Documentary summary of the environmental impact of renewable marine energy

MERiFIC
Marine Energy in Far Peripheral and Island Communities

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Documentary summary of the environmental impact of renewable marine energy

Task 3.2 of WP3 of the MERiFIC Project

Report prepared within the framework of the MERiFIC Project
“Marine Energy in Far Peripheral Island Communities”

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Table of Contents

Table of figures 5
Acronyms 7
1. INTRODUCTION 8
Preamble 8
CONTEXT 9
The concept of impact and framework of reading 13
2. IMPACT STUDIES AND LEGAL FRAMEWORKS 17
Regulatory Tools 17
EIE 17
ESIE 17
The Guidelines - Fauna Flora Habitats and Birds and the Natura 2000 network 19
The (DCSMM) 21
Institutional Tools 22
Marine Protected Areas in France 22
The "Joint Nature Conservation Committee" (JNCC) UK 22
The "Natural England" 23
"Sites of Special Scientific Interest" (SSSI) in the UK 23
Governance Tools 23
The BACI 23
The ICZM 23
Marine Natural Parks in France 23
2. MARINE ENERGY 25
The different types of marine energy 25
Hydrokinetic Devices 26
Tidal Power Plants 26
The Tidal Turbines 26
Wave Power Devices 30
Offshore Windfarms 34
The life cycle of a renewable energy project and related effects 37
Construction 38
The Operational Phase 39
The Dismantling 40

Scale of Development and Cumulative Effects 41
The Concept of Mitigation 42
3 SUMMARY OF THE ENVIRONMENTAL IMPACT OF MARINE RENEWABLE ENERGY 44
Impacts on hydrodynamics and sediment dynamics 44
Physical presence; flow disturbances 44
Energy Extraction 45
Effects on biological processes 46
Physical Presence of Plants: Reef Effect 48
The "Reef" Effect 48
Colonization of new habitats 48
Alternative Activities 51
The Ecological Trap 52
"Subspontaneous" Invasions 52
Physical Presenceof Plants: The "Barrier" Effect 52
The Risk of Collision 52
In Marine Species 52
Birds 53
Risk Avoidance 56
Loss/ degradation of habitats 57
Noise 59
Pile Driving 59
Noise during the Operation Phase 65
Cables and Electromagnetism 67
Lighting 70
Chemical Products 72
Anti-fouling 72
Accidental Pollution 72
Historical heritage and landscapes 73
4. CONCLUSION 74
Reminder of the Context 74
Impact Studies 74
GIS / Information Management and modelling 75
ANNEXES 76
Bibliographies 99

Table of figures

Figure 1: MERiFIC Project partners 1
Figure 2: The tip of Finistere in Brittany 10
Figure 3: The tip of Cornwall UK 10
Figure 4: Bathymetric map of the Celtic Sea and the Gulf of Gascogne 11
Figure 5: Photographic Board of the Biodiversity in the Iroise Sea 12
Figure 6: Framework of environmental effects of MRE 14
Figure 7: Environmental stressors and receptors, associated with the development of kinetic energies 14
Figure 8: Example of the impact assessment matrix according to Polagye et al., (2010), for the stressors 15
Figure 9: Example of matrix studies impacts according to Polagye et al., (2010), for the receptors 15
Figure 10: Main differences between the EIE and ESIE, adapted from Eales et al., 2003 18
Figure 11: The location of candidate sites in the UK of Special Areas of Conservation 20
Figure 12: Natura 2000 sites in France 21
Figure 13: MRE projects in RTA regions 25
Figure 14: Tidal dams at Rance, France (left) and at Sihwa, South Korea (right) 26
Figure 15: Image of a synthesis demonstrator Sabella D10 immersed in the passage of Fromveur to Ouessant . 27
Figure 16: The Paimpol-Brehat Turbine 27
Figure 17: SeaGen turbine in Strangford Lough (UK) 28
Figure 18: Maximum speed of currents: Channel, North Sea and St. George's Channel 29
Figure 19: Significant wave height, 19 February 2011 in accordance with the Previmer model 30
Figure 20: The "Limpet" system (Land Installed Marine Power Energy Transmitter) 31
Figure 21: Some examples of offshore wave devices 31
Figure 22: The "PELAMIS" system 32
Figure 23: The SEAREV 33
Figure 24: The Wave Hub 34
Figure 25: Wind Farms of Horns Rev and of Nysted Park Offshore in Denmark 34
Figure 26: The different foundations for offshore wind turbines 35
Figure 27: Floating Wind turbine WINFLO 1
Figure 28: Vertiwind Project 36
Figure 29: The lifecycle of a Renewable Energy Park 37
Figure 30: The main activities for each phase of a lifecycle of an MRE Park 37
Figure 31: Wind turbine during construction 38
Figure 32: Conceptual diagram of the effects of construction 39
Figure 33: MRE Hierarchy of Mitigation 42
Figure 34: Leveling around a monopile 45
Figure 35: Hydrodynamics changes in the wake of a wind turbine monopile 1
Figure 36: Drawing of zonal communities on structures placed in waters deeper than 15m 1
Figure 37: Photos of communities and species associated with the colonization of offshore wind farms UK . 49
Figure 38: Colonisation by mussels (Mytilus Echilij) on protective structures of the Horns Rev offshore wind farm, Denmark 50
Figure 39: Illustration of the eventual evolution of activities in a Wind Farm 51
Figure 40: Culture of blue mussels 1
Figure 41: Dimensions of wind turbines at Horns Rev, Denmark 53

Figure 42: Estimated depths of selected turbines and fishing depths of diving birds 55
Figure 43: Flight paths of birds during the commissioning of the wind turbines at Nysted Offshore Wind Park in Denmark Detection by radar. 57
Figure 44: A simple sinusoidal waveform describing different units of measurement of sound 60
Figure 45: Levels of anthropogenic noise generated by various activities (pile driving) 60
Figure 46: Zones of noise influence 61
Figure 47: Approximate frequency intervals of marine mammal sounds and the prevailing background anthropogenic noise 62
Figure 48: Some factors affecting the reactivity of marine mammals 62
Figure 49: Changes in the number of porpoises detected at Beatrice (Scotland) before (June), during (July and August) and after (September and October) the installation/construction of wind turbines 63
Figure 50: Drawing reflecting a Wave Hub cable network 1
Figure 51: Magnetic radiation field of a standard 13kV submarine cable (Tesla) buried 1m deep. The seabed surface is represented by the horizontal blue line 68
Figure 52: Pelamis warning lights 70
Figure 53: Lights from an onshore Wind Farm 71
Figure 54: Combined Positive and Negative effects of MRE 74

Acronyms

AMP : Aires Marines protégées (PMA: Protected Marine Areas)
AAMP : Agence des Aires Marines Protégées (PMAA: Protected Marine Areas Agency)
AIS : Automatic Identification System
CE : Communauté Européenne (EC: European Community)
CEFAS : Centre for Environment, Fisheries & Aquaculture Science
CEM : Champs électromagnétique
CNRS : Central National de Recherche Scientifique (NCSR: National Centre for Scientific Research)
COWRIE : Collaborative Offshore Wind Research Into the Environment
CSRPN : Conseil Scientifique Régional pour le Patrimoine Naturel (Instance consultative de proximité pour les collectivités territoriales, à compétence scientifique en matière de patrimoine naturel)
DCP : Dispositif de Concentration de Poisson (Fish Concentration Device)
DCSMM : Directive-Cadre Stratégie pour le Milieu Marin (Strategy Framework Directive for the Marine Environment)
DML : Délégation de la Mer et au Littoral
DPMA : Direction des Pêches Maritimes et de l'Aquaculture
EIE : Etude d'Incidences sur l'Environnement (Evaluation of Environmental Impact)
ESIE : Etude Stratégique d'Incidences sur l'Environnement (Strategic Assessment of Environmental Impact)
EMEC : European Marine Energy Center (centre européen sur les energies marines)
EMF : Electromagnetic Field
MRE : Energies Marines Renouvelables (RME: Renewable Marine Energy)
GIZC : Gestion Intégrée des Zones Côtières (ICZM: Integrated Coastal Zone Management)
ICES : International Council for the Exploration of the Sea = CIEM : Conseil International pour l'Exploration de la Mer.
MERiFIC Marine Energy in Far Peripheral and Islands Communities
MMO: Marine Management Organisation
MNHM : Muséum National d'Histoire Naturel (National Museum of Natural History)
NCC : Nature Conservancy Council
NERC : Natural Environment Research Council
NOAA : National Oceanic and Atmospheric Administration
ORED : Ocean Renewable Energy Development
PNMI : Parc Naturel Marin d'Iroise (Iroise Natural Marine Park)
RTA : Réseau Transnational Atlantique (Atlantic Transnational Network)
SEAREV : Système Electrique Autonome de Récupération de l'Energie des Vagues (Autonomous Electrical Power System for the Recovery of Wave Energy)
SSSI : Sites of Special Scientific Interest
SGAR : Secrétariat Général pour les Affaires Régionales (General Secretary for Regional Affaires)
VMS : Vessel Monitoring System
ZNIEFF : Zone Naturelle d'Intérêt Ecologique, Faunistique et Floristique (Zone of Natural Ecological, Fauna and Flora Interest)
ZPS : Zone de Protection Spéciale (Zone of Special Protection)
ZSC : Zone Spéciale de Protection (Special Protection Zones)

1. INTRODUCTION

Preamble

Today, many countries have become aware of the need to integrate 'renewable energy' into their energy policies to compensate for their limited resources of combustible fossil fuels, achieve energy security for the future and reduce the effects of climate change that result from human activities (MacKay, 2009).

There are numerous possibilities for using the sea to producing energy. Notably the energy of waves (houlomotrice), the energy of currents (hydrolienne), the energy of tides (maremotrice), the energy of the wind (eolienne), the thermal energy (ETM), energy related to gradients of salt content (salinity), etc.

Suitable sites are selected by the promoters based on technical criteria: depth, reasonable distance from the coast, near a landfall point, nature of the seabed, etc. These sites could correspond with areas important for the good functioning of ecosystems (such as spawning and nursery) or pathways of migratory species. Generally, the coastal zone is a key area for the whole of the food chain (plankton, fish and invertebrates, marine mammals, birds). Marine energy has an impact on all compartments of the marine environment and land in relation with these: the water column, the seabed, the airspace etc.

To avoid impacting these important ecological and trophic areas, it is necessary to know the levels of conservation, sensitivity and resilience of species and habitats when planning this type of project. These assessments are used to define sites with the least environmental constraints. Subsequently, integrated environmental impact assessments, both positive and negative, will identify some of the environmental benefits and damage that will occur during implantation and implementation of MRE, and thus provide plans for evasive action, repair and restoration to compensate for these damages.

The scientific literature points out that the potential impacts of this type of activity will be different depending on the various phases of construction, operation and dismantling. These effects are of concern as they will have an impact on habitats and species displacement, changes in turbidity of the water, effects on species associated with vibrations and noise, the magnetic fields of cable networks, the effects of collisions with birds (Annex 1).

CONTEXT

Because of their physical characteristics, the seas of Cornwall UK and Iroise are ideal locations to benefit from the expected growth of marine renewable energy (MRE). Wave action generated by offshore winds and tidal currents, which are among the strongest in Europe (up to 8 knots during spring tides), makes these regions good locations for the implementation of energy recovery devices for waves, currents and wind.

However, the use of MRE is a technical and scientific field that is still relatively new with little experience in commercial / business practices and for which many economic, social and environmental questions arise.

That is why the Cornwall Council (equivalent to "*Conseil général*" of Cornwall UK) and the *Conseil général du Finistère* have developed an innovative strategy to capture this future market through the creation of a cross-border project (Interreg IVa) MERiFIC (Marine Energy in Far Peripheral Island Communities). This project aims to analyse the potential of our regions for the implementation of MRE and develop tools for support of that decision. It focuses on 4 themes called "work packages" (WP):

- Technological support (WP3)

-Public policies and regulations (WP4)

- Sustainable economic development (WP5)

- The local population (WP6).

This project brings together 10 partners and has a target end date of June 2014.

Figure 1: MERiFIC Project partners

Cornwall Council, *Conseil général du Finistère*, *Pôle Mer Bretagne*, *Technopôle Brest-Iroise*, *Parc naturel marin d'Iroise*, IFREMER, *Bretagne Développement Innovation*, Cornwall Marine Network, the University of Exeter, and the University of Plymouth.
Source: merific.org

The islands at the tip of Brittany (Ouessant, Molene, Sein) and Cornwall UK (Isles of Scilly) are not connected to the mainland electricity transmission grids and rely entirely upon local thermal electricity generating machines.

This island electricity production method is, on the one hand pollutant in a fragile ecosystem and, on the other hand very expensive (shipping, storage and handling of fuel) leading to a cost per kWh produced that is 5 to 6 times higher than the comparative mainland cost per kWh.

Figure 2: The tip of Finistere in Brittany
Source: geoportail.gouv.fr

Figure 3: The tip of Cornwall UK
Source: geoportail.gouv.fr

Although the environmental impact of renewable energy production technologies may be lower than diesel, these technologies are still susceptible to disrupting or having a negative impact on the environment (Bickel et al., 2003).

Given their isolation, the peripheral regions and islands have unique, sensitive and fragile ecosystems. At the cross roads of several bio-geographical provinces: the English Channel, the Celtic Sea, the Bay of Biscay, St George's Channel (figure 4), the regions of Cornwall UK and Finistère both have a rich marine biodiversity which reflect the range of habitats from the coast to depths greater than 2000m.

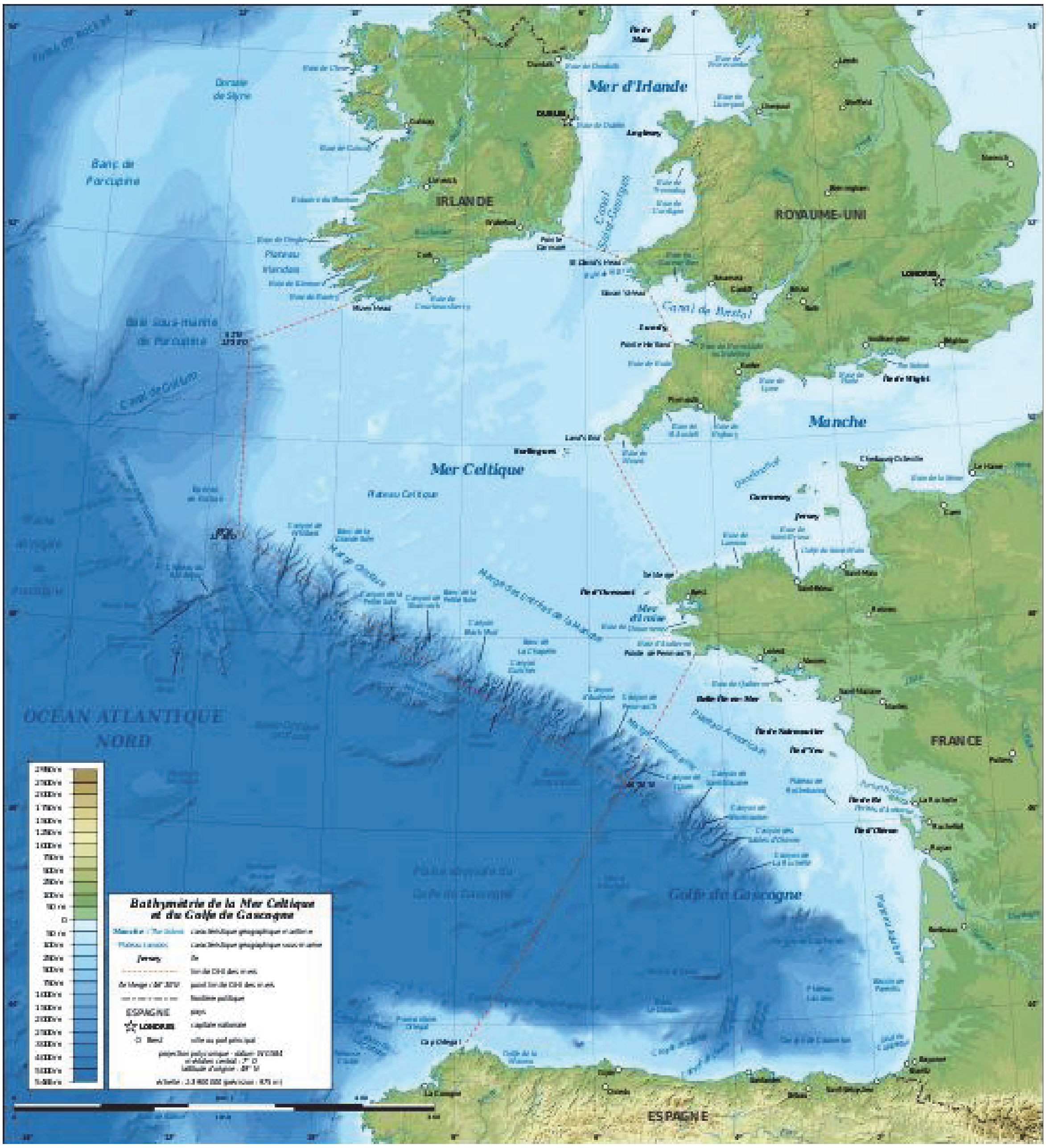
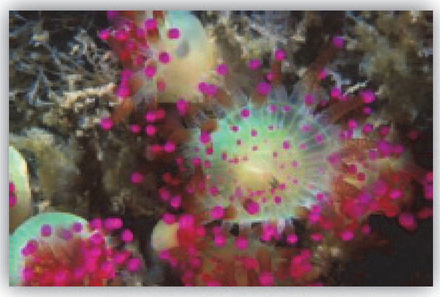


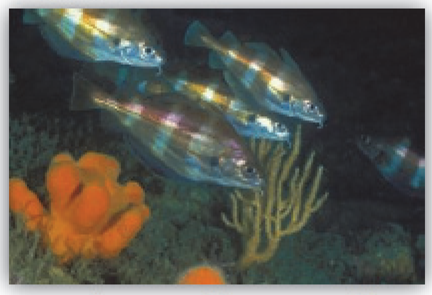
Figure 4: Bathymetric map of the Celtic Sea and the Gulf of Gascogne
Source: wikipedia.org

This report is prepared in line with the project requirements of work package 3 (WP3) MERiFIC project ('technology support'). Through a study of existing literature, this paper summarizes and compares different conclusions from observation campaigns and monitoring reports, scientific articles and internet websites and aims to provide a key to understanding environmental impacts, proven or suspected, generated by marine energy extraction devices.



Corynactis – Anémone bijou (Corynactis Viridis)

Grand dauphin (Tursiops Truncatus)



Tacauds communs (Trisopterus Luscus)

Himanthales (Himanthalia Elongata)

Vue aérienne de l'archipel de Molène

Homard européen (Homarus Gammarus)

Mouettes tridactyles (Rissa tridactyla)

Phoques gris (Halichoerus Grypus)

Figure 5: Photographic Board of the Biodiversity in the Iroise Sea

©PNMI, Yves Gladu (except for grey seals, ©Cornwall Seal Group, Sue Sayer)

The concept of impact and framework of reading

Firstly, it is important to distinguish between an effect and an environmental impact. Environmental effects refer to the wide range of measurable interactions, likely to occur between devices and the marine environment (Polagye et al., 2011). Environmental impacts refer to the effects that have a high probability of environmental nuisance (Boehlert & Gill, 2010).

Scientific studies of the impacts and environmental effects of MRE are still immature, uncertainties exist and it is important to provide a framework for common reading and analysis to assess the state of knowledge. Boehlert & Gill (2010) and Polagye et al., (2010), propose clarification and an analytical framework (according to work by McMurray (2008) on wave energy) and puts the effects of the use of MRE in the context of ecological risk assessment, considering stress factors and receptors. They speak of “stressor” and “receptor”. The “stressors” are stress factors that cause a change in the physical, chemical or biological ecosystem. It depends on the phases of construction, operation and dismantling of the facilities. The “receptors” are the elements of the ecosystem that can respond in one way or another to a ‘stress factor’ (Boehlert & Gill, 2010), changes are observed in the different compartments of the ecosystem (biotope, biocenosis) (Carlier & Delpech 2011). The effects vary depending on the scale and the receptors; if the effects are large enough to have an impact, these may be experienced at different levels, biotic and abiotic population processes.

Gill (2005) counts various stressors generated by MRE projects on the marine environment:

- Exploitation and barriers to energy flow: hydrodynamic disturbance regimes;
- Disturbance of the sea bed and re-suspension of materials: disturbance of sediment regimes;
- Physical presence of structures: alteration of habitats and seabed organisms;
- Physical presence of structures: interference with the movements and migrations of species;
- Physical presence and action of the machines: collision with the species;
- Noise and vibration during the construction and operational phases;
- Emission from the electromagnetic fields;
- Toxicological presence of paints and anti-fouling and the risks of accidental pollution.

Acceptable levels of disturbance will depend on the sensitivity of a habitat, a community or a species, its vulnerability and resilience as well as the state of local / regional conservation of the species and habitats in question (McLeod, 1996).

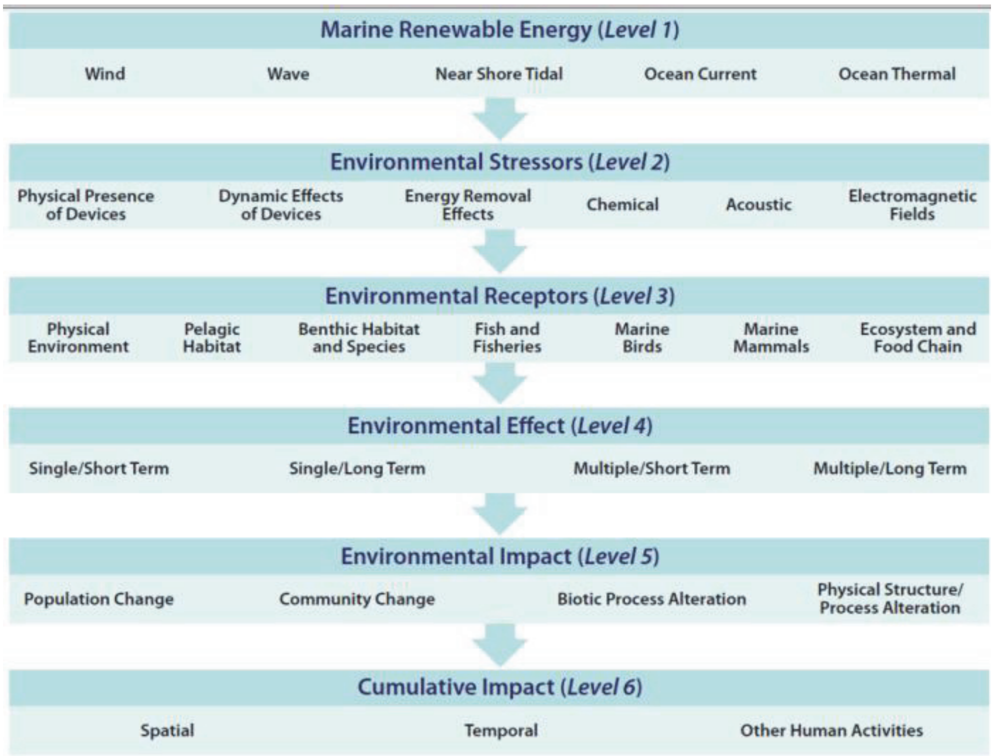


Figure 6: Framework of environmental effects of MRE
Source: Boehlert & Gill (2010)

The cumulative effects are the result of the accumulation and interaction of several direct and indirect effects generated by a project or by several projects in time and space, can lead to a synergistic effect, that is to say an effect greater than the sum of the elementary effects. According to Boehlert & Gill (2010), cumulative impacts should be taken as an additional dimension and the current state of knowledge attained is level 4 rather than level 5.

Polagye et al., (2011) has developed a conceptual approach to the environmental effects of the use of the kinetic energy.

Stressors	Receptors
Presence of devices: static effects	Physical environment: near-field
Presence of devices: dynamic effects	Physical environment: far-field
Chemical effects	Habitat and invertebrates
Acoustic effects	Fish: migratory
Electromagnetic effects	Fish: resident
Energy removal	Marine mammals and seabirds
Cumulative effects	Ecosystem interactions

Figure 7: Environmental stressors and receptors, associated with the development of kinetic energies
Source: Polagye et al., (2011)

Each stress factor is analysed within a common framework. Firstly, the importance of each stressor compared to the receptors is qualitatively assessed as “high”, “medium”, “low”, “not acceptable” or “unknown”.

Then the uncertainty associated with this assessment is described as “high”, “medium”, “low” or “unknown”. The results are presented as a matrix of interactions between stressors and receptors. The colour of a cell indicates the degree of importance of the interaction. The number and colour of the triangles indicate the uncertainty associated with the level of significance.

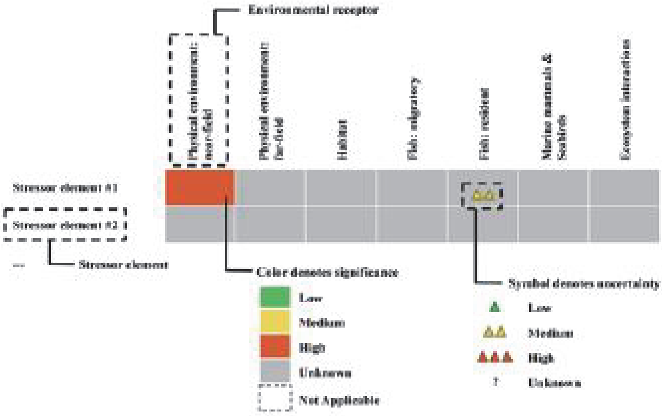


Figure 8: Example of the impact assessment matrix according to Polagye et al., (2010), for the stressors
Source: Polagye et al., (2010)

A similar framework applied to the stressors is used to analyse each receptor. Firstly, the importance of each receptor is evaluated against environmental stressors as ”high”, “medium”, “low”, “not applicable” or “unknown”. Then the uncertainty associated with this assessment is described as “high”, “medium”, “low” or “unknown”.

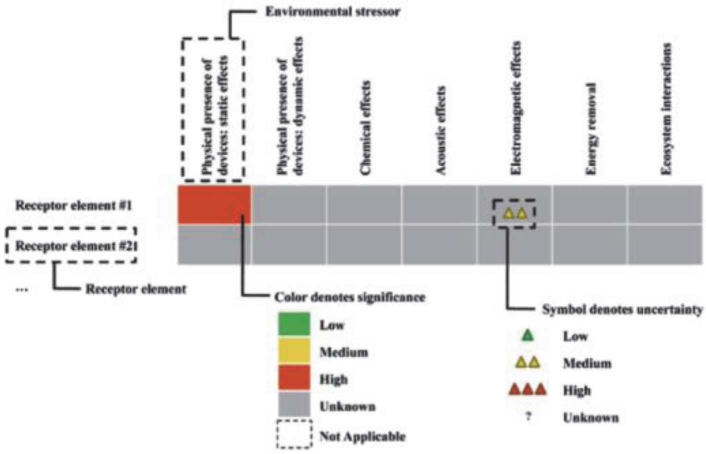


Figure 9: Example of matrix studies impacts according to Polagye et al., (2010), for the receptors
Source: Polagye et al., (2010)

The degree of importance and uncertainty associated with a specific interaction (stressor/receptor) may vary depending on the size of the operation. To reflect this variation, a distinction is made between the pilot deployments (to indicate areas of high priority in the short term) and deployments of a commercial scale / level (to indicate areas of high priority for the long term).

