact assessment will be particularly important (see section 7.2).

These recommendations could be reconsidered in the light of new fundamental knowledge on the benthic ecosystems targeted by tidal stream turbine projects. Indeed, the offshore circalittoral zone, where some tidal stream projects are likely to be installed and where there are smaller seasonal fluctuations, could potentially be subject to a longer monitoring interval (1 annual survey).

7.1.4. Identification of relevant indicators

Given the lack of perspective on the nature and intensity of the ecological changes that the tidal stream turbine technologies are likely to impose on the benthos, it is currently difficult to propose pertinent and reliable indicators to effectively measure and monitor the level of perturbation generated by a tidal turbine project. This is therefore a research problem that will need to be explored in the coming years, integrating a maximum of feedback.

As a first step, it is necessary to perform a review of the indicators of anthropogenic perturbations (comparable to those for a tidal stream project) adapted to coastal ecosystems with strong hydrodynamics.

The criteria for identifying pertinent indicators include for example:

- Morphology of the animal (erect vs. encrusting species);
- Lifespan of the species (rapid vs. slow renewal rates);
- Sensitivity to mechanical perturbations;
- Sensitivity to a high load of particles in suspension or deposited at the water-sediment interface if it exists.

7.1.5. Possible methods for information acquisition: bibliography and data acquisition

*** Bibliographie :**

Bibliography

The definition of the initial ecological states of the installation zone and reference zone can potentially be based on existing data that have been acquired recently (less than 5 years old) and are sufficiently precise. For the current tidal turbine projects concerning coastal zones that have been little studied, it is often necessary to perform one (or several) data acquisition campaigns to complete the bibliographic information.

Diverse bibliographic sources can provide useful information on the existing benthic biodiversity:

- Cartographies of benthic habitats. The French REBENT network provides information on the geographical distribution of the main types of habitats, but concentrates on localized, shallow coastal areas (www.rebent.org).
- Data on the Sextant server (http://www.ifremer.fr/sextant/fr/web/guest/accueil), hosted by the Ifremer, provides a catalogue of georeferenced data on various issues related to the marine domain (biodiversity, integrated management of coastal zones, fishing, exploration and exploitation of the seabeds).
- Results of the CARTHAM programme (cartography of natural habitats at offshore Natura 2000 sites). This inventory of metropolitan France's marine heritage habitats was undertaken at the request of the Department of sustainable development, to meet community commitments in relation to designation of sites of ecological importance that should be integrated in the Natura 2000 European network, under the 'Habitat, fauna and flora' directive of 1992. Launched by the Agency of Marine Protected Areas in 2010, this programme covers more than 40% of the territorial waters. The majority of the marine heritage habitats will be mapped once the inventory is completed. However, the methodologies used by the various research departments involved in this programme are not always homogenous and the spatial resolution of the data will not necessarily allow definition of the initial ecological state of the tidal turbine installation zone (if it is located in a Natura 2000 zone).

Regulatory measures for the protection of natural heritage, defined at the international, national or regional levels (action programmes, treaties, conventions, directives, etc.) are all key aspects for the assessment of the vulnerability of tidal turbine installation sites. The sensitive species to consider are notably those on the Red List of the International Union for Conservation of Nature (IUCN). The application of the European "Habitats" directives (production of high resolution habitat maps on Natura 2000 sites, definition of indicators, species list annexed), the "Water Framework Directive" (WFD; consideration of the composition and abundance of the benthic macroflora and macrofauna for the assessment of the ecological state) and now the "Marine Strategy Framework Directive" (MSFD; extension of the WFD to the French EEZ) provides a source of relevant information.

More locally, the management measures applied on the coastal domain of a region or a territory should also be taken into account. For Brittany for example, a list of benthic species of strong ecological and heritage interest (benthic fauna and flora of the Brittany coast) has been established by a group of experts to describe zones of floral and faunal interest at sea (ZNIEFF-mer) (Table 25).

List of species (or taxa)	Determinant species	Supplementary list
	List 1: Endangered species List 2: Unusual species with especially developed facies List 3: Proposal for "protected species" status List 4: Ecological marginal species List 5: Rare indigenous species List 6: Engineer species and/or species playing an important indicator role, allowing a diversified habitat	List A: Species at the limit of the distribution area List B1: Species to be monitored: possibly in decline List B2: Species to be monitored: possibly in expansion

Table 25 Definitions of the 6 lists of determinant benthic species proposed for Brittany and the supplementary lists proposed for insufficiently known species; classification validated by the IUEM-UBO-Lebham, the MNHN-Station de Biologie Marine de Concarneau, the UPMC-Paris VI & CNRS-Station Biologique de Roscoff, the IUEM-UBO-Lemar and the IFREMER (Derrien-Courtel, 2010).

In the same way as for the other biological compartments, it is essential to identify all the zones where the benthic compartment has a particular ecological richness, a high environmental sensitivity, or major conservation issues.

*** Acquisition of new data**

The benthos monitoring stations (sampling points) should be distributed on the different biomorphosedimentary units defined based on the acoustic data ("sonar" image mosaic), bathymetry (detailed bathymetric map), sediments (qualitative samplings to validate the sonar interpretation, when feasible) and video (preliminary footage obtained to validate the sonar interpretation).
These stations should allow the census of the benthic species (macrofauna and macroflora; epifauna and possibly infauna) and should be representative of the complete zone concerned by the project.
The number of monitoring stations and their spatial distribution depend on the observed degree of heterogeneity of the nature of the seabeds. This number decreases with the homogeneity of the seabeds. In the light of the results of the biological analysis of samples taken on these stations, additional ones may be added (e.g., on the transition zones between two distinct biosedimentary units). Methods exist to determine the minimum number of samples that are representative of the composition of a given population (number of species sampled as a function of the sampling effort).
If sedimentary samplings are possible to characterise more precisely the nature of the sediment (on soft substrate zones), they should be coupled with the benthos monitoring stations (i.e., taken at the same place).

Hard seabeds
In the context of the current tidal turbine projects, the seabeds consist mainly (or exclusively) of hard substrates (level bedrock, boulders) and/or very coarse seabeds (pebbles, stones), at least in the machine installation zone. Analysis techniques for rocky substrate benthic communities should therefore involve essentially video and potentially diving operations (when the depth and hydrodynamics allow this).

Video acquisitions can be performed in different ways.
To cover a large sector (for the initial state, for example), a video camera towed by a ship is probably the most suitable (with the video frame suspended or adapted for a benthic sled, when the morphology of the seabed allows it (Seehan, 2010)). Remote controlled video (ROV) concerns the monitoring of more restricted zones, which have been identified beforehand. It can notably

be used to analyse the near-field of the machines during the operation phase. Videoing by divers is strongly constrained by the depth, the currents and the distance from the coast. It is useful for the precise monitoring of specific stations (monitoring of benthic colonization). Finally, autonomous video cameras can be fixed on the bottom (deployed on sea bottom observatories), but only allow coverage of the near-field of the sectors to be monitored. This approach is adapted to the monitoring of the behaviour of mobile species (crustaceans) attracted or repelled by the structures and/or the perturbations generated (noise, electromagnetic field). This latter approach is the subject of in-depth technological research.

When the depth and the currents are compatible with the intervention of divers, quantitative samples of benthic organisms should be carried out using quadrats (0.25 to 1m²) or transects (length of a few tens of metres).

The following analyses are then required:

- A determination to the lowest possible taxonomic level (to the species level for the individuals that are most characteristic of the site, including species of commercial interest, and to the genus level, or family level, for certain groups).
- A count of the number of determined individuals, if possible. Based on video data only, the analysis can be more restricted (presence/absence, semi-quantitative counts, % coverage).
- A comparison with the existing lists of possibly sensitive species for the close geographical environment (regional list of heritage species).

The results should be presented in the form of tables indicating, for each of the sampled stations:

- Station name.
- Geographical position.
- Probe (i.e., the water depth corrected by chart datum).
- Sedimentary facies (biotope).
- Species abundance (number of individuals per m² and standard deviation; semi-quantitative index; presence/absence).

As stated above, these results can then be represented in the form of distribution maps (quantitative or not) of the dominant species and the species of commercial interest, and a summary map of the main facies (for rocky substrates). This can be based on the typology of the benthic marine habitats for the circalittoral, established in the context of REBENT, which proposes different levels that can be adapted to the characteristics of the studied site, with the possibility of descending to the finest level of the EUNIS classification (Bajjouk *et al.*, 2011).

Soft seabeds

For the monitoring of soft substrate fauna, biological samples are taken using grabs adapted to each type of substrate (mud, sand, gravel), dredges or corers. The conditions of use for the different sampling devices are described in the technical data sheets available on the REBENT website (http://www.rebent.org/documents/index.php).

The use of a weighted Van Veen grab (sampling surface: 1/10 m²), a Smith-Mac Intyre grab (sampling surface: 1/10 m²), a Day-Grab grab (sampling surface: 1/10 m²) or a Hamon grab (sampling surface: 1/4 m², 1/8 m² or 1/10 m²) allows quantitative sampling to be performed. It is worth noting that the NF ISO 16665 standard defines guidelines for quantitative sampling and analysis of samples of the marine macrofauna on soft seabeds.

The Shipeck-type grab, restricted to sampling for the purpose of chemical and granulometric analyses, is not advised for biological sampling. The use of dredges only allows qualitative, or at best semi-quantitative, sampling (e.g., Rallier du Baty dredge). In the cable landing area (on the foreshore), the samples can be taken using hand corers (sampling surface: 0.01 m²).

At each station, it is recommended to perform:

- 3-5 replicates depending on the prior knowledge of the environment and the degree of heterogeneity of the population; replicates are essential to account for the natural spatial variability of the species distribution at a given point;
- 1 additional replicate for the analysis of the sediment (granulometry).

It is useful to photograph each (labelled) sample to facilitate the description of the sampled facies.

All the samples should be sieved through a 1mm sieve mesh (preferably of round mesh). For the coarser sediments, a pre-sieving can be done with a 5mm or 2mm mesh. Each sieve residue is fixed with formalin (diluted to 5%, and buffered) or directly conserved in alcohol (70°). It should then be subject to a series of analyses comprising:
- Biological sorting.
- Identification to the lowest possible taxonomic level (see *Hard seabeds*).
- A count of the number of identified individuals.

7.2. Methods for the identification and analysis of potential ecological changes

The potential ecological changes to the benthic compartment strongly depend on the modifications of the hydrodynamics, sediment dynamics and the nature of the seabed potentially induced by a tidal stream project. They can also be linked to an increase in turbidity, pollution of the water mass, and/or modifications in the acoustic or electromagnetic environment.

It should be pointed out that the magnitude and intensity of the potential impacts depend on the technical choices and the spatio-temporal scale of the project deployment. Expertise specific to each project is therefore necessary to adapt the recommendations in this guide to the specific ecological context of each project.
In theory, the impact monitoring programme should follow a "BACI" type approach (Before-After-Control-Impact; Smith *et al.,* 1993).
This method involves parallel monitoring of the tidal stream project site and one (or more) reference sites (control zones that are not impacted by the project), before and after the construction phase. The BACI approach therefore covers the ecological changes both in time (initial ecological state and operation phase) and in space (tidal stream turbine site and reference sites). This optimal impact assessment programme therefore includes these reference site(s) in the monitoring strategy from the outset.

7.2.1. In the installation phase

*** Destruction of benthic habitats**
The direct destruction of benthic habitats is highly localized in space and the impacted surface depends heavily on the different options for installation of the elements on the seabed (see chapter 4; section 4.2).
- For a fixed or laid tidal turbine, the destroyed area theoretically corresponds to the surface of the bases (Fig. 45), i.e., 3 to 30 m² per machine (DGEC, 2012), plus that of the temporary anchoring systems. However, the seabed preparation prior to installation (seabed levelling operations are sometimes necessary) can cause damage to larger surface areas.

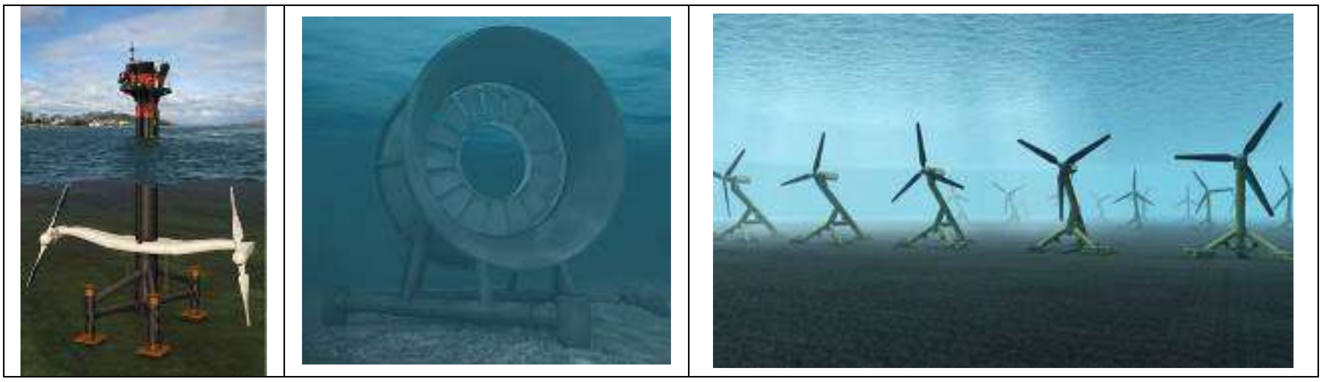


Figure 45 Footprints for different models of tidal stream turbine foundations (from left to right: SeaGen; OpenHydro; Hammerfest Strom)

- For a floating tidal turbine, the destruction of the seabed is limited to the anchors, and potentially to scouring on the bottom at the base of the chains connecting the floating structure to the anchors.

On the route of the cable, a localized destruction of benthic habitats and fixed or less mobile species occurs, at the trench (when the cable is embedded) or under the cable (when it is laid), at the rate of about 2000 m² of surface destroyed per kilometre of cable (DGEC, 2012). The loss of habitat, and of species endemic to these habitats (including exploited species), therefore generally concerns a very limited surface area. Concerning the cable at the test site for the SEM-REV wave turbine for example, the passage of the embedder crossed the classified scallop reserve (Capella) over a surface corresponding to 0.0036 km², or 0.002% of the surface of this reserve. The impact is most significant when it touches the sensitive benthic habitats and the species playing a special ecological role (phanerogam meadows, maerl beds, kelp fields). At the level of the actual landing and in shallow areas for example, the beds are a matter of concern because little is known about the potential and the time needed for recolonisation. An experimental study of the eelgrass beds in the context of the Paimpol-Bréhat tidal stream project shows the start of a spontaneous recolonisation in the months following the installation works, when the sediments in the cable trench were sufficiently consolidated (Barillier *et al*., 2013).

*** Displacement of mobile benthic species**

The more mobile benthic invertebrate species (large crustaceans) are likely to be displaced during the installation phase. However, the temporary nature of this impact remains to be demonstrated.

7.2.2. In the operation phase

Changes in the nature of the substrate

The potential impacts on this ecosystem component (biotope) are addressed in chapter 4. The impact of the machine operation and/or the physical presence of the foundations on the nature of the substrate (localised around the machines or situated in the far field) remains poorly understood and this lack of knowledge worsens with the scale of the industrial deployment considered (SGWTE, 2012; Polagye *et al.*, 2011).

A priori, this type of impact does not concern the turbine technologies at the demonstrator stage, installed on a substrate that is exclusively or mainly rocky (level rock; boulders). On the other hand, it may concern single devices installed on soft substrates (stones, gravel) where it is technically feasible, and tidal stream farms with several machines (including those installed on hard substrate, but near soft substrates). It is difficult to qualify and quantify the potential impacts of very coarse sediments (blocks, pebbles), which are not (or much less) mobile (SGWTE, 2012).

A modification of the nature of the substrate by the tidal stream project (due to the physical presence of the machines, the converter and/or the cable) may be accompanied by a change in the faunal composition of the benthic communities.

On the mobile parts (blades), the biological colonization of the structures is not desirable, since biofouling limits the efficiency of the machine.

On and between the elements installed on the bottom (bases/machine foundations; materials for the protection of the cable when it is laid), the "artificial reef" effect applies and depends on the nature of the materials used and their disposition on the bottom. An epifauna develops on the surface of these submerged elements (Fig. 46), and it is expected that the faunal composition of these new organism communities will, in the long-term (10 years), become similar to that of the surrounding natural hard substrate communities, but not identical (Thanner *et al.*, 2006). The introduction of artificial hard substrates can also promote the establishment of introduced species (including invasive species), or promote their geographic expansion by playing the role of "bridgehead" (Sheehy and Vik, 2010). This "reef" effect was highlighted on the bases of offshore wind turbines (Linley *et al.*, 2007). However, the colonisation of concrete structures has not been well studied so far (DGEC, 2012), and there is little feedback on the effect of metallic structures (even with respect to the platforms at sea).

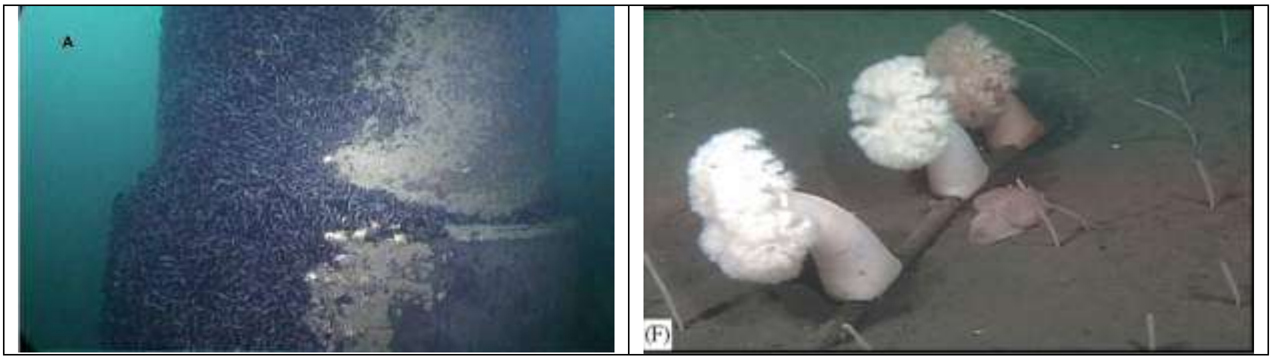


Figure 46 Colonisation of artificial structures by hard substrate benthic organisms (left: base of the Sea-Gen tidal stream turbine; right: marine observatory cable (Kogan et al., 2006))

There may also be a "refuge" effect for some species, which find favourable habitats between the artificial structures. Certain forms of foundations or certain protective structures for the laid cables can accommodate benthic species that are of potential interest from a heritage or commercial perspective (large crustaceans) (Langhamer et Wilhelmsson, 2009).

*** Hydrodynamic changes**

Concerning the faunal changes caused by a modification of the hydrodynamics and/or by phenomena of kinetic energy extraction around the installed systems, there is a real lack of knowledge, however. This question also represents a knowledge field that needs to be enriched. Some feedback exists for the soft bottom benthos around the foundations of offshore wind turbines or of wave turbine systems (Langhamer, 2010), but it would be difficult to transpose them to tidal stream turbine technologies.

It will be necessary to acquire faunal data for a gradient of hydrodynamic changes linked to the positioning and operation of tidal stream turbines (following a transect oriented in the wake axis of the machines, for example), at a spatial scale that will depend on the deployment scale of the machines. Modelling can help to identify the sectors to be monitored as a priority, and these should be included in the definition of the initial state. In the case of the SeaGen project for example, the changes observed on one such transect were similar to those in the reference zone, and thus could not be easily attributed to the hydrodynamic change (Figure 42).

*** Modification of the electromagnetic field**

The influence of the electromagnetism generated by the cables in operation may cause a “barrier” effect. This is a general issue, already addressed in the case of other MRE technologies (Carlier and Delpech, 2011; OSPAR, 2008). However, certain technical and/or environmental specificities of tidal turbine technologies deserve to be taken into account to better understand this type of potential impact.

Among the marine species naturally sensitive to electrical and/or magnetic fields, there are few benthic invertebrates *a priori*, but there are notably some large crustaceans. The electrical fields generated by the cables may seem small to humans, but they are often easily perceptible for naturally electro-sensitive species. Generally, and because of the rapid decline of the EMF as a function of distance from the source, benthic species will be more vulnerable to these perturbations than pelagic species. In England, the electromagnetic field measurements taken near the connecting cables of two operational offshore wind farms (Burbo Bank and North Hoyle) show that the species naturally sensitive to EMFs may detect the artificial field of the cable at a distance of 295m, which represents a relatively wide detection corridor (Gill *et al.*, 2009).

Experimental work has been done on the crab *Rhithropanopeus harrisii*, the isopod crustacean

Saduria entomon and the blue mussel *Mytilus edulis*, using a static magnetic field of 3700 µT. The results showed no difference (in terms of survival rates) with the "control" groups. Although it cannot be called a real impact, sensitivity to artificial magnetic fields seems to have been demonstrated for the marine species *Idotea baltica* (an isopod), and *Talorchestia martensii* and *Talitrus saltator* (amphipod crustaceans). More recently, American experiments have focused on several invertebrate species (crabs), submitted to low intensity fields (0.1 to 3 mT). The preliminary results show little significant difference (in terms of growth, survival, physiological or behavioural response) between the test and control groups (Woodruff *et al*., 2012).
Nevertheless, *in situ* work on invertebrates is virtually non-existent, most studies having been made on fish species, and notably the eel (see Chapter 8).

*** Temperature increase**
Benthic organisms are sensitive to temperature variations (natural or anthropogenic), even of small amplitude (Hiscock *et al.,* 2004). In the operation phase, the passage of electric current in the converters and cables generates a temperature increase around these structures, which could potentially lead to impacts on the surrounding benthos. These impacts are *a priori* highly localised in space, since the heat produced by the cables (and *a fortiori* by the converters) is likely to be dissipated rapidly. Nevertheless, there is not enough feedback (Merck and Wasserthal, 2009) to make precise recommendations. There is a real need for *in situ* experimentation and surveys at small spatial scales to better characterize the potential impacts of a temperature increase on the benthic compartment.

