GHYDRO: METHODOLOGY GUIDE FOR ASSESSMENT OF ENVIRONMENTAL IMPACTS OF TIDAL STREAM ENERGY TECHNOLOGIES AT SEA

Morgane Lejart[1], Cédric Auvray[2], Agnes Barillier[3], Bernard Cadiou[6], Antoine Carlier[4], Jean Paul Delpech[5], Thomas Folegot[7], Cyril Giry[8], Jean Marie Loaec[3], Ludivine Martinez[9], Jehanne Prévot[2]

[1]France Energies Marines
15 rue Johannes Kepler
29200 Brest
Email : morgane.lejart@france-energies-marines.org

[2]DCNS
Incubateur Industriel "Energies Marines"
ZAC du Port – Immeuble Balise Rouge
415 rue Jurien de la Gravière – 29200 Brest

[3]EDF
Centre d'Ingénierie Hydraulique
Développement Durable
Savoie Technolac
73373 Le Bourget du Lac

[4]Ifremer
Laboratoire Ecologie Benthique
DYNECO-EB
29280 Plouzané

[5]Ifremer
Centre Manche Mer du Nord
Département RBE
Laboratoire Ressources Halieutiques
150 Quai Gambetta BP 699
62321 Boulogne-sur-Mer Cedex

[6]Bretagne Vivante - SEPNB
186 rue Anatole France
29200 Brest

[7]Quiet Oceans
65, place Nicolas Copernic
29280 Plouzane

[8]Energie de la Lune S.A.S
DARWIN Bât. Nord
87 quai des Queyries
33100 Bordeaux

[9]Pelagis
ULR Valor/Observatoire Pelagis
Université de La Rochelle - CNRS
5 allée de l'Océan
17000 La Rochelle

ABSTRACT:

The objective of GHYDRO, a France Energies Marines project, is to draw up a methodology guide that provide stakeholders in tidal stream energy projects with decision-making help for the environmental integration of generators and tidal farms. 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 physical and biological compartments of the marine ecosystems have been addressed separately in the guide, 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. To bring together the broadest range of expertise, France Energies Marines has created a consortium of specialists in tidal power technologies and in the marine environment coming from both research institutes and companies.

KEYWORDS: methodology guide, environmental impact, tidal stream energy.

INTRODUCTION

Due to the fact that there are currently just a few devices tested in tidal stream pilot farms around the world, and the continued lack of knowledge concerning the marine environments targeted by tidal stream projects, the structural context in which environmental monitoring will be developed is still in draft form. The main objective of the guide is to promote the environmental integration of these new projects at sea for which there is very little feedback about the potential ecological impacts. This guide proposes recommendations and methods that allow, for the first time in France, different aspects to be taken into account: environmental knowledge (physical and biological), as well as the regulatory and technological aspects (machines, installation, maintenance...). An important asset of this guide is that it was produced by a consortium of experts from both research institutes and companies reunified by France Energies Marines amongst its members. Specialists from marine environment field, technology developers, state services and users were also consulted.

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 technical perimeter mainly concerns:

- Projects from test sites to industrial parks scale.
- 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).

The guide is organised according to the different physical and biological compartments of the ecosystems in order to propose methodologies adapted to each one. For each, 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.

PHYSICAL ENVIRONMENT

1. SEABED

a. DESCRIPTION OF INITIAL STATE

Objectives: The three mean parameters that should be measured to characterize the seabed where a tidal stream farm will be built are the bathymetry, the nature of the sea bottom and the thickness of unconsolidated sediments.

<u>Spatial coverage:</u> The study zone includes several km2 around the project area (machine installation zone) and the route of the cable to the landing point.
<u>Methods:</u> There are two information acquisition methods, bibliography and geophysical surveys. The main bibliographic sources in France are SHOM (http://data.shom.fr/) and Ifremer (www.ifremer.fr/sextant). Acquisition of bathymetric data required an accurate positioning system, an attitude reference system and a bathymetric multibeam sounder. Acoustic imaging acquisition should be done by a side scan sonar or, better, by a multibeam sounder. Recommendations about the data representation and quality are précised in the guide.
<u>Time span</u>: One survey on the initial state

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

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.