The set of matrices for each stressor and receptor is presented in Appendix 5.

The impacts can be classified according to several criteria. The nature and magnitude of an impact on the ecosystem depend on the extent of the duration and the intensity of the changes caused by the development (Carlier & Delpech, 2011). There are hundreds of concepts of energy exploitation of the seas that exist. Impacts are therefore to nature and variables of intensity. Hence it is difficult to define a standard of protocol for assessment.

However, tools do exist to establish the extent of the effects that project implementation could have as an impact on the environment. These tools allow common protocols to be defined, the limits of environmental acceptability and require the state to be accountable for the level of conservation of natural areas. These tools help to ensure a level of respect for the environment, in line with the concept of "sustainable development".

2. IMPACT STUDIES AND LEGAL FRAMEWORKS

The challenge for scientists is to develop information, from both the qualitative and the quantitative approach, integrating all elements of an ecosystem, for the assessment of impacts on the environment. Decision making tools should be in place to help guide developers, both for optimisation of project conception as for strict control requirements (Linely et al., 2009).

Regulatory Tools

EIE

The "EIE", "Evaluation of Environmental Impact" determines the authorisation of certain projects, public or private, that have or might have a physical effect on the environment, is assessed by a 'national authority'. This assessment should determine the direct and indirect effects of these projects on human beings, fauna, flora, soil, water, air, climate, landscape, material assets and cultural heritage, as well as the interaction between these elements (europa.eu).

The EIE facilitates the integration of environmental issues in the design of projects and thus save on budgetary resources, both public and private, because the cost of an EIE are considered "negligible" compared to the high costs that could be caused by unanticipated environmental problems that arise at an advanced stage.

In addition, the EIE formalises public participation by allowing it to contribute to the design concept of the project. This generally promotes acceptability of projects.

The problem is that the EIE currently lacks baseline ecological data (initial state of the environment), which limits their implementation. As emphasised by Gill (2005), the major problem with the integration of ecology in planning and decision making is the lack of adequate information. On the other hand, it is rare that the EIE address the cumulative effect of existing activities or other locations provided. The ESIE (Strategic Study of Environmental Impact) on the other hand, takes into account cumulative effects and synergies at larger scales than the project (Wilhelmsson, 2010).

ESIE

The "ESIE" ("Strategic Assessment of Environmental Impact") Directive is intended to supplement the EIE (europa.eu).

The Member State responsible for the development of a project is required to send a copy of the project, together with a copy of the report on environmental incidences to neighbouring States where it considers that the project is likely to have environmental incidences on their territory, or at the request of the other member State/s. These can initiate consultations on cross-border impacts of the projects with the responsible member State, as well as the measures envisaged to reduce or eliminate these incidences.

When a project is approved, the Member State responsible shall inform all stakeholders and provide them with the following:

- Planning or programme adopted;
- Statement summarizing how environmental considerations have been integrated and their relationship to the environmental incidences;
- Opinions and the results of consultations;
- Reasons for the choice of the project as adopted;
- Statutory requirements/measures for monitoring.

This assessment takes into account the likely significant effects of the implementation of the project, including the short, medium and long term effects, permanent and temporary, positive and negative effects, side effects, cumulative and synergistic and correlations with:

- Biodiversity, habitats, fauna and flora;
- Geology, substratum and coastal geomorphology;
- Landscape or seascape;
- Aquatic environment;
- Air quality;
- Climate and weather;
- Population and health;
- Other users, physical assets (infrastructure, other natural resources);
- Cultural heritage;
- Protection of sites and species.

(DECC, 2011)

Member States can provide coordinated or joint procedures in order to avoid duplication of environmental assessment when the project is covered by this Directive and other Community Acts.

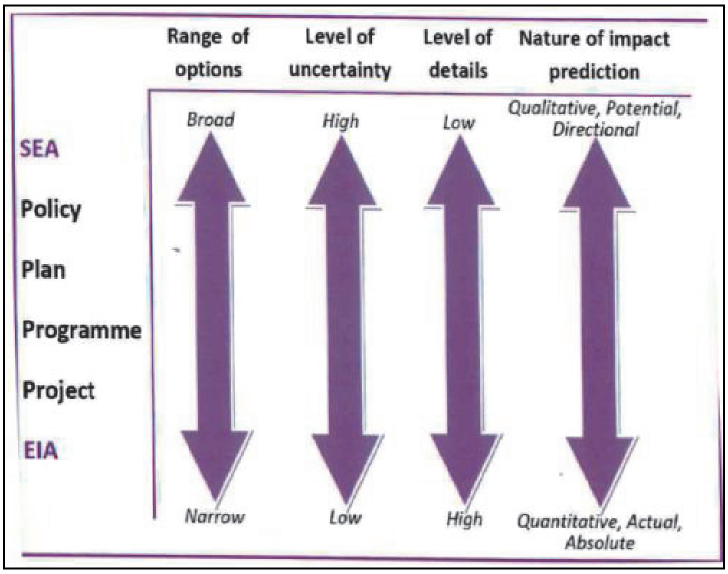


Figure 10: Main differences between the EIE and ESIE, adapted from Eales et al., 2003

Source: Wilhelmsson et al., (2010)

The Guidelines - Fauna Flora Habitats and Birds and the Natura 2000 network

The 'Birds Directive' (79/409/CEE, 1979) offers the long-term conservation of wild birds in the European Union targeting 181 species and sub-species, in particular migratory birds and those considered rare and vulnerable. More than 3000 sites have been classified by the member States of the European Union as Special Protection Zones (ZPS).

The directive “fauna flora habitats” (92/43/CEE, 1992) establishes a framework for community action conservation of fauna and flora and their habitats. This directive lists over 200 types of natural habitat, 200 animal species and 500 plant species of community interest in need of protection. Special Conservation Zones (ZSC), currently more than 2000 for 12% of European territory, aim to promote the maintenance of biodiversity, taking account economic, social, cultural, regional, and establish measures to maintain or restore a favourable conservation status, natural habitats and species of interest to the European Union.

The ZPS and ZSC form a network of conservation areas called “Natura 2000”.

The Natura 2000 network is a collection/grouping of European zones of nature, land and marine, identified for rare or fragile wildlife, animals or plants and their habitats. Natura 2000 balances nature conservation and socio-economic concerns (development-durable.gouv.fr). Networking sites extend throughout Europe in order to make this initiative consistent with preservation of species and habitats. (Annex 3, Natura 2000 Iroise Sea)

According to the strategy for biodiversity in the European Union, the implementation of MRE (Marine Renewable Energy) devices must take account of Natura 2000 sites/zones in order to underpin the objectives of these guidelines. In France projects, plans, programmes or events that may significantly affect the natural habitats and species present on a Natura 2000 site must have the impacts assessed. A simplified evaluation form is provided by the departmental territories of the sea, and if it can demonstrate that the issues of conservation of habitats and species or sites/area are not threatened, there will be no need for further studies.

In France, the Natura 2000 network in the sea stretches to 39,848km2 of marine areas, nearly 40% of its territorial sea (in February 2010).

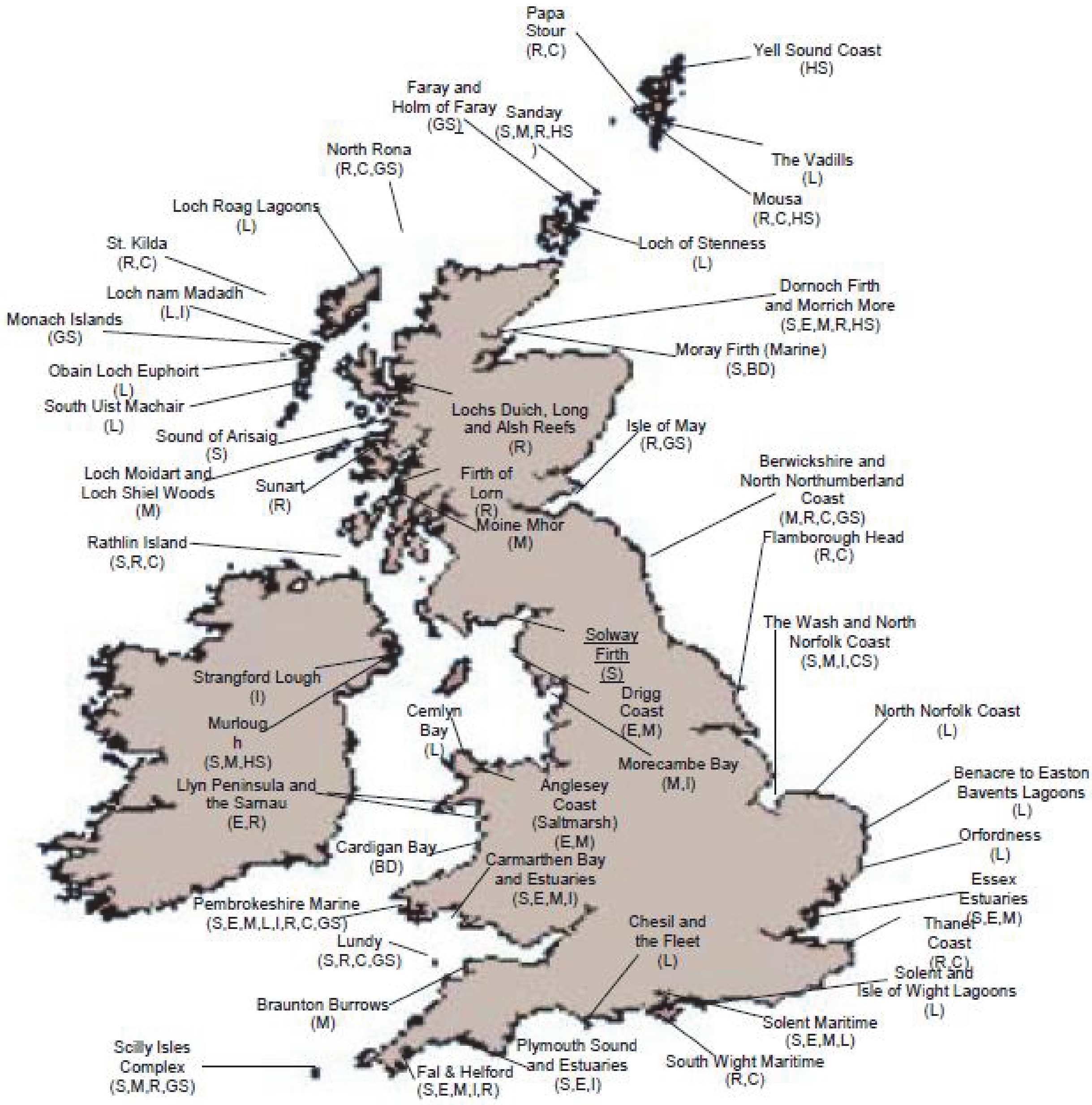


Figure 11: The location of candidate sites in the UK of Special Areas of Conservation
S - Sandbanks slightly covered with water; E - Estuaries; M - not covered mudflats during low tide; I - Large shallow inlets/coves/creeks and bays; L - Lagoons; R - Reefs; C - Sea caves; HS - Harbour seal (seals); GS - Grey seal; CS - Common Seal; BD - Common Dolphins

Source: Hiscock et al., (2002)

The above document (Figure 11) shows the diversity of the Natura 2000 network sites (in the UK).

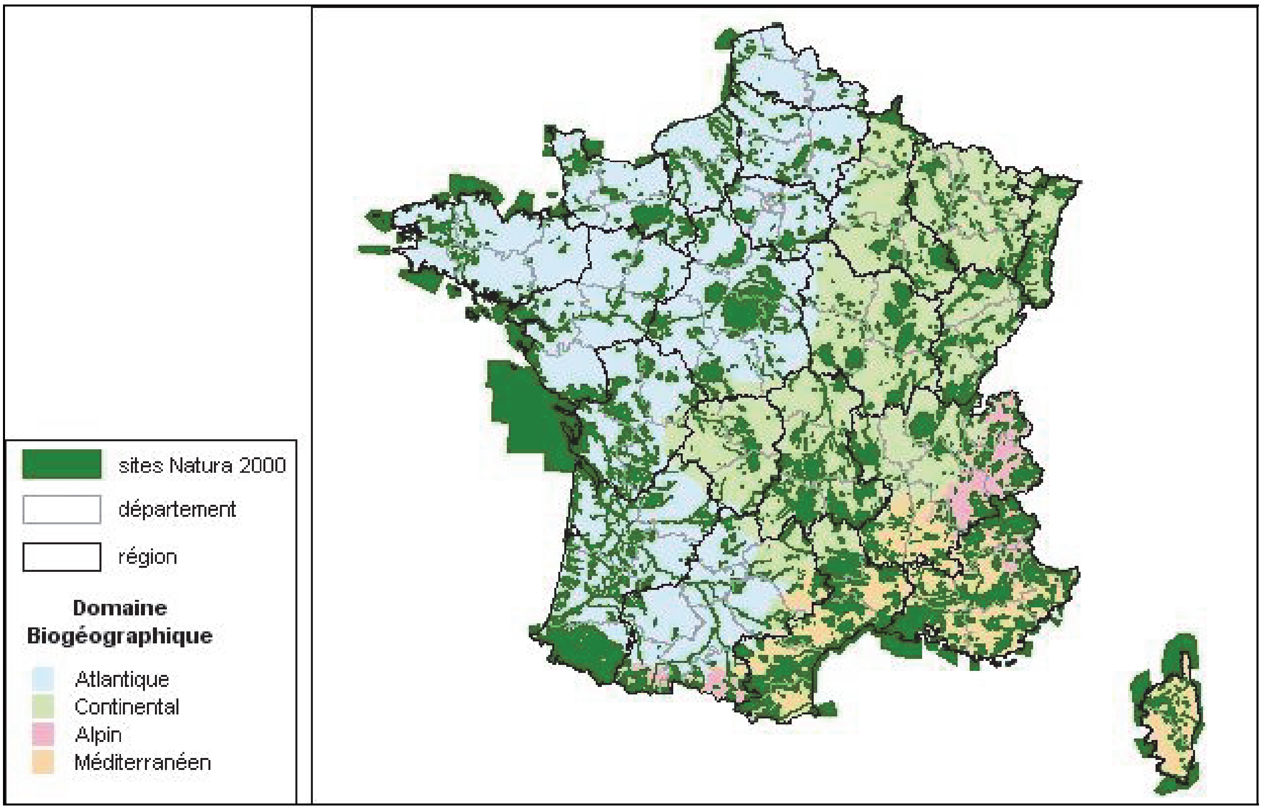


Figure 12: Natura 2000 sites in France
Source: ria-etel.n2000.fr

__The (DCSMM)__

The (DCSMM)(Strategy Framework Directive for the Marine Environment) (2008/56/CE) requires Member States to identify the major anthropic pressures exerted on the marine environment, and to develop a comprehensive framework for coordination of local actions to fight against threats to the marine environment such as the impoverishment or the degradation of habitats, the disappearance of biological biodiversity, contamination by dangerous substances etc. In line with the habitats and flora-fauna-birds and the framework directive (2000/60/EC), it aims to maintain or restore the proper functioning of marine ecosystems (conserved biodiversity and correct interactions between species and their habitats, dynamic and productive oceans) while permitting continuing use of the Seas for future generations.

(developpement-durable.gouv.fr)

Eleven qualitative descriptors**,** common to all Member States of the European Union, serve to define the ecological status (biological diversity, non-native species, fish stocks, the marine food chain, eutrophication, seabed integrity, the permanent alteration of hydrographical conditions, the concentration of contaminants, the quantity of contaminants in fishery resources, marine debris, the introduction of energy).

This Directive obliges the Member States to carry out sanitary and biological checks, necessary for reporting to the European Commission. Thus, the information reported by the Member States, namely: characteristics, pressures and impacts (Annex III), programmes for monitoring and surveillance (Annex VI); which can be used to facilitate impact studies (Wilhelmsson, 2010).

Institutional Tools

Marine Protected Areas in France

In France, law no. 2006-436 of 14th April 2006 relating to National Parks, Marine Parks and Regional Parks, has created a national public department of an administrative nature: the Maritime Protection Agency (AMP) for the protection of the marine environment.

It supports AMP managers to strengthen the work dynamics and trade policies, contributes to the development and management of the AMP network, contributes to the knowledge of the marine environment, and allows France to fulfill its international commitments for the protection of the marine environment (aires-marines.fr).

There are six categories of marine protected areas that exist, each meeting its own objectives while being complementary (to the others): the National Parks, Nature Reserves, the Prefectoral Regulations for the protection of habitats, Natura 2000 sites, the public parts of the coastline assigned to the Conservatoire and Marine Parks. By Ministerial Order dated 3rd June 2011, the list of marine protected areas created in 2006 was supplemented by nine new categories. These new AMP's are recognised internationally as a new approach to protection: RAMSAR sites, the World Heritage Sites of UNESCO biosphere reserves, sites under Barcelona (Mediterranean) agreements, OSPAR (North East Atlantic), Nairobi (East Africa) Cartagena (Antilles) and CCAMLR (Antarctica), and sites of national hunting reserves and with part of the marine wildlife in the Gulf of Morbihan.

The AAMP emits no opposition to the establishment of marine energy devices within them. Structure for the preservation and management of marine space, AMP provides a framework for experimenting with new uses and technological innovation allowing closer monitoring and increased environmental focus.

The "Joint Nature Conservation Committee" (JNCC) UK

JNCC is a public institution that advises the UK government on environmental protection at national and international levels. Originally created under the law "Environmental Protection Act 1990" the JNCC put together the "Natural Environment and Rural Communities (NERC) Act" in 2006 (jncc.defra.gov.uk). With regards to the marine environment, the JNCC addresses issues for the area outside the 12 miles limit. They are in charge of the process of designating new marine areas for protection (Marine Conservation Zone – MCZ project).

The "Natural England"

Natural England is a British government agency that is in charge of issues for nature conservation throughout the United Kingdom. With regards to the marine environment, Natural England addresses issues for the coastal zone within the 12 miles limit from the coast.

"Sites of Special Scientific Interest" (SSSI) in the UK

SSSI's (Sites of Special Scientific Interest (SSSI) are designate as protected areas. This is a fundamental element in British legislation for the conservation of natural sites and on which many other notions of British law are based, such as the National Nature Reserve, sites under the Ramsar Convention, ZPS's and ZSC.

Governance Tools

The BACI

Wherever possible, demonstration projects apply the BACI (Before After Control Impact, pre-assessment and post assessment of impacts). The purpose of this method is to evaluate the state of the environment before and after any change and compare changes at reference sites (or control sites) to those observed in the impact zones. The monitoring programme consists of three phases: initial three years of monitoring, monitoring during construction and three years of monitoring the operation (DONG Energy, 2006).

The ICZM

The ICZM (Integrated Coastal Zone Management) (2002413/CE) is an approach to governance of coastal areas for sustainable development. Born as a result of the Rio Summit (1992) and the 21 Agenda approach, it is especially recommended by the Ramsar Convention (2002) and Johannesburg (2002).

The ultimate goal of ICZM is to build structures and regulatory instruments to ensure or restore the balance between human activities and natural resources, particularly in order to avoid the over-exploitation of resources difficult to replace, fisheries and tourism in particular, generally the goal is sustainable development.

Marine Natural Parks in France

The marine parks in France are structured for the protection of the environment while integrating the management of human activities. They do not aim to 'sanctuarise' a maritime zone of particular biodiversity, but rather to reconcile the exploitation of natural resources with the maintenance of ecological environmental functions.

Law no. 2006-436 of 14th April 2006 relating to National Parks, Marine Parks and Regional Parks and their functioning are based on the principles of good governance. This important dynamic dialogue–involves all stakeholders (elected officials, state agencies, the marine professionals, associates, users etc.). The stakeholder management team meets to discuss and vote together on measures that will be applied.

Within marine parks, certain activities that may affect the environment, are submitted for authorisation in accordance with the procedure “notice of conformity” in the case of significant impacts or with the procedure “simple notice” in cases of minor impact (all fishing activities).

We still have very little leeway on the environmental impacts of MRE, due to the low number of sites. Scientific knowledge comes mainly from the existing/installed offshore wind farms. The diversity of the types and systems for the collection of data must be taken into account to adapt the devices for minimal impact on the environment.

2. MARINE ENERGY

The different types of marine energy

The sea is a fluid rich in energy flows that can be exploited in the following forms: offshore wind energy, wave energy (houlomotrice), tidal / currents energy. The harnessing of all these energies is possible and has already started in different locations around the world, at different stages of development.

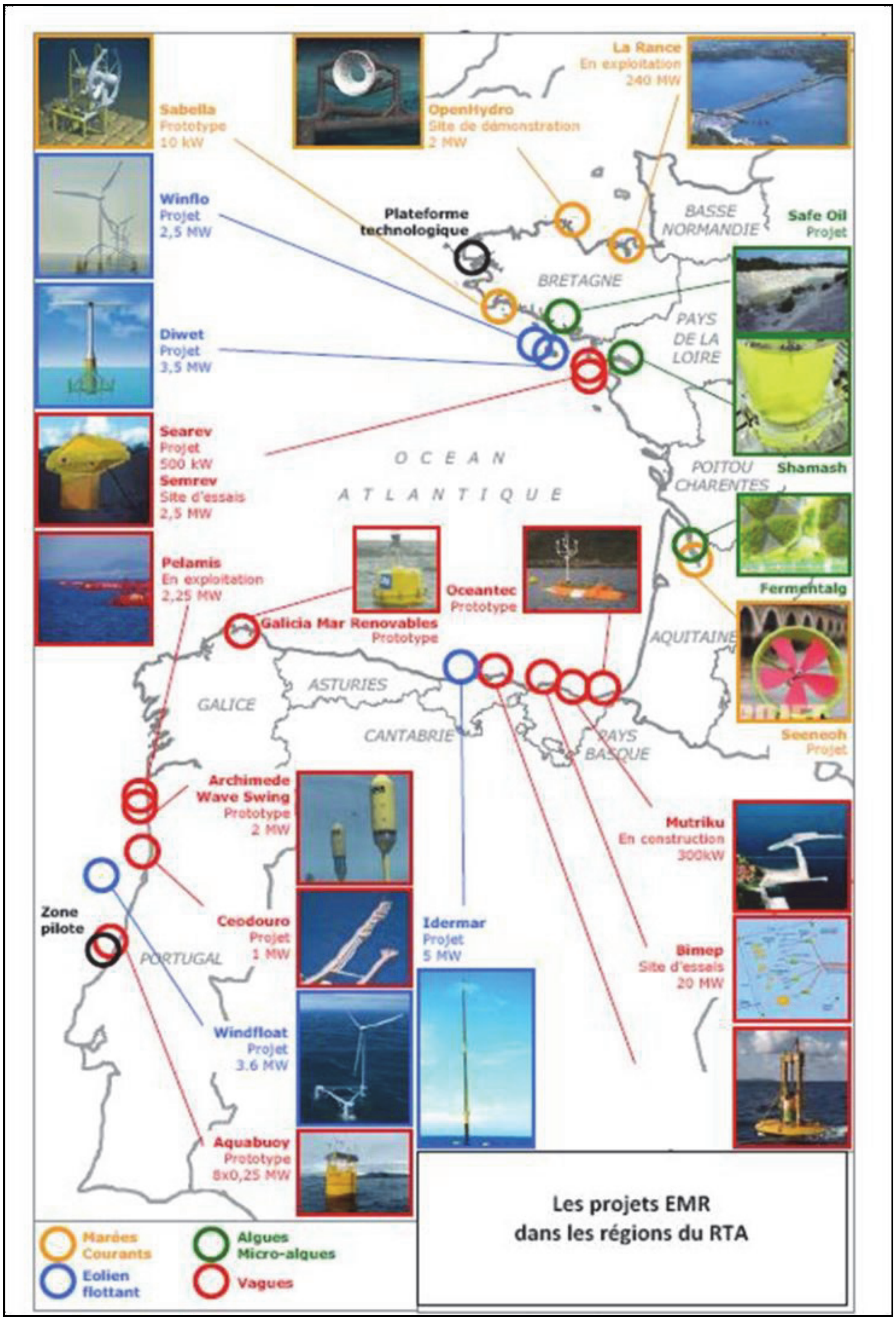


Figure 13: MRE projects in RTA regions

Source: erergiesdelamer.blogspot.fr

Theoretically exploitable MRE are many and varied. We will only consider those which we estimate are technically feasible and pertinent for installation between Brittany and England.

Hydrokinetic Devices

It is important to remember that tidal energy can be used in two forms: energy created by the elevation of the level of the sea, that is to say the different levels between two masses of water (tidal) and the kinetic energy of a mass of water set in motion by marine currents and tides (hydrolien). Hydrokinetic energy corresponds to the speed of the displacement of a mass of water generated by currents, and more specifically, by tidal currents. It differs from tidal energy which is based on water depth and not current speed.

Tidal Power Plants

These Plants exploit variations in sea level. This type of Hydro-electric Power Plant requires a suitable site (bay or estuary) where tidal amplitudes are important. The Rance Power Plant in France and the Sihwa Lake Power Plant in South Korea are the two largest tidal power plants in the world. That of France is the main source of electricity for Brittany, around 60% of its total electricity production in 2009 (pierre.hautefeuille.free.fr; wikipedia.org).

A dam established across the site forms a basin, the plant operates on the principle of inter-connected basins. At each tide, rising and falling, the water passes through turbines creating electricity. The ecological consequences of this form of MRE, are however, open to criticism and will not be studied in this report.

Figure 14: Tidal dams at Rance, France (left) and at Sihwa, South Korea (right)
The yellow line on the photographs represents a distance of 2km.
Source: Google Earth

The Tidal Turbines

A hydrolienne (tidal turbine) is a turbine that uses the speed of marine currents to produce mechanical energy, which is then converted into electrical energy by a generator. Compared with windmills, tidal turbines, take advantage of the density of water, which is 832 times greater than that of air, therefore, despite fluid velocity generally being lower, the recoverable power per unit area of helix is much greater than for a wind turbine.

Ocean currents are predictable, notably thanks to tidal currents, we can accurately estimate their production of electricity.

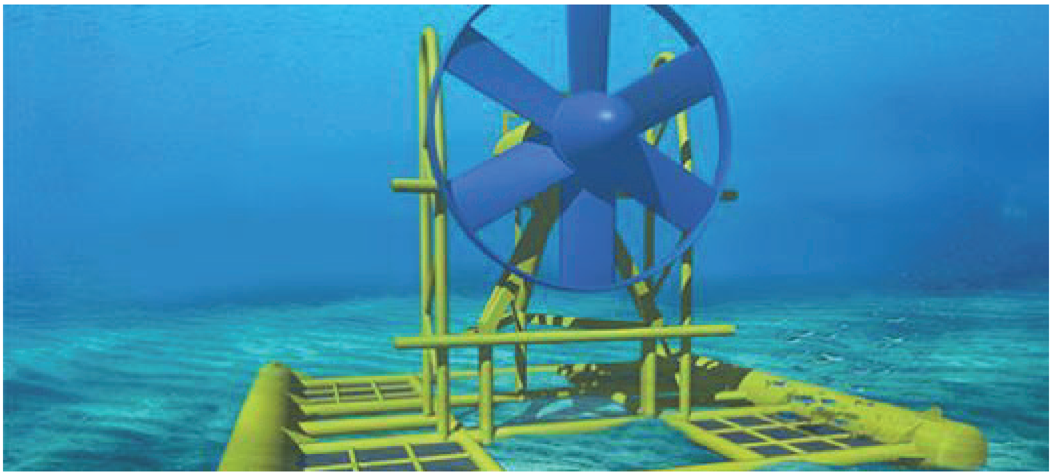


Figure 15: Image of a synthesis demonstrator Sabella D10 immersed in the passage of Fromveur to Ouessant
Source: connaissancedesenergies.org

Source: fr.dcnsgroup.com   Source: letelegramme.com
Figure 16: The Paimpol-Brehat Turbine

Marine Turbines are very expensive to maintain, which is frequent, and is difficult because of their immersion in water. For this reason, some turbines have a structure that can be raised above the water. Ballast systems can raise and lower the production units, as at SeaGen in Strangford Lough in the United Kingdom.