*** "Reserve" effect**
In cases where the installation zone of the machines and/or of the landing cable are closed to any other human activity, a 'reserve' effect may occur in the long term, due to the prolonged absence of the pre-existing anthropogenic impacts (fishing, extraction of aggregates, boating, scuba diving, etc.). Studies are currently underway at Scottish tidal or wave turbine sites to investigate the dynamics of lobster populations present on the installation sites and the potential beneficial effects of these sites (EMEC, 2012).

*** Chemical pollution**
Accidental risks of leakage and diffusion of polluting compounds (oil; cooling liquid...) cannot be totally excluded and concern the 3 phases of the project (installation, operation/maintenance, and decommissioning).
However, the chemical risk represents a minor potential impact for the benthic compartment, given:
- The nature of the potential pollutants: these correspond to substances that are *a priori* of low toxicity (cooling liquid from the converters; liquids from the maintenance ships) and are unlikely to affect the benthos specifically (by settling on the bottom). However, the nature of the potentially polluting substances and the extent of their biodegradability remain to be clarified.
- The relatively low amounts potentially released into the environment: cooling liquids from the converters or possibly contained in the cables correspond to low volumes. However, these volumes still need to be clarified.

The risks of remixing of polluted sediments during the installation phase should also be considered.

*** Modifications of the underwater landscape**
This type of impact does not concern *a priori* the submerged turbine technologies, installed by definition in strong current zones that are not (or very little) sought after by the community of recreational divers.
On the other hand, it may concern the landing zone of the cable, temporarily (during installation works), or more durably (if the foreshore benthic habitats are modified).

7.2.3. In the decommissioning phase

At the end of the project lifetime, the question remains whether it is less impacting to leave the structures in place or to withdraw them. In cases where the physical presence of a foundation or a cable laid on the seabed (and its protective structures) allowed the creation of a new habitat on which a hard substrate community was able to settle progressively and durably, the decommissioning could cause more important perturbations for the fauna than those generated during the installation phase (Wilhelmsson *et al.,* 2010; Polagye *et al.,* 2011).

7.3. Identification of cumulative impacts

It is important to take into account the cumulative impacts into account because the overall impact of several perturbations is not simply the sum of the impacts of each perturbation taken independently ("1 + 1 = 3"). Cumulative impacts arise in 2 ways:

- Cumulative impacts due to the multiplication of machines in space and in time (scale effect).
- Cumulative impacts due to the conjunction of the impacts of the tidal stream project with the impacts of other anthropogenic pressures on the same zone and in the same time period.

It should be noted that these 2 categories of cumulative impacts are not exclusive and can generate other cumulative impacts of a more complex nature. By definition, cumulative impacts are very difficult to define and thus to evaluate.

Concerning the benthic compartment, "expert" approaches reveal that the cumulative impacts can be very significant on the abundance and spatial distribution of sessile species, or even on the composition of faunal communities in the influence zone of the tidal stream project (Polagye *et al.,* 2011). Once again, there is considerable uncertainty about the nature of these cumulative impacts.

Considering the first category, it can be inferred that benthic organisms may be heavily impacted by a significant modification in the sediment dynamics and/or the hydrodynamics due to the operation of tens, or even several hundreds of machines.

7.4. Description of a environmental monitoring programme

The goal of environmental monitoring is to monitor, over the lifetime of the tidal stream project, the evolution of the structure and functioning of the benthic communities (i.e., their biodiversity and their ecological function) in the zone potentially affected by the project and to assess the changes with regard to the initial state and the reference zone monitoring (Fig. 47, Table 26).

From the regulatory point of view, the monitoring program is part of the regulatory impact study, and is therefore submitted to the state services to be taken into account.

When the installation phase takes place too long after the end of the initial state assessment (longer than 3 years between the submission of the regulatory impact study and the first installation works), a final initial state survey will be necessary, just before the start of the installation phase. This will ensure that no significant changes have occurred during this long time frame.

In the case of structures that are submerged and installed on the bottom, a monitoring operation of the evolution of the seabed is desirable soon after the end of the installation phase, to identify any immediate effects.

This first survey should include 2 seasons (late winter and late summer), in an order depending on the period in which the installation is completed.

An optimal assessment strategy should include 2 other surveys, 2 and 3 years after the end of the installation (at the rate of 2 seasons per year), to compare the interannual variability measured after installation with that measured during the initial state. This allows the detection of potential impacts caused by perturbations that are of low-intensity but continuous (modification of the hydrodynamics for example). In any case, a survey is recommended 5 years after the end of the works to assess the impact of the operation phase.

Given the lack of scientific perspective on the question of the impacts of the tidal stream turbine on benthic ecosystems, the frequency at which subsequent monitoring operations should be performed is very difficult to determine at this stage. On the basis of the results obtained during the first 5 years of project operation, the monitoring operations could potentially be extended to a frequency of less than 5 years.

Concerning the decommissioning phase, there are no specific recommendations at the moment for the monitoring of potential environmental impacts induced during this phase. Although the decommissioning is often regarded as the inverse of the installation process, causing similar perturbations to the environment, it is very difficult to make recommendations at this stage. Note that recommendations only exist for the decommissioning of abandoned offshore oil and gas installations (decision 98/3 of the OSPAR).

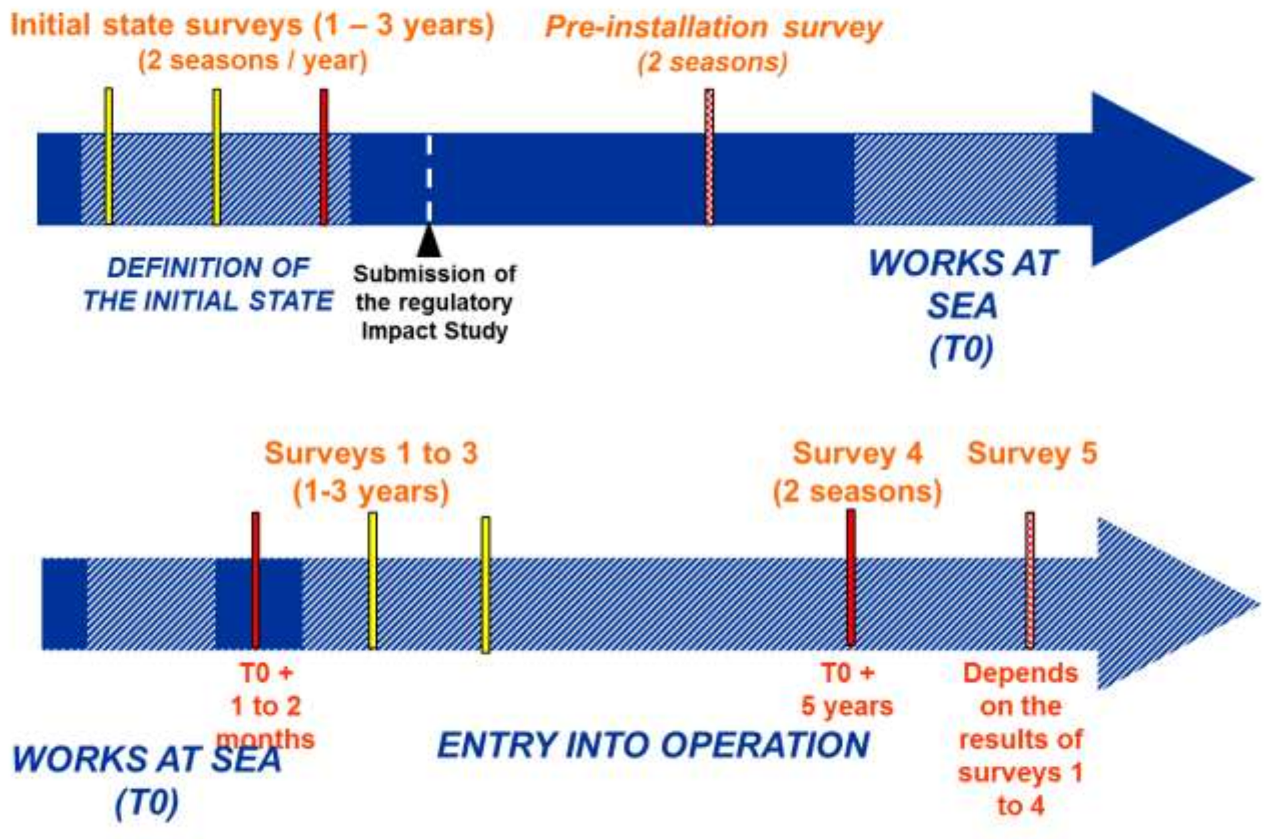


*Figure 47 Theoretical schema of the benthic monitoring implementation strategy for the duration of a tidal stream project, from the definition of the initial state to the end of the operation period (the optimal impact assessment strategy also includes the monitoring surveys represented in yellow) * if the installation works occur more than 3 years after the end of the initial state assessment.*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Definition of the initial state</th><th colspan="3">Monitoring during the operational phases of the tidal turbine project</th><th rowspan="2">Post-decommissioning monitoring</th></tr>
<tr><th>Installation</th><th>Operation</th><th>Decommissioning</th></tr>
<tr><td>Objectives</td><td>Define a benthos reference state. Identify habitats and benthic species (animals, plants) in the zone, assess their sensitivity, ecological state and their spatio-temporal variability</td><td>Assess the impact of the installation works for the different components of the project (machine foundations and converters, anchors, cables) on the benthos</td><td>Assess the impact of the presence and operation of the turbines (possible reef effect, change in surrounding benthic communities) by a comparative BACI-type approach.</td><td>Assess the impacts of the decommissioning works on the benthos</td><td>Assess the conditions for a return to an ecological state close to the initial state (or the ecological state of the reference zone)</td></tr>
<tr><td>Study perimeter</td><td colspan="5">Study areas potentially affected by the project (fixed benthic species; mobile benthic species) + reference zone (outside the influence of the tidal stream project)</td></tr>
<tr><td>Duration</td><td>3 years</td><td rowspan="2">Possibly just before (T0), and within 2 months of the end of the installation (T0+2 months); 2 seasons / year</td><td rowspan="2">Complete operation phase (T0+2, 3 and 5 years, with 2 seasons / year; then monitoring frequency defined according to previous results)</td><td>To be defined depending on the technologies and the environment</td><td>To be defined depending on the technologies and the environment</td></tr>
<tr><td>Recommended periodicity</td><td>2 seasons / year</td><td colspan="2">To be defined depending on the results of the initial state</td></tr>
<tr><td>Methods</td><td></td><td colspan="4">Environmental parameters

- Measure of parameters potentially modified and conditioning the structure and function of the benthic communities: current, temperature, turbidity, electromagnetism, acoustics.

Benthos / hard seabed

- Dive monitoring (if possible): quantitative samples of benthic flora and epifauna (megafauna and macrofauna) with quadrats, photo imaging and/or video on quadrats and/or transects.

- Monitoring by video imaging: with suspended frame, towed benthic carriage, ROV. Identification of epibenthic organisms (megafauna, possibly flora and macrofauna) on georeferenced profiles.

Benthos / soft seabed

- Quantitative sampling by grabs or cores, and/or semi-quantitative sampling by dredging. The number of sampling stations and their distribution will depend on the observed spatial heterogeneity. These stations will be linked to sediment sampling points.

At each station, it is recommended that at least 3 replicates (number to be defined depending on local specificities and the chosen grab) to account for the species distribution at a given point and their dispersion.

According to the nature of the sediments, the samples are sieved through a 1-mm mesh sieve (preferably a round mesh) for fine or muddy sediments, and 2mm for coarse sediments. The retained fraction is fixed (formol; alcohol) and analysed:

- Biological sorting.

- Identification at the lowest possible taxonomic level (individual characteristics and species of commercial interest) and count of the number of individuals determined.

To define the initial state, video exploration of soft seabed may be considered to complete the morphosedimentary monitoring and identify the flora (depending on the depth) and the aboveground megafauna.</td></tr>
</table>

Data to be collected		List of species present; specific richness; abundance (or semi-quantitative indices) ; biomass (optional) ; list of communities or facies observed
Presentation of results		The results are presented in the form of: - Tables showing for each species (or taxon), the geographical position of the station (or profile), the probe, the nature of the seabed (biotope), number of individuals per m2 (or abundance index), standard deviation for each of the stations sampled, identification of species of commercial interest and ecological quality indices of the benthic compartment (e.g., M-AMBI index). - Small-scale maps of the quantitative distribution of dominant species, heritage species or species of commercial interest. - A summary map of the main biosedimentary units (communities, facies); - A typology of the observed habitats according to the current references (e.g., EUNIS).

Table 26 Summary of a monitoring programme for the benthic compartment

7.5. Impact mitigation measures

As specified in article R. 122-5 of the environmental code, mitigation measures should be presented in the regulatory impact study to reduce the most significant negative impacts of the tidal stream project.

The goal of these mitigation measures is to maintain the ecological state of the benthic compartment to a level close to that revealed by the definition of the initial state and thus ensure an environmental equilibrium. It is imperative that these measures are considered according to the logic of the triptych “avoid / reduce / offset". Whenever possible, the negative impacts should be avoided (for example, by changing the route of the landing cable to bypass a vulnerable benthic habitat). When an impact cannot be avoided, the project promoter should ensure that its intensity is reduced to a minimum (for example, by reducing the spatial footprint of foundations on the bottom, or by spreading the installation works over a period of time). Finally, only after taking into account the first two steps, the significant residual impacts should be offset (for example, by restoring a damaged benthic habitat).

In addition, mitigation measures should be proportional to the relative intensity of the potential impacts of the project and their probability of occurrence. However, this should not prevent the project promoter applying the precautionary principle whenever it is warranted.

7.5.1. Avoidance measures (or suppression measures)

The avoidance measures may include the selection of alternative locations, modification of the installation methods, or modification of the structure design (e.g., base/foundations of machines).

The presence of habitats or benthic species of high ecological or heritage interest (protected species) and/or that are particularly sensitive to perturbations, (slow-growing 'engineer' species) can justify the choice of an alternative site for the installation of the machines or the laying of the cable (Fig. 48).

An avoidance measure can also concern the choice of the installation period of the project elements, for example, to avoid the migration periods of certain species (e.g., large crustaceans such as the spider crab), or the reproductive periods of other species.

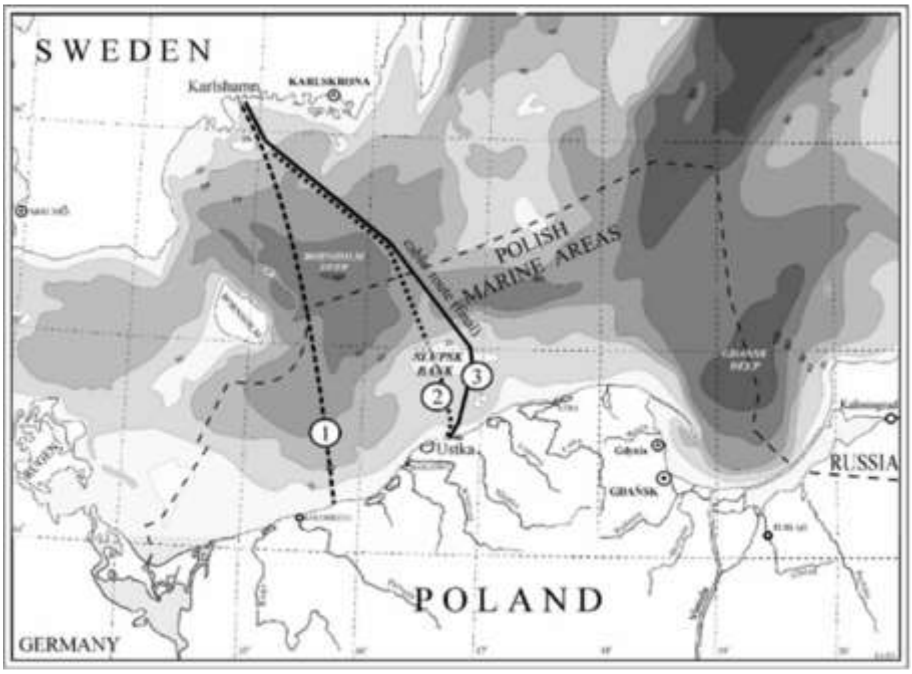


Figure 48 Successive modifications of the route of the SwePol cable during the planning phase, due to potential conflicts with users and the presence of a marine protected area (MPA) (Andrulewicz, 2003)

Une mesure d'évitement peut également concerner le choix de la période d'installation des éléments du projet pour épargner par exemple les périodes de migration de certaines espèces (ex. grands crustacés comme l'araignée de mer), ou les périodes de reproduction d'autres espèces.

7.5.2. Reduction measures

Impact reduction measures may concern the spatial footprint of the machine foundations, converters or anchors on the seabed, in order to preserve the integrity of the benthic communities present at the installation site. This can be significantly reduced through the design of bases deployed on a limited number of feet. The design of anchoring systems that minimize the seabed chafing phenomenon by the chains should be favoured.

They may also concern the embedding depth of the cable, which can be used to decrease the potential impacts of the cable's electromagnetic field on sensitive benthic species (large crustaceans, such as lobsters for example).

Regarding the modification of the hydrodynamics, the goal is to limit the energy absorption (decrease of currents) to that strictly necessary for the production of electricity. In other words, apart from the turbines, all the elements of the tidal stream project should be designed to minimize the perturbation of the currents, in order to reduce the possible impact on the benthic species sensitive to this parameter.

7.5.3. Offset measures

These measures are used to maintain a suitable level of biodiversity and functions within the benthic ecosystems impacted by the project. They may be of various natures. As far as possible, offset measures should specifically concern the impacted species and/or functions and should be implemented primarily on the installation site or in the immediate vicinity. For example, a phanerogam meadow destroyed by the landing cable installation can be replanted at the same place (after installation) or nearby (on a site judiciously chosen, favourable to the implantation of a meadow).

When the offset cannot target the site of the tidal stream project itself, it may address the preservation of neighbouring benthic habitats (from an ecological point of view, similar to those impacted by the installation of the turbines or the cable). It can also involve the improvement of knowledge and monitoring of the benthic ecosystems affected by the tidal stream project.

7.6. Deficiencies and research programmes

Fundamental knowledge about coastal benthic ecosystems remains fragmented and insufficient to foresee the potential impacts of the tidal stream turbine on this compartment. This is especially true for the ecosystems in the circalittoral zone. Research is needed to identify indicator species of the major perturbations expected and to make the environmental monitoring more effective (more focused).

The impact of the hydrodynamic modifications induced by the operation of the turbines is poorly understood, and represents a priority issue at the industrial deployment scale (commercial farms).

The characterisation of the "reef" effect of the submerged structures, even if it is not an original scientific question, should be the subject of long-term monitoring targeting the different components of the tidal stream projects (foundations, laid cables and their protective structures). The goal here is to clarify to what extent the communities that colonize the artificial substrates resemble the communities of natural hard substrates (in terms of benthic biodiversity and ecological role).

The impact of the noise generated by tidal stream projects (and noise of anthropogenic origin in general) on benthic invertebrates is poorly understood. This problem is currently the subject of collaborative research work as (BENTHOSCOPE project).
The impacts of the electromagnetic field modification and the temperature increase generated by the cable during the operation phase should be studied in depth, notably by field-based approaches (*in situ*).

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8. Fisheries

This section covers all fisheries resources: fish, crustaceans and molluscs (cephalopods and shell-fish).

8.1. Description de l'état initial

8.1.1. Les méthodes

Knowledge of the initial state from existing data (bibliography) is a prerequisite but, as such information can sometimes be inadequate or obsolete, it is then necessary to obtain new data through field work.

One point that should be considered is the temporal scale of natural variability, as conditions may change with the season and from year to year. The length of the period over which data are collected depends on the sensitivity of the site with respect to the project and the compartment studied (identification of species or areas of functional importance to fisheries such as spawning and nurseries); each site has specific characteristics. Species that should be considered include those listed on the IUCN Red List (inventory of the global conservation status of species, which are classified into nine categories) and in the annexes of the Habitats Directive.

Sites are characterised through a large-scale description of the distribution of fish, shellfish and other marine resources, and their abundance and ecology in and around the area expected to be influenced by the planned project (Judd, 2012). This characterization includes: i) identification of important and/or sensitive species (including migratory species) and their habitats, ii) the distribution and scale of commercial fisheries, including temporal and spatial perspectives; iii) spawning and nursery areas. One source of information is the local empirical knowledge of professional fishers.

A description should be made of the environmental parameters that could be significantly affected by positive or negative impacts of the project, whether such parameters fall within physical, chemical, biological and socioeconomic fields (Bald *et al.,* 2010.).

The objective of the environmental inventory is to establish a "baseline" that will be used for comparison with the monitoring program and surveillance to check whether the actual impacts correspond to those predicted, therefore enabling corrective measures to be made.

It should be emphasized that it is not always necessary to monitor all environmental parameters, we could only study those that are directly related to a possible impact of the installation, knowing that the fish and fishery resources (from a socio-economic point of view) are considered to undergo a significant impact (Solaun *et al*., 2003 in Bald, 2010).

Solaun *et al*. (2003) thus made a guide for identifying the variables that should be considered:

- Historical information must be available to analyse the evolution of the variables.
- These must be comparable to data collected according to regulations.
- They must affect the dynamics of the system under study.
- They must be measurable.
- Their meaning should be obvious.
- They should not replicate one another.
- They must be understandable by non experts.
- They should be easy to use and reproduce.

Clearly, the variables must be adequate for the studied cases and make it possible to identify the impacts and the highest variance likely to appear in relation to the time available and the budget allocated for the completion of the study.