Table 1. shows the example of potential changes characterization present in the guide related to cable laying during the construction phase.

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 modelling	-
		Modification of the morphology	Definitive	Definitive but localised	-	Visual checks
	Embedded	Remixing of sediments	Temporary	Moderate	Estimation of volumes remixed	Visual checks
		Re-suspension of sediments	Temporary	Weak	-	
		Creation of a pit	Temporary		Sedimentary study to estimate behaviour of the pit	-

Table 1. Potential changes during the construction phase, related to cable laying

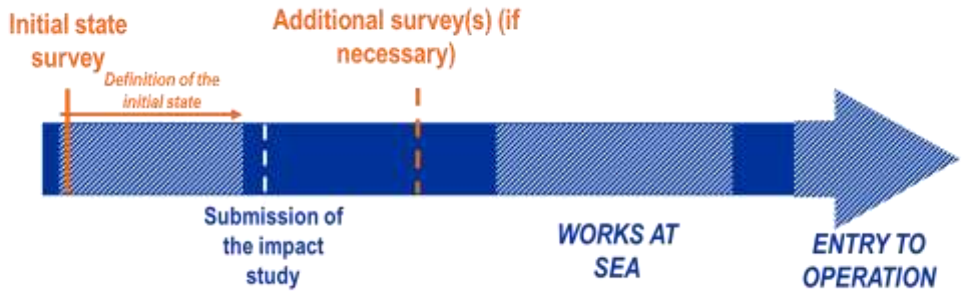
c. Description of the environmental monitoring programme

A first survey at one year of operation, then every 5 years if impacts are observed. Figure 1. shows the example of monitoring programme present in the guide related here to seabed.

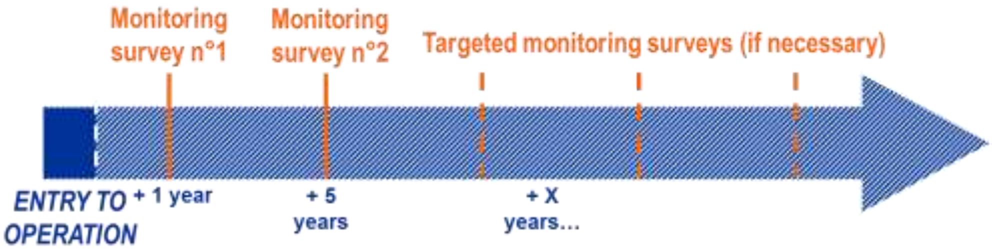
d. Measures for impact mitigation

Adaptation of the design of the structures, technical choice to reduce or avoid cable chafing (rock dumping, concrete mattress…) and limit the scouring around the foundations (plastic or live algae).

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



- In the operation phase:



- In the decommissioning phase :

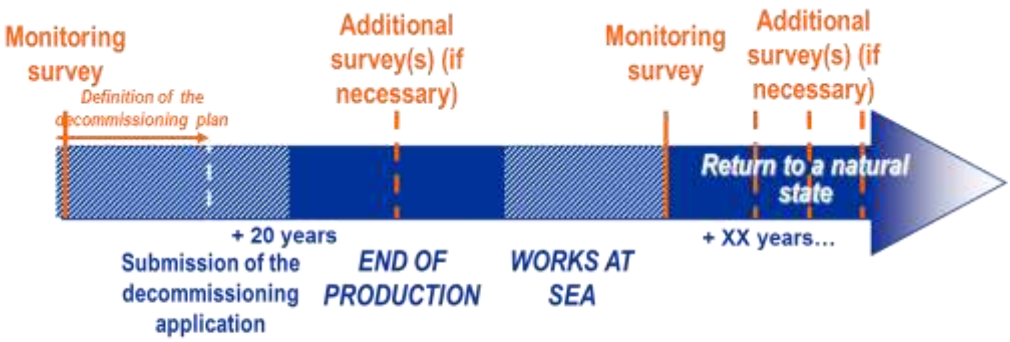


Figure 1. Theoretical schema of the strategy for the implementation of seabed monitoring, for the duration of the tidal stream project

e. Deficiencies and research programme

The impacts of tidal project structures on the sediment dynamics and associated sediment deposits are still relatively unknown at the scale of the hydrosedimentary cell (or sub-cell) and need to be studied. Improvement of imaging tools would allow a better characterization of the sub-seabed and would help project promoters to better understand their study zones during the development phases of farms.