Source: dailymail.co.uk Source: energiesdelamer.blogspot.com

Figure 17: SeaGen turbine in Strangford Lough (UK)

EMEC (European Marine Energy Center) is the European center for testing and research on marine energy**,** based in the Orkneys, Scotland, has documented numerous projects around the world. In Europe, significant potential exists: the British Isles together with the north-west of France, most of the tidal potential in Europe. It is estimated at 6GW in the UK, 3GW for France and about 1 GW for the rest of Europe (enerzine.com). The best sites are those where tidal currents are strongest. The major deposits are located in areas of high tidal ranges, where accidents of topography (such as islands, peninsulas, straits, passes**,** etc.) and/or of bathymetry (such as shoals, submarine canyons, landforms, etc.) inducing restrictions on the flow of water masses forming current veins greater than 2m/s in spring tide (impact study Sabella D10).

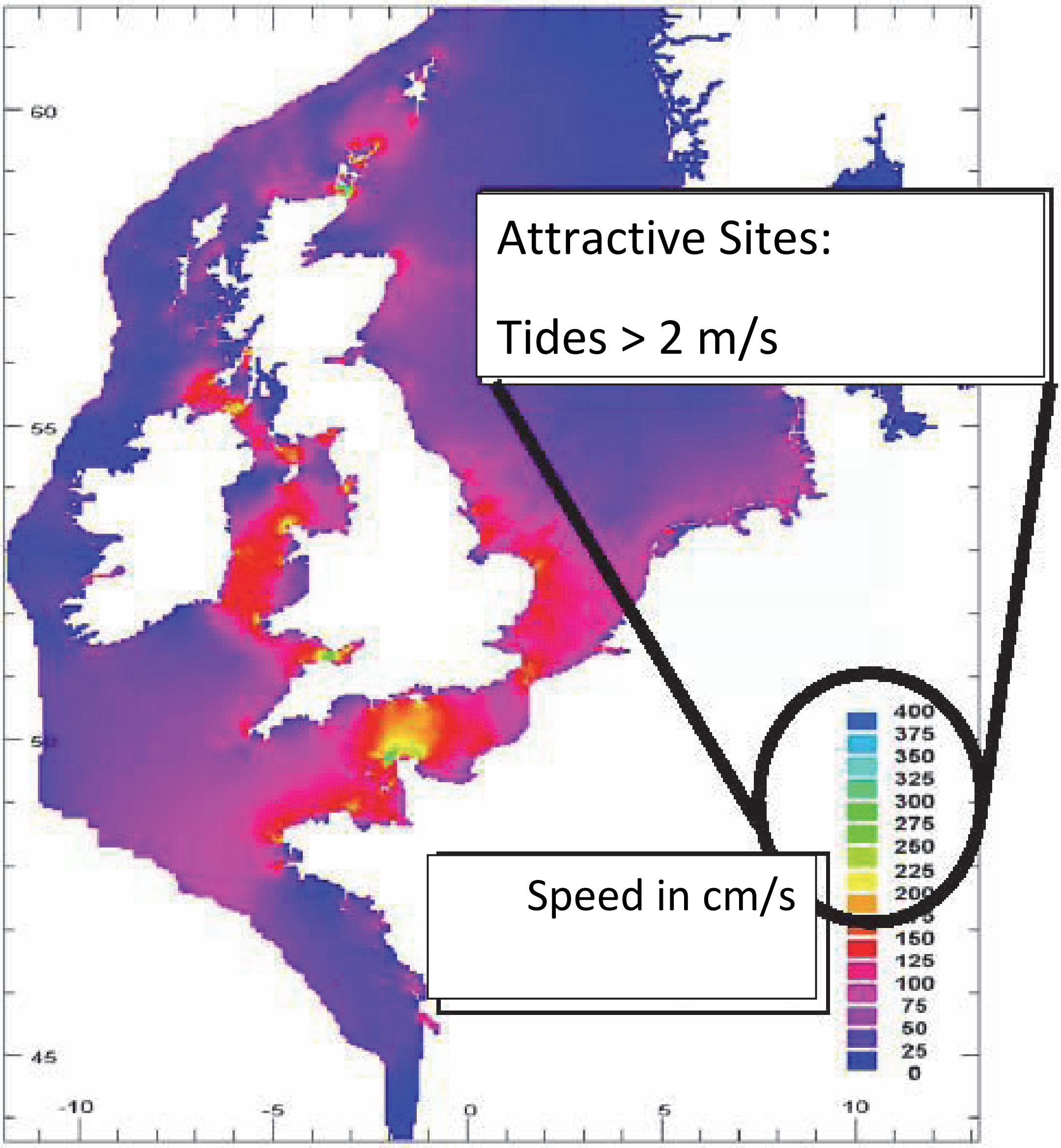


Figure 18: Max speed of currents: Channel, North Sea and St. George's Channel
Source: manicore.com

Restrict (to) locations where the tidal current is greater than 3m/s, in France, areas suitable for development of energy currents and tides are few and particularly vulnerable to storm surges and high seas. The Raz of Blanchard, the Raz of Sein Ushant or Ouessant are examples (Appendix 2).

Therefore, the technologies developed today in the EMEC, in sheltered seas, cannot be used in open seas.

Wave Power Devices

Wave energy is a concentrated form of wind energy. Wind blowing over large surface areas creates agitation in the form of a succession of waves (Abonnebgjutsyjkl et al., 2006).

Significant wave height and direction 19/02/2011 16:00 update 20/02/2011 15h04

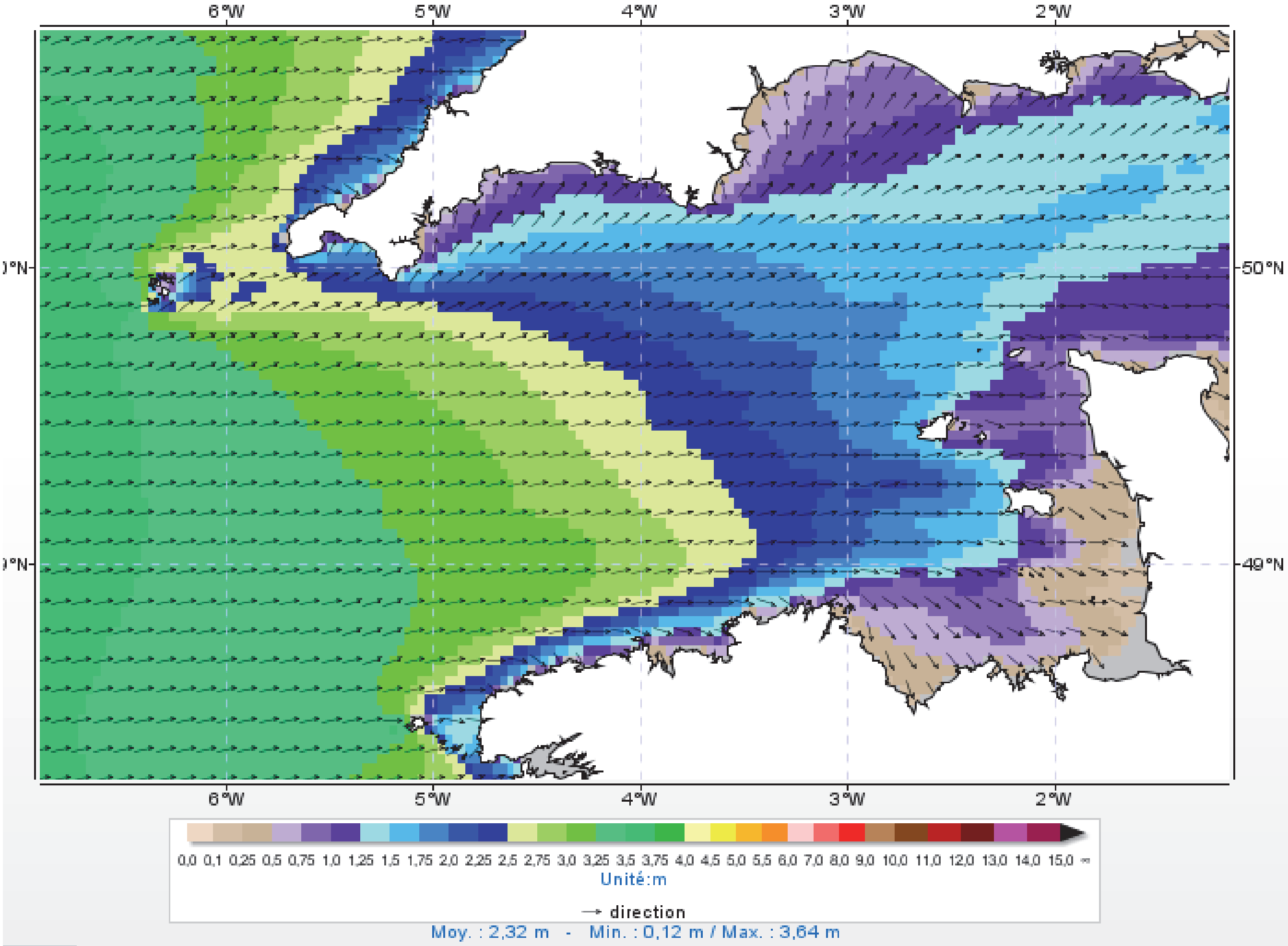


Figure 19: Significant wave height, 19 February 2011 in accordance with the Previmer model, between Cornwall UK and Finistere

Source : previmer.com

There are many patented methods for recovering energy from waves (Falnes et al., 1991), different forms and functionality and several have already proven their ability to produce commercially viable electricity (Baird et al., 1991).

For thirty years, the so-called first generation systems have been tested in different countries (Japan, India, Portugal, United Kingdom, Norway). These systems recover the energy of breaking waves and are generally characterized by the construction of the *chambers of oscillating water* (http://tpe-energiesmarine.e-monsite.com).

LIMPET (Land Installed Marine Power Energy Transmitter), in Islay Scotland, is a good example. The limpet is a concrete caisson 20 meters wide and 7 meters long, installed on the coast. The wave breaks on an inclined plane in the box and just compresses and forces the air through a turbine.

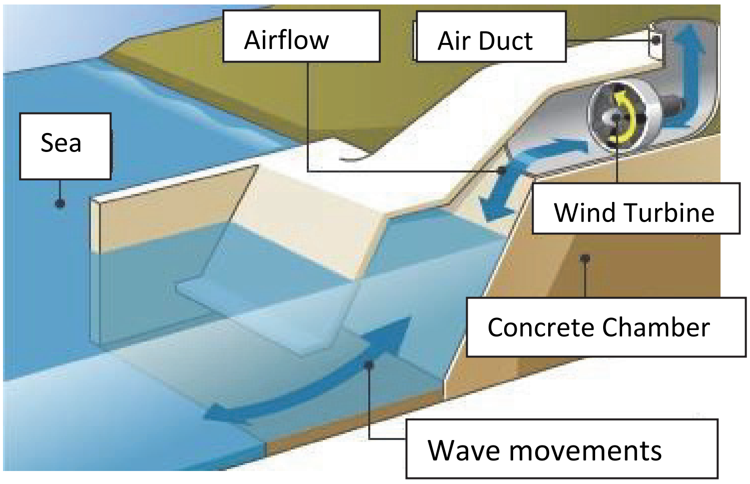


Figure 20: The "Limpet" system (Land Installed Marine Power Energy Transmitter)
Source: aquaenergiebelgium.com

These systems are infralittoral, they capture the energy of the waves coming to the shore after dissipation in the shallows, and have a major impact on the coast, because of the large infrastructure.

The second generation systems are offshore installations further out to sea. Various devices exist.

		Systèmes OWC	Systèmes oscillants – Translation	Systèmes oscillants – Rotation	Systèmes à franchissement	Autres
Offshore	Systèmes ancrés au fond (ou en mvt / à une structure ancrée au fond)	OceanLinx *(Mighty Whale)* OceanEnergy Sperbuoy	Wavebob, OPT Powerbuoy, *(Aquabuoy)*	Pelamis, SEAREV, PS Frog	Wave Dragon	Anaconda Polymères electroactifs (SRI)
Nearshore	Systèmes fixés/articulés au fond (ou en mvt / à une structure fixée au fond)		FO3 WaveStar CETO, AWS Seabased Wavetreader (sur éolienne)	Oyster, WaveRoller, BioWave ECOFYS (sur éolienne)		Rotors de type Savonius (au fond ou sur éolienne)
	Systèmes fixés/articulés ou intégrés sur un ouvrage côtier ou portuaire	Wavegen (Mutriku, Ile Lewis) Sakata Estuaire Douro		SDE (Israel)	SSG	
Côte	Systèmes spécifiques construits à la côte	PICO, Wavegen (Limpet, SeWave)			TAPCHAN (avec concentrateurs)	

Figure 21: Some examples of offshore wave devices

Source: unknown

The Pelamis is an oscillating offshore rotating system, floating equipment in the form of a snake. The one at Agucadoura, Portugal measures 120 meters long, 3.5 meters in diameter and is composed of four sections, seperated by cylinders (where electricity is produced). The sections bend and flex against each other when the waves move along the length of structure.

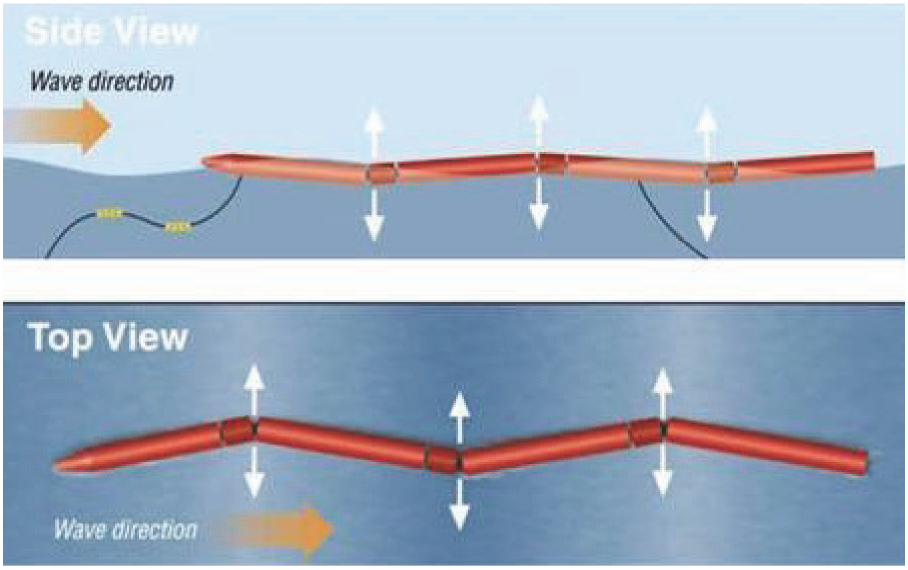
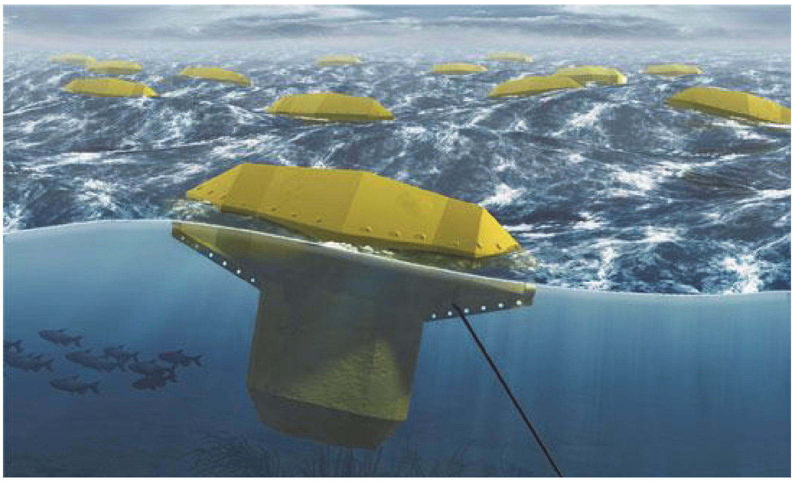
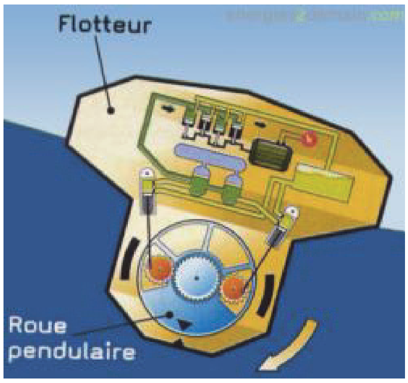


Figure 22: The "PELAMIS" system
Source: energiebleue.e-monsite.com

SEAREV (Autonomous Electrical System for the Recovery of Wave Energy) is a French project proposed by the ‘Ecole Centrale de Nantes’ (Nantes University) and the CNRS. A fully enclosed float is moved by the wave motion. This is a mechanical system similar to a pendulum placed inside a buoy. The movement of the mass influences the hydraulic pumps in the storing of energy in hydraulic accumulators that are discharged by driving electricity generators (Clement, 2006). The actual size of the System (24m by 14m) should have an installed electric capacity of 500kW. A wave farm would consist of tens of these SEAREV modules anchored 30m-50m deep, 5 to 10km from the shoreline (Muslim, http://www2.cnrs.fr/sites/communique/fichier/08searev.pdf).



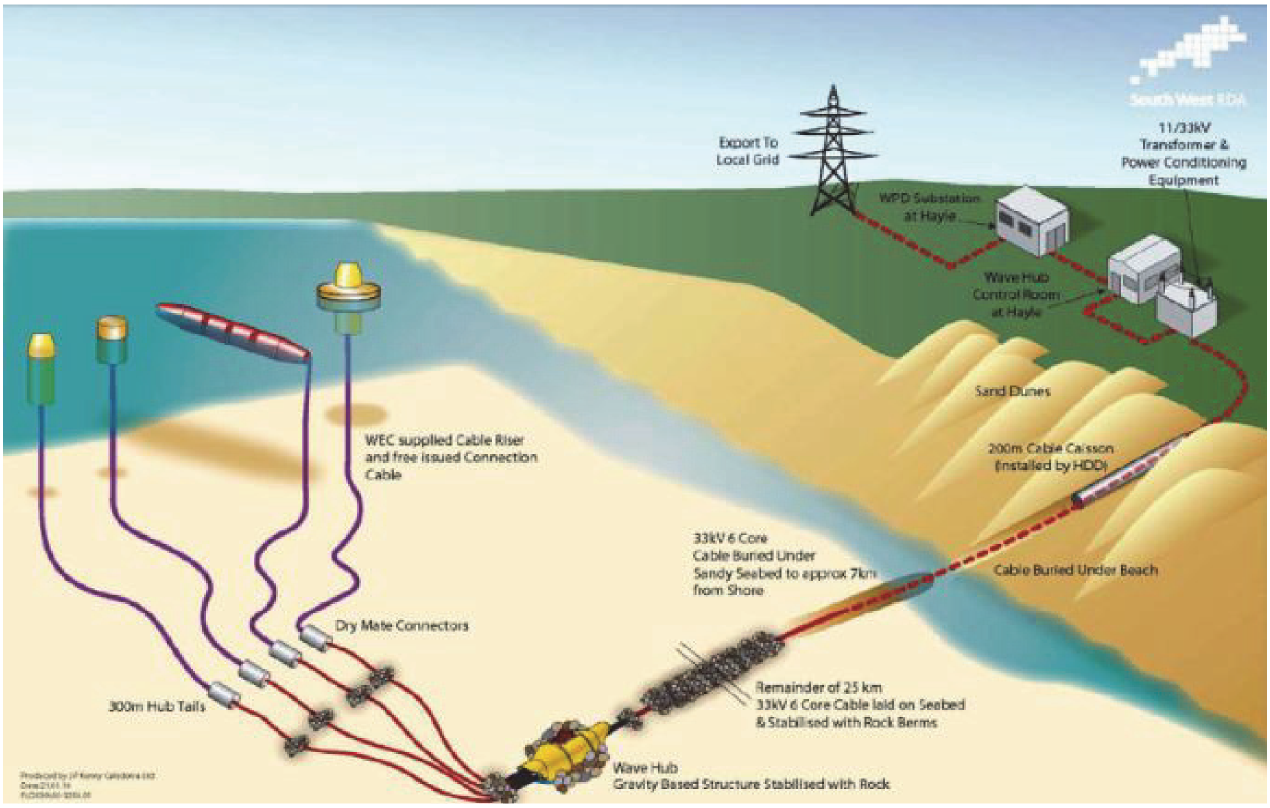


Source: electricite-de-l-eau.webnode.fr   Source: Energies2demain.com (pendulum wheel and float)

Figure 23: The SEAREV

The Wave Hub is a platform for sea trials, connected to the electricity Grid and located in the Southwest of England. It will test large-scale power generation technologies using the force of the waves. The Wave Hub will allow developers to test new wave energy technology.

The Wave Hub has permits and agreements to produce up to 20 MW at a well-defined and fully equipped site. Four separate anchorages each with a capacity of 4-5 MW will be leased. The 12 ton platform is connected to the 11kV electricity Grid in the United Kingdom by a 25km long submarine cable weighing 1300 tons.



Source: bbc.co.uk

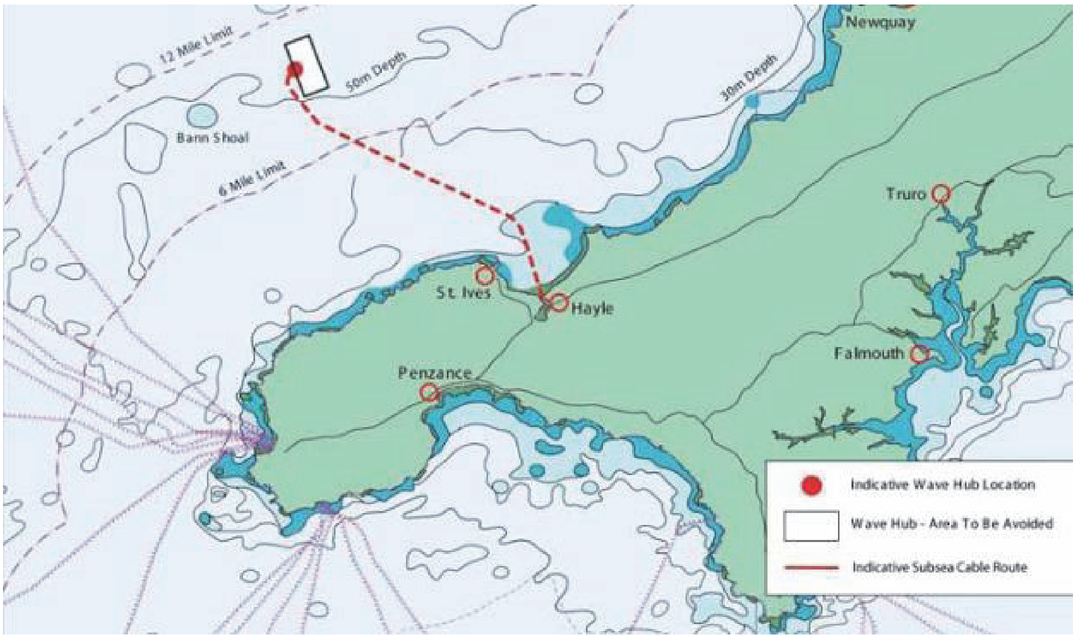


Figure 24: The Wave Hub
Source: energiesdelamer.blogspot.fr

Witt et al., (2012) published a study on the effects of biodiversity on the Wave Hub.

Offshore Windfarms

The wind is much stronger and more constant at sea than on land. It establishes over wide areas free of obstacles (ifremer.fr).

Source: infoniac.com Source: kk-electronic.com
Figure 25: Wind Farms of Horns Rev and of Nysted Park Offshore in Denmark

Offshore wind farms differ in their anchoring system. Can be distinguished:

- Gravity based foundations, attached to the bottom by their own weight or dense materials. These devices are generally limited to shallow waters and require preparation of the seabed.
- Single pile foundation or Monopile foundation

- A steel pile (which is an extension of the mast) is driven 10 to 20 meters into the seabed. Compared to the gravity foundations, the monopiles are much lighter and more resistant and can be installed in water depths of up to 30 meters. No preparation of the seabed is required, but where bedrock is encountered, a suitable hole must be drilled for each monopile and anchored in concrete
- Tripod foundations and Jacket foundations are made up from three steel piles. Jacket type foundations usually have four legs connected by a trellis. Tripods and Jackets are suitable for deeper water (30m to 60m), but not in water depths less than 6m or 7m
- Floating Wind Turbines. Wind turbines and floating platforms must be anchored to the sea-bed, to be held in place. The engineering involved is more complex, because of the random nature of the forces (wind and waves) acting on the wind turbines. These devices can be installed in very deep water (70 meters or more).

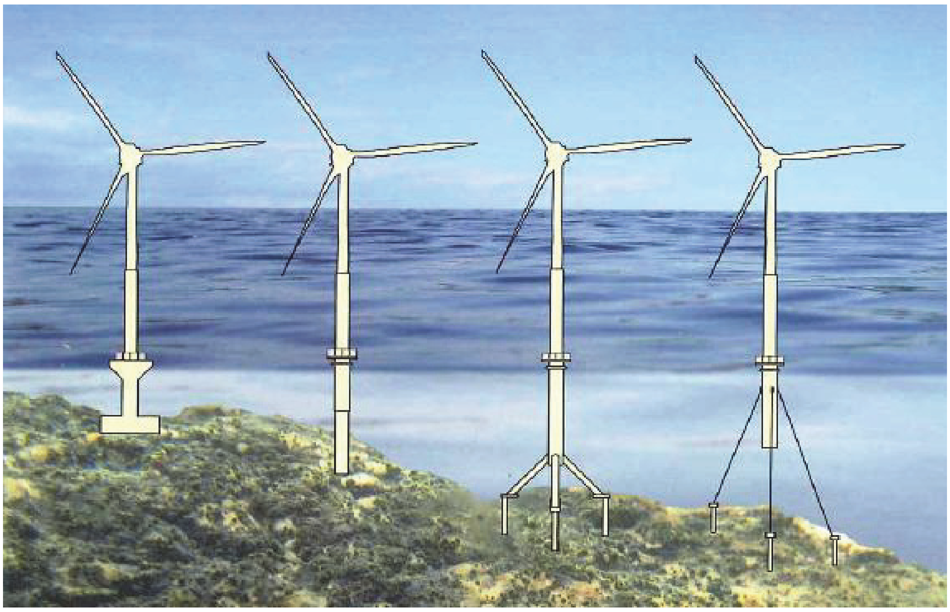


Figure 26: The different foundations for offshore wind turbines
Source: Wilhelmsson et al., (2010)

At present, most wind farms are located in shallow waters, less than 20 meters deep and at a maximum of 20 km offshore. Floating machines expand the fields of geographical development for wind farms in many countries such as the United Kingdom and France.