Assessment methodologies for ichthyological communities fall into two main groups: capture methods and observation methods (Table 27).

	Techniques	Typology
Capture methods	Traps	Barriers Baskets
	Trawling / dredging / nets	Seines (Danish, sliding) Floating nets, semi-pelagic trawl Bottom trawl
	Hooks and lines	Longlines (bottom or drifting) Hand line
Observation Methods	Visual underwater observation	Transects Seasonal counts
	Hydroacoustics	Scientific multi-frequency fish sounder
	Video	Video camera with or without a diver

Table 27 Fish sampling techniques used in ecological studies (in Bald et al., 2010, after Watson, 2008)

A combination of techniques can be used: trawl (bottom and pelagic) and dredging to describe the species present in the water column and on the bottom (including buried), acoustic methods for species with small populations and visual observations for those that cannot be assessed with these techniques (Fig. 49). The method or methods chosen depend/s on the chosen objectives (for example, which species or species group/s are sought: pelagic, benthic etc.?) and the biases associated with each of them.

The advantages and disadvantages of each technique consist of: adapting the machinery to the type of bottom studied, the selectivity of the gear (intra-and interspecific), possibilities of escape, the capacity to produce abundance indices per unit area, the amount of variance between each sample, the damage caused by the capture (Bald *et al*., 2010).

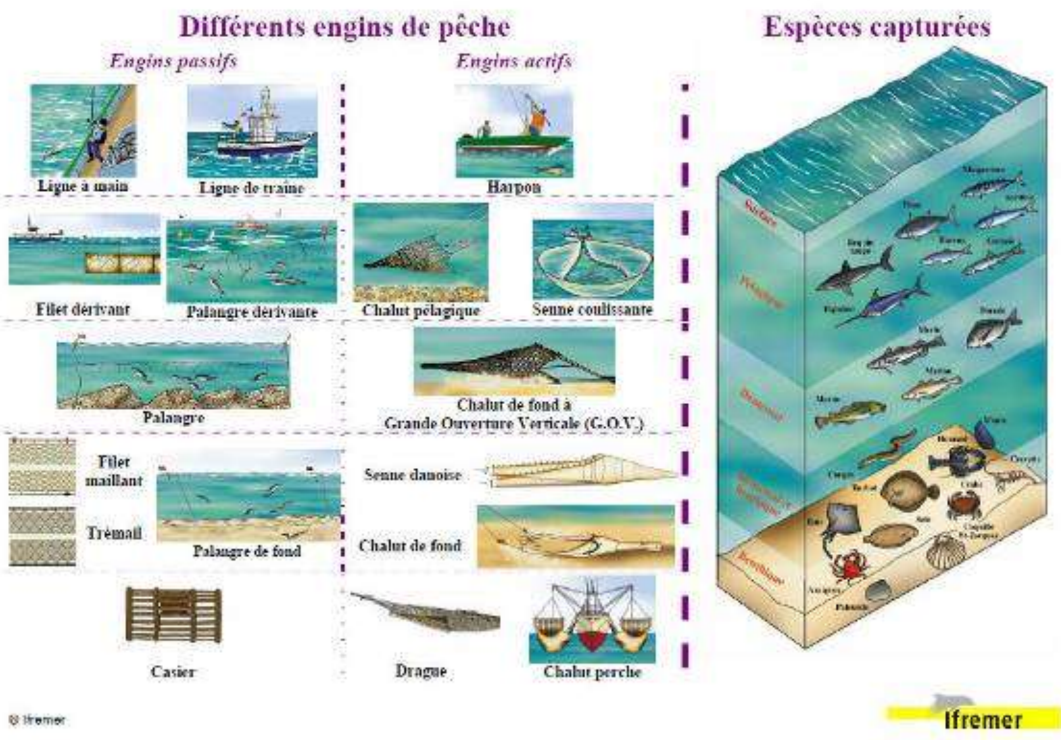

Figure 49 Fishing techniques and target species (source Ifremer)

While observational methods are of interest, visual observation can be severely limited by the current and turbidity of the environment.
Judd (2012) pointed out that studies to characterize sites for the fisheries compartment site should be considered from two aspects: i) the biology and ecology of the main commercial species and those important from a conservation perspective; ii) professional and recreational fisheries.
In cases where commercial species need to be taken into account, then the gear and techniques used by local commercial fishermen should be chosen for research cruises and the involvement of the latter in the development of the protocol and data collection is highly recommended, when possible (Judd, 2012).

Judd (2012) therefore proposes an “information box” that is particularly interesting for deciding in advance which data are important for the problem in hand:

1) What species of fish and shellfish are present on the site in the surrounding area?
   - Which of these are highly important for professional and recreational fisheries (including elasmobranch species: the shark and ray family, as these are electro-sensitive)?
   - Which are highly important from a conservation perspective?
   - Which are important because they are prey of species of commercial interest or for species important from a conservation perspective?
   - Are there other locally abundant species in the area?

2) For species of commercial or recreational interest:
   - Are there important spawning areas in the locality?
   - Are there important nursery areas in the locality?
   - Are there important feeding areas in the locality?
   - Do their migration routes pass through the area (is the site a wintering area for crustaceans)?
   - Are there sites important for their prey in the locality?

3) For species important from a conservation perspective:
   - Are they present in the area and, if so, what is their abundance?
   - Do they have a vital habitat in the area or are they in transit?

4) If a species has a spawning site in the area:
   - When does it come to spawn?
   - Will the construction affect the physical habitat used by species that lay their eggs on the bottom?
   - How will construction activities affect the spawning behaviour and the physical nature of the bottom in the spawning site?
   - What is the relative importance of this particular area with respect to the overall area of spawning for each species?

5) If a species has a nursery site in the area:
   - What is the relative importance of the habitat for species in the area in the broad sense?
   - Will the construction reduce the habitat available or increase it?

6) If the planned installation is close to an estuary:
   - What is the status of diadromous fish (migratory fish that spend a part of their life cycle in a river and the rest at sea, or vice versa) in the area?
   - Will the planned installation hinder the migration of diadromous fish in the area, taking into consideration other types of estuarine and coastal development?
   - What are the periods of migration at the site?
   - Is the site important for spawning in estuarine fish species such as the flounder, which spawn in the open sea?

It may not be necessary to study all the potential ecological impacts in the same degree of detail. Emphasis can be put on the elements or resources that are important enough to merit detailed attention, and where impacts due to the project are known to have major effects (IEEM, 2010).

Judd (2012) proposed a sampling protocol that describes: i) the area to explore (the site itself and its immediate surroundings); ii) the number of traits (at least 5 but preferably more, depending on the size of site, in order to reduce the variance); iii) the seasonal (spring spawning period for many species of fish, with additional samples in summer and/or winter to better understand the seasonality of fisheries) and iv) the tide, with samples taken during both day and night because it can influence species behaviour.

It is wise to choose a sampling strategy according to behaviour and the presence of the species targeted by the study protocol (e.g., day or night, summer or winter).

In the Bay of Fundy (Minas Passage) the installation of a tidal OpenHydro by FORCE (Fundy Ocean Research Center for Energy, 2011) was monitored, consisting of the implementation of adaptive exploratory and innovative management protocols derived from conventional protocols.

For fish, the use of echo sounders and pelagic trawls made it possible to describe the population present (presence, abundance, seasonal variations), while fish movements could be tracked using acoustic tags (VEMCO type, with a set of thirty receivers placed on the bottom; this technique is considered to be suitable for use in the pre-operating and operating phases of a marine tidal stream energy site). Strong currents, water depth and turbidity made it difficult to use video cameras. Acoustic tracking allowed behavioural observations on three species of fish (bass, sturgeon and American eel) under natural conditions but not during turbine operation.

The use of drift nets has also proven effective in such conditions of strong hydrodynamics. Lobster catches (using a capture technique with lobster traps) were monitored before and after the installation of the turbine, and before and during the fishing season.

In the particular case of MRE systems, which by definition are located in areas with strong hydrodynamics, it is important to take into account this specificity in the choice of techniques to use, as it must be possible to operate them in such conditions.

8.1.2. Definition of the potentially affected area and choice of reference area

To reduce environmental impacts, it is essential to understand how the structures affect the current regime in the on near-field (<1 km), far-field (1–10 km) and regional (>10 km) scales (Shields, 2010).

The campaign to be carried out should including enough replicates and covering a large enough geographical area to take into account the mobile nature of fish populations (Judd, 2012).

The site will include the turbine installation and cable corridor to the mainland site

The zone of influence of the set up can vary over time, notably between the installation and exploitation phases; activities related to the different phases will change. Their location should be given on maps. The area of influence should be reviewed regularly and updated as the project progresses.

Where appropriate, this area will be identified using hydrodynamic models incorporating factors such as changes in current regimes, temperature, salinity and sediment. These models show the possible extension of changes under different conditions and will be useful for estimating the potential impacts on the communities in place. If there is no information available to properly determine the area of influence, it will need to be specified (IEEM, 2010).

In the preliminary analysis stage of the project, it may be difficult to identify the total spatial extent of the changes caused, so it is advisable, as a precautionary measure, to ensure that the studies include all areas where impacts are likely to occur throughout the lifecycle of the project (IEEM, 2010).

<u>Concept of near-field and far-field (Polagye *et al.*, 2011.)</u>

The near-field is the area in which interference from machines can be easily distinguished from

other natural or anthropogenic disturbances. According to the environmental parameter considered (hydrodynamics, sound, electromagnetism, etc.) the distance from the turbine that should be taken into account will vary. It therefore varies from a few metres (for a submarine visual stimulus) to several tens of metres (for hydrodynamic disturbance of the rotor or support structure), and up to several hundred meters (for acoustic stimuli). In a physical sense, the near-field includes elements of the immediate environment of the turbine for which specific direct effects of the turbine can be detected. Such elements include water movement (hydrodynamics, currents, pressure and stratification), water quality (physical, chemical and biological properties, such as turbidity, dissolved oxygen, chlorophyll, nutrients ...), noise and electromagnetic fields, and sediment properties. This combination of elements contributes to the biological characteristics of the sector and is therefore a key parameter to monitor. The significance of the effects of these elements will be specific to the environment and scale of the project (a pilot project would probably have few effects).
The far field is the area in which the disturbance from machinery cannot be easily distinguished from other natural or anthropogenic disturbances, in contrast with the near field. From a physical perspective, this field is defined as the area surrounding the machines beyond which the specific character of the park is not directly discernible. The elements to be considered here are water quality, primary production, sediment transport and the nature of the intertidal zone.
However, it is often difficult to put a reference station in an area where there are strong currents. Small-scale differences in a habitat or current regime can mean that a chosen sampling point will not correspond to this definition (Polagye *et al.*, 2011).

8.2. Methods of identification and analysis of potential ecological changes

The physical environment (nature of the substrate, currents, sediment dynamics, etc.) largely determines the biological compartment: the associated benthic fauna and flora, which are a large part of the diet of predators (including fish) living in the water column (Sotta *et al.*, 2012).
In general, the area of habitats that will be affected depends on the type of machinery (technology used) and the type of foundations, as well as the number of machines to be installed (prototype, test scale or industrial scale park).

The scale of individual structures to be installed and of the park as a whole should be taken into account. A structure consisting of a single unit will have a very different impact to a park, so a research programme should be chosen to take into account this scale (OSPAR, 2006).

Effects on biological resources include the alteration of animal behaviour, damage and mortality of individuals, and potentially greater long-term change for human and communities (Gill, 2005; DOE, 2009).

The impacts of marine tidal stream equipment, such as noise or interference with other activities, can be understood as pollution under the Marine Strategy Framework Directive MSFD (Bald *et al.,* 2010). Indeed, in Article 3.8, pollution is defined "the direct or indirect introduction into the marine environment, as a result of human activity, of substances or energy, including human-induced marine underwater noise, which results or is likely to result in deleterious effects such as harm to living resources and marine ecosystems, including loss of biodiversity, hazards to human health, the hindering of marine activities, including fishing, tourism and recreation and other legitimate uses of the sea, impairment of the quality for use of sea water and reduction of amenities or, in general, impairment of the sustainable use of marine goods and services".

In the MSFD and the decision of the European Commission of 1 September 2010 regarding criteria and methodological norms concerning the good environmental status of marine waters, notably through descriptors 7 and 11:

- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems:

Permanent changes in hydrographical conditions caused by human activities can include, for example, changes in the tidal regime in sediment transport or freshwater or in the current action or waves, which can change the physical and chemical characteristics listed in Appendix III, Table 1 of Directive 2008/56/EC.

- Descriptor 11: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment:

In addition to underwater sound sources, which are dealt with in Directive 2008/56/EC, other forms of energy such as thermal energy, electromagnetic fields, noise and light can have an impact on components of marine ecosystems.

Tin fact, the objective of impact studies and ecological monitoring is now to evaluate whether present human activities, or those concerned with the project are compatible with the Good Environmental Status of marine waters as defined by the MSFD.

8.2.1. During the installation phase

Installing turbines can cause significant disturbance to the local environment. Apart from the fact that the structures (machines and cables) will remain in place, most of the effects associated with the installation are considered temporary (a few weeks to a few months, with a few residual effects). Stressors during this phase include noise, increased vessel traffic and habitat disturbance associated with the installation of anchors and cables (Polagye *et al*., 2011).

Impacts related to noise (descriptor 11a of the MSFD)

Fish have a greater diversity of auditory systems than mammals because there are several different groups of species with different anatomical characteristics (Nedwell *et al*., 2004; Thomsen *et al*., 2006).

Some fish use sound to locate their feeding grounds and it is supposed that noise can interfere with this ability (Langhamer *et al.*, 2010). Several species use sound to communicate and to detect their prey and their predators. Although fish of the family Gadidae (e.g., cod, whiting, pout) respond to shots from seismic air guns by fleeing, their subsequent behaviour and distribution are not affected. In these species, communication by sound is an essential component of behaviour during the breeding season, and it is known that the pile driving or other noise can disrupt this behaviour (Moura *et al.*, 2010).

If installation of the equipment requires pile driving, the use of explosives or seismic campaigns, it is likely that the surrounding noise level will exceed thresholds for the protection of fish (at the level of individuals or populations) and marine mammals (MMS, 2007; Frid, 2012). In general, the response of fish is to avoid areas of pile driving. Overall, juveniles and small species will have more difficulty escaping than large or pelagic species (Engas *et al*., 1996).

According to Gill (2005), noise above 260 dB can cause hearing damage to certain species within 100m.

The studies conducted as part of COWRIE showed that relatively low levels of acoustic pressure (in the 140-161dB re 1mu.p range) cause a change in the movement of cod and sole. After having heard the sound repeatedly, the response of these two species is less intense than the first time, indicating that these fish can get used to the noise. Further studies need to be done on this adaptation to manage the effects of pile driving on marine fish (Sotta *et al.*, 2012).

There can be permanent or temporary physiological damage that may affect animal survival. For example, herring are sensitive to sudden increases in sound pressure (during pile driving) which may cause damage to their inner ear and make them more vulnerable to predators. Clupeids (e.g., herring) have a very low sensitivity threshold, ranging up to ultrasound, and their behaviour and distribution are more affected. Herring are known to emit sound using their swim bladders to release air bubbles through the digestive tract, which may have a role in communication. Temporary exclusion from breeding grounds or disruption of behaviour during spawning period can have serious consequences for populations of this species (Moura *et al.*, 2010).

The effects of noise on marine invertebrates remain poorly known (Moriyasu *et al*., 2004). Invertebrates include a great diversity of faunal groups (e.g., molluscs, crustaceans) and we therefore cannot generalize the effects of all these groups. The potential reaction is known to be highly variable and little information is available about the possible effects at different stages of in the lives or these organisms (Sotta *et al.*, 2012).

Impacts related to habitat disturbance (MSFD descriptor 6):

Habitat use and migration patterns of susceptible species should be studied during the period of machine construction. For marine species that avoid the construction area, this phase inevitably leads to a loss of habitat, which may include areas of feeding, nesting, breeding and rest (in the case of migratory species) (Sotta *et al.,* 2012).

Boehlert *et al.* (2008) noted that during the installation and operation phases, MRE systems can cause changes in the physical structure of benthic and pelagic ecosystems, and thus changes in habitats.

Impacts related to water quality (MSFD descriptor 4):

Impacts on water quality and benthic communities during the installation phase are considered to be of short duration and therefore not to significantly alter food resources for fish (Gill, 2005). Fish generally flee from areas where the water is very turbid. High levels of suspended solids can damage the gills of young fish.

8.2.2. During the operating phase

Rotating turbines, underwater noise, chemical pollutants and electromagnetic fields are often cited as stressors associated with working machinery. Other, less well known stressors include those associated with energy extraction and cumulative effects due to interactions between environmental parameters or the increasing numbers of machines. For example, when the machines are not in operation (i.e., when the currents are below their power actuation level), acoustic, electromagnetic, energy collection and dynamic effects (rotation of the turbines) are reduced, lowering the stressors accordingly. Depending on the current regime and machine design, a turbine may operate almost continuously, or for less than half of the time. No effects are expected from energy capture projects at the pilot/demonstration level (Karsten *et al.*, 2008. Polagye *et al.*, 2009.).

Fisheries-related receptors in the marine environment (fish, crustaceans, cephalopods...) can also vary over time (e.g., seasonal variation, migratory behaviour) and can be exposed to other anthropogenic stress factors. Additionally, interactions between environmental parameters and receptors can have a greater temporal variability than the environmental parameters themselves or those of the receptors (Polagye et al., 2011). Similar considerations may apply to the spatial variability of environmental parameters (e.g., received sound levels will vary depending on the proximity of the machines in operation), the receptors (e.g., species are not evenly distributed in a given geographical area), and their interactions.

Normal operation of a tidal park involves **maintenance** activities, which imply that the machine or its components are brought to the surface. Several environmental parameters associated with maintenance are similar to those encountered during installation: (e.g., an increase in vessel traffic).

There is insufficient data to definitively decide on the impact of operational turbines on fish and their habitats (Frid, 2012). Observations made on the tidal project on Roosevelt Island in East River in New York (Anon, 2008) showed that the number of fish in and around the turbines was generally low (ranging from 16 to 1400 individuals observed per day) and these fish were predominantly small. Videos of the site showed that there was generally no fish when the velocity was greater than 0.8 m/s and the turbines were in motion (Polagye *et al*., 2011).

Noise (see sections 8.2.1 and 6.3 also):

The solution to the problem of noise-related impacts requires knowledge of the acoustic signature of structures (e.g., noise levels throughout the frequency range) for both unit structures for parks, the characterization of ambient noise in the vicinity of park, auditory sensitivity of fish (and marine mammals) using the site, and their behavioural response with regard to anthropogenic noise (e.g., avoidance, attraction, change in shoaling or migratory behaviour) (Frid, 2012).

It is likely that the fish adapt to relatively continuous noise, as observed in many ports and in other circumstances involving human activities (such as maritime traffic or diving) (Schwartz, 1985; Wahlberg and Westerberg, 2005 in Sotta *et al.*, 2012). However, the extent of noise impact depends on the weather, the composition of the sea bed and several other site-specific variables (Folegot, 2010).

Electromagnetic fields (EMF): see “EMF" inset and sections 7.2.2 (barrier effect) and 7.5.2.
Some marine species are electrosensitive and others are magneto-sensitive. For example, certain fish species (particularly eels and sharks) use the earth’s magnetic field for orientation, navigation and migration (Kirschvink *et al*., 2001), while others (elasmobranchs: sharks and rays) can also use weak electric fields to locate their prey (predator-prey interaction). Physiological impacts on mortality or reproductive success can be critical for some of these organisms, while behavioural responses, such as migration or shoaling may appear more critical for others. Duration (short or long term) and the type of exposure (e.g., alternating or direct current, permanent or temporary) may be another factor that adds to complexity (Polagye *et al.,* 2011). Migrating eels can detect EMF emitted by an unburied three-phase 130 kV cable but does not interrupt their migration (Lagenfelt and Westerberg, 2008).
Information on habitats and migration routes of susceptible species should preferably be taken into account in spatial planning and installation of cables (Sotta *et al.*, 2012).
Many studies were made on EMF as part of the COWRIE programme, and showed that there was an interaction between electrosensitive species and the EMF caused by the cable of offshore wind turbines (Gill, 2005; 2009). However, it was also shown that while organisms may be affected at the cellular and behavioural level, it was still not possible to determine what type of response could be expected and if it could be considered positive or negative. Recorded results are therefore unpredictable and appear very specific to species and perhaps even to individuals.

In situ study results

Several field studies have been conducted in the southern Baltic Sea. Migration models of European eel (*Anguilla anguilla*) were analysed by telemetry at the point where they crossed a submerged AC power cable (intensity of CM product: 5µT at 60m distance). The results suggest that the trajectory of the fish was altered at the cable, but did not provide any strong evidence for this as the spatial resolution of the method was low. The same technique failed to demonstrate a change in migratory behaviour in the same species at an offshore wind farm, at least not beyond 500m from the wind turbines.
Finally, a more recent study in the Baltic Sea (near Öland island) showed that the speed of swimming eels was significantly lower near an unburied cable (AC, 130kV) than on parts of their migration route located to the north and south of the area of the cable (Lagenfelt and Westerberg, 2008). The authors considered the impact of the cable on eel migration to be low and that the cable was not an obstacle to the movement of this species.
Field investigations were also carried out on the cable of the Danish offshore wind farm Nysted (AC, 132kV) between 2001 and 2004 to measure the impact of the EMF on behaviour of four fish species (cod, Baltic herring, eel and flounder; DONG Energy, 2006). The data collected suggest avoidance behaviour or attraction depending on the species, but are too fragmented to be interpreted unambiguously. During the study, only the flounder (*Platichthys flesus*) showed a correlation between behaviour and estimated EMF power (but this was not measured directly).
In the Danish wind farm of Vindeby, the magnetic field generated by the connecting cable (AC, 10kV; maximum current for each phase of the 260A cable) was calculated according to the distance from the cable (Engell-Sørensen, 2002). The magnetic field strength would be 33.1microT at one metre and 3.31microT at 140m. The author considered that fish that are sensitive to magnetic fields and those living near the bottom could be affected by this field within a strip of one metre to either side of the cable. At more than one metre away, this magnetic field is no longer distinguishable from the earth's magnetic field, which is about 50µT in this region.