2. OCEANOGRAPHY

a. Description of initial state

Objectives: Different processes should be studied and measured to characterize the meteoceanic conditions of a tidal stream turbine site. The main forcings concerned are the tide, the wind, currents, sea states and sedimentary dynamics.

Spatial coverage: The definition of the study zone varies according to location. Oceanographic measurements will generally be done at the scale of the concession (several km²), 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).
Methods: The major types of methods are listed in the guide, in chronological order of appearance in the project: bibliography and existing database, onsite measures and numerical modelling.
Time span: For onsite measures, time step from a few seconds to 10 minutes, and for modeling, reconstitution over a period of about 20 years

b. METHODS FOR THE IDENTIFICATION AND ANALYSIS OF POTENTIAL ECOLOGICAL CHANGES

Impacts on oceanography:
- are directly related to the presence of an obstacle in the water column and that of installations on the bottom
- and are mainly linked to the operational phase of a tidal stream project.

c. DESCRIPTION OF THE ENVIRONMENTAL MONITORING PROGRAMME

It is recommended to install an operational oceanography platform that will function throughout the lifespan of the project:
- Measuring devices (current, swell, turbidity) at the different monitoring points within and outside the tidal stream park.
- Continuous numerical modeling by real time data assimilation (swell gauge, ADCP, CTD, HF radars, etc.).

d. MEASURES FOR IMPACT MITIGATION

- 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

e. DEFICIENCIES AND RESEARCH PROGRAMME

- The park effect: 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 interac-tions: 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, and, in general, the optimisation of measures for sites with strong currents is a baseline for tidal stream projects.

3. UNDERWATER NOISE

a. DESCRIPTION OF INITIAL STATE

Objectives: Seasonal characterisation of the ambient noise. Initial underwater sound chorus from a combination of three origins, noise of physical nature, noise of biological origin and anthropogenic origin.
Spatial coverage: 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".
Methods: Bibliography and onsite measurements.

The characterisation of the sound chorus and its variability can be obtained by:
- Passive measurement for noise of physi-cal and biological origin.
- Measurement and numerical modelling for noise of anthropogenic origin.

Time span: The statistical seasonal characterization of the ambient noise covers statistically representative periods with seasonal in situ measurement campaigns with a time step of 1 second.

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

Impacts on underwater noise:
- Are directly linked to the 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.

c. Description of the environmental monitoring programme

During the construction and decommissioning phases, 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.

d. Measures for impact mitigation

- Establishment of measures to reduce the levels of individual noise sources.
- Establishment of measures to reduce 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.

e. Deficiencies and research programme

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.
- Characterization of the levels emitted by the new generations of tools and techniques for anchors specific to the tidal stream turbines.

BIOLOGICAL ENVIRONMENT

4. BENTHOS

a. Description of initial state

Objectives: 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).

Spatial coverage: Slightly larger than the zone under exploitation and the route of the cable.

Methods: - Bibliography / database: 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.

- Data acquisition: The number of monitoring stations and their spatial distribution depend on the observed degree of heterogeneity of the nature of the seabeds.

Time span: 2 seasons per year over 1 year for the minimum scenario and 3 years for the optimal scenario.

b. METHODS FOR THE IDENTIFICATION AND ANALYSIS OF POTENTIAL ECOLOGICAL CHANGES

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.

c. DESCRIPTION OF THE ENVIRONMENTAL MONITORING PROGRAMME

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.

d. MEASURES FOR IMPACT MITIGATION

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.

e. DEFICIENCIES AND RESEARCH PROGRAMME

- Fundamental knowledge about coastal benthic ecosystems (fragmented and insufficient especially for the ecosystems in the circalittoral zone).
- The impact of the hydrodynamic modifications induced by the operation of the turbines.
- The characterisation of the "reef" effect of the submerged structures, should be the subject of long-term monitoring targeting the different components of the tidal stream projects
- The impact of the noise generated by tidal stream projects on benthic invertebrates.
- The impacts of the electromagnetic field modification and the temperature increase.