WINFLO is a floating wind turbine designed to be installed at locations with depths greater than 50m. The lightness of the gondola, buoyancy and anchoring flexibility makes it adaptable to all types of seabed and allows this type of turbine to have a lower Impact on the environment. (energiesdelamer.blogspot.fr/)

Figure 27: Floating Wind turbine WINFLO Source: meretmarine.com

Also to be noted is the development of the vertical axis wind turbine. Vertiwind, is a floating vertical axis wind turbine. Initially the turbine is tested onshore, then offshore at the first French site dedicated to floating wind turbines: Fos-sur-Mer.

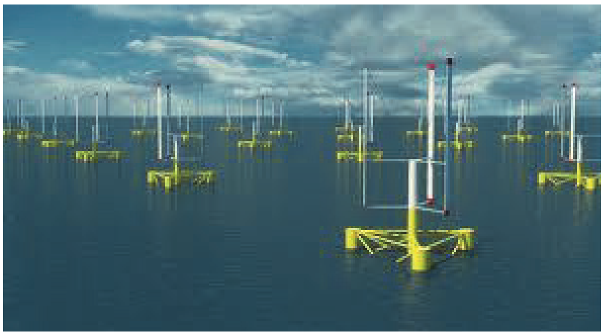


Figure 28: Vertiwind Project
Source: lenergeek.com

Particular attention should be given to the type of turbine, the construction technique and appropriate mitigation measures in the process of exploration, planning and obtaining authorization. Decisions in the planning stage have implications for the subsequent phases of the project life. Many impacts can be avoided during the planning phase which will reduce the need to implement mitigation measures which can be costly later on in the project. A lot of the problems that could not be mitigated during the project conception phase can be managed early in the project during the planning phase, including conservation priorities (Wilhelmsson, 2010).

The life cycle of a renewable energy project and related effects

The life cycle of a project refers to a logical sequence of activities to achieve the project objectives. Every project goes through a series of stages during its life. Firstly, there is a phase of feasibility studies during which success factors are defined, followed by a planning phase,-characterised by the breaking down of the project into multiple tasks and an execution/construction phase in which the project is executed, and finally the end/closure phase which marks the completion of the project.

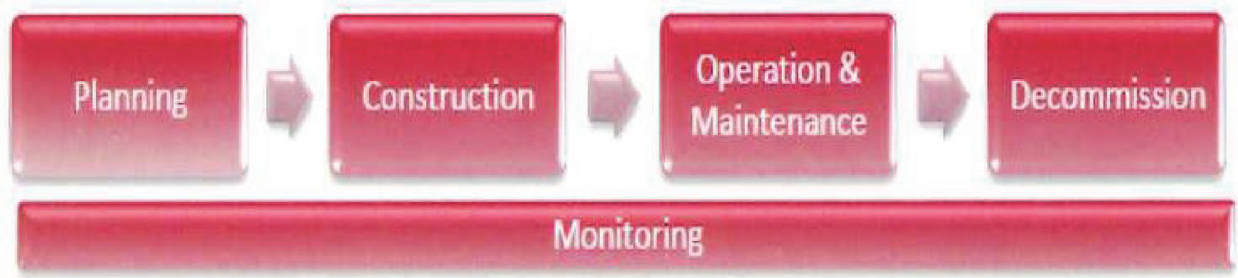


Figure 29: The lifecycle of a Renewable Energy Park

Source: Wilhelmsson et al., (2010)

Currently offshore wind farm projects have a lifespan of approximately 20 years (METOC 2000)

Hiscock et al., (2002) presented a summary of the potential environmental effects of an offshore wind farm. Their work distinguishes between the different phases during the life cycle of a project and separates the geographic extent of the effects of the project (Appendix 4).

Project life cycle	**Planning**	**Construction**	**Operation & Maintenance**	**Dismantlement**
Principals Activities	– Site selection – Machine design (gear type, anchor) – Licenses and permits – Implementation of appropriate mitigation measures	– Site preparation, dredging and leveling – Installations of foundations/ piles – Cabling – Maritime Traffic – Transport (Air)	– Repairs – Painting and sandblasting – Change Oil in transformer substations	– Dismantle – Maritime Traffic
Disturbance Factors		– Noise – Disturbance of ground – Increased activity	– Physical presence of machinery – Noise – Maintenance – Electromagnetic fields	– Noise – Disturbance of ground

Figure 30: The main activities for each phase of a lifecycle of an MRE Park
Source : Wilhelmsson et al., (2010)

Construction

The construction phase is probably the most disruptive. Work on the development of a wind farm requires the use of powerful and imposing machines. The artillery deployed during this phase generates an elevated level of activity in an environment usually undisturbed by human activity, in terms of traffic and disturbance.

The noise generated by the leveling of the seabed (a phase that sometimes includes the use of explosives), the installation of foundations (in particular pile driving in the case of monopiles for wind turbines) and maritime traffic, creates noise nuisance and increase the turbidity of the water deeply disturbing some benthic species. Site leveling and seabed construction will inevitably destroy the existing benthic (Delpech & Kalaydjian, 2009). However, most of the effects generated by the construction work are temporary (in the order of weeks to months) (Polagye et al., 2011). We can consider a reduced impact during the construction period, with a rapid return to the original condition (Delpech & Kalaydjian, 2009).

Figure 31: Wind turbine during construction
Source: Simmonds & Dolman (2008) in Evans (2008)

The deployment of ships and machinery (barges, cranes, etc) involves the risk of accidental spills of toxic substances, particularly in the case of devices using hydraulic fluid (Boehlert & Gill, 2010).

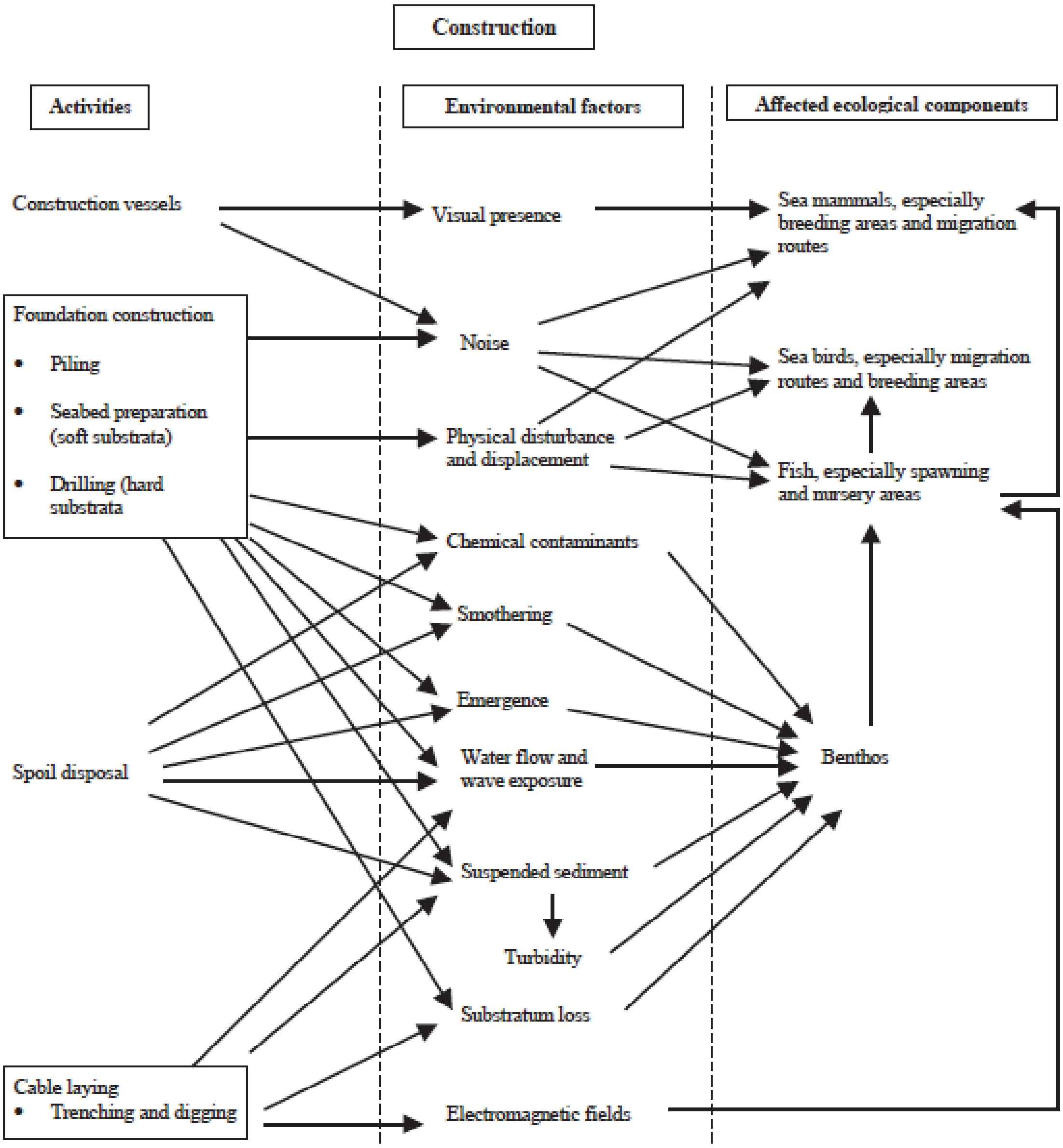


Figure 32: Conceptual diagram of the effects of construction (adapted by Elliot 2002; Parkinson, 2002)
Source: Hiscock et al., (2002)

The Operational Phase

During the operational phase, rotating machinery, movement of beacons, underwater noise and electromagnetic fields are often cited as stressors in addition to the removal of energy which acts on the hydrodynamics and cumulative impacts due to the interaction of multiple devices and / or activities.

But the physical presence of machines has an artificial reef effect that will be colonised by sessile species (animal or vegetal) (Delpech & Kalaydjian, 2009).

The Dismantling

Experience gained in the petroleum and gas industries can be adapted to the MRE sector (particularly with respect to the offshore wind farms because of the structural similarities). Therefore ~~us~~, the facilities could be dismantled and recycled, used as landfill or renovated and reused (Wilhelmsson et al., 2010).

In the first instance, it can cause problems by disturbing the sedimentation, particularly if the cables were buried, resulting in disruption of any habitat that has recreated and developed around these cables. Current experience with oil rigs favours explosives and cutting. Explosives kill most animals nearby. Given the large number of turbines in the area covered, the use of this technique involves significant impacts.

In the second case, if not dismantled, the installations could become permanent, given the very slow rates of degradation of the materials (steel, carbon). Habitat created around all the devices would be preserved.

In the third case, keeping the installations operational will involve continued maintenance. It remains to be said that both positive and negative effects remain on the marine environment.

Scale of Development and Cumulative Effects

The scale of any project may prove to be a major factor. A small scale installation can have very localised effects, and as a consequence, may be tolerable or even negligible. Projects at multiple locations require to take into account large portions of the coastal environment and will probably increase the duration and frequency of stressors over a larger geographic area. Which will require different terms of compensatory measures, applicable to a larger scale. (Masden et al., 2010).

Upon completion of the initial stage (in compliance with the requirements of the EIE and ESIE, it is essential to assess the ecological integrity and ecological risks in order to understand the effect of the implementation of one or more Wind Farms in a region (Nunneri et al., 2008).

Cumulative effects can be felt on an international scale because of the wide distribution of many marine species (ICES, 2011). Administrative boundaries rarely take into account the ecology and it may be necessary for an impact study to cross state or national borders and even across oceans. A high level and wide ranging Strategic Study of the impact on the environment (ESIE) might be the best way to ensure that the cumulative effects identified are associated with both active oceanographic processes in systems far larger than the operating site and to external effects such as interactions with other uses and users of resources.

Detailed modeling of the ecosystems is needed, but the models must be based on realistic data on patterns of interactions (Polagye et al., 2011).

The Concept of Mitigation

To the extent where the production of wave energy, hydrokinetic or wind farms (in deep waters) is only in its infancy, it is possible to study the effects (both positive and negative) of pilot projects with a view to mitigating (if negative) or promoting (if positive) effects of future commercial-scale farms (Inger et al., 2009). The mitigation can be done in several steps as shown in the "hierarchy of mitigation".

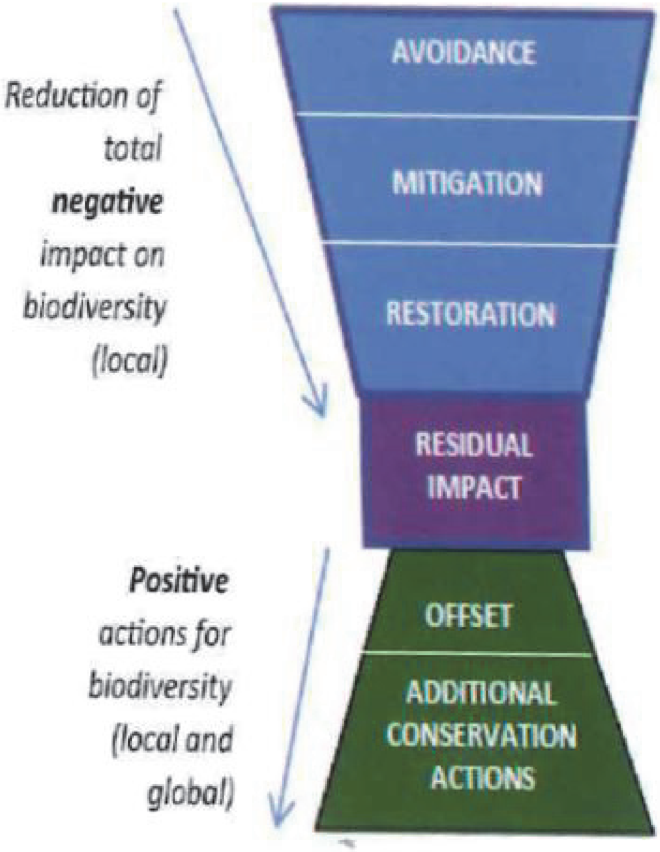


Figure 33: MRE Hierarchy of Mitigation
Source: Wilhelmsson et al., (2010)

It is necessary to quantify and anticipate compensatory methods and predict biodiversity losses and put them in balance with predictable gains, taking into account the composition of species, habitat structure, functioning ecosystems and mans' utilization of the resource (Linley et al., 2009).

Impacts and the opportunities to reduce them are dependent on the stage of completion of the project. Taking into account the stress associated with the MRE operation, based on the stage of exploitation (bathymetric survey, construction, operation and decommissioning) and the scope of stress in time and space, especially in terms of its duration, frequency and intensity (Boehlert & Gill, 2010).

Characteristics of environmental and social impacts can be acquired through experience from pilot plants of a significant size. Wave and tidal power technologies are in their infancy, but the lessons learned from the operation of offshore wind farms are applicable to the operation of hydrokinetic energy and wave energy, as they are independent of the type of devices for energy production.

In the future, wind farms and wave power could share the same foundation**s**, the same electricity transmission lines and maintenance costs; a sharing accompanied by a decrease in the overall disturbance of the marine environment (Wilhelmsson et al., 2010).

Each MRE project is characterized by its site and technology implementation that will affect a given space in a given period.

3 SUMMARY OF THE ENVIRONMENTAL IMPACT OF MARINE RENEWABLE ENERGY

Impacts on hydrodynamics and sediment dynamics

The physical presence of structures can disrupt coastal dynamic processes in the fields near to and far from MRE installations and change the landscape. The recovery of energy from waves and currents involves intercepting the kinetic energy which, in other circumstances, would be dispersed elsewhere in the marine environment. The interruption of the natural dynamics of marine energy will affect other physical processes (sedimentation, currents) and ecological (dispersal of food resources, larval recruitment, reproduction of species, etc), as well as human activities that are influenced by the functional dynamics environment or dependents.

The scale of the impact felt will depend essentially on the amount of energy extracted rather than the extraction method (Ian Walkington), although it is clear that different types of facilities cause different types of impacts (Bell & Side, 2011).

The consequences of such disturbance can have a direct impact on many environmental receptors: flora and fauna, navigation channels, coastal terrain, coastal defenses, etc. (Huddleston et al., 2010).

Physical presence; flow disturbances

Obstacles to flow tend to affect transportation of sediment, the order of a meter or kilometer and erosion around the installations (Walkington & Burrows, 2009).

Disturbance to flows induced by the mere physical presence of under-water elements, generate an increase in the water velocity around the foundations and therefore causes a winnowing (erosion) at the foot of the foundations creating a "scour pit" which can range from 0 to 100 meters.

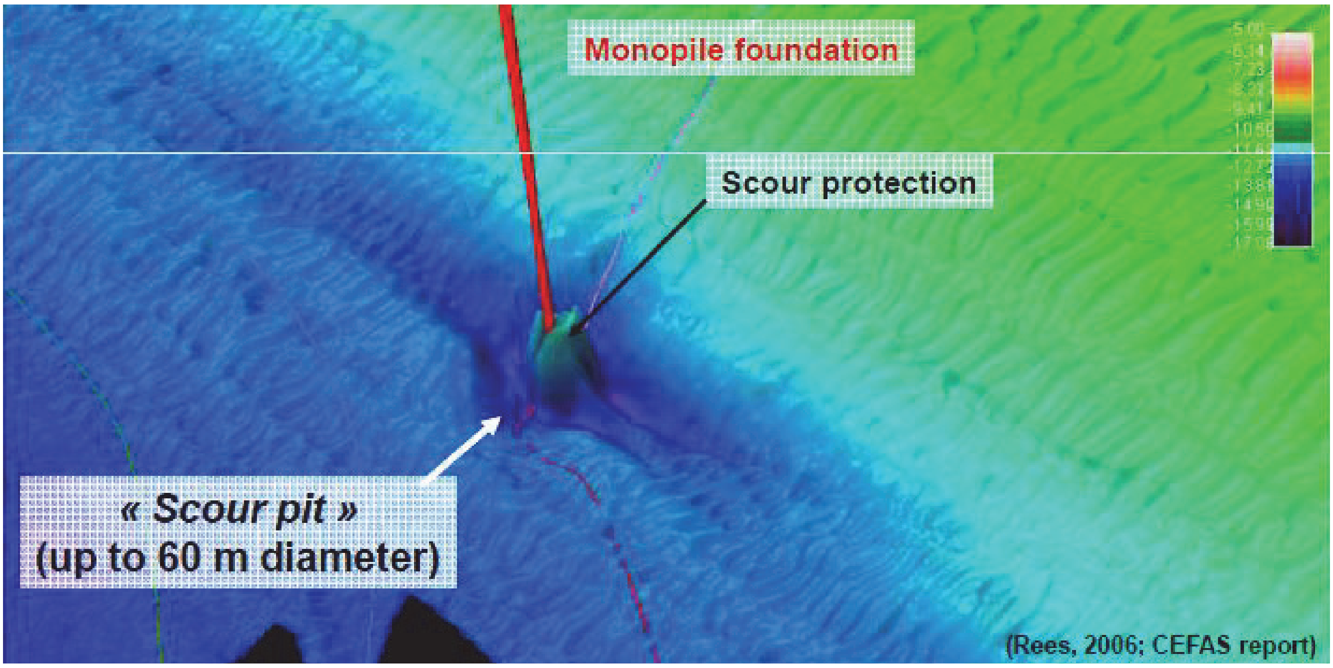


Figure 34: Leveling around a monopile
Source: Rees, 2006

It is recognised that the size of this type of sedimentary winnowing is limited to 10 times the diameter of the obstacle (OSPAR,2006).

Technically this effect can be reduced by the introduction of anti-scouring materials around the obstacle.

<u>Energy Extraction</u>

The removal of sufficient kinetic energy causes an aerodynamic change in the wake of the obstacle (hence the hydrodynamics in the wake of a Wind Turbine support).

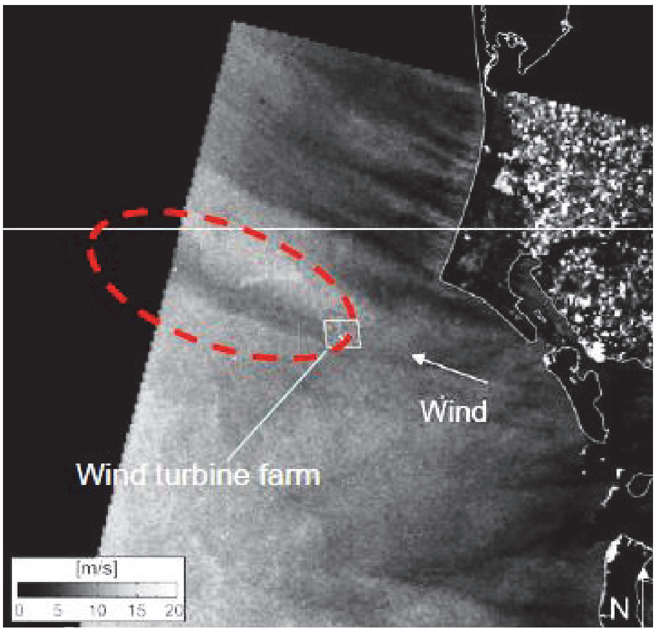


Figure 35: Hydrodynamics changes in the wake of a wind turbine monopile

Source: Christiansen (2005)

A decrease in velocity would lead to increased sedimentation downstream of the project in relation to the direction of the current, especially in areas of convergence of residual currents (Bell & Side, 2011).

It is likely that the change in hydrodynamics around structures and the extraction of energy will have long term effects on coastal morphology. A decrease in energy (height & force) of the waves and a change in currents (direction & force) will be felt at or near the coast, where, under natural circumstances, a large part of the energy is dispersed (Denny, 1988). A reduction in waves, especially those from a specific direction (i.e. downstream from a device) could lead to a change in the littoral drift and therefore materials and ultimately, the morphology of the beaches, bathymetry of shallow waters and substrates (Defo et al., 2009).

On the other hand, the exploitation of wave and tidal power could significant changes in tidal ranges along the coast and have an impact on the profile of the coastline.

Shapiro (2010) simulated large scale circulation changes, caused by the removal of energy from currents off the northern costs of Cornwall, UK. He used the three-dimensional model of ocean circulation POLCOMS (Holt & James, 2011) that had been applied to the Celtic Sea and the Bristol Channel, by incorporating, in addition to tides, wind forces, gradients of temperature and salinity and bathymetry constraints. For elevated levels of energy extraction, the model indicated changes in current velocity and kinetic energy. The highest being in the 12km diameter area of the park and within a radius of 10km to 20km around it. The impact was also felt at the level of circulation on a larger scale with changes in patterns of residual current observed up to 100km away.

Effects on biological processes

Some organisms must withstand extremely powerful hydrodynamic forces associated with breakers and / or tidal currents. Specific communities of species exist in highly dynamic infralittoral and littoral areas and these species are vulnerable to changes in the functioning hydrodynamics (Shields, 2010).

Wave Power Plants act as breakwaters that calm the sea (Pelc & Fujita, 2002), and cause a reduction in turbulance and breakers (Shields, 2010), and thus the mixing of the upper ocean layers, resulting in changes in the composition of phytoplankton species (Witt et al., 2012). These changes could have a negative impact on the rest of the trophic chain and fishing.

Little research has been done on the implications of the use of MRE for water-column communities. The reason being that decision makers do not consider that the communities of the water column have a significant impact and that there are no legal provisions covering the lower levels of the food chain. However, the vireo-bacterio-phyto-zooplanctonnique assembly is fundamentally important to ensure ecosystem services ultimately depend upon on the whole marine food chain and therefore productivity and biodiversity at all organizational levels (Linley et al., 2009). Sharples (2008) showed that primary productivity is strongly linked to the mixing process by tidal currents, which implies that intervening in the collection of energy is likely to affect marine productivity at an elementary level (Bell & Sde, 2011).

On the other hand, many fish species depend partly on the currents, for the transportation of small fish. Therefore, facilities that have an impact on currents between spawning grounds and food could be harmful (Shaw, 1982). Many sessile or sedentary organisms depend on water flow for transport of gases, nutrients and food and to assist in the dispersal of propagules and waste (Abelson & Denny, 1997; Nowell & Jumars, 1984; Jumars & Nowell, 1984; Koehl, 1996; Denny et al., 1992; Gaylord, 2008).

The removal of sufficient tidal energy could modify tidal ranges, which could then have an impact on the communities that depend on periodic exposure (Goss-Custard et al., 1991 in Boehlert & Gill, 2010). Changes in the quantity of priority species could occur if the energy extraction causes changes to traffic patterns, affecting subsequently the ecological connectivity and trophic links (CIEM, 2011).

The physical environment (nature of the substrate, currents, sediment dynamics etc.) largely conditions the biological compartment: associated benthic fauna and flora, which themselves will be important in the diet of predators who can live in the water-column (Delpech & Kalaydjian, 2009). Fish populations may be affected by changes in methods of sedimentation, the turbidity and the water flow as well as any associated change ocurring in the benthos. These factors are likely to affect fish populations at different life stages, with subtle effects on spawning grounds, feeding and migration (Bell & Side, 2011).

No significant effect, resulting from the collection of energy, is expected on the scale of pilot projects (demonstrator) (Karsten et al., 2008; Polagye et al., 2009). But to mitigate environmental impacts, it is essential to understand how MRE exploitation devices, affect water flow in close proximity (<1 km), distant (1km - 10 km) or regional dimensions (>10 km) (Shields, 2010). M The measures in test basins and fluid mechanics models can address performance and hydrodynamic properties of specific devices, and the results can then guide the design of devices and help define the space within networks (see Bai et al., 2009; Harrison et al., 2009; Myers & Bahaj, 2009).

Physical Presence of Plants: Reef Effect

The "Reef" Effect

Just as wrecks attract fish, which benefit from the shelter provided by these structures (Hiscock et al., 2002), the supports of the various immersed MRE devices become artificial reefs. Generally, artificial reefs are colonized quite quickly and attract many species of fish and crustaceans. The construction and the deployment of artificial reefs in coastal waters are practised throughout the world in order to manage fishing, protect and facilitate the rehabilitation of certain habitats and water bodies, or increase the recreational value of a zone (Ambrose, 1994; Brock, 1994; Guillen et al., 1994; Hueckel et al., 1989; Milon, 1989; Pickering et al. 1998; Wilehlmsson et al., 1998; Jenson, 2002; Claudet et Pelletier, 2004; Seaman, 2007).

Colonization of new habitats

Wind turbine foundations, anchor systems, turbine support structures, scouring protection rocks, become supports on which organisms fix themselves, this is what we call "fouling" (or bio-fouling). Fouling is a natural phenomenon where a wide range of organisms (bacteria, algae, barnacles, sponges, etc.) come and colonize underwater installations. Species colonizing structures vary depending on the depth, size and exposure (light, current) of the structures and the geographical location.

Anchor cables and buoyant structures undulate in the current providing better oxygenation and / or better contact with the nutrients in suspension and get covered with living epiphyte organisms and become micro-habitats, attractive to young alevins and organisms.

In this way these underwater structures may also become an interesting habitat for mobile species (including commercial species), crustaceans and molluscs, and invasive species.