In England, measurements of the electromagnetic field made near cables connecting two offshore wind farms in operation (Burbo Bank and North Hoyle) show that species naturally sensitive to EMF could detect the artificial field of a cable 295 m away, This represents a relatively wide detection corridor (Gill *et al.,* 2009).

Chemical pollution (MSFD descriptor 8):

This type of pollution is considered to be a low stress factor for fish, at the scale of both pilot and commercial parks. Polagye *et al.* (2011) suggest that this risk is greater during phases of installation, maintenance and decommissioning of facilities because of higher risk of collisions at sea.
In the cases where sacrificial anodes are used to protect underwater metal structures, the zinc released may pose a risk to marine life.
Antifouling: *see section on plankton at the end of this chapter*

Increase in temperature
The impact of thermal pollution on fish populations is similar to the characteristics already mentioned for other organisms (effect on metabolism, reproduction and behaviour); although the high mobility of fish means that they seek areas corresponding to their thermal preferences (MEDDE, 2012).

Interactions with moving fish (Moura *et al*., 2010.)

- <u>Collisions and injuries:</u> evasion or flight.

A collision is defined here as an interaction between animal and machine that can lead to physical injury (where there is contact between the two). Fish will perceive the presence of the machines from a visible or audible signal. They can respond to this signal directly or through learning. Animal responses to such sensory signals can happen at different scales but are classified into two categories according to the perceived threat: evasion or flight.

- In general, exclusion occurs at a greater scale than the size of the animal concerned. Exclusion will be at a spatial scale such that the animal will be kept away from all parts of the machine. At this scale, it is unlikely that visual detection plays any great role. The sounds emitted by machinery can however be detected at such a distance that exclusion is possible.
- Flight is defined as the direct response to a perceived attack or aggression. Fish and many invertebrates also are capable of this type of reaction when faced with such signals, often relayed neurologically by reflex responses, in order to escape predators or to prevent a collision with a submerged object. A model based on visual responses to threatening objects was developed for Equimar, and preliminary results indicate that the fish is the escape probability increases with the size of the fish, as the maximum swimming speed increases, but also dependent on the thickness of the turbine's blades. The rotational speed of the turbines is also critical. The risk of collision increases rapidly at flow velocities greater than 2m s^{-1}.
- Ecological models have been built to estimate the rate of such encounters (Wilson *et al.*, 2007.) and used in Scotland to predict the rate of encounters between vertebrates and the blades of marine tidal turbines. Encounter rate depends on the spatial and temporal variation in the behaviour of individuals within the park. Indeed, although some species may be present in a given area, their interaction with the tidal stream systems will depend on their spatial distribution (including vertical) and how this distribution varies at different time scales (e.g., diurnal, tidal and seasonal). For example, fish can avoid the most intense currents tide moving to sheltered areas (bays) where there is a lower hydrodynamic intensity, or towards the bottom.

- Effect of pressure (cavitation) and risk of cutting:

Cavitation phenomena related to the turbine may have effects on fish: their swim bladders should not be damaged by a rapid increase in pressure, causing a reduction in volume, but could be by a rapid expansion during the phase pressure reduction.
The other possible effect is on fish hearing: Clupeidae (herring, sardine, etc.) have gas-filled organs that can be damaged by rapid pressure changes. Their subsequent behaviour and ability to escape from predators could then be altered and cause a decrease in survival.

Animals can also be damaged by cutting by moving parts of machinery. This sensitivity varies greatly depending on the species; the most vulnerable are those who can easily lose their scales (such as herring).
The survival of larvae and juvenile fish that encounter turbines is currently unknown. Studies conducted in a testing tank on three species of freshwater fish (Schweizer *et al*., 2012) showed that there are differences in mortality profiles of the blades, the flow velocity of water, depending on species and their life stages (larvae or juveniles).
Direct mortality of fish passing through the turbine can be high (Deng *et al*., 2011).

Interactions with animal migrations
The establishment of large-scale tidal stream systems (industrial) can potentially disrupt movement patterns of marine animals. The questions in this area are the same as those related to the effects of noise. Anything that causes an animal to change their migration routes may have a long term effect on the fate of individuals and their contribution to fitness. If avoidance requires a fish to swim a greater distance, there will be a direct energy cost. If avoidance requires a fish to swim in less favourable conditions, e.g., where there is a higher risk of predation or diminished feeding opportunities, there will again be a direct cost for the fitness of individuals (Moura *et al.*, 2010).
There are potentially direct interactions between moving turbines and migratory or resident fish (in their different stages of life), an issue of great importance with regard to endangered or threatened species.
Migratory fish such as salmon are often regarded as being at risk and, as such, are protected by ad hoc regulations. Salmonids (e.g., salmon and sea trout) and other anadromous fish are known to use tidal currents for navigation in areas with strong currents (Moser and Ross, 1994; Levy and Cadenhead, 1995; Barbin, 1998; Lacoste *et al.*, 2001; Metcalfe and Hunter, 2003).
Installing tidal stream systems in ecological corridors (migratory paths) between the coast and the continental shelf can directly affect certain species at particular life stages (e.g., elasmobranchs – the family of sharks and rays –, and salmonids) leading to changes in their behaviour.

Many species of fish partially depend on currents for transport of smaller individuals. Consequently, structures that have an impact on the current regime between spawning and feeding areas can be harmful because they affect ecological connectivity and trophic relationships (ICES, 2011; Shaw, 1982).
Fish populations may be affected by changes in sedimentation, turbidity and flow currents, as well as by any change in the benthos. These factors are capable of affecting fish populations at different stages of the life cycle, with effects on the spawning grounds and migration routes (Bell and Side, 2011).
For diadromous migratory fish whose populations are classified as endangered (e.g., U.S. Endangered Species Act list), according to Polagye *et al.* (2011) a "zero impact" may be required to the extent that their presence in the area may require the turbines to be stopped. For other species, a degree of injury, mortality or change in behaviour may be acceptable.

It is unlikely that the turbines affect the processes of reproduction and recruitment except when the individual structures are positioned very close together. In such cases, there may be an effect on the transportation and larval recruitment related to changes in the current and the substrate (Frid, 2012).

Generally though, it is accepted that knowledge of fish behaviour in interaction with tidal stream power systems is limited and insufficient to fully understand the potential effects.

Effects related to the physical presence of marine energy installations
1) Reef effect
In the same way as wrecks, which attract and provide protection for fish, tidal stream power structures (anchoring systems, turbine support structures or protective riprap) will become covered with a biofilm and develop into artificial reefs (Hiscock *et al*., 2002). In general, such artificial reefs are colonized quickly. These underwater

structures can become valuable habitats for mobile species (including commercially important fish), crustaceans and molluscs, as well as for invasive species. Such attraction can lead to changes in the species composition of the study area and modify predator-prey relations (Boehlert, 2008).

Opportunistic wildlife can invade reefs (Gill, 2005, in Sotta *et al.,* 2012), increasing the inter-specific competition. Such colonisation is “subspontaneous" invasion, because it is due to an anthropogenic change of habitat. Dominance by the species that have highest adaptability can then follow (Milinski and Parker, 1991) and will have a cascade effect on the composition of local wildlife (Pimm, 1991; Daskalov, 2002).

In general, this reef effect should be considered carefully; location of marine power systems should be optimized from this perspective, taking into account their design, but keeping in mind that the site will have been chosen for its energetic rather than biological productivity.

2) Reserve effect

The physical presence of structures will change the usage of a site, and such changes are often accompanied by access restrictions. From the perspective of biodiversity, these access restrictions can be similar to those associated with Marine Protected Areas (ICES, 2011; Lindeboom, 2011). The creation of this type of “MPA" and denial of access for fishing can have positive effects on fish stocks (Witt *et al*., 2012). Trawling will be strictly regulated or prohibited, and by combining the MPA and artificial reefs, tidal stream parks can increase the diversity and quantity of commercial species (Langhamer and Wilhelmsson, 2009; Martins *et al*., 2010.).

Polagye *et al.* (2011) summarized the reserve effects on so-called resident fish (as opposed to diadromous fish) in the two matrices below (Tables 28 and 29), respectively, at the scale of a pilot site and a commercial site:

	Presence of structures: disturbances: static effects	Presence of structures: disturbances: dynamic effects	Chemical disturbance	Acoustic disturbance	Electromagnetic disturbance	Energy decrease	Cumulative impacts
Population (increase or mortality)	Green; ΔΔ	Green; ΔΔΔ	Green; ΔΔ	Green; ΔΔ	Grey; ΔΔΔ	Green; Δ	Green; Δ
Physical interaction*	Green; Δ	Yellow; ΔΔΔ	Green; ΔΔ	Green; ΔΔ	Green; ΔΔ	Green; Δ	Green; ΔΔ
Behaviour**	Red; Δ	Yellow; ΔΔ	Green; Δ	Yellow; ΔΔΔ	Grey; ΔΔΔ	Green; Δ	Yellow; Δ
Community (species robustness/resilience)	Green; ΔΔ	Red; ΔΔΔ	Green; ΔΔ	Green; ΔΔ	Grey; ΔΔΔ	Green; Δ	Green; Δ

* Lethal and sublethal effects: stress, reproductive failure, toxic disorders, changes in growth
**Avoidance of and/or attraction to structures

Table 28 Matrix of receptors: resident fish; case of a pilot site

	Presence of structures: disturbances: static effects	Presence of structures: disturbances: dynamic effects	Chemical disturbance	Acoustic disturbance	Electromagnetic disturbance	Energy decrease	Cumulative impacts
Population (increase or mortality)	Yellow; ΔΔ	Red; ΔΔΔ	Yellow; ΔΔ	Yellow; ΔΔΔ	Grey; ΔΔΔ	Grey; ΔΔΔ	Yellow/Red; ΔΔΔ
Physical interaction*	Green; Δ	Red; ΔΔΔ	Yellow; ΔΔ	Green; ΔΔΔ	Yellow; ΔΔΔ	Grey; ΔΔΔ	Red; ΔΔΔ
Behaviour**	Red; Δ	Yellow; ΔΔ	Green; Δ	Yellow; ΔΔΔ	Grey; ΔΔΔ	Grey; ΔΔΔ	Red; ΔΔΔ
Community (species robustness/resilience)	Yellow; ΔΔ	Red; ΔΔΔ	Yellow; ΔΔ	Yellow; ΔΔΔ	Grey; ΔΔΔ	Grey; ΔΔΔ	Yellow/Red; ΔΔΔ

* Lethal and sublethal effects: stress, reproductive failure, toxic disorders, changes in growth
**Avoidance of and/or attraction to structures

Table 29 Matrix receptors resident fish, case of a commercial-sized site

Levels of significance for colours

- Green: Weak
- Yellow: Moderate
- Red: High, very high
- Grey: Unknown

Levels of significance for colours

- Δ Weak
- ΔΔ Moderate
- ΔΔΔ High, very high
- ? Unknown

Plankton, a special case

Antifouling chemicals are toxic and can cause increased mortality of planktonic species or affect their health (Sotta *et al.*, 2012). Modern products do, however, tend to have lower toxicity than older ones and be biodegradable. In addition, the implementation of the relevant regulations in the marine area should limit the risk of contamination (Boehlert *et al.*, 2008; DFO, 2009).

Zooplankton can also be directly affected and suffer increased mortality when passing through the moving parts of machinery (Bickel *et al.*, 2011, Witt *et al.*, 2011), which can also affect their predators, including juvenile fish, seabirds and marine mammals (Witt *et al.*, 2011).

Possible disruptions due to changes in currents and therefore larval transport could, in the most extreme cases, affect the ecological connectivity between functional areas of the life cycle of populations and trophic relationships (ICES, 2011; Shaw, 1982).

An example of feedback: The case of the Bay of Fundy (FORCE, 2011)

From an extensive literature review, the inventory of fish species present in the area was established and a useful classification of these species built based on their potential risk of interactions with turbines and accidental damage. Three categories are defined as follows: i) species that have a high probability of interaction and/or significant damage to their population, ii) species with moderate interaction and a low to moderate risk of damage probability iii) species with low interaction probability and damage. Factors conditioning damage potential include size of individuals and their probability of experiencing an impact during their passage through the turbine (large size increases the likelihood of injury, the effects of pressure and cavitation), habitat (pelagic or benthic, pelagic being more sensitive), their importance in fisheries and the status of their population (from the point of view of conservation: endangered, threatened, etc.).

Apart from any considerations about species status, these large, pelagic and scavenging species are considered vulnerable as they may be attracted by dead animals close to the turbines, which is the case with some sharks such as dogfish (*Squalus acanthias*). Herring has also been cited for the effects of pressure.

8.2.3. During decommissioning

Les impacts sur les communautés ichthyologiques durant cette phase sont considérés comme semblables à ceux observés en phase d'installation (Bald *et al*., 2010). Le bruit et les vibrations peuvent affecter les systèmes auditifs de certains poissons dans un rayon de 100m environ (Gill, 2005). Selon Boehlert *et al*. (2008) le démantèlement des ancrages et des infrastructures électriques peut avoir des impacts classés à un niveau moyen pour plusieurs espèces (poissons ronds démersaux, poissons plats, raies).

8.3. Identification of cumulative impacts

8.3.1. Cumulative impacts related to the scale of spatial and temporal deployment

Physical impacts on habitats of pilot structures are considered reversible after disassembly, as the geographic areas best suited for this type of MRE installation are located where strong currents naturally generate large disturbances of the sediments. The cumulative effects of industrial parks should be considered at the far-field impact scale (Frid, 2012; see also section 8.1.2).

For noise, it is important that its effects are assessed at the scale of the whole park and not just for individual turbines (U.S. Department of Energy, 2009).

The cumulative effects of different stressors of a commercial-scale park (multiple turbines) on migratory fish (modification of migration corridors and behaviour) need to be better understood (Polagye *et al*., 2011).

8.3.2. Cumulative impacts due to interactions with other anthropogenic pressures

Other uses of the area (including other types of MRE system, for example) must also be taken into account since these can also be a source of pressure on populations.

Electromagnetic fields: the number of cables is likely to increase significantly in coming decades with the growth of MRE. The increase in the cable network could cause potentially harmful cumulative effects on fisheries, which are difficult to predict and for which few results are available from scientific studies (Carlier and Delpech, 2011).

Accidental pollution (Sotta *et al.*, 2012): The increase in the number of offshore and industrial structures in coastal waters will increase the hazards to ship navigation. The increase in activities has had the effect of increasing pollution risks from oil and other marine pollutants (Wilhelmsson *et al*., 2010). Additionally, leaks of hydraulic fluid from maintenance devices are also a potential source of pollution.

If migratory fish are already stressed by the environmental conditions in the park, or because of their life stage (e.g., migration for reproduction in salmonids), the effects of their passage through the park may be greater (Polagye *et al*., 2011).

8.4. Description of the environmental monitoring programme

General Note: Environmental monitoring during MRE operation must be adapted to the particular sites and consistent with any monitoring established for the initial state. Such programmes can, however, be adapted to the observations from the initial state.

According Simas *et al.* (2010), to optimize effort, protocols should balance scientific, regulatory and industrial approaches. Because the tidal stream power industry is still in its infancy and little feedback is available, there remains a great deal of uncertainty about the environmental impacts that may result from these industrial deployments. The protocols provided by Equimar should therefore be considered as good practice guides with regard to the experience available today. Where possible, knowledge gaps will be identified in order to develop protocols further as knowledge improves. The concept of an **adaptive protocol** should be applied.

Bald *et al.* (2010) recommended that an annual campaign comprising at least five transects with video estimating parameters including abundance. Other methods such as the use of fishing gear can be implemented if the feasibility is proven for the site. So as to collect continuous information on the presence of fish, a system of three sonobuoys can be deployed for a minimum period of a year. If behavioural changes are observed in migratory fish, telemetry and marking techniques may be used.

For similar reasons, OSPAR (2006) recommends the monitoring of fish aggregations around the structures.

Moura *et al.* (2010) recommend making video and photo transects on the site and its surroundings to monitor fish, monitoring ship routes and analysing the reef and reserve effects in case of access restriction for fishing.

Drift nets and acoustic systems should be considered for monitoring fish communities. Acoustic systems may include active systems (sonar), acoustic cameras and acoustic telemetry (with fixed receivers and hydrophones to track the movements of tagged fish). However, the probability of detection of small fish using active systems may be low in some places because of high sediment load, turbulent mixing of fresh and salt water, and high bubbling (Polagye *et al.*, 2011).

For migratory fish, active acoustic systems have been used with some success on the RITE project (Roosevelt Island Tidal Energy in New York), though at a high cost and without highly conclusive results. New methods such as acoustic telemetry and marking should be considered. Existing models for the analysis of fish behaviour should be adapted to the monitoring of tidal stream projects (Polagye *et al.*, 2011).

To study the effect of electromagnetic fields, experiments need to be conducted in a controlled environment for young individuals, while for large mobile species, methods of marking and capture / recapture should be considered (Underwood, 1992; Westerberg and Langenfelt, 2008; Gill *et al*., 2009).

Polagye *et al.* (2011) recommend that clear protocols for environmental monitoring and innovative approaches (improved hydrodynamic models) in terms of instrumented monitoring are developed and implemented. These protocols should specify the type of data to be collected, the means of collection and application of treatments, they must take into account the natural variability and be flexible enough to adapt to the specific case study.

The following Ifremer sites also provide useful information, particularly on data treatment:
http://wwz.ifremer.fr/drogm/Cartographie/Plateau-continental/Energies-marines-renouvelables/Protocole
http://wwz.ifremer.fr/drogm/Ressources-minerales/Materiaux-marins/Protocoles/Ressources-halieutiques

In 2012, the ICES Study Group SGWTE (Study Group on Environmental Impacts of Wave and Tidal Energy) encouraged the development of sensors and measuring methods. It also proposed the creation in 2014 of a new Working Group on (WGME: Working Group on Marine Energy) to coordinate the scientific work done in this area and its application to management.

For the decommissioning phase, there are no specific recommendations for data acquisition. Januario et al. (2007) consider that this phase is the reverse of the installation process and can have negative effects on the environment and commercial activities in the same area. Decision 98/3 of OSPAR provides guidelines for the decommissioning of oil and gas installations, but there is no equivalent for MRE; OSPAR only provided recommendations for offshore wind turbines.

8.5. Mitigation of impacts

Mitigation of impacts may include the selection of an alternative site, a change in construction methods or modification of the structural design.
The presence of areas colonized by a sedentary fauna (of commercial interest, such as natural shellfish beds; or of heritage interest, because of rarity) or a notable for their flora (seagrass, exploitable or non exploitable algae), will be an obstacle to area selection for the development of tidal stream projects, these areas may already be classified as areas that need to be protected.

Many of the impacts associated with the construction phase (e.g., noise associated with foundation building) can be reduced with by careful timetabling (e.g., by avoiding critical year periods such as the breeding season or migration periods of important species) for marine mammals and fish (Frid, 2012; Gill, 2005; Evans *et al.* (2008, in Sotta *et al.*, 2012.)).
There is extensive experience with the engineering for turbines in river environments that can help to reduce the dragging of fish into such systems (Coutant and Whitney, 2000); such measures need to be taken into account in the design of marine energy systems. A rotation speed of 25 to 50rev/min is considered to minimize fish mortality caused by physical contact with the blades (Pelc and Fujita, 2002).
To reduce electromagnetic field (EMF) effects, the burying of cables (where the type of bottom allows this technique) is often presented as a possible strategy. Although is probable that this technique provides protection from the strongest electric and magnetic fields because the substratum of the sea bottom acts as a physical barrier, there are indications that it does not effectively block magnetic fields entirely. Conversion of electricity to 60 Hertz AC synchronous and cable shielding are also factors expected to limit EMF. The principle of the Faraday cage may also be considered for machinery and submarine stations (COWRIE, 2008).
Evans *et al.* (2008, in Sotta *et al.*, 2012) recommends that more reducing measures are implemented during the construction phase:

- Use of bubble curtains (Wursig *et al.*, 2000; CALTRANS, 2011), which act as a barrier to sound propagation. Another measure for reducing potential noise is insulating the piles (Illingworth and Rodkin, 2001; Thorson, 2004; Reyff and Thorson, 2004).
- The effectiveness of repellent pinger systems, like as those used for seals, should also be examined.

Measures to reduce the risk of collision with machines: visual responses in animal flight depend on the contrast between the threatening object and the background environment. To maximize escape likelihood, it is essential that the machines have surfaces painted so that their underwater visibility is consistent with the light spectrum at the immersion depth and sensitivity spectra of animals and their responses (Moura *et al.*, 2010)

8.6. Research programs and target knowledge

Today, turbines have only been set up on an experimental basis, so the prediction of impacts is based on a limited number of data (Frid, 2012). A summary of environmental issues and gaps in our knowledge is given in OSPAR (2006), suggesting that most potential problems are related to the design of structures and are site-specific.
Areas of the fish compartment identified on which research is needed are (SGWTE, 2012):
- Interference with migration routes.
- Behaviour of resting sharks in relation to oceanographic fronts.
- Electromagnetic fields.
- Information on pelagic fish.
- General fish interactions with structures and their behaviour in the area.
- Adaptation of monitoring methodologies.

For electromagnetic fields, the findings of studies conducted as part of the COWRIE programme left many unanswered questions that still need to be addressed in order to understand the impacts that may arise. Marking (acoustic tags, for example) could be considered in future field studies to examine the effect of EMF on migration. Indeed, few laboratory experiments have been conducted in this area. It is also important to consider the impacts that EMF may have on different life stages of fish because the young tend to be more vulnerable, especially because they migrate to the coast to feed.