5. FISH

a. DESCRIPTION OF INITIAL STATE

Objectives: 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.
Spatial coverage: From a few km^2 to several tens of km^2.
Methods: -Bibliography
- Data acquisition: capture methods and observation methods.

Time span: Depends on the cycle of the species
Acquisitions should covered both day and night periods.

b. METHODS FOR THE IDENTIFICATION AND ANALYSIS OF POTENTIAL ECOLOGICAL CHANGES

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.

c. DESCRIPTION OF THE ENVIRONMENTAL MONITORING PROGRAMME

. 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.

d. MEASURES FOR IMPACT MITIGATION

Adaption of installation methods.
Adapted timetable of activities liable to cause temporary disruptions.
Adaption of the design of structures.
Burying of cables.
May include selection of alternative installation sites.

e. DEFICIENCIES AND RESEARCH PROGRAMME

Areas of the fish compartment identified on which research is needed are:
- 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.

6. MARINE MAMMALS

a. DESCRIPTION OF INITIAL STATE

<u>Objectives:</u> Establish the baseline of marine mammal frequentation for the area, in terms of diversity, abundance and spatio-temporal distribution.
<u>Spatial coverage:</u> One proposed solution to define the area of study is to base this on two complementary areas: the noise footprint of the project and an area of ecological interest where individuals are likely to interact with machines (directly or indirectly).
<u>Methods:</u> Bibliography and data acquisition: visual and acoustic observations.
<u>Time span:</u> On the time scale, for the characterization of the initial state, monitoring should follow marine mammals over at least one biological cycle, i.e., a year.

b. METHODS FOR THE IDENTIFICATION AND ANALYSIS OF POTENTIAL ECOLOGICAL CHANGES

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.

c. DESCRIPTION OF THE ENVIRONMENTAL MONITORING PROGRAMME

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 that should be possible to reduce by combining several methods: Visual observations, passive acoustic methods, underwater imaging methods, telemetry, HD photography…

d. MEASURES FOR IMPACT MITIGATION

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.

e. DEFICIENCIES AND RESEARCH PROGRAMME

- Much information still needs to be gathered to identify the crucial areas (including: feeding zones, migration patterns and areas of passage or of use as overall habitat) and spatio-temporal assessment of the distribution of marine mammals. If it is not the responsibility of project to finance such research needs, environmental monitoring carried out under site surveys could contribute.

Monitoring of the use of areas with strong currents and the behaviour of marine mammals in these areas is to be encouraged.
- 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.

7. BIRDS

a. DESCRIPTION OF INITIAL STATE

Objectives: This initial baseline must make it possible characterize the bird populations (seabirds and coastal birds) that frequent the study area and their exploitation of the marine environment for different types of activities related to their biology.

Spatial coverage: 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. That corresponds to an area from a few km^2 to several hundreds of km^2.

Methods: Bibliography and data acquisition.

Time span: 1 to 2 years with a monthly time step.

b. METHODS FOR THE IDENTIFICATION AND ANALYSIS OF POTENTIAL ECOLOGICAL CHANGES

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

c. DESCRIPTION OF THE ENVIRONMENTAL MONITORING PROGRAMME

- 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.
- 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. 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).

d. MEASURES FOR IMPACT MITIGATION

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.

e. DEFICIENCIES AND RESEARCH PROGRAMME

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 prior investigations to choose research methods and suitable monitoring plans.

CONCLUSION

The guide is freely available, in French and in English, on the France Energies Marines website.
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.

ACKNOWLEDGEMENTS

The authors want to thank all the experts in tidal stream technologies and the marine environment from industry, research and associations who contribute to the guide.

REFERENCES

France Energies Marines, 2013, Guide to the environmental impact evaluation of tidal stream technologies at sea: GHYDRO. http://dx.doi.org/10.13155/29025