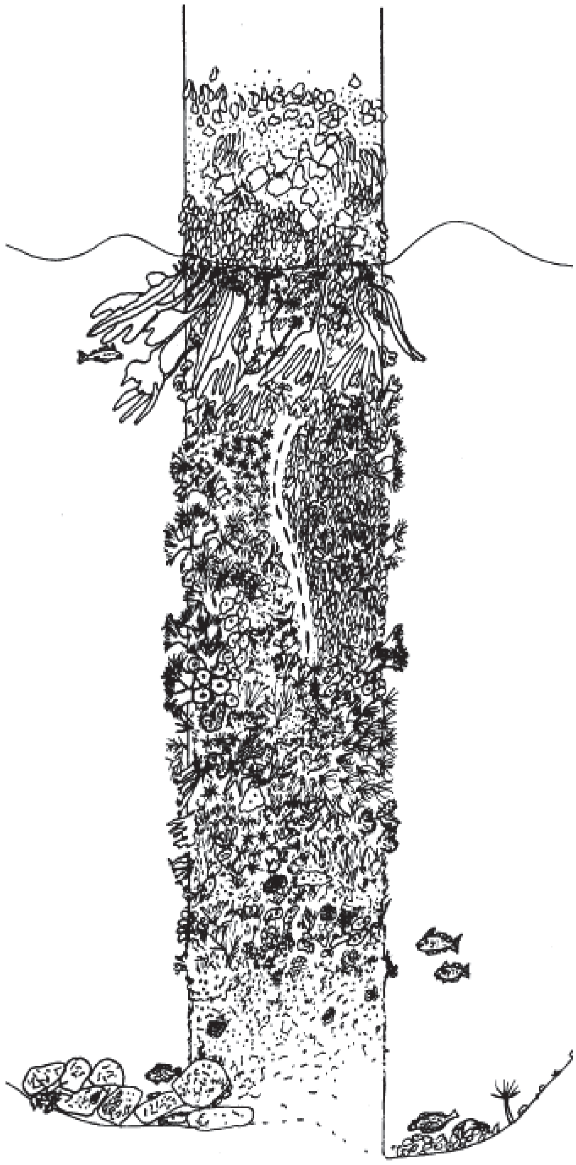
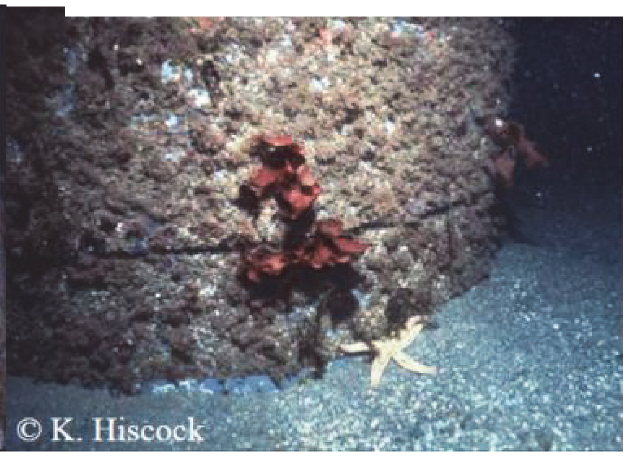


Figure 36: Drawing of zonal communities on structures placed in waters deeper than 15m
Source: Hiscock et al., (2002)

Communities in shallow waters where the kelp (Laminaria Sp) predominate

Plumose anemones (Metridium Senile) should be seen on wind farm structures subjected to strong movements.

Sea anemones (Actiniaria), overlapping ascidians (Ascidiacea),sponges (Porifers) and algae characteristics on intermediate depth ~~s~~ offshore structures



Community on a coastal jetty pile along a coastline occasionally exposed to waves, showing a slightly covered wildlife and areas occasionally covered by sand, with tube-worms characteristic of scoured areas.

Figure 37: Photos of communities and species associated with the colonization of offshore wind farms in the UK
Source: Hiscock et al., (2002)

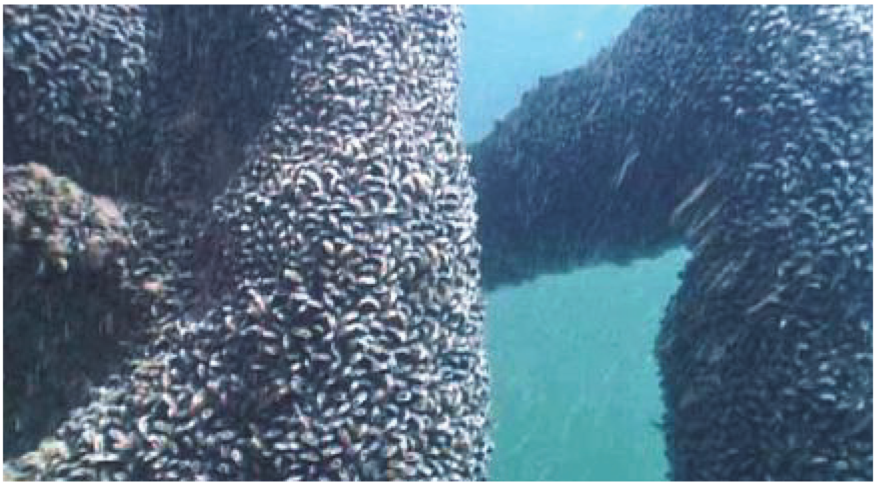


Figure 38: Colonisation by mussels (Mytilus Echilij) on protective structures of the Horn Rev offshore wind farm, Denmark
Source: DONG ENERGY (2006)

Artificial reefs usually shelter fish densities and a biomass higher than in the pelagic zone void of any-structures (Ambrose et Swarbrick, 1989; Beets, 1989; Rountree et al., 1990; Bohnsack et al., 1991; Bohnsack et Sutherland, 1985; De Martini et al., 1989; Brock et Norris, 1989; Bohnsack et al., 1994; Kim et al., 1994; Pickering & Whitmarsh, 1996; Wihelmsson et al., 1998; Arena et al., 2007) This phenomenon has been exploited by fishermen for centuries (Castro et al., 2001). Some systems involve imposing an imposing means of mooring, which, in addition to the devices themselves, should act as isolated reefs or as fish aggregating devices (DCP). They could be effective in the recruitment of certain species of fish and affect the attraction of predators (birds, fish and marine mammals) (Witt et al., 2012). The efficiency of fishing predators may increase with the increasing density of prey (Enstipp et al., 2007). However, this assumes that seabirds do not avoid the structures and / or can fish around without encountering an injury (see collision risk of birds, page 52).

The "Reserve" Effect

The physical presence of facilities will change the use of the affected zones, often with restricted access. Such restrictions may lead to conflicts with other users of the sea notably in sectors related to fishing and navigation. From the point of view of biodiversity, access restriction can have effects similar to those associated with marine protected areas (AMP) (CIEM,2011; Lindeboom, 2011).

The creation of this type of AMP and the prohibition of access for fishing may have a positive effect on fish stocks (diversification and increase in stocks) (Witt et al., 2012). Trawling is strictly regulated, not allowed, in certain MRE Parks, which allows restoration of bethnic communities on degraded seabeds.

Combining AMP and the deployment of artificial reefs, MRE Parks may help to restore areas where the seabed is degraded (Pitcher et al., 1999; Claudet & Pelletier, 2004) and increase the diversity and quantity of commercial species (Langhamer & Wilhelmsson, 2009; Martins et al., 2010). Research is underway to identify the preferred habitats specific to different species to develop foundations to optimize the desired species biomass (Wilhelmsson et al., 2010). A plan to restore and re-introduce could then be associated with the project.

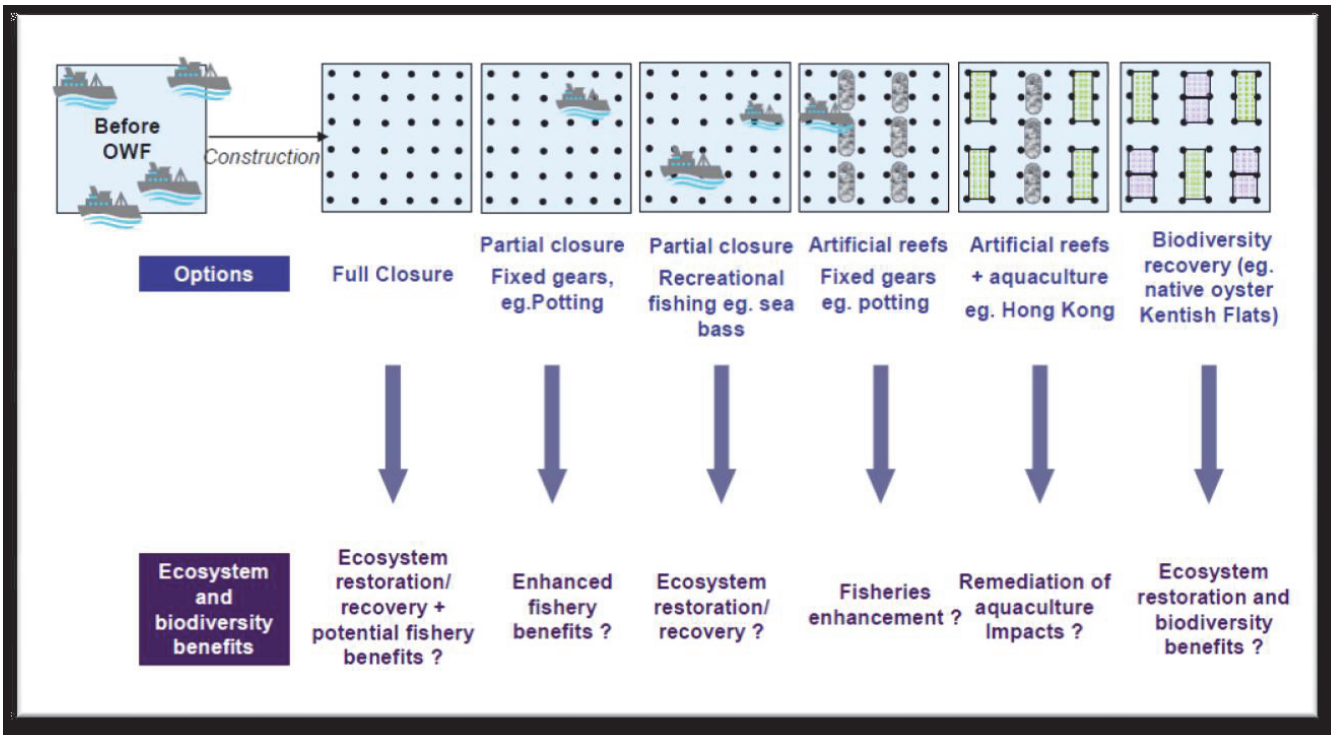


Figure 39: Illustration of the eventual evolution of activities in a Wind Farm
Source: Linley et al., (2009)

Alternative Activities

The positive effects generated by the "reef" and "AMP" of an MRE Park can be put to alternative uses such as aquaculture and / or fish farming, fishing and leisure activities, diving and underwater photography and even sightseeing. However, these activities are only possible with the wind farm projects. The movements of floating devices and the forces generated by the currents do not allow this type of co-operation.

Figure 40: Culture of blue mussels Tony Holm, Azote, in Wilhelmsson et al., (2010)

The Ecological Trap

An artificial reef is both an attractive device for fish (DCP) and for increasing increase in biological productivity, but as a device of attraction, it can also become an ecological well i.e. an ecological trap. An ecological trap is a “preference constraint” for unsuitable habitat artificially and falsely made attractive. Consequences may result in avoidance of better quality habitats nearby, or the introduction of new species.

"Subspontaneous" Invasions

Opportunistic fauna can also invade the reefs (Gill, 2005), increasing the inter-specific competition. We call this type of invasion "subspontaneous" because it is habitat modification caused by humans. The predominance should go to the most adaptable species (Milinski & Parker 1991) and are likely to have cascading effects on the composition of the local fauna (Pimm, 1991; Daskalov, 2002).

Physical Presenceof Plants: The "Barrier" Effect

The Risk of Collision

In Marine Species

The presence of rotors is an obstacle to free movement of mobile species, especially when they are located in high traffic areas (eg between islands) more or less narrow, hindering movement. Marine mammals use these locations to connect to other bodies of water for food (Johnston et al., 2005; Mendes et al., 2002). A recent modeling exercise (Batty et al., 2008) suggested that, in the context of implementation of 100 turbines, with two blades, with a radius of 8m and a peripheral speed of the blades 2m/s, off the West coast of Scotland, 10.7% of the population of harbor porpoises (approximately 1300 individuals) would face a blade rotation in the space of a year (Wilson et al., 2007) and that the risk of collision increases with the size of the animal. However, sound emitted by the blade rotation would cause a flight reaction and may reduce (or possibly eliminate) the risk of collision, whatever the time of day or night and even in conditions of turbidity (Linley et al., 2009).

Little is known of the risks of collisions with fish.

It is less likely that collisions with other devices such as ~~a~~ wave power systems are a problem, although it is possible that animals find themselves trapped in the mooring lines or collide with surface devices in agitated seas (Linley et al., 2009). In contrast and for reasons that are not identified, the fish often congregate around floating objects (for example, see Castro et al., 2002).

The risk of collision, on the scale of the population is considered minimal as regards to fixed wind turbines / farms.

Birds

Migration and commuting are disturbed by wind farms and birds can collide with the dynamic parts of the installations (Drewitt & Langston, 2006). For a long time, this is one of the main environmental issues associated with wind farms (DONG Energy, 2010). It is also a major risk of impact to avian life (Huppop et al., 2006).

The risk of collision depends on the species, concentration and behaviour of individuals in flight, weather, topography and the extent to which the Park is lit (Brown et al., 1992; Drewitt & Langston, 2006).

The flight altitude of migratory birds is generally lower offshore than inland (Kruger & Garthe, 2001; Huppop et al., 2004). For most seabirds, the average flight altitude is between 0 and 50 meters (Dierschke & Daniels, 2003). Anatidae fly at an altitude of less than 20 meters, so below the rotors of wind turbines.

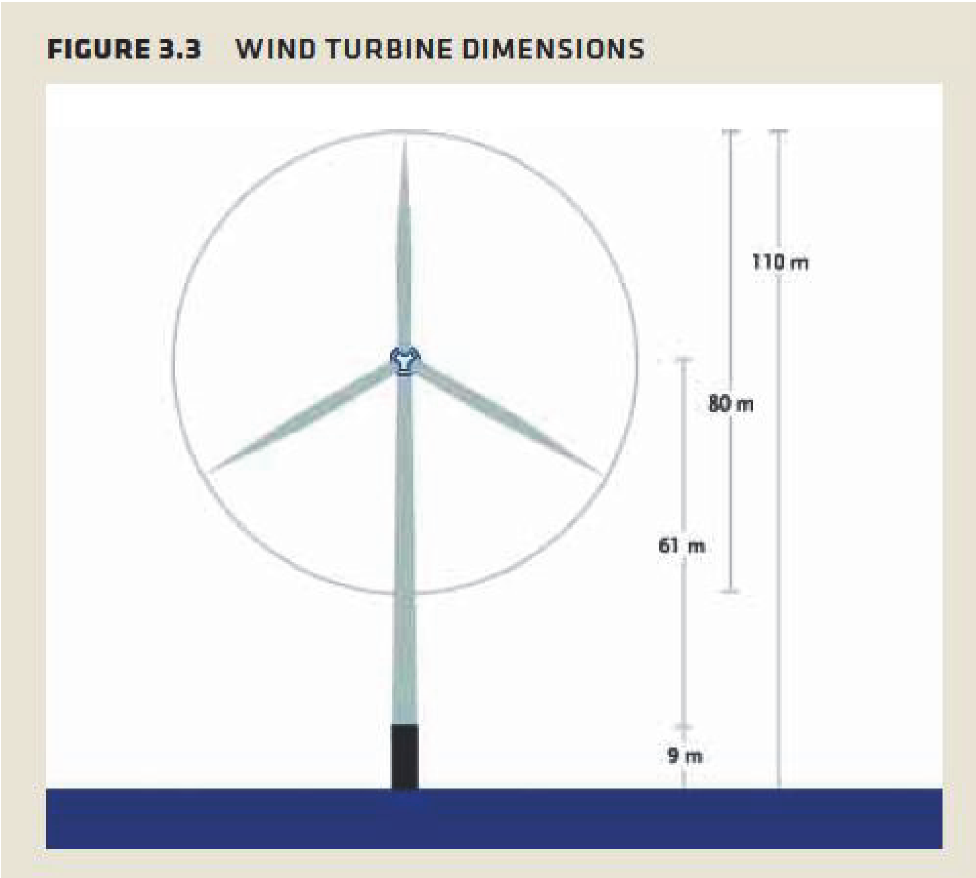


Figure 41: Dimensions of wind turbines in Horns Rev, Denmark
Source: DONG ENERGY et al., (2006)

Many studies certify that collisions are much more likely to occur during storms or at night when birds lose their vision and their sense of direction. Huppop et al., (2006) indicates that the majority of collisions occur only a few days a year, during bad weather.

Likely interactions between birds and the surface structures are less well known, but we can consider that the effects of wave devices are less constant than wind turbines (Thomsen et al., 2006; Snyder & Kaiser, 2009), because of their low height.

However, the problem of birds flying at night at low altitude and colliding with wave energy structures has already been mentioned.

Diving birds may also face subsurface structures including tidal turbines (Wilson et al., 2007). It has been suggested that if an interaction between a turbine and a bird was to occur, they could pass between the blades, driven by the flow of water (Fraenkel, 2006). However the lack of direct proof to support this hypothesis, moreover, implies a movement of animals in the water column which may not be the case (Langton, 2011). Even seabirds possess the agility and sensory perception to avoid collisions (Fraenkel, 2006), they should be aware that the turbine blades move and be able to predict their speed to avoid them. The sensitivity of birds to a collision, depends on their hunting methods. It is beleived that birds diving from the surface have relatively controlled diving trajectories and thus have a good ability to avoid obstacles. In contrast, species directly performing their dive from their flying height have a weaker capacity to avoid obstacles and get injured more easily (Ropert-Coudert et al., 2004).

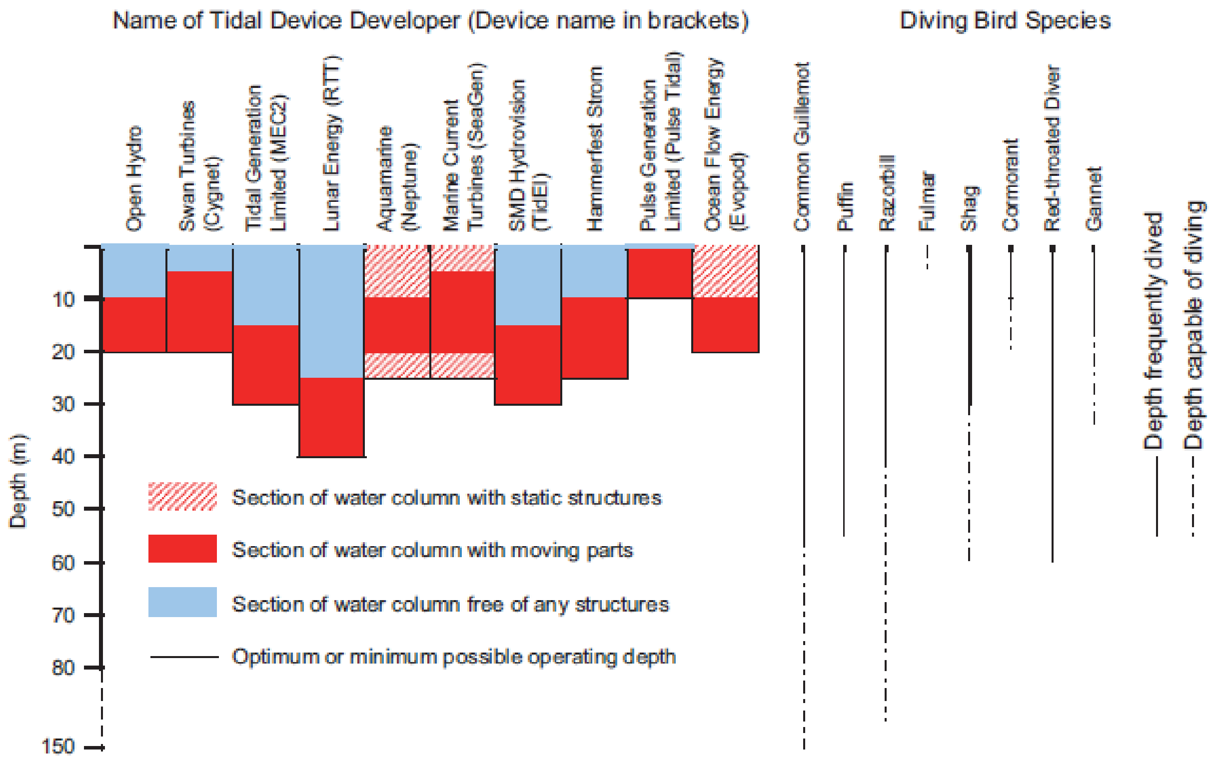


Figure 42: Estimated depths of selected turbines and fishing depths of diving birds
Source: Langton et al., (2011)

There is only limited data on the avoidance behaviour of birds approaching wind turbines, yet it is a key factor for the calculation of collision rates from models (Chamberlain et al., 2006). In the case of onshore wind farms, empirical data can be obtained by collecting carcasses, a practice impossible to implement in the case of offshore wind farms. It is still possible to observe the flight altitudes, speeds and behaviour of seabirds which can provide data on the vulnerability of some species and the parameters needed to create models for collision risk assessments (Garthe & Huppop, 2004). The studies at Horns Rev and Nysted (Baltic Sea) from the system TADS (Thermal Animal Detection System - a detection system for animals using thermal cameras) and the use of radar at the forefront of technology that can track individuals in flight over the sea, have provided strong evidence that it was very unlikely that there are fatal collisions with seabirds, so that the impact would not be significant on the population.

Risk Avoidance

When encountering offshore Wind Farms, marine birds and / or migrators tend to bypass the Farm rather than pass between the wind turbines. This behaviour causes a change in the length of the migration route (Masden et al., 2009) and therefore a greater effort associated with the longer distance (Tulip.et al., 1999; Petterson & Stalin, 2003; Drewitt & Langston, 2006; Laresen & Guillemette, 2007). It changes the way birds use the habitat (Langton, 2011). These obstacles could be on travel routes preferred by certain species of birds, the route connecting areas / locations for feeding, resting**,** nesting, etc. (Drewitt & Langston, 2006). This effect of avoidance was observed from 100 to 3000m from offshore installations (Winkelman, 1992; Christensen et al., 2004, Kahlert et al., 2004), during the day or at night (Winkelman, 1992; Dirksen et al., 1998).

A detailed study of the cumulative effects of several wind farms in the same area is required. An assessment of the impact of several offshore wind farms in the coastal region of Germany. Indicate that, depending on the species, 2 - 6% of the seabird population in the country could be affected (Dierschke et al., 2006). Modeling tools are available for different scenarios and different types of turbines (Garthe & Huppop,2004; Desholm & Kahlert, 2005; Huppop et al., 2006; Desholm, 2009). But it is important to consider that it is this accumulation of activities impacting the movement of species which increases collision risk and enhances the amplitude of the barrier effect.

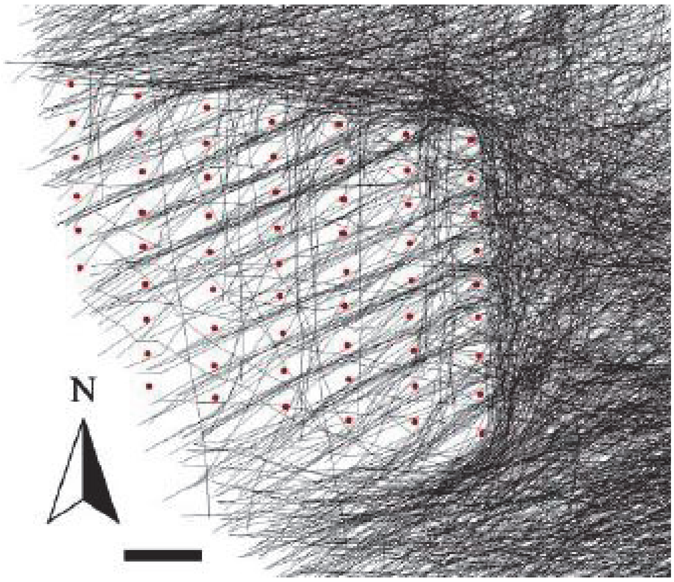


Figure 43: Flight paths of birds during the commissioning of the wind turbines at Nysted Offshore Wind Park in Denmark
Detection by radar. The black lines indicate the flights of migratory birds, the red dots represent the wind turbines.
Graphic scale bar: 1000m
Source: Desholm & Kahlert (2005)

The severity of the effects on local bird population largely depends on the ability of the birds to find replacement habitats (Whilelmsson, 2010).

The "barrier" effect on marine fauna is very poorly documented. Globally it results from two distinct effects: electromagnetism and noise. Both stress factors will be addressed in specific chapters.

Loss/ degradation of habitats

Avoidance of wind turbines results in a loss of effective habitat, not only in the area of the wind farm but also in the buffer zone around the park. The effects of collision or avoidance could cause a loss / degradation of habitats. The inappropriate implementation of MRE in sensitive zones or of interest such as spawning grounds, resting areas, feeding, strategic routes or regions with rich biodiversity is susceptible to having a negative impact on certain taxons (Inger et al., 2009). Especially when these habitats are limited in terms of availability, size and that the dependent species have a low number of recruits or develop slowly (as with the elasmobranchs). If the substitute habitats are limited in terms of quality and caliber they are already occupied (that is to say they have achieved or are approaching their capacity), then the increase in density would result in strong competition for the available resources and so, there would be an increase in the mortality rate and lead to a decline in the size of the local population (Linley et al., 2009).

Because of their physical presence and mobility, MRE facilities effect the environment, both positively and negatively. The “reef effect” is known to attract fish (DCP) and thus significantly increases the biotic potential its environment. The "reserve effect" is significant in the case of restricting access for trawler fishing (arts trainants is trawling or mobile fishing. Arts dormant is when the boat does not move as with bottom line fishing) resulting in an increase in the productivity of the natural environment and therefore potentially beneficial to the zone and its surrounding areas. But the "barrier effect” related to the risk of collision avoidance, is still ill-defined, it could have adverse consequences in terms of the space available if several MRE projects appear in the same geographical area, and the use of that space by the species. It is therefore very important to understand the role and experience of habitats by the different species and to define conservation status of these habitats so as not to impact key zones for their evolution.

Noise

The oceans possess an important diversity of sounds. From a biological point of view, the sound is of capital importance for communication, reproduction, orientation and the perception of prey and predators (Boehlert & Gill, 2010). A large number of species of different taxons (cetaceans, pinnipeds, teleosts, crustaceans) use underwater sounds to interact with their environment and echolocation (Misund & Algen, 1992; Popper & Hastings, 2009; Langhamer et al., 2010). Sound effects on aquatic life may vary depending on many internal and external factors (Thomsen et al., 2006) and can be divided into the following broad categories; masking, behaviour disturbance, hearing loss (temporary or permanent) and injury (up to a lethal level).

Underwater noise propagates according to local bathymetry, temperature and salinity. Depending on the location, season and local climate conditions, the sound can be spread in the ocean over large distances and focus at different depths separated by several tens to several hundreds of kilometers from the source of its sound (Folegot, 2011). In so far as the sound is usually spread in all directions from the source, the areas influenced by the noise are given in terms of distances from the source, thus indicating a radius rather than a straight line. For example, a radius of 10km corresponds to an area of audibility 314.16 km² ($A = \pi \times r^2$) (Thomsen et al., 2006).

The driving of piles during construction is without a doubt the most intense noise generating the highest sound pressure levels most damaging to fauna, it influences the behaviour of seals (Madsen et al., 2010) and cetaceans (Carstensen et al., 2006), fish etc.

Pile Driving

The activities associated with pile driving are of particular concern because they generate very high sound pressure levels for a relatively wide frequency range (202 Hz - >20Hz) (Nedwell & Howell, 2004; Madsen et al., 2006).