The use of tidal currents by marine vertebrates requires further research to understand and predict the risk of collisions. New multidisciplinary research should be undertaken to develop models that can predict the flight of animals in response to the pressure field around the moving parts of machines (Moura *et al.*, 2010).
Monitoring of animal interactions with turbines is very difficult. Marking and monitoring with ultrasound is a possibility, as is the use of ecological models to estimate the effects (at individual and population levels) (Moura *et al*., 2010).

The development of sedimentary hydrodynamic models should also be continued (Polagye *et al*., 2011).

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Polagye B., Van Cleve B., Copping A., Kirkendall K., 2011. Environmental Effects of Tidal Energy Development (Proceedings of a Scientific Workshop March 22-25, 2010 No. NOAA Technical Memorandum NMFS F/SPO-116). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Simas T., Moura A., Batty R., Wilson B., Thompson D., Lonergan M., Norris J., 2010. Uncertainties and road map (No. Deliverable D6.3.2). Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact (EQUIMAR), 22pp.

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9. Marine Mammals

Waters under French jurisdiction provide habitats for about 50% of the global biodiversity of marine mammals. In France, twenty mammal species can regularly be found on the Channel, Atlantic and Mediterranean coasts. In the channel, there is a high density of harbour porpoises. Although this species disappeared from French coasts in the 1960s following overexploitation, its numbers are now increasing on Channel and Atlantic coasts. Channel coasts are also home to grey and common seals: the southernmost populations of these species. The grey seal colonies inhabit the Molène Archipelago, Jentilez and the bays of Somme, Canche and Authie. As for the common seal, the colonies are found in the bays of Mont Saint Michel, Veys and Somme. The western channel is also home to the largest resident population of common bottlenose dolphins in Europe, distributed from west of Cotentin and in the Norman-Breton gulf. The largest species diversity has been recorded on the Atlantic coast, where common dolphins, harbour porpoises, common bottlenose dolphins, long finned pilot whales, striped dolphins and minke whales are permanently resident on the continental plateau and slope. Many deep diving species such as sperm whales or beaked whales are also present in the south of the Bay of Biscay. There are also resident common bottlenose dolphins on the Atlantic coast, around the Molène archipelago In the Mediterranean there are several mammal populations, including striped dolphins, common bottlenose dolphins, harbour porpoises, minke whales or Cuvier's beaked whale, although their degree of isolation is not yet known. There are also sedentary common bottlenose dolphins around Corsica (Martinez *et al.*, 2011). In France, like in the rest of Europe, marine mammals have a specific protected status. Cetaceans and pinnipeds are the object of numerous international regulations and protection texts, such as the Washington convention (CITES), Berne convention, Convention on migratory species (CMS), OSPAR… They are also directly concerned by international agreements such as ASCOBANS, ACCOBAMS or the International Whaling Commission. On the European scale, the Habitats Directive (Natura 2000) mentions many species of marine mammals in Annexes IV (species protection) and II (protection of species and their habitats). The Marine Strategy Framework Directive (MSFD) also takes a close interest in marine mammals and the activities of man that threaten them, notably noise. The objectives of European directives are also echoed by national regulations, notably regulation 812/2004 that aims to reduce the accidental capture of marine mammals in fishing equipment. Finally, the marine mammals protection act of 1st July 2011 sets out a list of all the marine mammals present in French waters and reaffirms their protection, including when this concerns intentional disturbance or damage to their habitats.
Overall, marine mammals are largely present in French waters, and are therefore a key issue in the installation of marine energy equipment.

In France and the rest of Europe, marine mammals are subject to regular monitoring by scientists, and many data have been collected regarding their distribution. Although these data are insufficient to establish the initial state of an area, they nevertheless provide a wealth of information on the importance of the area for marine mammals.
Strandings have been monitored on French coasts for almost 40 years by the Réseau National d'Echouages (National Stranding Network), coordinated by Observatoire PELAGIS, providing one of the most important time series in Europe. Census campaigns have also been conducted at the European (SCANS I in 1994, SCANS II in 2005) and national level (SAMM in France, REMMOA overseas).

During the construction phase of a tidal stream park, the nuisances generated can be compared to those generated during the building of an offshore wind farm, depending on the technologies employed, leading to increased noise levels during the installation of the machines and burying of cables (Wright *et al.*, 2009). During operation, the stakes are potentially higher with tidal turbines since they can represent a risk of collision, especially for marine mammals (Carter, 2007).

9.1. Description of the initial state

The first step is to establish a baseline consisting of the initial state of the area, which means making a preliminary study to know how marine mammals frequent and use the site (sedentarity, seasonality, etc.) before the machines are installed.

Knowing the initial state allows a baseline of marine mammal frequentation to be established for the area, in terms of diversity, abundance and spatio-temporal distribution. This step is very important and essential to a project; both because it makes it possible to establish a T0 and because it requires a level of detail that should make it possible to detect any changes that occur during subsequent impact monitoring. In addition, the completion of this step and data acquired make it possible to consider expected potential impacts, the way they will they manifest themselves, and, particularly, the methods that can be used to measure them.

9.1.1. Definition of the area potentially affected

Assessment of the initial state requires a suitable area to be chosen. Marine mammals are highly mobile species that cover dozens of kilometres per day. It is therefore necessary to define a scale that is not only significant in terms of population, but also consistent with the potential impacts and the size of the future park.

One proposed solution to define the area of study is to base this on two complementary areas:

- ✓ The noise footprint of the project.
- ✓ An area of ecological interest where individuals are likely to interact with machines (directly or indirectly).

9.1.2. Identification of relevant indicators

To assess the initial status of marine mammals in a given area, information is needed about the following indicators as a minimum.

- ✓ Species diversity: species present or potentially present in the study site.
- ✓ Distribution: What are the most highly frequented areas? What species are present in these areas?
- ✓ Frequentation and use of the site: Are the species present throughout the year? Are they resident on the site or temporary visitors? What is the seasonality of their presence? What is the importance of the site compared with the surrounding areas? Do the animals use the area for any special purpose (feeding, breeding or nursery)?

9.1.3. Characterization of the natural variability of the installation site

Ecosystems are naturally subject to variations in environmental parameters that can generate variability (seasonal, annual, etc.) and should therefore be considered during monitoring. For marine mammals, it is recommended to study their attendance over at least one life cycle or two in order to reduce the bias of interannual variation (MacLeod *et al.*, 2010). This represents one or two years of monitoring for the characterization of the initial state.

9.1.4. Possible methods for collecting information

Before launching a dedicated monitoring program over several years, an inventory should be made of existing knowledge on the area. Information on marine mammals can be obtained from scientific publications or reports on the area before the monitoring is started. In addition, population monitoring programs may already exist. Although protocols or parameters recorded will perhaps not be suitable for regulatory studies, these data can be used to obtain valuable information (long time series, multiple monitoring, specific. knowledge, etc.).

In French waters, some data already exist, following the various campaigns that have been conducted (SCANS, CODA, REMMOA, PACOMM, etc.). These campaigns, conducted on a large scale and in a timely manner cannot provide an assessment of the initial state, but can be a source of contextual information. Strandings identified by the National Stranding Network over nearly 40 years may, however, provide insight into long-term trends, areas and origins of death. Other sources may exist (local programmes, and other opportunities for making observations, use of platforms, etc.) organised by laboratories or associations.

The ensemble of these data should improve knowledge of the area and its issues, making it possible to develop appropriate programmes.

On the other hand, the use of acoustic observation techniques (where marine mammals are observed via the sounds they make) can usefully complement visual measurements when it comes to characterizing a given area over the long-term at a reasonable cost, independently of the weather, and night/day differences (Gervaise *et al.*, 2012). These passive acoustic measures should be complemented by a statistical evaluation (Fig. 50 and 51)

- ✓ Of the range[25] of hydrophones over time, which is largely dependent on meteorological and oceanographic conditions, bathymetry, bottom type, existing ambient noise, and the biological species to be detected and identified.
- ✓ Performance of detection and false alarm of detection/classification algorithms, largely dependent on the algorithms, oceanographic and meteorological conditions, bathymetry, bottom type, existing ambient noise and noise of the biological species to be detected and identified.

For a tidal project, acoustic monitoring can be pooled with acoustic measurements made to describe the ambient noise in areas of interest.

[25] The range of a hydrophone is the volume of surrounding water in which a particular noise can be identified in the ambient sound chorus.

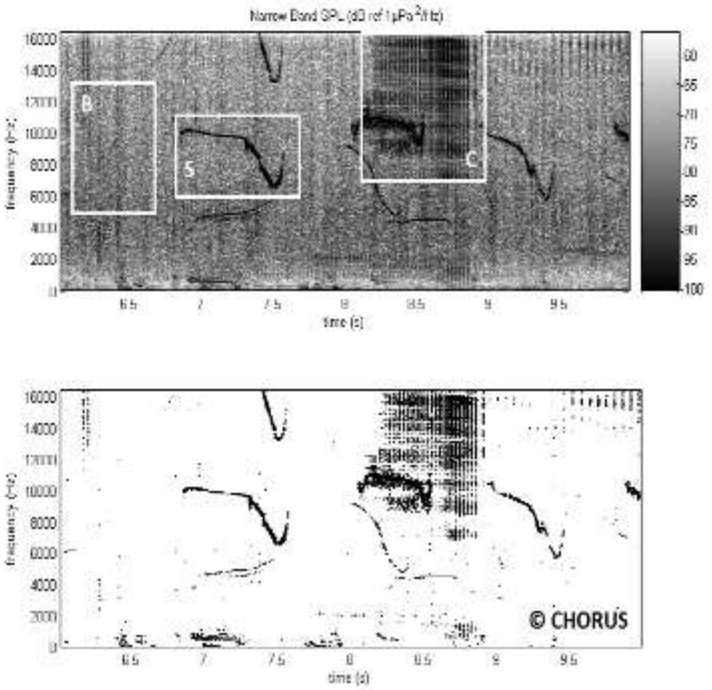

Figure 50 Example of the results of the application of processing tools on a short time segment (4 seconds).

Top: Spectrogram of raw data (mapping of sound energy received as a function of time and frequency), the spectrogram has background noise (Box B) to which are added the whistles of bottlenose dolphins (Box S) and echolocation clicks (Box C). Bottom: Result of low detection algorithms, black pixels correspond to automatic detection, which take into account the signals emitted by dolphins, source CHORUS.

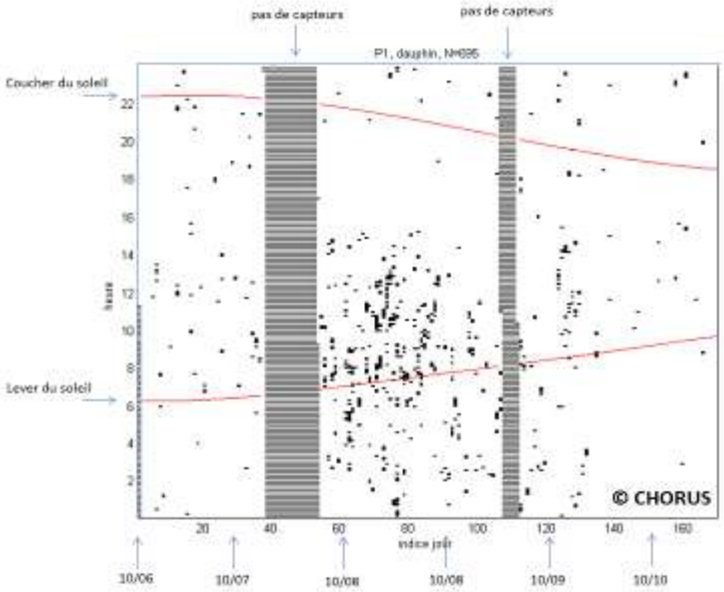

Figure 51 An example of analyses made possible by passive acoustics and used to study the population of bottlenose dolphins in the Molène archipelago.

Day (x-axis) and time (y-axis) acoustic dolphin detections, each black pixel represents 10 minutes of dolphin sound activity coverage. On examination, these detections demonstrate a significantly richer sound activity in August and September than in other months and show that sound activity mainly occurs between sunrise and noon. Source: Chorus.

9.2. Methods for identifying and analysing potential ecological changes

Marine mammals appear to be key species for close monitoring during marine energy projects. Particularly sensitive to noise nuisance, they can be strongly affected by such equipment, especially during the construction phase (Madsen *et al*., 2006).

9.2.1. The control area

Most impact studies for EMR are based on a BACI protocol (Before After Control Impact) (Green, 1979). This type of protocol requires that two sites be monitored in parallel: the site affected by the tidal stream equipment and a control site, irrespective of what tracking technique is used. The two sites must be comparable from all points of view to enable the detection of any change (species, abundance, etc.) relative to the installation of the turbines.
The choice of a control site is often practically difficult. The BACI protocol is easily used in the context of zones and impacts with clearly identifiable boundaries; most often this is not the case in tidal stream projects.

Another type of design that can be used is gradient sampling. This consists of monitoring the impact of disturbances on one site depending on the distance from the source (Ellis and Schneider, 1997). The approach is particularly suitable for passive acoustic monitoring, making it possible to estimate the different reactions of marine mammals depending on the distance from the noise source. However, it is poorly applicable in the case of parks only a short distance apart. Indeed, the cumulative impacts of individual projects make it impossible to estimate the impact of each one.
None of these design types is ideal. The characteristics of the area and the proximity of other projects mean that one protocol will be favoured over another.

One solution could be to combine these two types of monitoring. Another could be to perform monitoring at the scale of the ensemble of all the projects rather than site by site. Given the number of EMR and near some areas approached projects, it is difficult to conduct an isolated environmental study, without taking into account the effects of neighbouring sites.

9.2.2. Collisions/entanglements

One of the major risks involves collisions with the blades of the turbines, and to a lesser extent entanglement in the anchor lines (Carter, 2007). The risk is increased by the fact that turbines are often located in narrow and rough areas, exposed to the tides, which are also potentially feeding areas for marine mammals (Inger *et al*., 2009; Brown and Simmonds, 2010).
It is likely that in most areas the turbines are detected acoustically by marine mammals before they are seen (Wilson *et al*., 2007). Distances of detection and avoidance response with regard to the machines depend on environmental conditions (turbidity, visibility, noise, etc.). If the ambient noise levels are high and exceed the capacity of marine mammals to distinguish the sound of the turbines in operation from the other noise, it is possible that they will be unable either to detect the machines or to avoid collision (Carter, 2007). Various parameters, such as the size of an animal, its behaviour, activity, age, the presence of conspecifics, will contribute to its reaction to an obstacle (Wilson *et al.*, 2007).
During installation and maintenance, collisions with ships should also be considered. Collisions with ships are one of the most common causes of death, especially for large cetaceans (Evans *et al*., 2011).

9.2.3. Habitat modification

9.2.3.1. Resuspended sediments / pollutants

The installation of a tidal park will forcibly modify existing habitats. Resuspension of sediments during the installation of machinery and burying of cables will cause a temporary local increase in turbidity in the area. Moreover, this resuspension could, in some cases also release chemical, mineral or organic (organochlorine) pollutants depending on the nature of the sediments. Turbidity has little impact on marine mammals due to their preferential use of echolocation, especially in coastal areas. However, it may impact benthic and pelagic organisms, thus impacting other members of the food web through "bottom-up" effect (Whilhelmson *et al*., 2009).

For pollutants, it is even more difficult to describe the impact. Not only does the area concerned by their dispersion depend heavily on topographic conditions and aspects of current and tide, but the determination of their effects on marine mammals is difficult (Hall *et al*., 2006).

9.2.3.2. Impacts on the food web / reef effect

The installation of a tidal stream project will change the habitat and may change the ecosystem. It could mean a loss of habitat for some species, particularly those that occupy small territories (Dolman and Simmonds, 2010). It could also mean the disappearance of certain prey species from these areas, with repercussions throughout the food web (Gill, 2005)

Like any solid structure established in the environment, the tidal turbine could act as an "artificial reef" (Thomsen *et al*., 2006). The implanted structure can therefore become a new habitat for many species to colonize, especially if the substrate is soft (Vella *et al*., 2001). This settlement will lead to the reformation of a complex food web and act as "islands of biodiversity" potentially attracting predators including marine mammals. These islands can thus enable the development of new ecosystems, but they can also concentrate the biodiversity already present at the expense of surrounding areas (Grossman *et al*., 1997). This remains to be confirmed, however, as zones suitable for tidal projects are subject to specific current conditions that might hinder the development of such an ecosystem.

In the event that this reef effect develops, the tidal areas could then become feeding areas, notably for pinnipeds or cetaceans, as with wind farms are at sea (Scheidat *et al*., 2011). However, such an attraction would probably increase the likelihood of collision (Wilson *et al.*, 2007).

9.2.3.3. Physical barrier effect

The location of turbines is usually coastal, narrow and subject to strong tides. The proximity and orientation of the machines are important parameters because, depending on the characteristics of the area, the turbines can form a "barrier" for marine mammals. If the area is a migratory corridor, the turbines can block the passage of marine mammals (Wilson *et al*., 2007).

9.2.4. Habitat modification related to noise

9.2.4.1. Scientific context

Over the past ten years, a number of scientific institutions, government agencies and intergovernmental bodies have studied the effects of sound on marine mammals, leading to a number of review articles (Richardson *et al*., 1995; Würsig and Richardson, 2002; Popper and McCauley, 2004; Hastings and Popper, 2005; Hildebrand, 2005; National Research Council, 2003 and 2005; Wahlberg and Westerberg, 2005; Thomsen *et al*., 2006; Madsen *et al*., 2006; Southall *et al*., 2007; Nowacek *et al*., 2007). These studies also recorded the presence/absence of physiological effects and behavioural reactions of marine mammals, fishes and some invertebrates to a diversity of acoustic signals. Impacts on individuals correspond to physiological changes in the auditory apparatus (Temporary Threshold Shift (TTS), Permanent Threshold Shift (PTS)) or behavioural changes (acoustic masking, attention alteration, increases in stress hormones, changes in activity, flight), which, whether chronic or acute can eventually lead to population effects A synthesis of the different studies carried out by bio-acoustics researchers (Southall *et al.*, 2007) provides a basis for assessing the impact according to a 'Dose-Response' relationship.

9.2.4.2. Individual biological hazards and risks to populations

The evaluation of the impact of human activity on marine life can be done on a continuum of levels ranging from individuals to populations. The lack of knowledge and level of studies necessary at the population level is a knowledge gap recognized by the international scientific community. The work presented in this guide addresses three levels of impact on the individual:

- ✓ Permanent hearing loss.
- ✓ Temporary hearing loss.
- ✓ Behavioural disturbances that can lead to indirect effects.

In general, potential impacts can potentially occur at an individual and population level, with different effects:

- ✓ At the individual level, the scale of impacts covers one side of the spectrum, behaviour modification and ability to communicate, hunt or reproduce, and on the other end of the spectrum, the partial or total destruction of the physiological capacity to hear can lead to death in the most extreme cases.
- ✓ At the population level, the scale of impacts covers decline in the birth rate, increased infant mortality, or abandonment of the site.

9.2.4.3. Assessing the risk that thresholds will be exceeded

With present knowledge, it is only possible to estimate the impact on individuals from a statistical evaluation of the noise footprint of the project actually perceived by the species. Indeed, only the thresholds for individual tolerance and physiological damage are known, recognized by the international scientific community, and now quantified (Southall *et al.*, 2007).

The zones affected by the noise footprint of the project are thus converted in terms of sound exposure level. Audible noise exposure corresponds specifically to the noise perceived by each species during a given period. Risk areas are then identified based on the thresholds defined by Southall *et al.* (2007) (Table 30), and from the viewpoint of decision support:

- ✓ An area of low impact probability, because it is located outside the statistical footprint of the project. Any animal in this area should not "perceive" the noise induced by the project. If this be the case, "perception" should be weak and very limited in time.
- ✓ An area where there is low probability of direct physiological damage because the area, although within the noise footprint of the project (the animal can perceive some noise from the project) is below all known disturbance thresholds.
- ✓ An area of potential behavioural responses; to date, the tolerance thresholds are only known for high frequency species.
- ✓ An area where there is a high probability of temporary direct physiological damage of the auditory organs.
- ✓ An area where there is a high probability of permanent direct physiological damage of the auditory apparatus.

These assessments are made by statistical mapping from the prediction of the statistical distribution of noise levels on the one hand and information on potential frequentation by marine mammals on the other.

Table 3. Proposed injury criteria for individual marine mammals exposed to "discrete" noise events (either single or multiple exposures within a 24-h period; see Chapter 2)

Marine mammal group	Sound type: Single pulses	Multiple pulses	Nonpulses
Low-frequency cetaceans	Cell 1	Cell 2	Cell 3
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa^2-s (M_{lf})	198 dB re: 1 µPa^2-s (M_{lf})	215 dB re: 1 µPa^2-s (M_{lf})
Mid-frequency cetaceans	Cell 4	Cell 5	Cell 6
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa^2-s (M_{mf})	198 dB re: 1 µPa^2-s (M_{mf})	215 dB re: 1 µPa^2-s (M_{mf})
High-frequency cetaceans	Cell 7	Cell 8	Cell 9
Sound pressure level	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)	230 dB re: 1 µPa (peak) (flat)
Sound exposure level	198 dB re: 1 µPa^2-s (M_{hf})	198 dB re: 1 µPa^2-s (M_{hf})	215 dB re: 1 µPa^2-s (M_{hf})
Pinnipeds (in water)	Cell 10	Cell 11	Cell 12
Sound pressure level	218 dB re: 1 µPa (peak) (flat)	218 dB re: 1 µPa (peak) (flat)	218 dB re: 1 µPa (peak) (flat)
Sound exposure level	186 dB re: 1 µPa^2-s (M_{pw})	186 dB re: 1 µPa^2-s (M_{pw})	203 dB re: 1 µPa^2-s (M_{pw})
Pinnipeds (in air)	Cell 13	Cell 14	Cell 15
Sound pressure level	149 dB re: 20 µPa (peak) (flat)	149 dB re: 20 µPa (peak) (flat)	149 dB re: 20 µPa (peak) (flat)
Sound exposure level	144 dB re: (20 µPa)^2-s (M_{pa})	144 dB re: (20 µPa)^2-s (M_{pa})	144.5 dB re: (20 µPa)^2-s (M_{pa})

Table 5. Proposed behavioral response criteria for individual marine mammals exposed to various sound types; specific threshold levels are proposed for single pulses. See the referenced text sections and tables for severity scale analyses of behavioral responses to multiple pulses and nonpulses.

Marine mammal group	Sound type: Single pulses	Multiple pulses	Nonpulses
Low-frequency cetaceans	Cell 1	Cell 2[1]	Cell 3[6]
Sound pressure level	224 dB re: 1 µPa (peak) (flat)	Tables 6 & 7	Tables 14 & 15
Sound exposure level	183 dB re: 1 µPa^2-s (M_{lf})	Not applicable	Not applicable
Mid-frequency cetaceans	Cell 4	Cell 5[2]	Cell 6[7]
Sound pressure level	224 dB re: 1 µPa (peak) (flat)	Tables 8 & 9	Tables 16 & 17
Sound exposure level	183 dB re: 1 µPa^2-s (M_{mf})	Not applicable	Not applicable
High-frequency cetaceans	Cell 7	Cell 8[3]	Cell 9[8]
Sound pressure level	224 dB re: 1 µPa (peak) (flat)	[Tables 18 & 19]	Tables 18 & 19
Sound exposure level	183 dB re: 1 µPa^2-s (M_{hf})	Not applicable	Not applicable
Pinnipeds (in water)	Cell 10	Cell 11[4]	Cell 12[9]
Sound pressure level	212 dB re: 1 µPa (peak) (flat)	Tables 10 & 11	Tables 20 & 21
Sound exposure level	171 dB re: 1 µPa^2-s (M_{pw})	Not applicable	Not applicable
Pinnipeds (in air)	Cell 13	Cell 14[5]	Cell 15[10]
Sound pressure level	109 dB re: 20 µPa (peak) (flat)	Tables 12 & 13	Tables 22 & 23
Sound exposure level	100 dB re: (20 µPa)^2-s (M_{pa})	Not applicable	Not applicable

Table 30 Tables from Southall et al. (2007) giving thresholds and perceived levels of noise exposure for changes in the physiology of the auditory system (TTS) and behaviour.

9.2.4.4. Sound barrier effect

Increasing the noise at the entrance to a bay or a passage may generate a sound barrier effect. Indeed, when the effect of sound repulsion is high species may seek to get away from the noise zone (Fig. 52).

This may require special attention when the sound increase is located in specific areas of passage (between two islands at the entrance to a bay, etc.) or in places with a specific ecological role (e.g., migration transit zone) (Fig. 53).

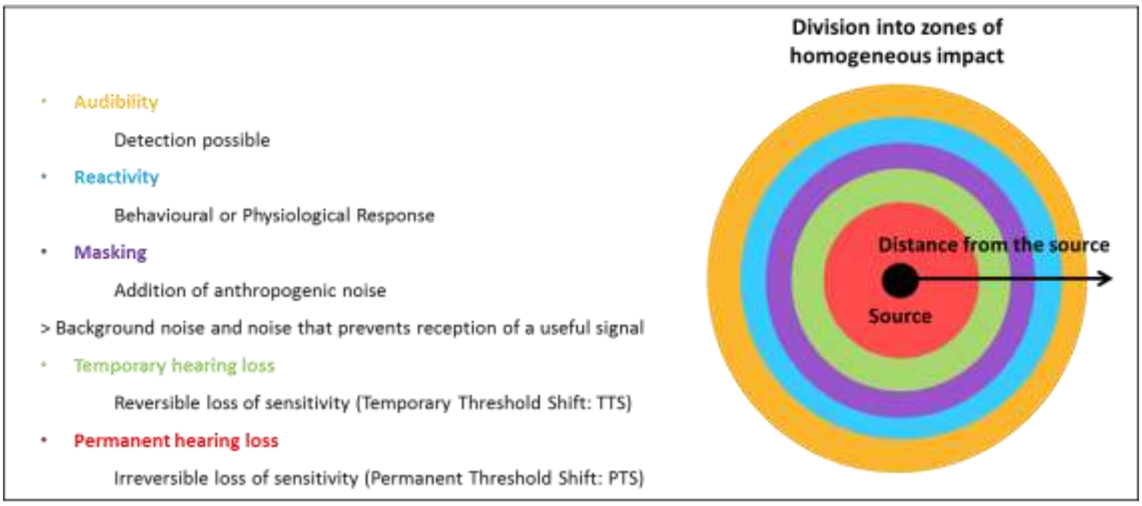

Figure 52 Partitioning the vicinity of a sound source into a homogeneous impact area in terms of its SEL or SPL; based on Richardson et al., (1995).

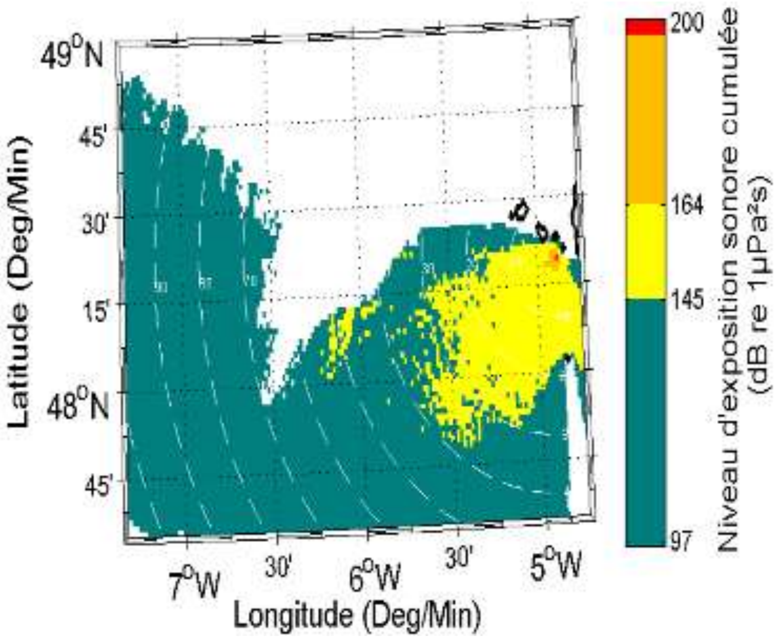

Figure 53 Example of a risk map of a construction operation with regard to a class of marine mammals (source Quiet-Oceans (Folegot and Clorennec, 2013)): in white, the area where the noise from the project is masked by other existing anthropogenic noise; in green, the emergence zone of project noise with a low risk impact; in yellow: the area where there is a probability of behaviour change; in orange: the area with a probability of temporary physiological damage; in red: the area with a probability of permanent physiological damage.

9.2.4.5. Knowledge gaps and methodological limitations on the assessment of noise impacts.

The evaluation of the impact of human activity on marine life can be made on a continuum of levels (National Research Council, 2005): from the individual to the population. This study clearly indicated the lack of knowledge and the extent of work needed at the population level. Given the difficulty of fitting live animals with equipment in the field, knowledge of the hearing of marine mammals and the impact of noise on this hearing was mostly acquired on a small number of individuals and species observed in pools (bottlenose dolphins, porpoises, beluga whales and orca) or potentially accessible from the coast species (seals). To date, the audiogram or hearing sensitivity to certain frequencies has only been measured in 32 species of marine mammals (Simard and Leblanc, 2010).

With current knowledge, studies can therefore only address the level of impact on the individual in three ways: permanent hearing loss, temporary hearing loss and behavioural disturbances (Southall *et al.*, 2007). Consequently, the field protocols proposed for individual assessment, based on the three levels of measurement, must incorporate measurement points for the collection of information useful for characterizing the impacts on populations.

According to the techniques used, noise may be spread over periods of up to several days. The methods for measuring the hearing capabilities of live animals limit the tests made such that the impact for long duration has never, to our knowledge, been evaluated. Recent experiments have recognized the need to look at noise duration and have focused on noise exposures ranging between 1 minute and 240 minutes (Popov *et al.*, 2011; Kastelien *et al.*, 2012.); but do not reach the durations associated with turbine installation work.

To compensate for these areas of uncertainly it is possible to interpolate following conventions of the scientific community. Generally, acoustic impact on marine mammals is a topic of great interest to the scientific community and is the subject of a large and diverse scientific output. The inclusion of a bibliographic update for marine mammal species in the study area is therefore recommended in impact studies.

9.2.5. Other impacts

9.2.5.1. Electromagnetic impacts

Some studies suggest that electric fields may have effects on the navigation of marine mammals (Dolman and Simmonds, 2010), but no proof yet exists of these impacts. The effects of electric fields are difficult to assess, as is the use of the Earth's magnetic field by cetaceans while travelling (Gould, 2008). Some mass strandings of cetaceans have however been associated with areas where the Earth's magnetic field is diminished (Walker, 2002). Specific research is needed in these areas.

9.2.5.2. Accidental pollution

Construction sites at sea can induce localized pollution of several kinds. This pollution can be caused by the construction phase, which brings about resuspension of sediments or pollutants (see section 2.2.3). This mainly concerns persistent organic pollutants (POPs) such as organochlorines (DDT, PCB, etc.). The impact on marine mammals is difficult to assess, and depends particularly on the concentrations that are resuspended.

The other main type of pollution concerns the discharge of harmful substances into the environment, in particular from ships (e.g., oil, fuel, etc.). Although protocols and standards ensure compliance with regulations, accidents are always possible. However, such localized pollution is too general a topic to be covered here.

The use of antifouling biocides can also lead to the release of chemical contaminants into the environment, as can oil or other products used for the maintenance of turbines.

9.2.5.3. Knowledge gaps and methodological limitations

Much is still unknown about these potential impacts. The impact of electromagnetic fields and pollutants on marine mammals are subjects of research in which little is yet known with certitude. The difficulty of studying these animals, coupled with the difficulty of identifying this type of impact on an individual, especially in order to extrapolate it to the population level, can partly explain the lack of knowledge in these areas.

9.3. Identification of cumulative impacts

The study of the impacts of tidal stream projects must take into account the cumulative effects with other human activities, namely:

- ✓ Cumulative impacts due to the spatial and temporal scale of the project.
- ✓ Cumulative impacts due to interactions with other anthropogenic pressures.

9.3.1. Cumulative impacts due to the spatial and temporal scale of the project

MRE projects are increasing in Europe, particularly in France. Whether they are based on tidal, wind or wave energy, these projects are numerous and cannot be implemented without some environmental impact. However, these impacts can occur over large distances (tens of kilometres during construction), sometimes over distances larger than those between two projects. Impacts could be magnified in this way or cumulative.
Cumulative impacts can occur if projects are spatially or temporally close together. If the construction phases are simultaneous it is possible that the cumulative impacts may be greater than the impacts of a single project. However, cumulative effects also occur over the long term (IWC, 2005). Indeed, repeated exposure of marine mammals to nuisance from nearby shipyards, even if these do not occur simultaneously, can have impacts, including a state of chronic stress (Wright *et al.*, 2007).
Different spatial and temporal scales should therefore be considered in the impact assessment. The assessment of long-term impacts of a tidal energy park on marine mammals needs an adapted monitoring program to address these issues.

9.3.2. Cumulative impacts due to interactions with other anthropogenic pressures

New pressures generated by marine energy, combine with existing anthropogenic pressures in the environment.
With the noise already generated by human activities (maritime traffic, construction and development work, aggregate extraction, etc.), collisions with ships or accidental capture in fishing gears, there are many pressures already weighing on marine mammals in France (Martinez *et al.*, 2011). It is essential to take these pressures into account in impact assessment, since the impacts generated by the tidal stream projects or EMR in general will be added to the existing ones. An evaluation of the overall impacts is therefore essential.

9.4. Description of an environmental monitoring program

9.4.1. Factors to be considered

Each park is unique: they may differ considerably in the technology used, the number of turbines, and type of foundation, type of substrate and water depth from one site to another. According to the foundations used, different construction operations will be needed, which thereby produce different types of noise at different emission levels that cause different levels of nuisance. All these factors affect the environmental impacts and underline the need for a case-by-case approach. Despite the feedback from existing projects or studies conducted abroad, it is impossible to generalize about the type of monitoring studies that need to be done (Wilson *et al.*, 2007). The species present can also vary. It is impossible to define standard protocols suitable for any tidal device in any area. Work must be done to customise the approach needed to each particular project.
To define a monitoring program it is essential to know its objectives. What are the questions that

need to be answered? What are the regulatory requirements and what are the wishes of the project developer? Depending on which questions are asked, the data to be collected, techniques to be used and resources required will be different.

Challenges presented by the project installation area also need to be considered.

An area of high ecological importance or one frequented by certain species will require rigorous and thorough monitoring of the issues identified in the impact assessment.

The cost of monitoring is largely dependent on the method used. The choice of technique is therefore based on its effectiveness and the results it provides, but also on its cost. The ideal is then to optimize the ratio between the cost of a technique and the results it produces. Most often, it seems appropriate to use several techniques to reduce bias. In this case, the methods that are the best for cetaceans will not be the same as for pinnipeds and vice versa. It is therefore necessary to combine the techniques that seem most appropriate for the situation.

9.4.2. General recommendations

9.4.2.1. Scales and objectives

One of the major challenges in monitoring marine mammals is to do this at a scale that with both spatial and temporal relevance. The definition of the surface of the area depends on the purposes of monitoring. Depending on whether we want to make an inventory of marine mammals in the area, assess their mode of use of the area, understand their seasonality or assess the impact of the implementation of a tidal park, the areas that need to be considered may differ. Overall, it is therefore necessary to clearly define the objectives of monitoring before the definition of the study area.

On the time scale, like for any living organism, monitoring should follow marine mammals over at least one biological cycle, i.e., a year.

9.4.2.2. Sharing resources

Before considering the installation of a commercial-scale tidal park, a project will go through demonstration and pilot park stages.

The budget for environmental studies differs in magnitude between these two types of parks. However, few sites are suitable for installation of tidal stream parks. Therefore it may be wise to pool the monitoring of several research projects to optimize these studies. Indeed, instead of each developer financing only a small study or one restricted in monitoring scope, pooling resources could allow one larger study to be made on a relevant scale, with the most appropriate techniques, for an overall lower cost. Indeed, by performing a single large monitoring scheme instead of several on small areas, the opportunity to pool effort, personnel and equipment reduces costs. This would imply a harmonization of protocols, targets and sampling (frequency, seasonality, design, etc.). Furthermore, apart from making the organization of monitoring easier, pooling may also be applied to data storage and analysis, in order to optimize costs. This will also provide an understanding of the phenomena that can be observed at a scale appropriate to the areas used by marine mammals, and take into account cumulative effects.

Furthermore, pooling is also possible between different compartments monitored on the same site, and should be considered prior to the launch of the studies. Visual aspects of marine mammal and bird monitoring can be easily shared.

Deployment / recovery / maintenance of acoustic devices can be combined with other maritime work etc.

9.4.2.3. Cooperation and integration

Little feedback is yet available on tidal stream projects. The installation of such devices in France raises many questions, but also paves the way for lines of research on them.

The installation of a tidal park and environmental studies require the involvement of a number of stakeholders to ensure that the studies are both relevant and well conducted, that they meet regulatory requirements and that they address the need for knowledge in this area.

The issues raised by tidal stream and MRE parks are generally in line with national and community concerns about the conservation of marine mammals and their habitats. In the context of European Directives (Directive Habitats, Fauna, Flora, Framework Directive Strategy for the Marine Environment, etc.), the acquisition of knowledge on marine mammals is at the centre of discussions in the scientific community. Programs conducted for monitoring marine mammals in the tidal stream parks must be considered in this context, and follow standardized protocols comparable both with each other and with national programs.

Although the question of public dissemination and especially the form of the published data remains difficult, however, it seems relevant to recommend the creation of a national database of monitored marine mammals as part of the MRE framework. All the data acquired, at least for marine mammals, could be compiled in a national database, respecting confidentiality clauses, and made accessible according to predefined rules. Two major arguments support this proposal: first, it could allow comprehensive visibility and overall data analysis and impact across different projects in progress or planned. In addition, it would offer transparency about information collected, while ensuring the pooling of different data sources and therefore harmonization, due to the compatibility required.

The successful coordination of the different parts of the project for its smooth running, while ensuring the transparency of education and acceptance of users and the public is a real challenge.

In this sense, the collaboration between the companies in charge of developing projects, the scientific community, consultants and, of course, government institutions should be encouraged.

9.4.3. Implementation

9.4.3.1. Definition of the monitoring area

Monitoring of a population must be done on a consistent spatial scale appropriate to the species and biological questions. Groups working on international agreements on noise (Wilson *et al.*, 2007) recommend conducting monitoring studies based on management units or populations concerned, without limits posed by borders. For species such as marine mammals, this implies very large spatial scales. It is therefore likely that the area covered by a single developer doing an impact study would be too small to obtain meaningful data for a population impact study. The challenge is to find a compromise between an area large enough to be of interest and an extent of the study that is economically viable. This means being able to measure impact while keeping monitoring costs affordable to developers.

Pooling monitoring effort between projects that are close may be considered when possible, to optimize costs and increase the relevance of monitoring.

Another approach is to define the area as a function of the maximum extent of the expected impacts. Even if it is not significant at the population level, this monitoring may confirm or refute the local impact on marine mammals.

9.4.3.2. Monitoring by visual methods

A monitoring program can be summarised in three main objectives:

- ✓ Characterize the species, their distribution and abundance.
- ✓ Track the status of populations and the impacts of human activities.
- ✓ Define the spatio-temporal habitat use to identify important areas (feeding, reproduction, etc.).

Many techniques are generally used to monitor marine mammal populations. These depend on the species studied, the characteristics of the area, the nature and location of the project, available resources and expected results. Each of these techniques has advantages and limitations (Table 31) that should be possible to reduce by combining several methods.

This is not an exhaustive list of different methods of population monitoring, but gives the main methods and those used specifically in France and Europe. For visual observations, we can distinguish three broad categories: those using dedicated platforms (aircraft, vessels), those using platforms of opportunity (research vessels, ferries, etc.) and observations made from the coast.

The main advantage of using platforms dedicated to marine mammal observation is the control it allows over a sampling scheme designed to optimize estimates of absolute abundances (MacLeod *et al*., 2010). These monitoring plans are relatively expensive. Platforms of opportunity are sometimes used to reduce the cost of dedicated monitoring. The sampling plan is then no longer controlled and may not match the requirements for observation of marine mammals. It is nevertheless possible to calculate relative densities and encounter rates, if the effort is recorded.

Observations from the coast may be possible from a number of sites. Although inexpensive, this method is very limited in terms of the sampling and analyses possible.

9.4.3.3. Monitoring by passive acoustic methods

Acoustic monitoring has two objectives:

- ✓ Characterization of the anthropogenic sound pressure of the project.
- ✓ Assessment of the ecological use of the site by sensitive species.

Marine mammals are species that use sound to move, hunt, move or communicate. Using the sounds they produce to detect their presence may therefore be an appropriate method of monitoring. Unlike visual tracking, passive acoustics is not dependent on weather conditions, and can be used both day and night.

However, the use of this approach is restricted to certain species and limited the range of the [26]hydrophone measurement area. Furthermore, extrapolation of acoustic detections to abundances or densities is currently undergoing methodological research and development, one promising avenue is to calibrate the acoustic observations with visual observations (Simard *et al.*, 2010)

The use of hydrophones for environmental site assessment can potentially be limited by the following effects:

- ✓ Reduction of the detection performance of biological noise by the current.
- ✓ Evaluation is limited to times when mammals vocalize (e.g., a zone may be used by species, but they will not be detected if they do not emit sounds).

9.4.3.4. Monitoring by underwater imaging methods

Some acoustic cameras enable imaging of a space at a given rate, which may be of interest for the immediate area around structures, in particular for evaluating the interactions and responses of individuals with the turbine. These have the advantage of providing a picture even when visibility is impaired.

Acoustic cameras, which can be expensive, operate at very high frequencies to provide images with sufficient resolution (Fig. 54). As a result, the range of these cameras is often reduced to a few tens of metres at the best. The speed of sound is 1500 m/s, the frame rate is of the order of 2-20 frames per second and is dependent on the range..

[26] The range of a hydrophone is the volume of surrounding water in which a particular noise can be identified in the ambient sound chorus.

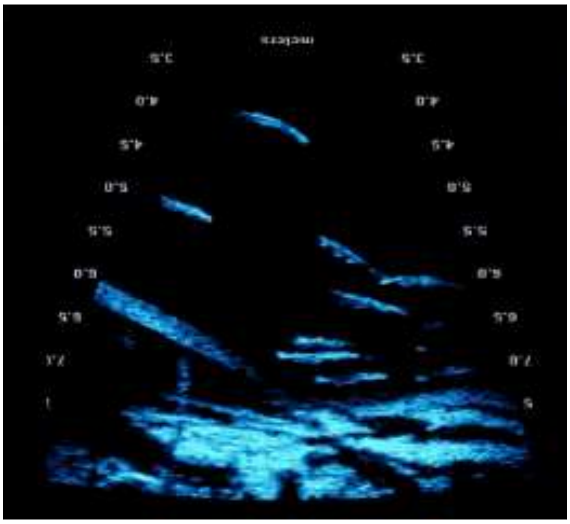

Figure 54 Example of an image of salmon from an acoustic camera (source: www.soundmetrics.com)

9.4.3.5. Other méthodes

Some monitoring methods are intended primarily for cetaceans (passive acoustic monitoring, visual monitoring at sea, etc.), others for pinnipeds (telemetry) (Table 31), although this is not exclusive and can be extended to monitoring seals on land. Telemetry can also be considered for cetaceans, although development is still needed. Furthermore, other techniques are being developed, in the same way as HD photography. Although at present these new technologies are still difficult to use, they have the potential to become useful tools in years to come. Stranding data have often been left out of monitoring strategies of marine mammals due to the lack of sampling strategy and significance of stranded individuals compared with populations at sea.