Pile diameter depends on the type of foundation (~4m monopile, tripod = 3m, jacket = 1.5m). Levels of noise impact associated with the pile driving depends on the length and diameter of the pile and the energy impact (Nedwell et al., 2003a).

Simple impulses last between 50 and 100ms, or about 30 to 60 blows per minute. It takes about 1-2 hours to drive a pile into the ground (Henriksen, 2002; Nedwell et al., 2003a; Nedwell & Howell, 2004; Madsen et al., 2006) and the sound could be measured far from the construction site, in some cases, very high sound pressure levels can greatly exceed 160 dB re 1uPa (="Peak-to-Peak" sinusoid) at distances of 10km (Huddleston, 2010).

Multiple units of measure can be used for dB values. "Peak-to-Peak" (dBp-p,) indicates the pressure between the maximum value and the minimum value of the wave.

The highest values refer to the amplitude of a given sound and do not depend on time. They are suitable for the description of short pulse sounds as in the case of pulses from pile driving.

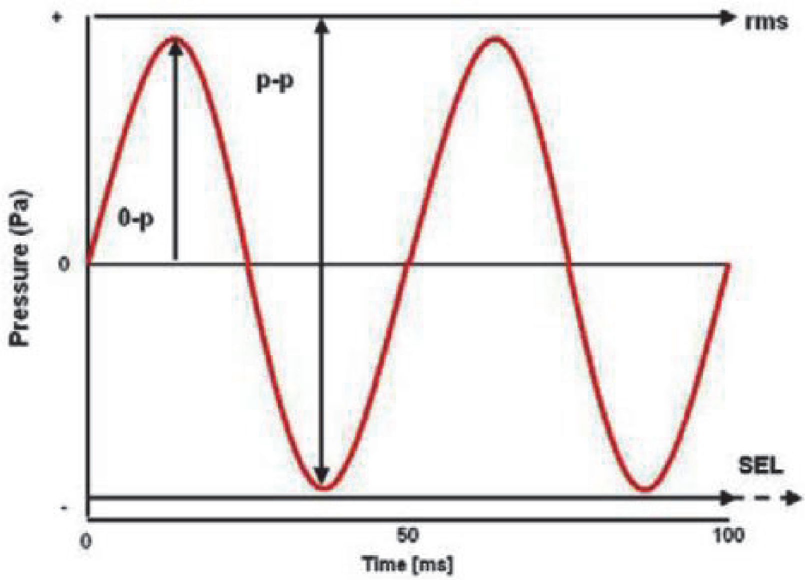


Figure 44: A simple sinusoidal waveform describing different units of measurement of sound
Source: Thomsen et al., (2006)

Activity/Source	Reported levels / Estimate	Reference
Pile driving (4.0-4.7m diameter piles)	243-257 dB re 1µPa at 1m (peak to peak)	Nedwell *et al.* (2007)
Pile driving (1.8m diameter piles)	226 - 250 dB re 1µPa at 1m (peak to peak)	Bailey *et al.* (2010)
Pile driving (2.4m diameter piles)	185-196 dB re 1µPa at 100m (rms) 197-207 dB re1µPa at 100m (peak to peak)	Caltrans (2001)
DP Drillships	190 dB re 1µPa at 1m (rms)	NRC (2003)
Larger vessels	180-190 dB re 1µPa at 1m (rms)	OSPAR Commission (2009)
Pile Drilling	160-180 dB re 1µPa at 1m (rms)	ICIT, Nedwell & Brooker (2008)
Small work-boats (with thrusters) and ships	160-180 dB re 1µPa at 1m (rms)	OSPAR Commission (2009) and ICIT
Wave and tidal devices	165-175 dB re 1µPa at 1m (rms)	OSPAR Commission (2009) – probably includes pile drilling for installation and

Figure 45: Levels of an anthropogenic noise generated by various activities (pile driving)
Source: 2011 report for SGWTE (Task Force on the environmental impacts of wave and tidal power) ICES Annex 6: Michael Bell & Jonathan Side, 2011

Impacts on Marine Mammals

Pile driving can cause behavioural changes in seals, dolphins (Tursiops truncatus, Globicephala, Delphinus delphis) and harbor porpoises (Phocoena phocoena) found at more than 20km (Edren et al., 2004; Tougaard et al., 2008; Tougaard et al., 2009; David, 2006; Madsen et al., 2006; Brandt et al., 2009; Tougaard et al., 2009).

Mammals could suffer hearing problems such as changes in their hearing thresholds (Franck, 2006; Madsen et al., 2006).

Southall et al., (2007) proposed to classify the species and sub-species of cetaceans in three groups of functional hearing (see also Ketten, 1997; Clark & Ellison, 2004):

- cetaceans low frequency: 13 species / subspecies that have functional hearing from 7 Hz to 22 Hz, including all mysticetes (baleen whales)
- cetaceans to mid-frequency: 57 species; hearing from 150 Hz to 160 Hz, with 32 species of dolphins, six species of larger Odontocetes (toothed whales) and 19 species of Ziphiidae (beaked whales)
- cetacean high frequency: 21 species; hearing from 200 Hz to 180 kHz, including 8 species and subspecies of harbor porpoises (for details, see Southall et al., 2007).

Richardson et al., (1995) define four areas of influence of the noise depending on the distance between source and receiver.

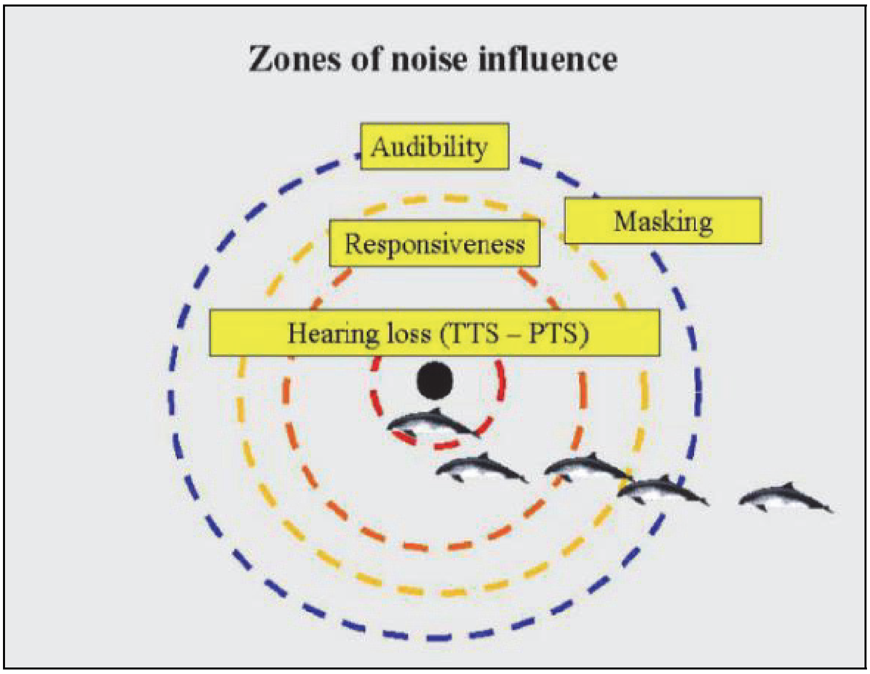


Figure 46: Zones of noise influence (after Richardson et al., 1995)
Source: Thomsen et al., (2006)

The Audibility Zone is defined as the area within which the animal can detect sound.

The Masking Area varies greatly and is generally smaller than the area of audibility. It defines the area in which the noise is loud enough to interfere with the detection of other sounds such as communication signals or echolocation clicks. Masking becomes important when the sound level of the masking noise reaches the same level of ambient noise in the signal frequency.

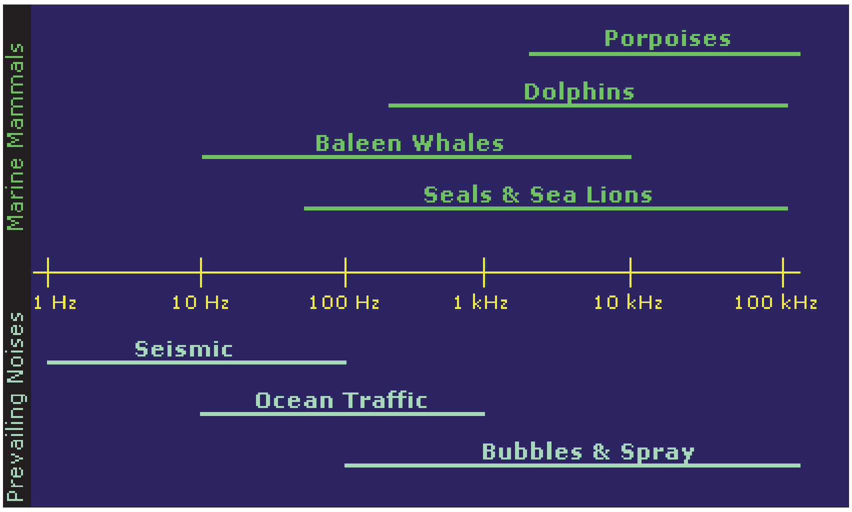


Figure 47: Approximate frequency intervals of marine mammal sounds and the prevailing background anthropogenic noise.
Source: www.dosits.org

<u>The Reactivity Zone</u> is the area where the animals show behavioral and physiological reactions.

Thomsen et al., (2006) suggest that the radius of reactivity to the sound of pile driving is large enough, and can only be temporarily reduced to several kilometers, leading to a reactivity zone of several hundred km2.

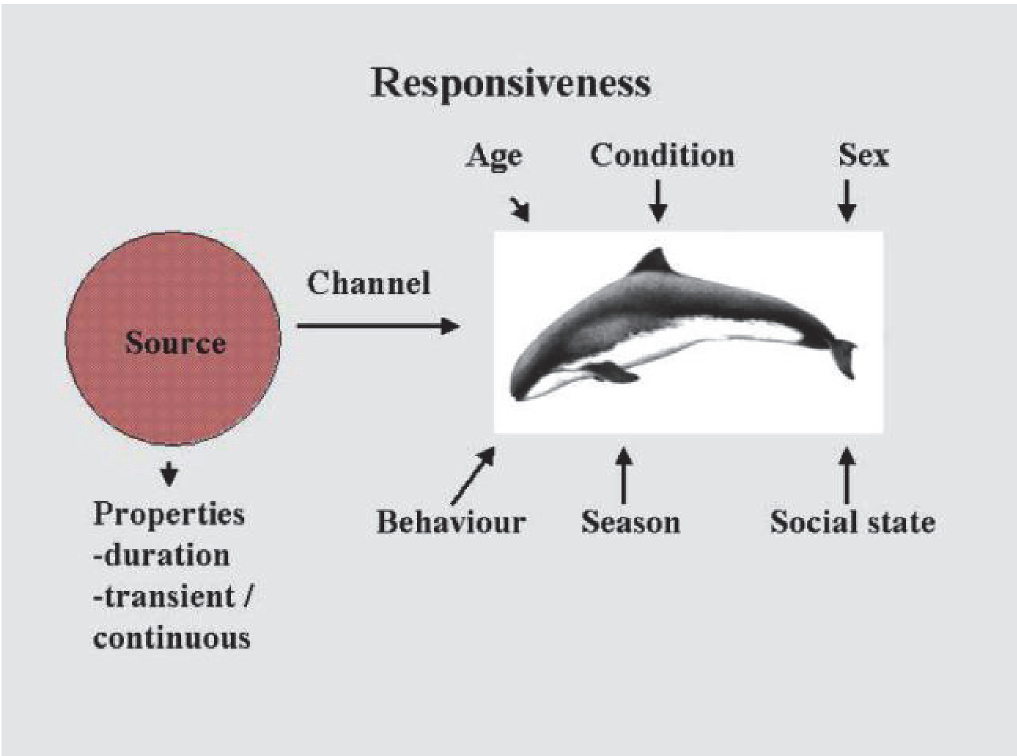


Figure 48: Some factors affecting the reactivity of marine mammals
Source: Thomsen et al., (2006)

Behavioral responses are varied and sometimes imperceptible (jumpstart, change of direction etc.) deeper disturbances could impact the key factors of survival (temporary or permanent abandonment of an area, eating disorders, reproductive disorders etc.**)** (Thomsen et al., 2006).

Some studies suggest that marine mammals have a reaction to move away from construction areas (Brandt et al., 2009 in Boehlert & Gill, 2010).

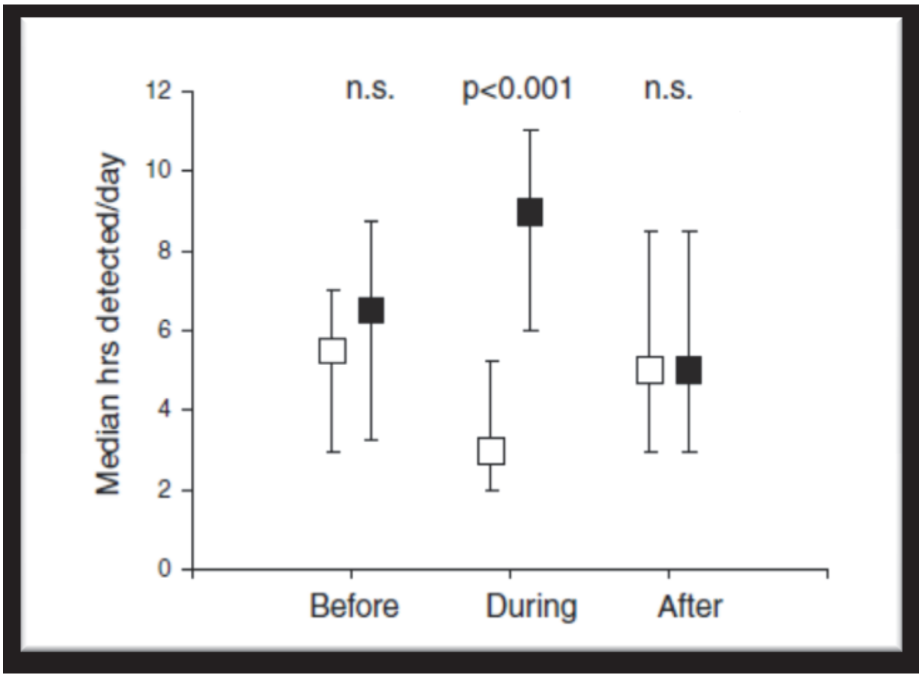


Figure 49: Changes in the number of porpoises detected at Beatrice (Scotland) before (June), during (July and August) and after (September and October) the installation/construction of wind turbines
White square = 2006; Coloured square = 2007
Source: Thompson et al., (2010)

The Area of Hearing Loss is the area close to the noise source where the level of sound experienced is high enough to cause tissue damage resulting in a change of hearing thresholds. It is possible to distinguish the temporary loss of hearing (TTS: Temporary Threshold Shift) permanent loss (PTS: Permanent Threshold Shift), which itself is caused by prolonged or repeated PTS or by brief exposure to sound of a very high intensity (Ros & Reeves, 2005). Hearing loss depends on the intensity of sound, frequency and duration of the animals exposure to it.

Bailey et al., (2010) conclude that, for pinnipeds (Seals), in the case of the Beatrice Wind Farm in the Moray Firth (Scotland), the PTS would be triggered within 20m around the point of piling and that of TTS within 40m. Measurements made from very close to the pile driving operations and all measures taken over a much larger area, they estimated that the noise levels ranged from 226 - 250 dB re 1 m 1uPa from the operations. They note that it is possible that, in the case of bottlenose doplhins (Tursiops truncatus), behavioral disturbances have occurred within a radius of 50km. Studies suggest that high pulse sounds affect more cetaceans than pinnipeds (McCauley & Cato, 2003; Gordon et al., 2004).

Impacts on Fish

The auditory diversity in fish is more complex than in mammals, because there exist different auditory groups according to anatomical features of the species (Nedwell et al., 2004; Thomsen et al., 2006). Some fish use sound to locate their breeding grounds and the assumption is made that noise could interfere with this ability (Langhamer et al., 2010).

The estimates of distances at which fish can detect noise vary from a few hundred meters to 50 -60 km (Nedwell & Howell, 2003; Wahlberg & Westerberg, 2005; Thomsen et al., 2006). Little research has been conducted on the effects on fish of pile driving and behavioral changes in particular (Popper & Hastings, 2009). These changes vary depending on the phase in the life cycle of the species (highly variable) and the size of the individuals (Nedwell & Howell, 2003; Wahlberg & Westerberg, 2005; Thomsen et al., 2006; Kastelein et al., 2007; Huddleston, 2010). Generally the reaction of fish is to avoid pile driving zones. However, juvenile fish and fingerlings would probably have more difficult to escape than larger species and pelagic fish (Engas et al., 1996). Many deep sea species of fish have no swim bladder and therefore less sensitive to sound pressure. They are still just as sensitive as other fish to high levels of moving particles generated by piling activities (Sigray et al., 2009).

COWRIE studies have shown relatively low levels of sound pressure received (range 140-161 dB re 1 mu.P) resulted in a change in travel patterns of cod and sole. After hearing the sound several times, the response of these two species is less lively than the first time, indicating that the fish could get used to the noise. Further studies on habituation need to be done to effectively manage the effects on marine fish of pile driving activities.

The effects of sound on invertebrates remain unknown (Moriyasu et al., 2004). Invertebrates represent a wide range of animal groups and generalizations about the effects suffered must be done with caution. Possible reactions are likely to vary widely and little information is available regarding the potential effects on different stages in their life cycle.

It is recognized, however, that during the construction phase, noise is of a short duration (Cristensen et al., 2006) and will have an impact at a local level (Wilhelmsson, 2010) and as a consequence will only slightly affect species (Wilhelmsson,2010).

The habitat utilization and migration patterns of the susceptible species must be studied in connection with the construction period of the facilities. For marine species that avoid the construction area, this phase inevitably involves a loss of habitat which may include feeding areas, spawning, reproduction and rest (in the case of migratory species). In the process of exploration, planning and obtaining authorisation, special attention should be given to key stages of the life cycle, the seasonal habitat usage and the approaches used (Anderson, 1990; David, 2006).

Evans et al., (2008) recommend several mitigation measures to be implemented during the construction phase:

i) Avoid seasons of high species high activity for the target start date of the construction phase.
ii) Do not start pile driving before the visual and acoustic monitoring has shown that no marine mammals are in the potential danger zone, this measure emphasizes the need to implement acoustic measures in parallel with monitoring.
iii) Use curtains of air bubbles (Wursig et al., 2000; CALTRANS, 2011) which act as a barrier to the propagation of sound. Other noise mitigation measures are possible, such as insulation around piles (offshore) and cofferdams (shallow waters) (see Illingworth & Rodkin, 2001; Thorson, 2004; Reyff & Thorson, 2004).
iv) Furthermore, investigate the effectiveness of acoustic repulsion devices such as used for seals or "pingers" (Evans, 2008).

Noise during the Operation Phase

Research carried out at offshore wind farms located along the coast of the Baltic Sea (Hoffman et al., 2000; Fristedt, Moren & Soderberg 2001) showed that wind turbines in operation produce sound that is added to the ambient acoustic environment (0,001 - 0,4 kHz, 80 - 110 dB re: 1uPa), and that the sound level depends on the number of wind turbines and their period and speed of operation at low frequencies (Gill, 2005).

Seals are capable of detecting wind turbines at distances of 360 - 10,000 meters (Koschinski et al., 2003; Thomsen et al., 2006; Tougaard et al., 2009). It has been demonstrated that seals react to simulations of noise from wind turbines of 2MW without showing signs of fear (Koschinski et al., 2003). Wilhelmsson (2010) mentions that the operational noise does not deter these mammals, but changes in the selection of resting places were noticed (Madsen et al., 2006), which eventually could lead to changes in habitat.

Several species of whales (belugas, orcas, humpback whales) have also shown behavioral responses to avoid low frequency sounds from human activities such as oil and gas or marine traffic (Samuel et al., 2005). These sounds could disturb migratory patterns of these species (Wilhelmsson, 2010).

It is likely that fish become accustomed to relatively continuous operational noise, as observed in many port areas and in other circumstances involving human activities (shipping, scuba diving) (Schwartz, 1985; Wahlberg & Westerberg, 2005).

Wind turbines in operation generate vibrations that make noise underwater. Depending on the number of turbines the sound and the vibrations could effectively propagate to the seabed. But these effects are more intense at the tip of the blades and are effectively reflected from the surface of the water and should not add much underwater noise (Ingemansson, 2003).

More data suggests that noise and vibrations can have negative effects on a range of marine taxa, including marine mammals and invertebrates (Horowitz & Jasney, 2007; Slabbekoorn et al., 2001). But the impact of sound on marine life reveals many uncertainties. The scope of the impact that noise can have depends on the weather conditions, the composition of the seabed and its profile, the depth of the water and several other site specific variables (Folegot, 2010). On the other hand, the hearing in marine mammals and fish varies greatly. For sound pressure levels, very high sound pressure noise could seriously injure and even kill fish, marine mammals (Hardyniec & Skeen, 2005; Nowacek et al., 2007; Synder & Kaiser, 2009), or incite them to leave an area tens of kilometers from the site (Wilhelmsson et al., 2010). It should be noted that the relocation of any kind could have serious impacts on spawning and nursery areas if appropriate seasonal bans are not imposed (spring and summer are the main breeding season for many species in temperate zones.

With reference to the effects of noise on marine mammals, particularly those due to pile driving and seismic surveys, previous ESIE recommended to study the establishment of criteria for determining acceptable levels and to develop regulations that also take into account the cumulative effects (SEA UK Offshore Energy). Studies are needed to determine the effects of chronic and long term risks, which depend on the frequency of the noise, the energy emitted and the hearing range of the species (Slabbekoorn et al., 2010).

Cables and Electromagnetism

The electricity generated by offshore wind farms is transmitted to the onshore transmission network by high voltage cables as alternating current (ac) or direct current (dc). These cables emit electromagnetic fields or electric and magnetic fields (CEM), which will be detected by a wide variety of electro or magneto-sensitive marine organisms, such as bony fishes, elasmobranches, marine mammals and sea turtles (Witt et al., 2011).

Potential physical impacts of submarine electric cables refer to two large types of pressure: obstruction and abrasion. The obstruction is due to permanent structures attached to the seabed bottom while the abrasion phenomena means plowing and scouring caused by the installation and burial of objects (burying a cable for example), the trawling or earthworks (Carlier & Delpech, 2011).

Depending on the structure of the seabed, some years may be sufficient for the natural covering of seabed cables, the experience gained within the oil and gas sector shows that it takes 5 - 15 years for pipelines to be buried (OE, 1999; Knudsen et al., 2006). But burying cables (up to 1 meter deep) using techniques such as dredging and plowing (Vize et al., 2008) implies a certain risk of re-suspension and sedimentation and the direct elimination of fauna and benthic flora (Di Carlo & Kenworthy, 2008).

Regardless of the design and size, the facilities operating tidal and wave energy systems must allow for an important anchorage made from concrete or metal, mooring lines and a greater concentration of power cables than wind farms (Witt et al., 2001, Kogan et al., 2006). It has been shown that the movements of mooring lines and cables on the seabed (the phenomenon of chafing) were a constant source of habitat disturbance during the operation phase, due to the re-suspension of sediment (see re-suspension p. 38 for the effects of re-suspension). It was also shown that the friction action of cables (chafing phenomenon) caused incisions in rocky outcrops, but had only a minor impact on the seabed organisms (Kogan et al., CIEM, 2011).

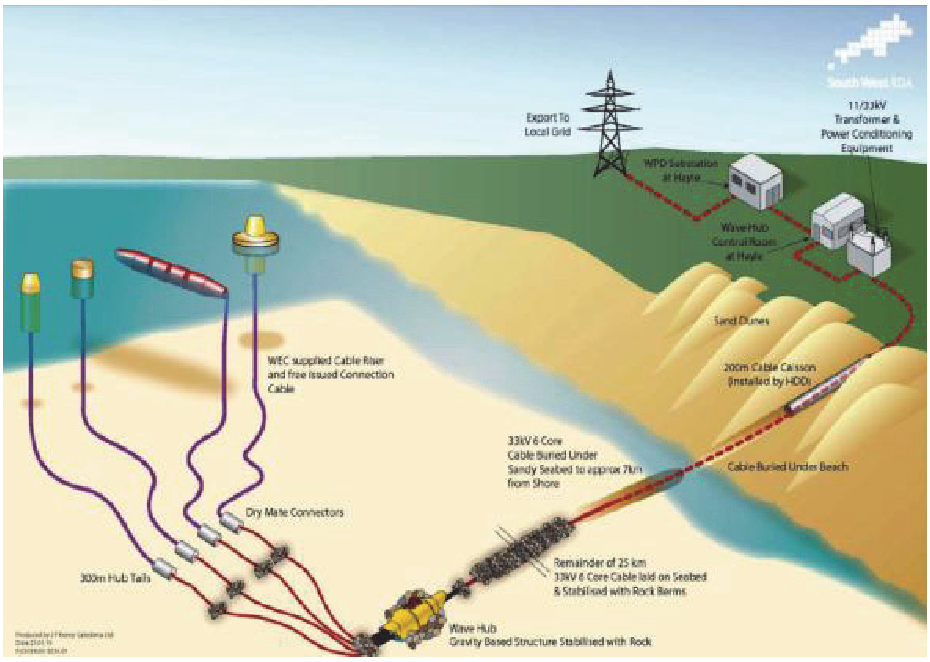


Figure 50: Drawing reflecting a Wave Hub cable network
Source: bbs.co.uk

When transporting electricity, cables emit low frequency electromagnetic fields (Boehlert & Gill, 2010). The electric fields are proportional to the voltage of the cable, while the magnetic fields are proportional to the current (CIEM, 2011). Cables carrying direct current (dc) from individual installations should carry 10 to 15 kV, a voltage that should not generate electric fields beyond a few centimeters around the cable (Westerberg and Begout-Anras, 2000).