Nevertheless, strandings are the only source of biological material for these protected species and their low cost is an argument in favour of their use as a source of indicators. Recent work (Peltier, 2011) has improved the understanding of the stranding process and to qualitatively and quantitatively define the relationship between stranded cetaceans and populations at sea. This work is based on modelling trajectories at sea of stranded cetaceans using a drift model. It has thus become possible to find areas of mortality at sea of stranded cetaceans. These indicators should be combined with other data sources that make it possible to establish relevant monitoring strategies at the scale of marine mammal populations.

Monitoring methods (example; reference)	Variables estimated	Advantages	Limits
Visual observations on linear double platform transects (SCANS campaign, Hammond *et al.*, 2002).	Distribution, absolute abundance (individuals), density corrected within a predefined area	Standardized methods, bias reduction, large geographical influence, suitable for offshore cetaceans	High cost, limited frequency measurement, takes into account complex observation bias
Visual observations of oceanographic campaigns (campaign PELGAS; Certain *et al.*, 2008).	Distribution, relative density (individus.km^{-2}) in relation to field environmental parameters in a predetermined area	Limited costs, environmental covariates collected simultaneously, annual periodicity	Partial control of sampling, certain biases unquantified but assumed constant
Visual observations on platforms of opportunity (ferries, Kiszka *et al.*, 2007).	Encounter rate (observations.unit effort^{-1} or individuals.unit effort^{-1}) on a predefined line	Limited costs, monthly or weekly frequency	Limited control over sampling
Counts on specific sites (GIS-seals; Vincent *et al.*, 2010)	Number of animals present	Moderate costs, especially applicable on resting sites and seal colonies	Little control over bias, probably variable between sites, seasons and conditions
Focal studies on sites of interest (*Tursiops*; Liret *et al.*, 2006)	Use of space by focal groups (time spent.grid cell^{-1}, by category of activity)	Moderate cost, high spatial understanding	Limited to groups of small cetaceans resident on coasts and the conditions for visual observation
Photo-identification (Iroise Grey Seal; Gerondeau *et al.*, 2007).	Probability of the presence of marked individuals, allows estimation of abundance (individuals), demographic parameters or connectivity between sites	Moderate cost, suitable for small localized populations with a high proportion of individuals naturally recognizable	Unsuited for abundant and dispersed populations with a low proportion of naturally recognizable individuals
Observation programmes linked to pressures (OBSMAM, OBSMER; *Ministère de l'Agriculture et de la Pêche*, 2008)	Impact of human activity (e.g., number of accidental captures per unit of fishing effort)	Direct evaluation of impact by an estimate of the additional mortality	Mainly limited to the programs foreseen by regulation 812/2004; difficulties with sampling, extrapolation and liaison with the professions concerned
Opportunistic observations (cetaceans in the channel; Kiszka *et al.*, 2004)	Presence of a species without quantifiable observation effort	Very low cost, can reveal rare species	No extrapolation possible
Strandings (Strandings network; Van Canneyt *et al.*, 2010)	Spatio-temporal variations of compositions of stranded animals (in terms of species, gender, age, cause of death, health, biological condition, etc.)	Low cost, high spatial and temporal coverage, access to biological samples, reveals rare species	Interpretation of the origin and meaning of strandings is complex
Acoustic observation of common bottlenose dolphins PNMI (AcDau project) (Gervaise *et al.*, 2012)	Time series of acoustic activity, study of activity rhythms (circadian, circatidal), seasonal variation, interaction with a temporal series of motorized surface activity	Low-cost, continuous monitoring over 6 months, access to spatio-temporal variability	Technical complexity of analyses Calibration phase between visual observations and acoustic observations.
Passive acoustic observation **(SAMBAH project; http ://www.sambah.org)**	Detection rate during the period of deployment (detections.unit effort^{-1}) to estimate seasonal and spatial presence	Detectability independent of visibility, non-invasive method	Limited radius of detection, limited species identification (according tool used) and numbers of individuals, high cost for applications with a large geographic influence
Individual telemetry (Seals; Vincent *et al.*, 2005; Vincent *et al.*, 2010)	Longitudinal monitoring of locations and activities of equipped individuals to analyse ranges and patterns of space use and connectivity between sites	Fine spatial understanding, independent of sea conditions and visibility	Essentially limited to seals and whales, labelling methods often complex, difficulties making extrapolation to populations

Tableau 31 Selection of the main methods for monitoring marine mammal populations and associated key references

9.4.4. Knowledge gaps and methodological limitations

Each of these methods has advantages and disadvantages. The method or methods to be used should be based on the questions asked, the characteristics of the area and the species present, but also the magnitude of the project and budget. It is generally good to combine several methods to reduce the biases inherent in each.

9.5. Impact attenuation measurement

9.5.1. Reduction

This step is based on the information produced by the step of mapping biological risk statistics related to the project. When a risk of physiological damage is found, risk mitigation can be achieved in four main ways:

- ✓ Implement measures to reduce levels of individual noise sources; this consists in modifying, when possible, the working technique, or the procedure to reduce the transmission level at the source.
- ✓ Implement measures to reduce cumulative noise levels; it consists of adapting, wherever possible, the organization and planning of work on the project, particularly when multiple tasks are conducted simultaneously.
- ✓ Establish systems that reduce the propagation of noise in the ocean; this is to limit the propagation of noise in the environment, particularly in directions that present a real challenge; it is essential to assess the technical relevance of these solutions, which, in a context of strong currents site can be difficult and/or inefficient (Greanjean, 2012).
- ✓ Implement measures to temporarily remove the species from areas of risk; a gradual increase in the noise before the start of construction workshops in particular, can play the role of warning and allow species potentially present to temporarily move away.

The effects of the above measures should be modelled in order to quantify the likely effects of their implementation and assess the economic relevance of the reduction measure.

9.5.2. Choice of periods for construction work

A solution for reducing impacts may also include organising the work schedule around the periods when there are likely to be marine mammals. While the habitat use of marine mammals is difficult to understand, some areas are known as breeding or feeding grounds. During their seasonal presence in these areas, they are particularly vulnerable to pollution. Minimizing disturbances in these periods reduces the probability of impacts on these species.

9.6. Knowledge gaps and research programs

The advent of marine turbines is recent, and little feedback exists. Much knowledge is still lacking about the impact on marine mammals.

Firstly, fundamental knowledge on the distribution of marine mammals remains fragmented, particularly in terms of seasonal and interannual variability. Much information still needs to be gathered to identify the crucial areas and spatiotemporal assessment of the distribution of marine mammals.

The determining mechanisms underlying such distribution also remain poorly understood for marine mammals, especially cetaceans; including: feeding zones, migration patterns and areas of passage or of use as overall habitat.

If it is not the responsibility of project to finance such research needs, environmental monitoring carried out under site surveys could contribute.

Moreover, the installation of turbines is done in areas with strong currents and specific environmental conditions. The use of these areas by marine mammals is unknown, but this information will be needed to understand the potential threat that MRE projects pose to these species. Monitoring of the use of the area and the behaviour of marine mammals in these areas is to be encouraged.

On acoustic impacts, knowledge about hearing abilities of marine mammals is often insufficient to allow a detailed evaluation of the impacts on these species. It is essential to improve our understanding of the reactions of marine mammals to noise in their environment. Studies can be considered in various forms, but the pilot farms or demonstrators appear to be highly appropriate contexts in which to study these effects.

Improved tools and methodologies will be necessary for all these lines of research as existing methods do not meet all their needs (particularly for underwater visual and acoustic tracking).

Key references

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10. Birdlife

Human activities at sea, such as fishing, ship transportation, oil drilling and mining, offshore wind farms and tidal stream parks can impact seabirds, sometimes to a strong degree. This can lead to direct mortality or indirect effects e.g., changes in abundance or availability of food resources, disturbance of areas important for their annual biological cycle. In the context of recent technological developments to exploit marine renewable energies, the implementation of tidal stream farms is likely to lead to changes affecting the habitat of marine and coastal birds. Some of these changes are likely to cause more or less significant impacts on such bird populations, which need to be evaluated as well as is possible

10.1. Description of the initial state

The first phase of a project consists of measuring the initial environmental state, before the start of human activities related to the project. This initial baseline must make it possible characterize the bird populations that frequent the study area and their exploitation of the marine environment for different types of activities related to their biology. The area may indeed correspond to an area of regular or occasional feeding or extended stay, for example in a period of moulting or rearing young. This first appraisal should also make it possible to put the role of the pilot site into perspective within a wider environment so as to better understand the real issues related to this site.

10.1.1. Definition of the potentially impacted area and choice of a reference area

The choice of the location for the development of a proposed tidal farm depends primarily on characteristics of currents and geography of the seabed. In terms of the physical and biological oceanography, these particular areas are likely to have an important role for various marine organisms, including marine birds, which, as top level predators that can use them for feeding (Zamon, 2003; Schwemmer *et al.*, 2009). To assess the potential impacts of human activities related to tidal stream projects as accurately as possible, it is essential to know the spatial and temporal variations in the use birds make of marine space, their abundance over the whole the annual cycle, and the feeding ecology of the species present. Out of the areas potentially directly affected by the project, the reference area must at least consider the potential breeding colonies located at a few kilometres or tens of kilometres (distance varies according to ecology of species present), and the associated marine space. It is also important to conduct the necessary investigations at a larger scale in order to assess the real ecological role of the site for birds in the context of the functional ensemble of which it is a part. The definition of this ensemble will vary according to the location of the project site and depend on local and regional oceanographic conditions, as well as the presence of avian populations.

10.1.2. Description of the ecological context of the project implantation site (ecological functions for birds)

10.1.2.1. Marine and coastal species

Species that should be considered include seabirds, or related species, that depend strongly on the marine environment for a long or short period of their annual cycle, and species of the coastal foreshore. The tidal stream project can have an impact on the first group of species at sea during the installation, operation and decommissioning phases, and an impact on the second group of species on land, mainly during the installation and decommissioning phases in the cable landing area.

Seabirds frequenting French waters include a diversity of species: Procellariidae (fulmars, shearwaters) Hydrobatidae (storm petrels) Sulidae (gannets and boobies), Phalacrocoracidae (cormorants), Stercorariidae (skuas), Laridae (gulls) Sternidae (terns) and Alcidae (guillemots, razorbills and puffins) (Fig. 55). In addition to these species, typically identified as marine birds, we should add other species that regularly exploit the marine environment. These are Gaviidae (divers), Podicipedidae (grebes), and certain species of Anatidae (ducks: eiders, scoters and mergan-

sers) and Scolopacidae (sandpipers) (Comolet-Tirman *et al*., 2007).
While the marine environment is the main environment for some of these species, which only come ashore to reproduce (e.g., Procellariidae, Sulidae and Alcidae), other species frequent both marine and terrestrial environments on a daily basis (e.g., Laridae and Phalacrocoracidae).

Coastal species restricted to the foreshore are conventionally grouped under the name of waterbirds and notably include waders: Charadriidae (plovers) Haematopodidae (oystercatchers), Scolopacidae (godwits, snipes, sandpipers, ruddy turnstone), in addition to some Anatidae (shelducks and geese in particular, and other species of ducks).

Figure 55 Guillemots (left) and shags (right), two species of marine diving birds on the French coast (photos by Matthew Fortin, Bretagne Vivante)

10.1.2.2. Spatio-temporal approach

For the different species, it is necessary to distinguish frequentation of the study area during breeding and non-breeding periods. Some species do indeed come to the French marine waters during their inter-breeding season, during their migrations between wintering areas and breeding areas, or during wintering (Comolet-Tirman *et al*., 2007). The type of activities at sea during different periods of their annual cycle should also be distinguished, namely the use of marine space as feeding areas, resting areas, moulting areas or transit areas (migration routes or regular journeys for fishing). It should be added that the radius of foraging adults can vary during the breeding period between the egg incubation and chick-rearing phases. Similarly, the species that frequent the foreshore can use this space as a feeding area or as a rest area; some also use the upper intertidal zone for reproduction (e.g., plovers).

10.1.2.3. Feeding ecology of species present

Seabird species have different modes of feeding and can exploit the water column to different depths. Some species feed exclusively or predominantly on the surface, other in the subsurface one and others by diving to different depths, sometimes more than 50 m (Langton *et al.*, 2011; RPS, 2011a; Furness *et al*., 2012). In addition, some species feed more in the coastal zone, which is the potential geographic location of tidal technologies, while others feed offshore. It is therefore essential to establish a list of species present at different periods of the annual cycle, according to their feeding ecology, in order to better assess the potential effects of a tidal stream project in terms of its impact on birds.

10.1.3. Assessment of the natural variability of the project site

The marine environment is not a static environment, and bird frequentation of a particular area is closely linked to natural variations that can influence, for example, the abundance or availability of prey exploited. Seabirds are mobile species that exploit a changing environment. It is therefore important not to jump to conclusions based on data that is fragmented or collected at fixed points in time on the spatial distribution and abundance of seabirds across the study area. The evaluation of the initial state must necessarily be spread over at least a complete year, although this time step does not allow the detection of any potential interannual spatiotemporal variations.

10.1.4. Identification of relevant indicators

The initial state of the birds in the study area should provide specific information on the diversity of the species present, their abundance and distribution, the type of use they make of the marine habitat and their behaviour at sea and ashore over the entire annual cycle.
Then, based on these results and according to species-specific biological characteristics, e.g., their feeding ecology, behaviour with regard to maritime traffic, demographic characteristics or conservation status, it is possible to define a sensitivity scale (Wilson *et al.*, 2007; Furness *et al.*, 2012; McCluskie *et al.*, 2012; see section 10.2).

10.1.5. Possible methods of information acquisition: bibliography and data collection

First, a literature review of publications and books on marine and coastal birds, breeding or wintering makes it possible to draw up a list of species present or potentially present in the area affected by the proposed tidal park.
With regard to seabirds at sea, knowledge of French waters as a whole is still incomplete (e.g., Castège and Hemery, 2009), but new data have recently been collected in the PACOMM program (*programme d'acquisition de connaissances sur les oiseaux et mammifères marins*, presently published in the form of a campaign report; Pettex *et al.*, 2012a, 2012b). Nesting seabirds are the subject of national surveys made every decade (Cadiou *et al.*, 2004., new survey made in 2009-2012), but more regular censuses are made at departmental or regional scales for some species. As regards nesting seabirds, it is relatively easy to find adequate documentation to list colonies situated in a study area and find out their numbers. The timing of seabirds breeding on the French coast is also well known and documented (area used, nest building, egg laying, rearing of young, dispersal, etc.).
For species of waterfowl and shorebirds present in coastal areas on the French coast, winter counts are conducted annually in January (Deceuninck *et al.*, 2013; Mahéo and Le Drean-Quénec'hdu, 2013). These species are also the subject of national surveys during their breeding season (the most recent survey was made in 2010-2011, results as yet unpublished).
The acquisition of new data remains essential, mainly for birds at sea, to obtain a more detailed picture of the situation across tidal park project areas (Fox *et al.*, 2006). Data collection should be done according to standardized methodologies typically used for monitoring birds at sea and adapted when necessary to the scale of the study area (see section 10.4).

10.2. Methods of identification and analysis of potential environmental changes

Potential impacts on birds at sea are related both to the technical facilities installed (depth of machine installation, technical characteristics of submerged structures, presence or absence of emerged structures, etc.), and their maintenance procedures (frequency of vessel rotation, length of presence in the area, etc.) (Fig. 56, Table 32).
Potential impacts on land concern the risk of disturbance in the landing area, mainly during installation and decommissioning. McCluskie *et al.* (2012) made a very detailed synthesis of the potential impacts of marine renewable energies on birds, including direct (effect of the structures themselves), indirect (for example effects of an increase in turbidity on birds searching for food, which represents a modification of their habitat), negative (mortality due to collision with the structures) and positive (concentration of prey) impacts. Given that marine renewable energies involve recent technology, there have been almost no studies of their impact on seabirds (RPS,

2011a; Witt *et al*., 2012.). The potential impacts are therefore still hypothetical. Some of those identified are similar to the ones put forward for offshore wind farms or mining for marine sediments (Garthe and Hüppop, 2004; Petersen *et al*., 2006; Cook and Burton, 2010).
The main risks concern mortality by collision with submerged structures (turbines, cables or anchor chains), with vessels operating in the area or any emerged structures; behavioural changes related to disturbance and avoidance of the implantation zone and marine habitat, and changes that may impact the food resources available for birds (Fox *et al.*, 2006; McCluskie *et al.*, 2012). Resuspension of marine sediment is likely to reduce visibility for birds fishing by sight and to decrease primary productivity due to reduced light penetration; it can also cause a release of pollutants into the environment (McCluskie *et al.*, 2012).
Other pollution risks also exist (McCluskie *et al.*, 2012), including the risk of pollution by oil (vessels carrying out maintenance) or hydraulic fluids used for certain types of machines (Boehlert and Gill, 2010). This may expose seabirds to chronic pollution or, in the case of accidents, to acute pollution, which can have consequences for bird survival.

During installation, operation or decommissioning, the main potential risks to birds are the same, but the intensity of these pressures may vary depending on the phase considered. It is therefore important to take into account the spatial and temporal aspects of the different types of potential disturbance, as well as their duration, frequency and intensity (Boehlert and Gill, 2010).

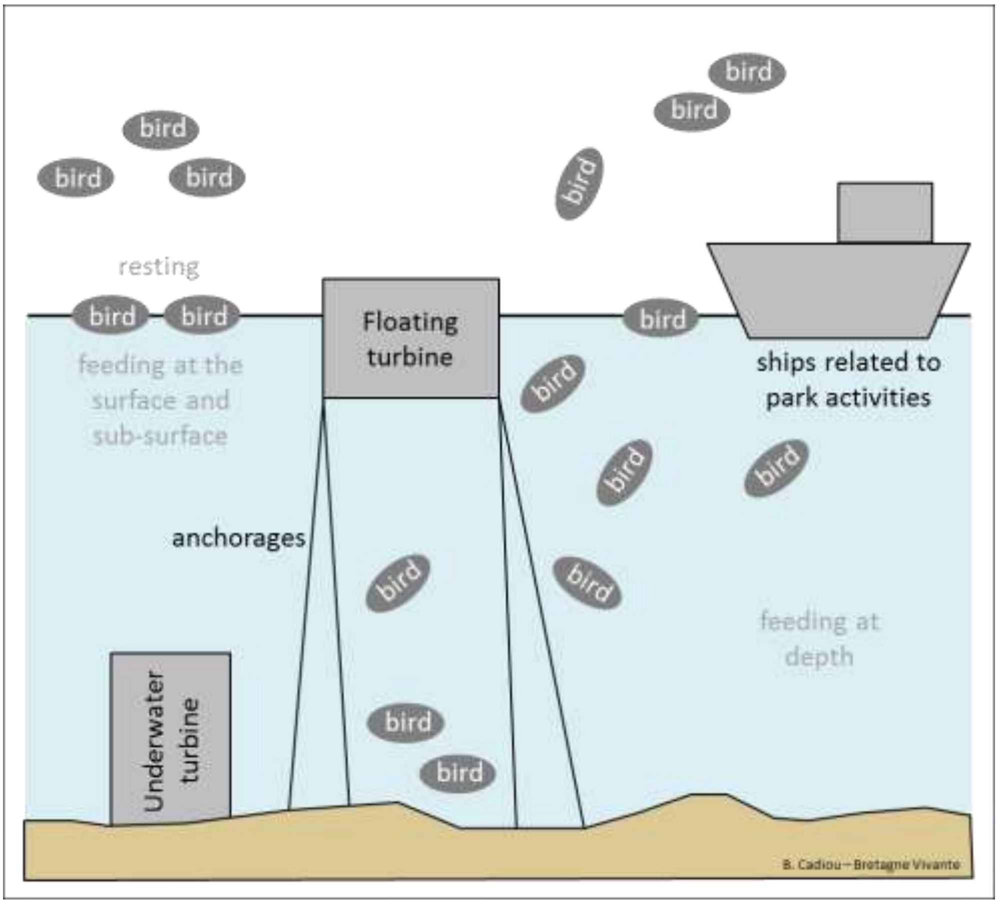

Figure 56 Simplified diagram of the interactions between a tidal stream park and marine birds

Technical hypothesis		Expected impact	Impact type		Method for identifying change
Zone*	Phases		Duration	Intensity and extent	
On land	Installation + decommissioning	disturbance	provisional	high and localised	monitoring of bird landings
At sea	Installation + decommissioning	habitat disturbance and loss	provisional	high and + or - localised	spatio-temporal evolution of bird abundance
	Operation	habitat disturbance and loss	definitive	low to high and + or - localised	spatio-temporal evolution of bird abundance
	Installation + operation + de-commissioning	collisions with struc-tures and ships	definitive	low to high and + or - localised	behavioural monitoring + frequency of bird groundings
	Installation + operation + de-commissioning	turbidity	provisional to definitive	low to high and potentially wide ranging	spatio-temporal evolution of bird abundance
	Operation	prey accessibility (increased or dimin-ished)	definitive	low to high and + or - localised	spatio-temporal evolution of bird abundance
	installation + operation + de-commissioning	pollution by hydro-carbons or other substances	definitive	low to high and potentially wide ranging	frequency of bird groundings

*Tableau 32 Main potential impacts likely to affect birds. * On land (landfall area) or at sea (site area of machinery and vessel transit zone).*

Direct impacts

Underwater, the species the most at risk in terms of collision with submerged structures are the birds that plunge the deepest, seeking their prey in the water column or near the bottom (auks and cormorants in particular, but also gannets and divers, see Figure 1 in Langton *et al*., 2011) The risk of collision is related to different parameters: the extent of the overlap between the feeding areas and tidal park, fishing method (depth of diving, swimming speed, etc.), the daily rhythm of foraging activity (frequency of the nocturnal feeding phase is variable according to the species), the level of attraction of the species to emerged structures (which can be used as perches), the potential effects of tidal park turbidity or currents (Wilson *et al.,* 2007). Today's projects usually consist of machines installed at the bottom with turbines over a base, but there are also floating technologies, which concern the surface and sub-surface layers of the water column. While the first group of machines only presents a risk to some species of seabirds that dive deep, the second type is likely to cause interactions with a greater number of species.