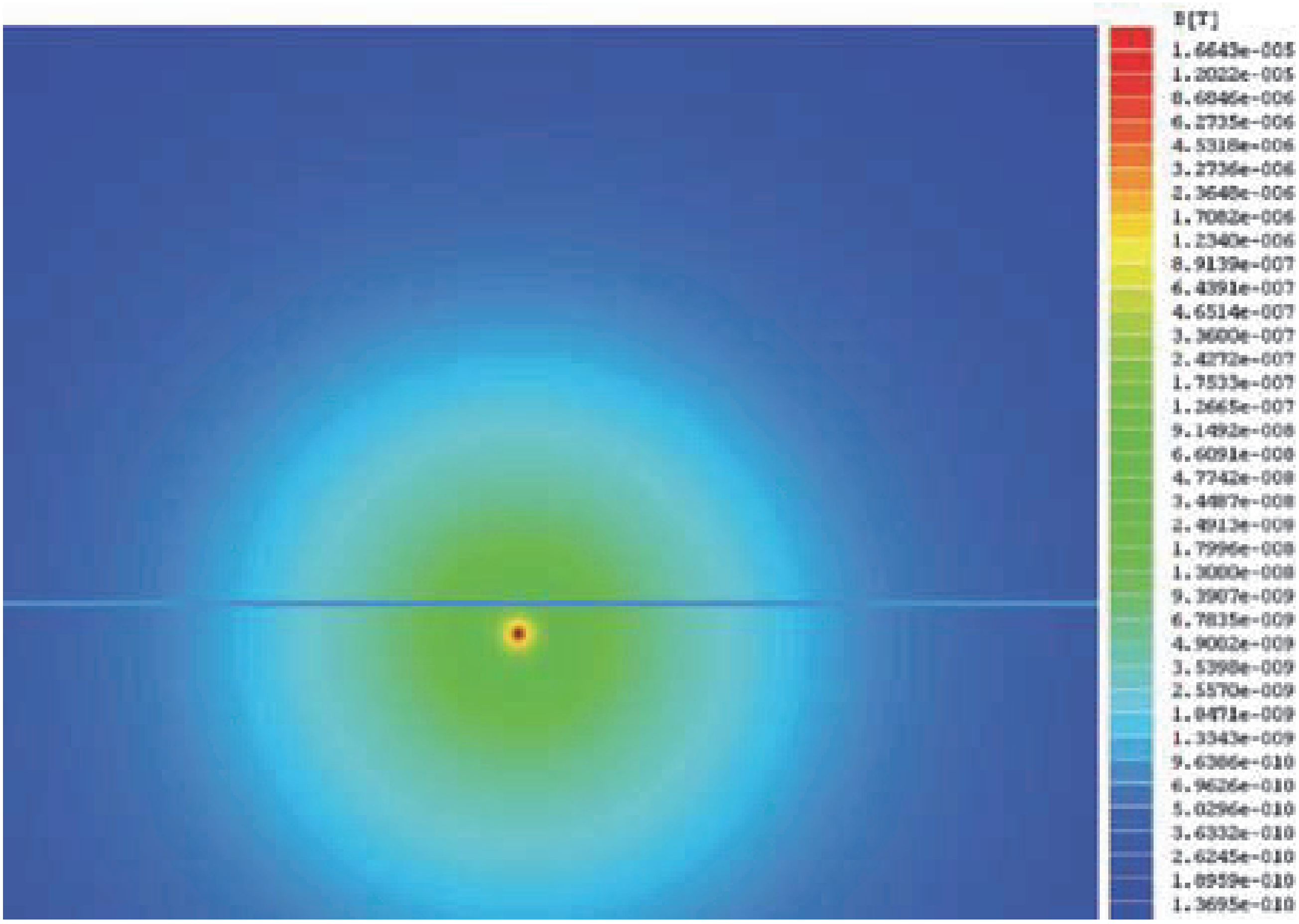


Figure 51: Magnetic radiation field of a standard 13kV submarine cable (Tesla) buried 1m deep. The seabed surface is represented by the horizontal blue line
Source: Centre of Intelligent Monitoring Systems, University of Liverpool, UK. In Boehlert & Gill (2010).

CEM (electro-magnetic fields) effect mainly fish, especially elasmobranches and marine mammals, which use the magnetic field of the Earth for orientation. All the taxonomic class of Chondrichthyes (cartilaginous fishes), the agnaths (fish without jaws with the mouth in a shape of a circle) and chondrosreans (sturgeon fish spatula, beluga) have a sensory apparatus that allows them to detect and respond to electric fields (Collins & Whitehead, 2004; Gill, 2005). Although the consequences of the disruption of CEM (electro-magnetic fields) on these populations are not yet clearly identified (Ohman et al., 2007), it is preferable that the data on the habitats and migratory routes of these species are taken into account in the planning of space for routing and installation of electric cables.

Physiology of some species of shrimp, crabs, sea stars, tube worms and mussels were studied in relation to level of CEM (electro-magnetic field) corresponding to the electrical surface intensity of subsea dc power cables in the Baltic Sea (Bochert & Zettler, 2004). No significant effect was observed in these species after 3 months of observations which also revealed no abnormalities in the functioning of bethnic communities (Malm, 2005).

Langhamer et al., (2009) note that with better cable technology, CEM (electro-magnetic field) only effects the immediate environment near the cable to the extent that the earth's magnetic field is generally predominant within in only a few decimeters of the cable. The association of this technology and the burial of cables in the ground leads to the elimination of problems due to CEM (electro-magnetic fields).

The number of cables is expected to increase significantly over the coming decades, together with the development of MRE. The expansion of these cable networks can cause cumulative impacts potentially harmful to the environment, difficult to predict, and for which no scientific fallback actually exists there now (Carlier & Delpech, 2011).

Lighting

Like all structures at sea, MRE devices must be identifiable in order to ensure their visibility to maritime vessels and air navigation. The machines have specific paints, systems for reflecting radar waves and lights to maximise visibility from a distance, day or night.

Figure 52: Pelamis warning lights
Source: pelamiswave.com

For wildlife, these lights can cause endocrine disruption or behavioral phenomena especially related to "positive photoaxie" (light attraction) or "negative photoaxie" (repulsion). For predatory species, lighting can affect food availability, prey distribution, the inter-specie competition. For gregarious species, breeding colonies, hibernacula, landing areas can be neglected or abandoned.

The most affected species are migratory of which two-thirds migrate at night. In birds, the sense of direction is based on the vision and the perception of the earth's magnetic field. This innate sense is disrupted by exposure to light at night, migration may be attracted by the warning lights of the devices (Montevecchi, 2006; Huppop et al., 2006; Dong Energy et al., 2006), collide with the structures or flying in the light rays until exhausted. The phenomenon is still poorly understood and poorly documented but ~~in~~ since the eighteenth century it has been observed that lighthouses attract birds, sometimes thousands, who swirl around it until exhausted.

Puffin chicks, like those of some other seabirds (petrels, shearwaters), are attracted by the lights being close to their nests. However, if the first flight, which can last only a few tens of a seconds, does not lead them to the sea where he will feed, his chances of survival are very low.

This effect also seems to increase in overcast weather conditions when the orientation from the stars or the moon is impossible (Russell, 2005). The surveys show significant migratory bird collisions with lighted structures at night time, rain or fog (Elkins, 1983; Cochran et al., 1958, Case et al., 1965, Cunningham, 1965; Herbert, 1970; Maehr et al., 1983 in California Energy Commission, 1995; Manville, 2000 in Erickson et al., 2011).

Many other aquatic organisms have migratory behaviours that are controlled by the brightness and / or the duration of the day. This could for example inhibit or on the contrary excite the activity of the animals. The night time cycle (circadian / nycthemeral) regulates / sets a part of commuting (horizontal and vertical movement) and the activity of many species of plankton, zooplankton and other invertebrates or fish.

Some species of algae produce melatonin. Functions that affect melatonin circadian cycles, some algae could then be disrupted by light pollution.

Figure 53: Lights from an onshore Wind Farm
Source: ecoco2.com

Different types of light have not the same effect on fauna. It is possible to choose the colour of light (wavelength range of the lamp, filter...) having a lesser effect on birds. Pulsed light emission and the white light particularly affect birds. In France, all wind turbines shall be equipped with a flash of 20,000 candles (unit of luminous intensity) radiating around the clock (24/7) on the site location. Light pollution from wind farms at night also causes ~~a~~ strong discomfort among residents of adjacent properties who file numerous complaints (ecoco2.com). However, this discomfort is recognised in the context of strong coastal lighting, such as port-industrial complexes or resorts.

Chemical Products

Concerning water quality, leaks of hydrocarbons during routine maintenance and shut downs as well as the continuous leaching of anti-fouling paints are the main impacts identified.

Anti-fouling

The anti-fouling chemicals are toxic and may cause increased mortality of planktonic species or affect their health. Zooplankton may also be directly affected and suffer increased mortality and / or a decrease in their health by passing between the moving parts of the machines (Bickel et al., 2011, Witt et al., 2011). Which will probably affect their predators such as young fish (fry), seabirds and marine mammals (Witt et al., 2011).

Modern facilities tend to have low toxicity and to be biodegradable and regulation implementation in the marine environment will limit the risk of contamination of the sea by facilities (Boehlert et al., 2007; DFO, 2009).

Accidental Pollution

The increase in the number of industrial facilities offshore and in coastal waters could increase the navigation dangers for ships. The accumulation of activities has the effect of increasing the risk of oil spills and other marine pollution (Wilhelmsson et al., 2010). On contact with the oil, marine animals die more often, through external contamination that destroys their protection against the cold and water, or by toxic by ingestion.

Leaks of hydraulic fluids from maintenance equipment is also a source of accidental pollution.

Historical heritage and landscapes

Whether or not protected by law, archaeological sites and landscapes of historic interest are among the criteria addressed by the EIE, that accompanies any application for a permit to build an offshore wind farm. The fact that the sites of historical and archaeological importance are not listed does not mean that they do not have cultural value. During the site survey and preparation, they can be found and their significance assessed, and legally protected. Thus, the results of archaeological research can contribute directly to the improvement of our collective knowledge of the marine historic environment (Huddleston, 2010).

Effects on the landscape obviously concern the surface devices in particular wind farms. Through a combination of their size, their number, concentration and movement of the blades, the offshore wind turbines have in fact a more powerful attraction of the gaze than other technologies. Seascapes and littoral coasts are often associated with wilderness, devoid of obstacles to the horizon. The arrival of these technologies can be misperceived by the inhabitants of the region on the one hand and by the tourists on the other, who find them irritating in their search for the "wild".

Coastal sites with a particular geomorphology or in estuaries for example, the installations are likely to contrast with a countryside background. Measures of integration and acceptance should then be taken into account.

COWRIE gives an example of a particularly sensitive area, a stretch of coast not far from Heysham in the North-West England: the Chapel of St. Patrick, which houses one of the oldest Christian relics. Intrinsic aspects of the site: the immediate vicinity of the coast and the views overlooking the sea. It is therefore necessary to consider how to balance the urgent needs of 21st Century sustainable energy production with a historical Christian site and its association with the sea (Huddleston, 2010).

4. CONCLUSION

Reminder of the Context

Finistere and Cornwall UK enjoy oceanic climate conditions favourable for the development of MRE, notably to provide power to peripheral locations at the end of the onshore networks and isolated communities dependent on fossil fuels. But the growth of MRE is accompanied by taking into account of potential impacts on the marine environment. At the cross roads between several biogeographic areas, the regions of Brittany and Cornwall UK enjoy a rich and varied nature, which remains in good ecological status is fundamental to biodiversity. Many of the proposed sites for implementation of MRE are areas where local conditions and the physical environment are poorly understood, mainly due to logistical difficulties associated with sampling marine dynamics (Gill, 2005; Shields et al., 2009; Linley et al., 2009).

It becomes urgent today to define the potential and actual impacts of MRE on the environment, associated with varying degrees of severity and uncertainty to measure the positive and / or negative impacts of these effects and therefore forecast compensatory measures.

Positive	Negative
– Improvement of habitat – DCP (Fish Aggregating Dispositive) – AMP (Marine Protected Areas)	– Degradation / Loss of habitat – Movement / Avoidance – Collision

Figure 54: Combined Positive and Negative effects of MRE

Impact Studies

The impact of each wind turbine project must be analyzed according to its location and therefore the nature of the ecosystems in which it operates (local and regional characteristics). It is important to understand the context in which the area is used by the species - for feeding, breeding or as a migration route, at key stages of the life cycle, seasonal habitat. This underlines the need for preliminary studies during the phases of exploration, planning and obtaining authorization (Anderon, 1990; David, 2006; Evans, 2008). Taking into account of the natural processes requires an overall perspective, monitoring, and research based on the best possible understanding of coastal ecology (Gill 2005) and the role of seasons. If rare species, birds and mammals have an intrinsic appeal, the ecological point of view it is important to consider the impacts on ecosystem structure and key functional species (Simberloff 1998). In addition, acceptable levels of disturbance will depend on the local / regional state of conservation of the species and habitats in question (Wilhelmsson et al., 2010) and the social acceptability of users in the zone.

In addition, the MRE industry is relatively new in the marine environment and must coexist with many other users and stakeholders of the sea such as the fishing sector, conservationists and navigation (CIEM, 2011). The EIE does not always involve itself with the environmental effects of pre-existing activities or other planned developments. To improve this state of affairs, it is necessary to develop and standardise the criteria and methods of assessing cumulative effects according to appropriate scales of time and space.

The ESIE provides a framework through which all environmental considerations related to use / specific programmes are integrated into policies at regional or national level and guide public funding and baseline guidance assessments at the regional level. This method should allow stakeholders to define the objectives and the thresholds as well as visualising in a transparent manner the results of pre-installation studies and the follow-up.

GIS / Information Management and modelling

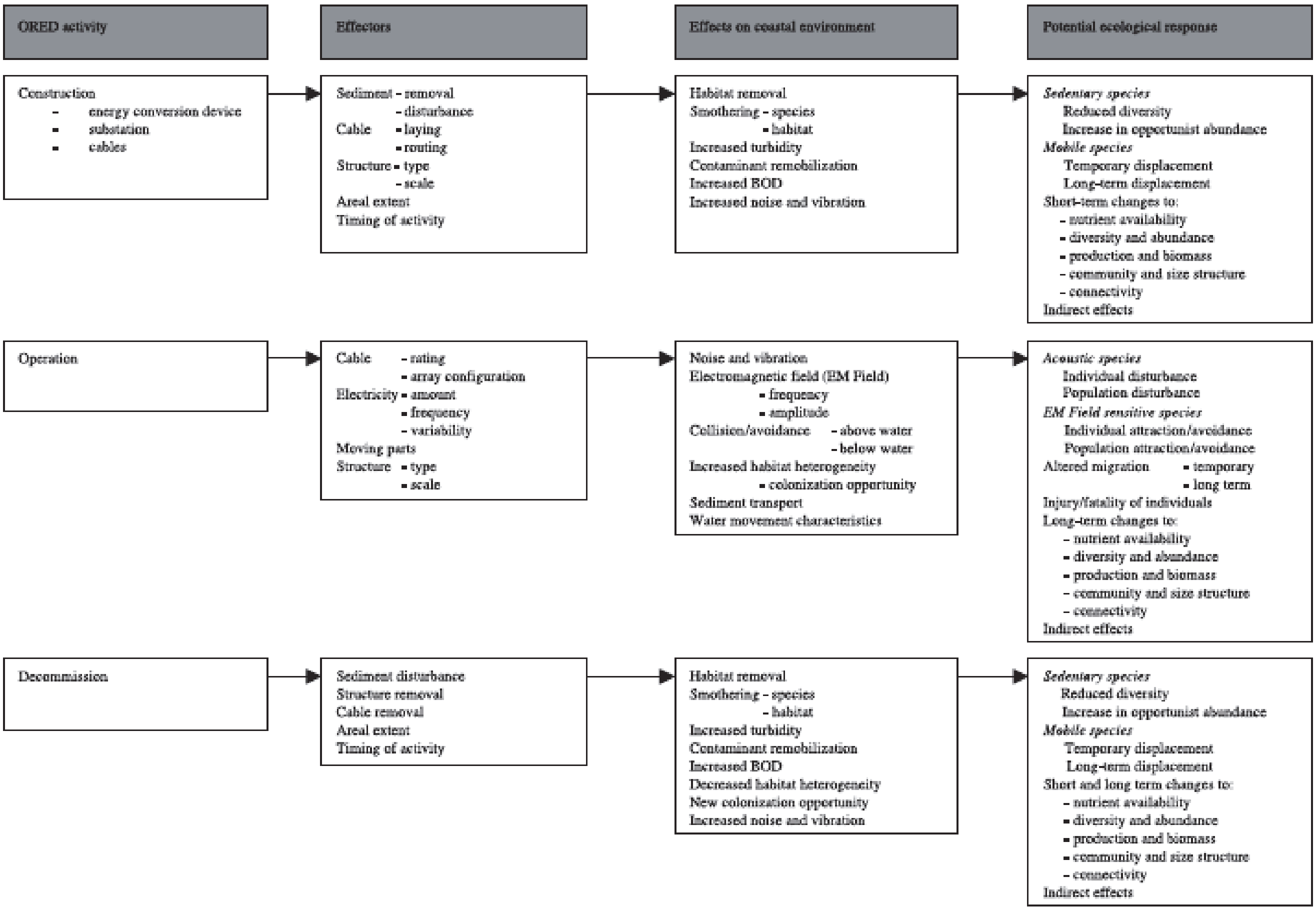
There are increasing concerns about the production of data on the marine environment, and investments placed in data collection and the dissemination of these data. These concerns are more important in the public sector where legislation and policies exist to improve both access to information and reuse. The directive INSPIRE (Infrastructure for Spatial Data in Europe - 2007/2/CE), developed by the General Management of Environment of the European Commission provides a framework for management of databases to ensure interoperability between databases and facilitate the dissemination, availability, use and reuse of geographic information in Europe. It is structured in five parts corresponding to the components of an infrastructure geographic data: (inspire.ign.fr).

- metadata (Gateway Infrastructure)
- geographic data (should be available in harmonized formats and structures)
- online services (data available via the Internet)
- sharing between public authorities (implementation of principles of trade, pricing and utilization)
- coordination and follow-up (establishing coordination structures both as contributors and as users)

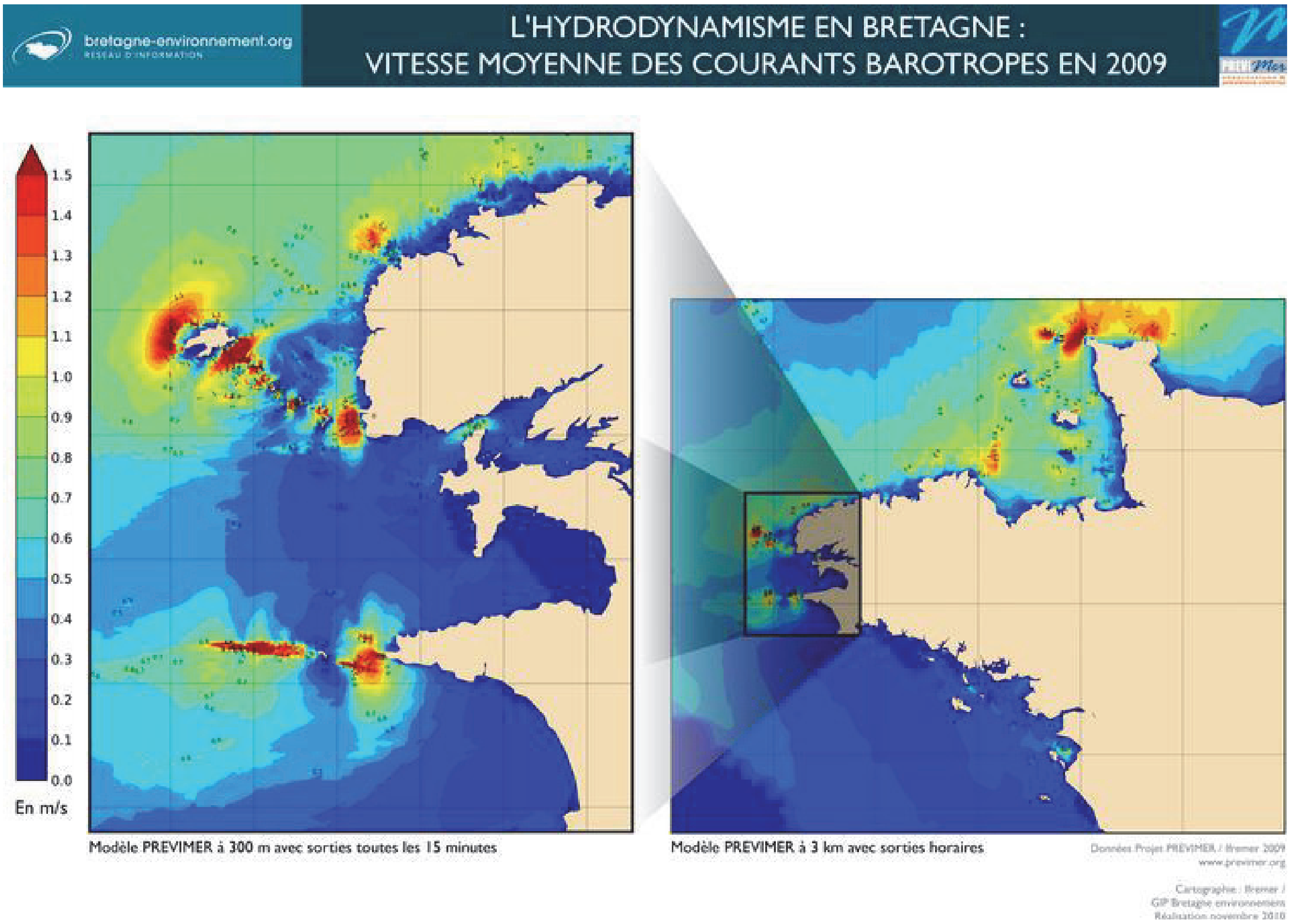
The consequences of the intensive exploitation of marine energy in all their forms are still unknown and research effort in proportion to development will be needed to understand the "sustainable" limits. It is necessary to develop and improve the quality of “predictive models” to forecast the evolution of environmental impacts and effects in the context of a broader view of the development of offshore activities and climate change (Linley et al., 2009).

ANNEXES

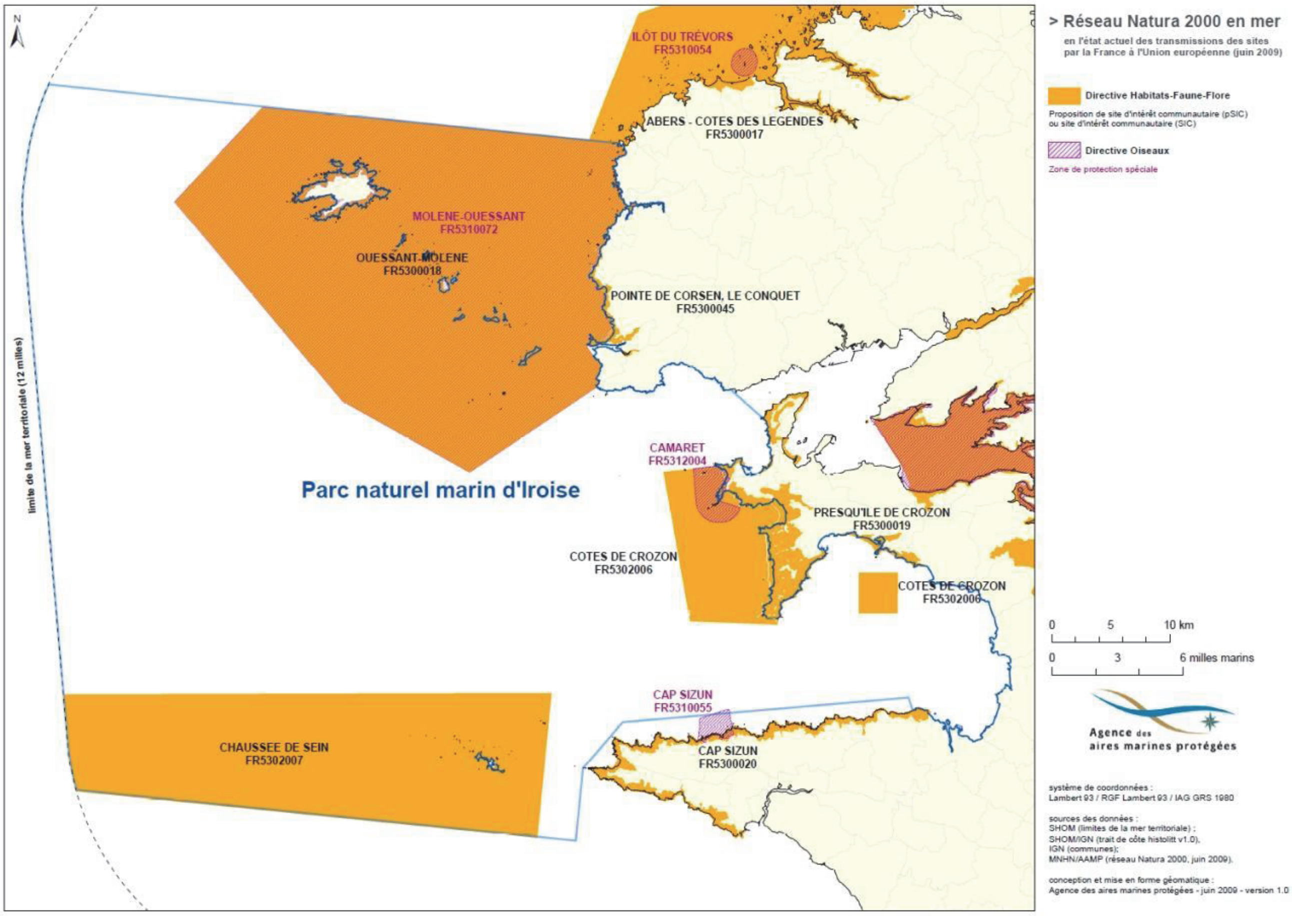
1. The MRE development and interactions with the environment, Gill (2005)



2: Hydrodynamics in Brittany



3. <u>The Natura 2000 network in the Iroise Sea, PNMI, 2009</u>



4. <u>Summary of potential effects of offshore wind farms, Hiscock (2002)</u>

	Environmental factors likely to be affected													**Potential effects and comments. (Estimate of extent and duration in bold)**
Developmental stage / activity	Substratum loss	Smothering	Suspended sediment	Turbidity	Emergence	Water flow	Wave action (climate)	Noise	Visual presence	Physical disturbance	Displacement	Chemical contaminants	Other	
PRE-INSTALLATION EXPLORATION														
Geophysical surveys • survey vessels • acoustic surveys								■	■		■			**Local, short term** • Potential physical damage of internal tissues (e.g. swim bladders), fish larvae or embryos and auditory sensors at short range due to underwater explosions or seismic survey arrays. • Stress and disruption of mating and social behaviour in cetaceans. • Disruption of fish shoals and feeding behaviour, startle response and potential reduction in catch rate (within 10m-10km) • Sonar induced flight responses in cetaceans, potentially resulting in increased incidence of live strandings • Interference with fish spawning areas **Area, short term** • Displacement of fish (within 10-1km) and sea mammals from the affected area, • Indirect effects on predatory seabirds
Core sampling of sea bed	■		■	■						■	■	■		Direct removal of samples of benthos and substratum, resulting in very localized increases in suspended sediment and turbidity and extraction of the benthic macrofauna. The use of drilling muds may expose organisms to chemical contaminants. Very localized and probably of low significance.