On the surface, the presence of vessels or emerged structures may cause changes in the flight paths of birds that pass over the area, disturb birds in their feeding or resting areas, or provoke movement to other, potentially less favourable areas, resulting in a loss of habitat for these species.

Indirect impacts

The presence of numerous underwater structures over a large area is likely to affect prey species exploited by seabirds, but the impact of turbines on fish remains poorly understood (see Chapter 8, Fisheries). There can be an effect of prey concentration around the structures (reef effect), disturbance to prey that makes them more accessible (collisions, currents, etc.), but also an inverse effect of reducing access to prey through local changes to the current or other factors (Langton *et al*., 2011; Shields *et al*., 2011). This change to the currents can occur at the level of the whole of the tidal stream project area (>1 km), at a greater distance (1-10 km), or even on a regional scale (>10 km; Shields *et al.*, 2011).

Summary

On the basis of sensitivity or vulnerability indices put forward by different authors (Cook and Burton, 2010; Wilson *et al.*, 2007. Furness *et al.*, 2012; McCluskie *et al.*, 2012), it is possible to identify the species to which special attention should be paid, given the greater likelihood of interactions with tidal technologies and activities associated with the maintenance of the park (Table 33).

10.3. Identification of cumulative impacts

Seabirds are subject to many anthropogenic pressures at sea (pollution, maritime traffic, water sports, overfishing, etc., Croxall *et al.*, 2012.), and recent developments in renewable energy projects at sea (wind, tidal, etc.) constitute an additional one which concerns both coastal and offshore areas. It is therefore necessary to make the best possible assessment of the cumulative effects of all of these pressure factors and the impacts measured, taking into account their relevant spatial and temporal scales, as well as the duration and intensity of the different environmental disturbances identified (Petersen *et al.*, 2006; Boehlert and Gill, 2010; Masden *et al.*, 2010.).

It is useful to draw on the recommendations made in the context of offshore wind farms (King *et al*., 2009), particularly in terms of disturbance at sea and bird movements related to habitat loss. It is thus possible to consider models of cumulative impacts on bird energy budgets, taking into account both their demographic parameters and their plasticity in terms of exploitation of habitats and resources (King *et al.*, 2009).

10.4. Description of an environmental monitoring program

The assessment of environmental impact requires the setting up of a program that will allow adequate monitoring to collect the necessary data on seabirds and other marine compartments. As in the case of offshore wind farm projects (Camphuysen *et al.*, 2004), the information that should be collected on birds across tidal stream project areas includes:

- Distribution of birds at sea.
- Abundance of different species.
- Type of offshore activity (feeding, resting, moulting, transit).
- Migratory routes and transit zones.
- Feeding areas.
- Factors affecting the distribution and abundance of species.
- The spatio-temporal variability of distribution and abundance (seasonality, daily cycle in relation to the tidal cycle).
- Assessment of the risk of collision and behavioural changes.

To better understand the issues regarding potential interactions between birds and a tidal project, two years of monitoring should be made following the assessment of the initial state, with data collection on a monthly basis. This is all the more essential because there is virtually no feedback yet available on tidal projects, unlike offshore wind farms.

Depending on the location and configuration of the area of a tidal project, observations must be made from the ground, from a ship or aircraft or by combining several means of investigation. Monitoring plans should be implemented using standard methods (Camphuysen *et al.*, 2004; Maclean *et al.*, 2009; Perrow *et al.*, 2010; RPS, 2011b, Table 34). Depending on the size of the selected study area, these general methods can be adapted to the local context (RPS, 2011b, see also Table 3 in Camphuysen *et al.*, 2004, which makes a comparison of methods using vessels and aircraft, and the feedback presented in Maclean *et al.*, 2009). In the context of offshore wind farms, data acquisition for tidal stream farms requires less monitoring, especially because the risk of barrier effect related to emerged structures is small or inexistent. For collisions with structures, these would not occur in the air but underwater and concern a limited number of species of birds. Given that the areas of tidal stream projects can have potentially significant access difficulties, particularly related to currents, the choice of monitoring methods and their timing should be adapted to assess spatio-temporal variability as well as possible. It is important to have data available on seasonal variations in relation to the annual cycle of the species (at least to consider the dichotomy between breeding and non-breeding periods).

The measurement of environmental disturbances and impacts on birds can only be done if the initial state has been rigorously evaluated, making it possible to compare the situation before the project started, then during the installation, operation and decommissioning phases. Depending on the species present and the potential risks based on their biological characteristics (mode of feeding, etc., see Table 33), specific monitoring can be set up to refine the measurement of impacts.

			after CT et al., 2007		situation in the Channel-Atlantic			UICN et al. 2011	UICN et al, 2011	
Common name	Scientific name	Birds directive	Coastal	Off-shore	Nesting	Migra-tion	Winte-ring	France Red List Nesting birds	France Red List Wintering birds	To be monitored in tidal projects
GAVIIDAE										
red-throated loon	Gavia stellata	Anx. 1	P	----	----	P	P		NA	YES
black-throated loon	Gavia artica	Anx. 1	P	----	----	P	P		NA	YES
great northern loon	Gavia immer	Anx. 1	P	----	----	P	P		VU	YES
PODICIPEDIDAE										
Great crested grebe	Podiceps cristatus	Migr. Art. 4.2	P	----	----	P	P		NA	yes
Red-necked grebe	Podiceps grisegena	Migr. Art. 4.2	P	----	----	P	P		NA	NO
Horned grebe	Podiceps auritus	Anx. 1	P	----	----	P	P		VU	YES
Black-necked grebe	Podiceps nigricolis	Migr. Art. 4.2	P	----	----	P	P		LC	yes
PROCELLARIIDAE										
Northern fulmar	Fulmarus glacialis	Migr. Art. 4.2	P	P	N	P	----	LC	NA	NO
Cory's shearwater	Calonectris	Anx. 1	P	P	----	P	----	VU	NA	NO
Great shearwater	Puffinus gravis	Migr. Art. 4.2	P	P	----	P	----		[NA]	NO
Sooty shearwater	Puffinus griseus	Migr. Art. 4.2	P	P	----	P	----		[NA]	yes
Manx shearwater	Puffinus puffinus	Migr. Art. 4.2	P	P	N	P	----	VU	[NA]	yes
Balearic shearwater	Puffinus	Anx. 1	P	P	----	P	P		[VU]	YES
Yelkouan shearwater	Puffinus yelkouan	Anx. 1	----	----	----	----	----	VU	NA	yes
HYDROBATIDAE										
Storm petrel	Hydrobates	Anx. 1	P	P	N	P	----	NT	[NA]	NO
Leach's storm petrel	Oceanodroma	Anx. 1	P*	P	----	P	----		*[NA]*	NO
SULIDAE										
Northern gannet	Morus bassanus	Migr. Art. 4.2	P	P	N	P	P	NT	[NA]	YES
PHALACROCORAC										
Great cormorant	Phalacrocorax carbo	Migr. Art. 4.2	P	P*	N	P	P	LC	LC	YES
European shag	Phalacrocorax	Migr. Art. 4.2	P	----	N	P	P	LC	NA	YES
ANATIDAE										
Brant goose	Branta bernicla	Migr. Art. 4.2	P	----	----	P	P		LC	NO
Common shelduck	Tadorna tadorna	Migr. Art. 4.2	P	----	N	P	P	LC	LC	NO
Greater scaup	Aythya marila	Migr. Art. 4.2	P	----	----	P	P		NT	NO
Common eider	Somateria	Migr. Art. 4.2	P	----	N*	P	P	CR	NA	YES
Long-tailed duck	Clangula hyemalis	Migr. Art. 4.2	P	----	----	P	P		NA	NO
Common scoter	Melanitta nigra	Migr. Art. 4.2	P	P*	----	P	P		LC	YES
Velvet scoter	Melanitta fusca	Migr. Art. 4.2	P	----	----	P	P		EN	YES
Common goldeneye	Bucephala clangula	Migr. Art. 4.2	P	----	----	P	P		NA	YES
Red-breasted	Mergus serrator	Migr. Art. 4.2	P	----	N*	P	P		LC	YES
SCOLOPACIDAE										
Red-necked	Phalaropus lobatus	Anx. 1	P	----	----	P	----		*[NA]*	NO
Red phalarope	Phalaropus fulicarius	Migr. Art. 4.2	P	P	----	P	----		NA	NO
STERCORARIIDAE										
Pomarine skua	Stercoparius	Migr. Art. 4.2	P	P	----	P	(?)		[LC]	NO
Parasitic jaeger	Stercocarius	Migr. Art. 4.2	P	P	----	P	----		[LC]	NO
Long-tailed jaeger	Stercocarius	Migr. Art. 4.2	P	P	----	P	----		[VU]	NO
Great skua	Stercocarius skua	Migr. Art. 4.2	P	P	----	P	(?)		[LC]	NO
LARIDAE										
Mediterranean gull	Larus	Anx. 1	P	P	N	P	P	LC	NA	NO
Little gull	Larus minutus	Anx. 1	P	P	----	P	P		LC	NO
Sabine's gull	Larus sabini	Migr. Art. 4.2	P	P	----	P	----		*[NA]*	NO
Black-headed gull	Larus ridibundus	Migr. Art. 4.2	P	P*	N	P	P	LC	LC	NO
Mew gull	Larus canus	Migr. Art. 4.2	P	----	N	P	P	VU	LC	NO
Lesser black-backed	Larus fuscus	Migr. Art. 4.2	P	P	N	P	P	LC	LC	NO
European herring gull	Larus argentatus	Migr. Art. 4.2	P	P	N	P	P	LC	NA	NO
Yellow-legged gull	Larus michaellis	Migr. Art. 4.2	P	P	N	P	P	LC	NA	NO
Glaucous gull	Larus hyperboreus	Anx. 1	P	P*	----	P	P		NA	NO
Great black-backed	Larus marinus	Migr. Art. 4.2	P	P	N	P	P	LC	NA	yes
Black-legged	Rissa tridactyla	Migr. Art. 4.2	P	P	N	P	P	NT	NA	NO
STERNIDAE										
Sandwich tern	Sterna sandvicensis	Anx. 1	P	P	N	P	----	VU	[LC]	yes
Roseate tern	Sterna dougallii	Anx. 1	P	P*	N	P	----	CR	NT	NO
Common tern	Sterna hirundo	Anx. 1	P	P*	N	P	----	LC	[LC]	NO
Arctic tern	Sterna paradisaea	Anx. 1	P	P	N*	P	----	CR	[LC]	yes
Little tern	Sterna albifrons	Anx. 1	P	P*	N	P	----	LC	[LC]	NO
Black tern	Chlidonias niger	Anx. 1	P	P*	----	P	----	VU	[DD]	NO
ALCIDAE										
Common guillemot	Uria aalge	Migr. Art. 4.2	P	P	N	P	P	EN	DD	YES
Razorbill	Alca torda	Migr. Art. 4.2	P	P	N	P	P	CR	DD	YES
Little auk	Alle alle	Migr. Art. 4.2	P	P*	----	P	----		NA	yes
Atlantic puffin	Fratercula arctica	Migr. Art. 4.2	P	P	N	P	----	CR	NA	YES

Table 33 List of seabird species potentially present on tidal stream park areas on the Channel-Atlantic coast, and identification of species with the highest probability of interactions with tidal technologies (legend below).

List of species, established after Comolet-Tirman *et al.* (2007):

*Status in the Channel and Atlantic: P = present, P * = present but very rare ---- = absent (no instances), N = regularly breeding birds, N * = occasional breeder (?) = Status poorly known or not assessed*

IUCN *et al*., 2011 = red list of birds of France
Breeding, wintering or passage (between []); in italics: occasional or marginal passage
CR: Critically endangered; EN; Endangered; VU: Vulnerable; NT: Near Threatened; DD: Least concern; DD: Data Deficient; NA: Not applicable; NE: Not evaluated

Monitoring methods	Variables studied	Advantages	Limits
From land	Distribution and abundance	More suitable for frequently covering small areas; Less dependent on the sea state	Distance between the favourable observation points and the study area
	Species identification (for diving birds)	More suitable for identification to species level	
	Bird behaviour	More suitable for collecting behavioural information	
From a vessel	Distribution and abundance	More suitable for frequently covering small areas or to cover large surface areas	More dependent on the sea state
	Species identification (for diving birds)	More suitable for identification to species level	
	Bird behaviour	More suitable for collecting behavioural information	
From an aircraft	Distribution and abundance	More suitable for large surface areas; Less dependent on the sea state	Less suitable for frequently covering small areas
	Species identification (for diving birds)		Less suitable for identification to species level
	Bird behaviour		Less suitable for collecting behavioural information

Table 34 Main methods of tracking birds at sea, with advantages and limitations in the context of tidal stream projects (simplified version created by Camphuysen et al., 2004. Maclean et al., 2009. Perrow et al., 2010. RPS, 2011b)

There are indeed a number of seabird species on which the development of tidal stream farms is likely to cause significant impacts. These therefore require special attention as part of an environmental monitoring program. It may be necessary, for example, to find out how activities vary on daily time scales (diurnal and sometimes nocturnal activity, which is often linked to the tides). Once the installation phase is completed, a new monitoring campaign must be conducted during the first maintenance work on the park (lifting machines for inspection, etc.).

10.5. Impact mitigation

At present, the lack of sufficient experience in the field of tidal stream technologies means that it is impossible to know the impact that the installation of marine tidal stream parks will have on birds. Nevertheless, it is possible to distinguish two types of case, namely temporary and permanent disturbances of the environment used by marine and coastal birds.

In cases where the disruption is temporary, of the order of weeks to months, the choice of the optimal period in which to conduct work on the site will be made in line with technical and logistical constraints inherent in tidal energy technology installation and the annual cycle of bird species (breeding, wintering, etc.) to minimize interactions or reduce the intensity.In cases where the impact is permanent (e.g., habitat loss), its scale and repercussions should be evaluated as best as possible in terms of significant impacts on the different species of birds concerned in order to consider mitigation measures.

10.6. Knowledge gaps and research programs

One of the main existing gaps in knowledge about tidal stream projects is the reaction of birds, and any behavioural changes that may occur with the installation of submerged structures (turbines, cables or anchor chains) in their usual feeding areas. This requires a study and comparison to be made of what is happening in the water column before and after the installation of the machines in terms of activity and foraging interactions: diving depth, type of swimming, avoidance of structures, collisions etc. This requires prior investigations to choose research methods and suitable monitoring plans.

Key references

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Conclusion

The consortium of specialists involved in the Ghydro collaborative project and the experts with different backgrounds who were consulted have allowed us to establish the present state of knowledge as exhaustively as possible. In particular, this document covers the evaluation of the initial state, characterisation of potential impacts and environmental monitoring of the different physical and biological compartments of marine ecosystems (Table 35).

However, these tidal stream technologies are not yet established at the industrial scale on the sites to be exploited so there is not enough feedback yet available from projects underway to characterise the potential impacts of tidal stream parks.

The Ghydro project is therefore the start of an iterative process, which will be updated every two years, making it possible to improve the document's content as feedback becomes available.

Research projects will also contribute to gradually building up our knowledge of these high energy environments (physical and biological parameters) and of their potential impacts.

France Energies Marines has already initiated R&D projects to improve knowledge in these areas, for example:

- ✓ Characterisation of the initial state of the benthos in a marine tidal power site.
- ✓ Use of passive acoustic methods to assess impacts on the benthos.
- ✓ Studies on the interactions between usages in marine tidal power zones.
- ✓ Studies on estuarine sites.

	Initial state.				Identification of potential ecological impacts	Proposed environmental monitoring programmes	Examples of impact attenuation measures
	Objectives	Spatial coverage	Time span	Methods			
Sea bottom	Bathymetry Nature of the sea bottom Thickness of unconsolidated sediments	Several km2 around the project area and the route of the cable	One survey on the inital state	Bibliography/cartography Geophysical surveys	Impacts on the sea bottom: - Are directly linked to technical choices: type of foundations, type of cable laying, technique of landing underwater cables. - Evolve over the three phases of the tidal stream project: construction, operation and decommissioning.	A first survey at one year of operation, then every 5 years if impacts are observed: bathymetric acquisition tools (multibeam echosounder, etc.) image acquisition equipment (sonar, etc.)	Adaptation of the design of the structures, installation techniques, etc.
Oceanography	Tides Current Swell Wind Sedimentary dynamics	From a few km2 to several tens of km2	. Reconstitution over a period of about 20 years . Time step from a few seconds to 10 minutes	Bibliography / Database Data acquisition Modelling	Impacts on oceanography: - Are directly related to the presence of an obstacle in the water collumn and that of installations on the bottom. - Are mainly linked to the operational phase of a tidal stream project.	Operational oceanography platform that will function throughout the lifespan of the project: Equipment for continuous digital measurement and modelling.	Choice of installation zone. Adaptation of working techniques. Optimisation of turbine geometry. Adaptation of design and setting up of anti-scouring devices around the piles and gravity base foundations.
Underwater noise	Initial noise	Sound footprint Range of sensitivity of species	. Four seasons . Time step of 1 second	Bibliography Data acquisition Modelling	Impacts on underwater noise: - Are directly linked to the phases in the life of a marine tidal stream project: contraction, operation and decommissioning. - Are directly linked to technical choices: tools for installation and decommissioning, and the conception of elements of a marine tidal energy park.	Phases of construction and decommisioning: passive acoustic measures to perform in concommitatnce with the phases of the work. Operation phase: passive acoustic mesurements done every trimester for (N), (N+1), (N+5), (N+10) etc.	. Establishment of measures to reduced the levels of individual noise sources. . Establishment of measures to reduced the levels of cumulative noise levels. . Establish systems to reduce noise propagation in the ocean. . Establish measures to temporarily keep species away from risk zones.
Benthos	Benthic communities	Slightly larger than the zone under exploitation and the route of the cable	2 seasons per year over 1 year for the minimum scenario and 3 years for the optimal scenario	Bibliography / database Data acquisition	Impacts on benthic communities: - Are directly linked to the technical choices: type of foundation, type of cable and the way it is laid and conception of the elements of the marine tidal energy park. - Depend on the vulnerability of the communities concerned. - Evolve during the three stages of the life of a marine tidal energy project: construction, exploitation and decommissioning.	First monitoring in the first two months following the end of installation and another season in the first year. Optimal scenario: 2 seasons per year at +2 and +3 years. Minimum scenario: 2 seasons at +5 years. Then, later monitoring frequency will be determined depending on the results of the first campaigns.	Avoidance measures: selection of alternative installation sites, modification of installation methods, modification to the design of the structures (e.g., base/foundations of the machines). Reduction measures: Spatial coverage of the foundations, depth of cable burial, modification to the design of the structures to minimise disruption from the currents. Compensation measures: Applied as much as possible on the species/functioning of habitats (or communities) affected.

	Initial state.				Identification of potential ecological impacts	Proposed environmental monitoring programmes	Examples of impact attenuation measures
	Objectives	Spatial coverage	Time span	Methods			
Fisheries	Fisheries resources	From a few km2 to several tens of km2	. Depends on the cycle of the species . Day and night	Bibliography Data acquisition	The impacts on the pelagic communities: - Are directly related to the presence of an obstacle in the water collumn that can modify the currents. - Are linked to the technical choice of the turbines because of the risk of collision. - Are mainly linked to the operational phase of of the tidal project. The installation phase should be taken into account for acoustic impacts.	. Methods using capture and methods using observation, adapted to conditions with strong hydrodynamics. . The monitoring program depends on the initial state: includes annual campaigns and systems from continuous acoustic observation on the site.	Selection of alternative installation sites. Adaption of installation methods. Adapted timetable of activities liable to cause temporary disruptions. Adaption of the design of structures. Burying of cables.
Marine mammals	Marine mammals	Sound footprint	1 or 2 years of monitoring	Bibliography Data acquisition	Impacts on marine mammals: - Are linked to the technical choices of turbines, moorings and ships for collision risks. - Are directly linked to the technical choice of methods used during installation and decommissioning phases and during maintenance for impacts related to noise. - Are linked to the impacts on their habitats.	Monitored by visual methods, passive acoustic methods and underwater acoustic methods at the turbines.	. Establish noise reduction measures for each individual sound source. . Establish noise reduction measures for cumulative sound levels. . Establish systems to reduce sound propagation in the ocean. . Establish measures that will temporarily keep species away from zones of risk. Adapted timetable of activities, adaptation of work methods and design of structures.
Birdlife	Seabirds Coastal birds	From a few km2 to several tens of km2	1 to 2 years Monthly time step	Bibliography Data acquisition	Impacts on marine birdlife are of three kinds: - Risks of collision with the turbines during the operational phase and with vessels during all 3 phases of a project's life. - Disturbance (noise, modification of access to prey) at sea (all 3 phases) and on the coast at the point of arrival of the cable (phases 1 and 2). - Modification of their habitat	Identification of a list of species to which particular attention should be paid. Monitoring methods adapted to the currentology of the sites and annual cycle of the species.	In the case of temporary disturbances, the choice of the optimal period for on-site activities. In the case permanent disturbances, the need for knowledge about the impact in order to determine attenuation measures.

Table 35 Synthesis table

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