CONSTRUCTION														
Transportation of foundations and turbines to site • Transport barges • Jack-up barges • Drilling barges								■	■	■				**Local, short term** • Disruption of fish shoals and feeding behaviour, startle response and potential reduction in catch rates (within 10m-10km) • Stress and disruption of mating and social behaviour in cetaceans • Sonar induced flight responses in cetaceans, potentially resulting in increased incidence of live strandings • Direct disturbance of feeding seabirds and waterfowl due to increased visual presence and noise; • Physical disturbance of benthic macrofauna due to anchoring and legs of jack-up barges on seabed **Area, short term** • Displacement of fish (within 10-1km) and sea mammals from the affected area • Indirect effects on predatory seabirds
Foundation construction (General effects)	■	■	■	■	■	■	■	■	■	■	■			**Local, short term** • Disruption of fish shoals and feeding behaviour, startle response and potential reduction in catch rates • Stress and disruption of mating and social behaviour in cetaceans • Physical disturbance, abrasion, displacement and damage of macrofauna, especially epifauna and biogenic reefs, due to anchoring and legs of jack-up barges on seabed • Removal of substratum and loss of benthic macrofauna **Area, long term** • Displacement of fish and sea mammals from the affected area • Potential changes in bed-form and height and hence hydrography, water flow and changes of wave energy impinging on the coast • Changes to the benthic macrofaunal communities with resultant indirect effects on fish and their predators • Provision of new substrata and habitats for colonization

	Environmental factors likely to be affected													Potential effects and comments. (Estimate of extent and duration in bold)
Developmental stage / activity	Substratum loss	Smothering	Suspended sediment	Turbidity	Emergence	Water flow	Wave action (climate)	Noise	Visual presence	Physical disturbance	Displacement	Chemical contaminants	Other	
A) Gravity foundations • seabed preparation • positioning of foundation on seabed • addition of scour 'prevention' material	■	■	■	■	■	■	■	■	■	■	■	■		**Local, short term** • Removal of sediment and associated macrofauna • Physical disturbance, abrasion, displacement and damage of macrofauna • Attraction of scavenging species • Plumes of suspended sediment, increased turbidity and potential for smothering of surrounding habitats • Re-suspension of sediment bound contaminants if present • Very localized deoxygenation and release of H_2S and nutrients form anoxic layer. **Local, short - long term** • Release of chemical contaminants (e.g. synthetic polymers and hydrocarbons) from cements and grouting chemicals **Area - region, long term** • Potential changes in bed-form and height and hence hydrography, water flow and changes of wave energy impinging on the coast (see below) • Changes to the benthic macrofaunal communities with resultant indirect effects on fish and their predators
B) Monopile foundations	■	■	■	■		■	■	■	■	■	■	■		**Sedimentary habitats (pile driving)** **Local, short term** • Noise and visual presence (see foundation construction above) • Physical disturbance, abrasion, displacement and damage of macrofauna, especially epifauna and biogenic reefs • Attraction of scavenging species **Rocky habitats (drilling)** **Local, short term** • Noise and visual presence (see foundation construction above) • Destruction of species attached to affected rock surface and removal of substratum. • Suspended sediment and smothering • Physical disturbance, abrasion, displacement and damage of macrofauna, especially epifauna and biogenic reefs • Attraction of scavenging species • Release of chemical contaminants from drilling muds
C) Tripod foundations	■	■	■	■		■	■	■	■	■	■	■		Effects similar to monopile foundations above
Disposal of excavated spoil		■	■	■	■	■	■							**Local-area, short term** • Plumes of suspended material and increased turbidity • Smothering of benthic organisms on site and the wider area • Potential modification of seabed sediment types and resultant changes in benthic community **Region, long term** • Changes to the seabed height and hence wave action on the coast • Changes to sediment dynamics in the wider area

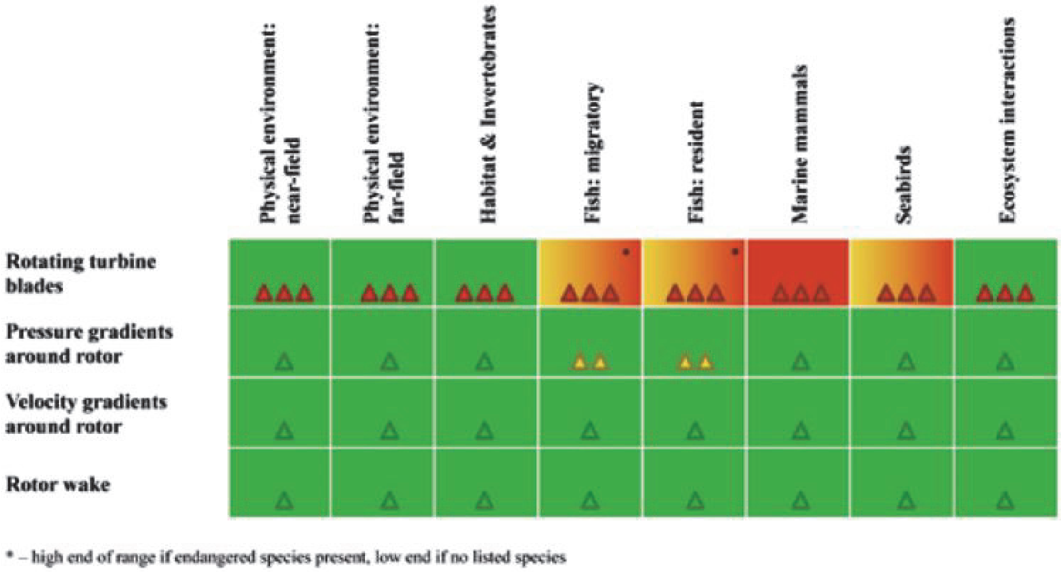
Developmental stage / activity	Environmental factors likely to be affected: Substratum loss	Smothering	Suspended sediment	Turbidity	Emergence	Water flow	Wave action (climate)	Noise	Visual presence	Physical disturbance	Displacement	Chemical contaminants	Other	Potential effects and comments. (Estimate of extent and duration in bold)
Installation of the turbine														Installation of the turbine and its support structure is unlikely to have additional direct effects on marine organisms at the construction stage.
Cable installation • cable laying vessels • trench digging, • plowing • electromagnetic fields	■	■	■	■				■	■	■	■	■	■	**Local, short term** • Noise and visual presence effects as above • Removal of sediment and associated macrofauna • Physical disturbance, abrasion, displacement and damage of macrofauna, especially epifauna and biogenic reefs • Attraction of scavenging species • Plumes of suspended sediment, increased turbidity and potential for smothering of surrounding habitats • Re-suspension of sediment bound contaminants if present • Very localized deoxygenation and release of H_2S and nutrients form anoxic layer. • Release of chemical contaminants (e.g. synthetic polymers and hydrocarbons) from cements and grouting chemicals • Disturbance of feeding water birds, seal pupping sites and damage to sensitive or important intertidal sites where cables come onshore **Area-region, long-term** • Potential changes in bed-form and height and hence hydrography, water flow and changes of wave energy impinging on the coast • Potential changes in macrofaunal communities with indirect effects on fish and their predators • Potential electromagnetic disruption of feeding behaviour in sharks and rays and migration is sharks and bony fish.

Developmental stage / activity	Environmental factors likely to be affected: Substratum loss	Smothering	Suspended sediment	Turbidity	Emergence	Water flow	Wave action (climate)	Noise	Visual presence	Physical disturbance	Displacement	Chemical contaminants	Other	Potential effects and comments. (Estimate of extent and duration in bold)
OPERATION														
Physical presence of the turbine towers	■					■	■	■	■	■	■	■	■	**Local, long term** • Resultant changes in the benthic communities in the vicinity of the turbines • Disturbance of feeding birds in the vicinity • Displacement of bird flight paths, a potential barrier to flight paths or migration routes and mortality due to bird strike • Loss of preferred feeding habitat in bird due to displacement • Provision of new substrata and habitats for colonization and formation of an artificial reef • Attraction of fish species to the artificial reef and their predators (seabirds and sea mammals) • Potential collision hazard with shipping **Area-region, long-term** • Potential changes in bed-form and height and hence hydrography, water flow and changes of wave energy impinging on the coast • Changes to the benthic macrofaunal communities with resultant indirect effects on fish and their predators • Potential disturbance of baleen whale communication and migration routes • Potential effect on electromagnetic fields on fish migration and feeding behaviour, especially in elasmobranchs (sharks and rays) • Provision of 'non-fishing' or 'no-take' zones
DECOMMISSIONING														
	■	■	■	■		■	■	■	■	■	■	■	■	**Local, short term** • Noise and visual presence as above • Removal of foundations and cabling resulting in considerable sediment disturbance, substratum loss, re-suspension of sediment and turbidity, potential smothering of surrounding habitats and physical disturbance • Loss of the artificial reef and associated species and habitats **Area-region, long-term** • Potential changes in bed-form and height and hence hydrography, water flow and changes of wave energy impinging on the coast • Changes to the benthic macrofaunal communities with resultant indirect effects on fish and their predators

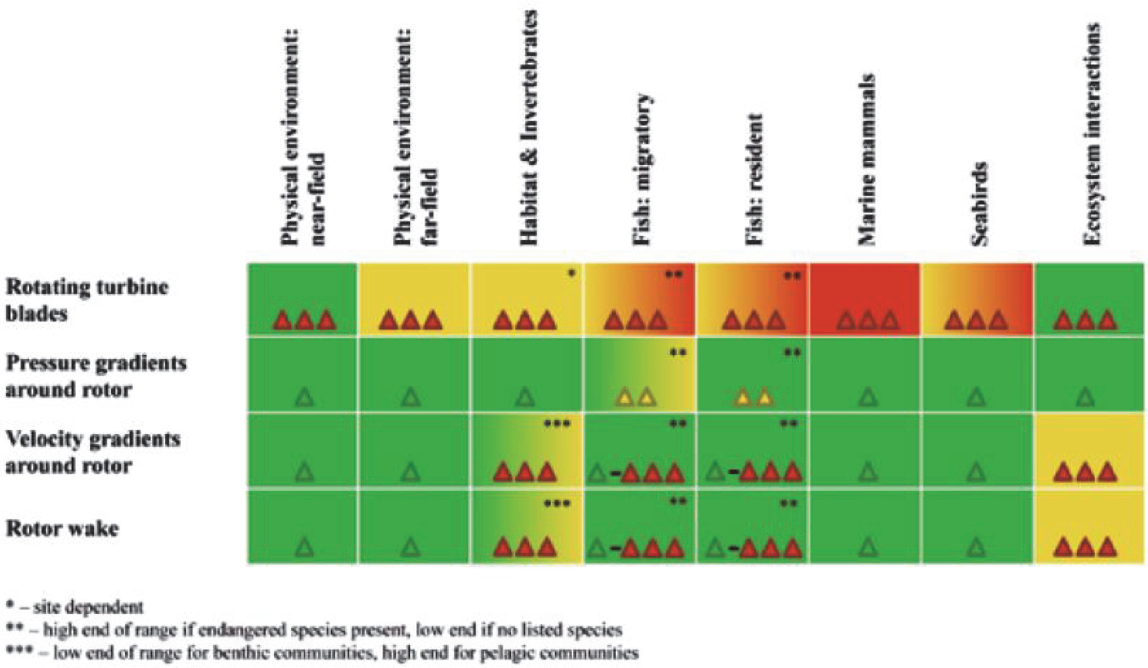
	Environmental factors likely to be affected													Potential effects and comments. (Estimate of extent and duration in bold)
Developmental stage / activity	Substratum loss	Smothering	Suspended sediment	Turbidity	Emergence	Water flow	Wave action (climate)	Noise	Visual presence	Physical disturbance	Displacement	Chemical contaminants	Other	
CUMULATIVE IMPACTS														
	■					■	■			■	■		■	Potential cumulative effects of multiple developments within a region may include: • Potential changes in bed-form and height and hence hydrography, water flow and wave energy impinging on the coast • Potential changes to the benthic macrofaunal communities with resultant indirect effects on fish and their predators • Potential effects on spawning and nursery areas for fish due to habitat loss or changes in hydrography • Potential changes to preferred feeding habitats for seabirds • Potential disturbance of baleen whale communication and migration routes due to emission of low frequency sound • Potential effect on electromagnetic fields on fish migration and feeding behaviour, especially in elasmobranchs (sharks and rays) • Provision of new substrata and habitats for colonization and formation of an artificial reef • Provision of 'non-fishing' or 'no-take' zones.

5. Polagye matrices (2010)

*The environmental stressor: **presence of devices: dynamic effects***

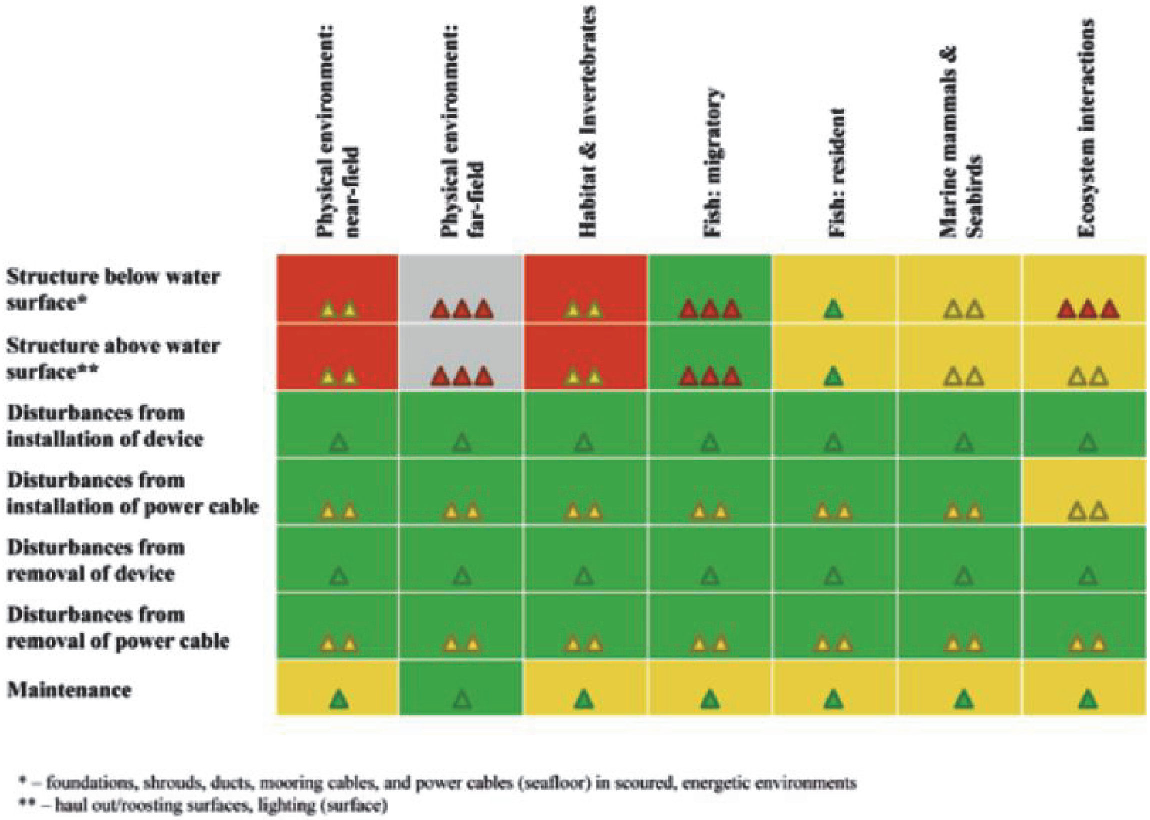


Stressor matrix: Presence of devices: dynamic effects – pilot-scale deployments.
Source: Polagye et al., 2010.

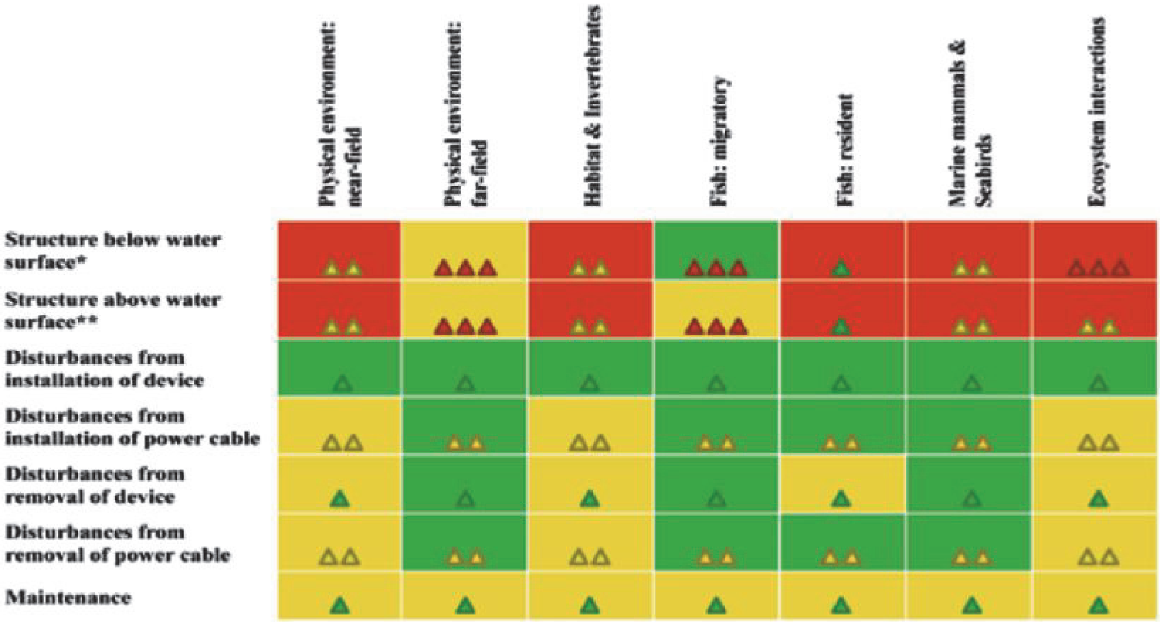


Stressor matrix: presence of devices: dynamic effects – commercial-scale deployments.
Source: Polagye et al., 2010.

The environmental stressor: ***presence of devices: static effects***



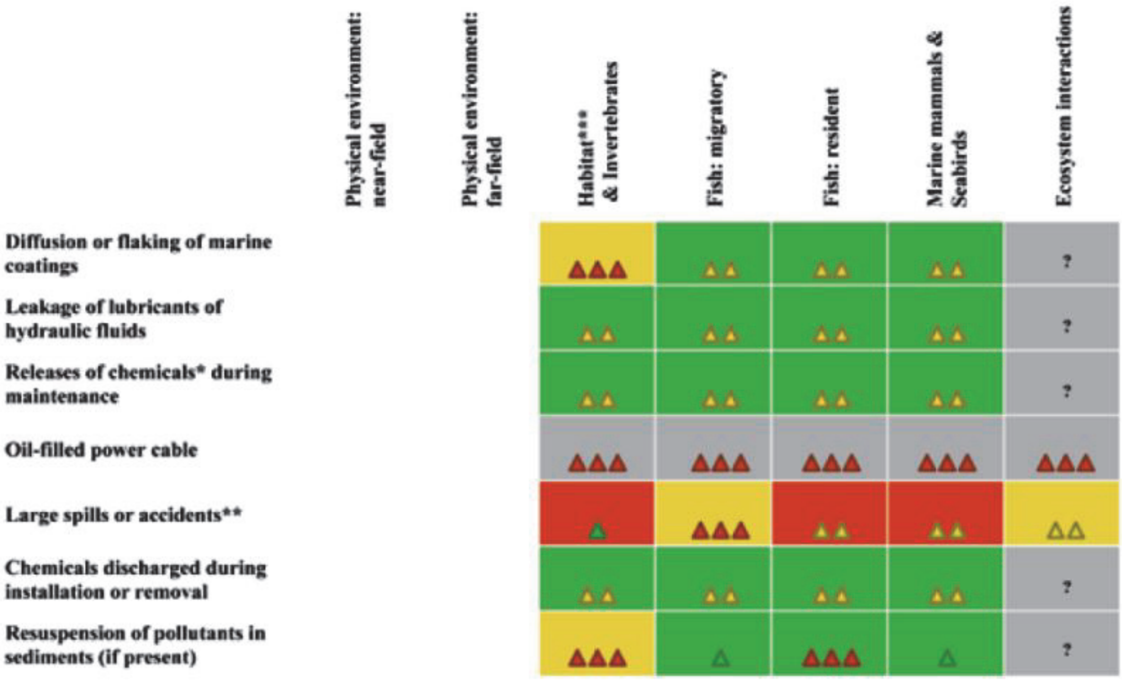
Stressor matrix: Presence of devices: static effects – pilot-scale deployments.
Source: Polagye et al., 2010.



* – foundations, shrouds, ducts, mooring cables, and power cables (seafloor) in scoured, energetic environments
** – haul out/roosting surfaces, lighting (surface)

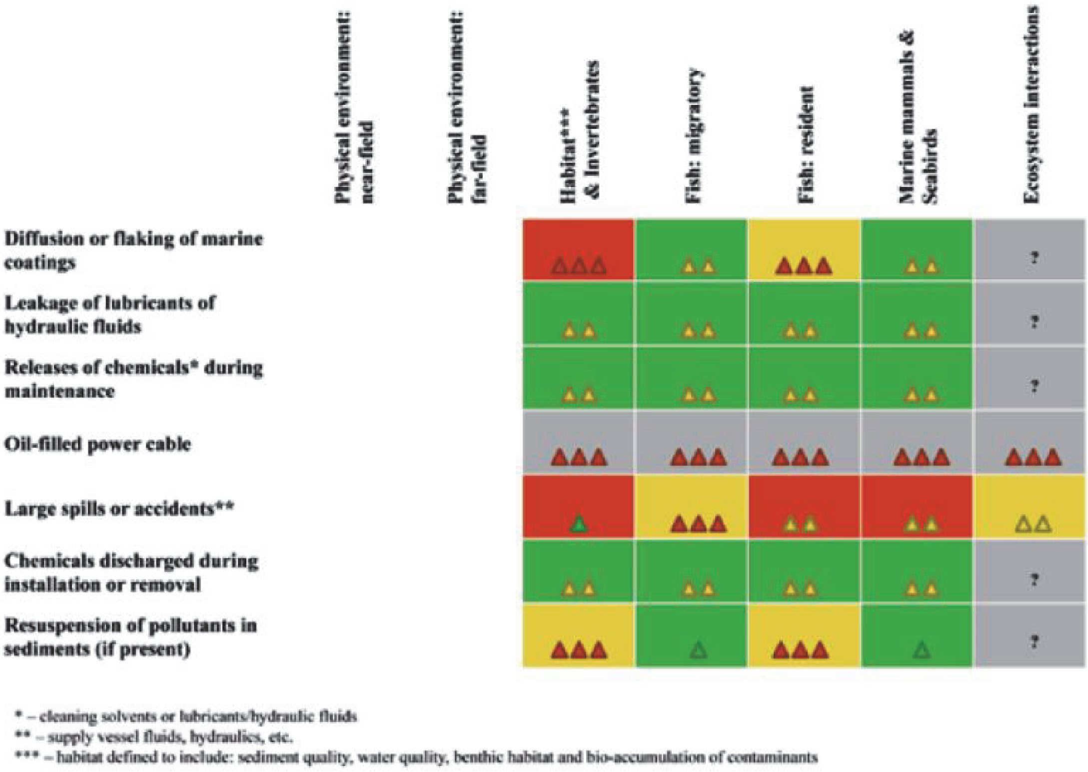
Stressor matrix: Presence of devices: static effects – commercial-scale deployments.
Source: Polagye et al., 2010.

*The environmental stressor: **chemical effects***



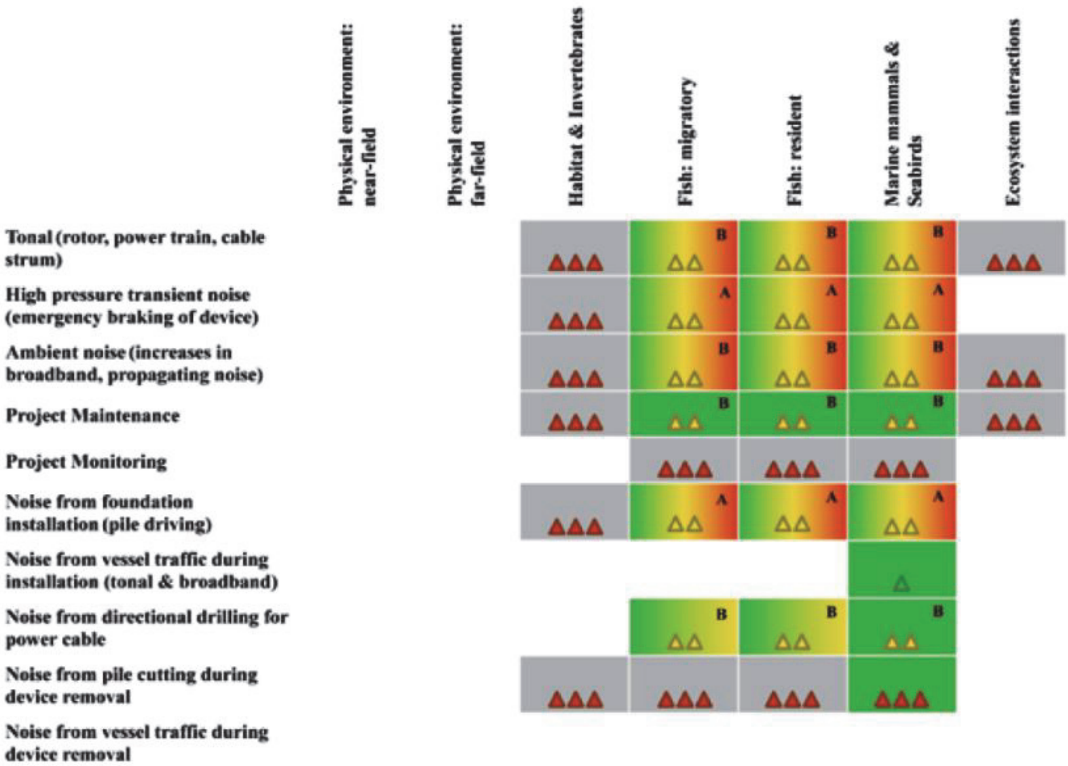
* – cleaning solvents or lubricants/hydraulic fluids
** – supply vessel fluids, hydraulics, etc.
*** – habitat defined to include: sediment quality, water quality, benthic habitat and bio-accumulation of contaminants

Stressor matrix: Chemical effects: pilot-scale deployments.
Source: Polagye et al., 2010.



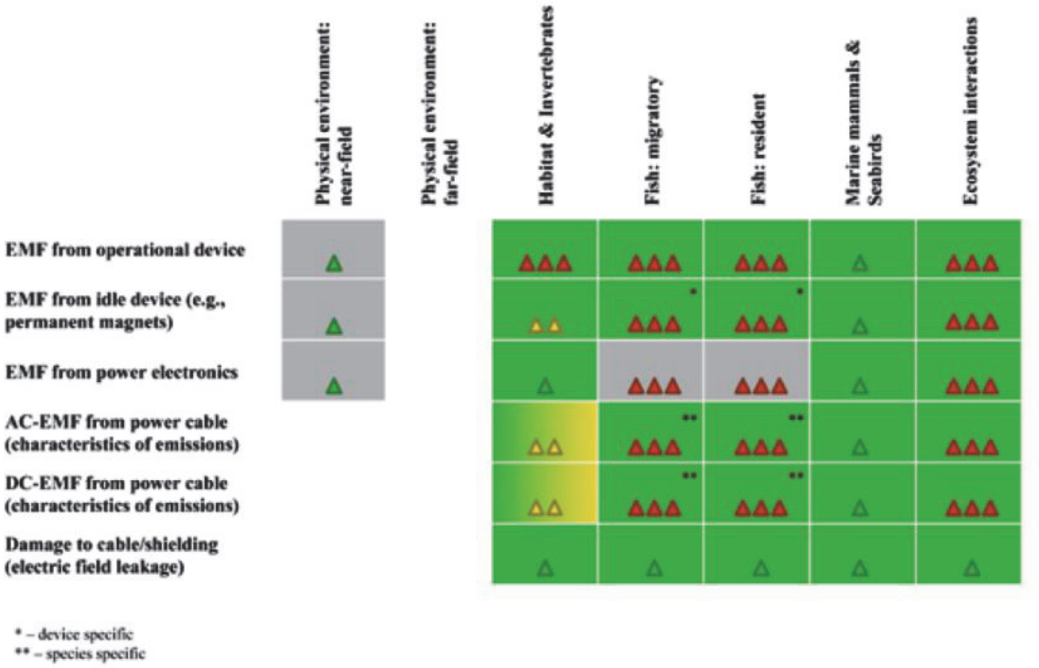
Stressor matrix: Presence of devices: static effects – commercial-scale deployments.
Source: Polagye et al., 2010.

The environmental stressor: ***Acoustic effects***

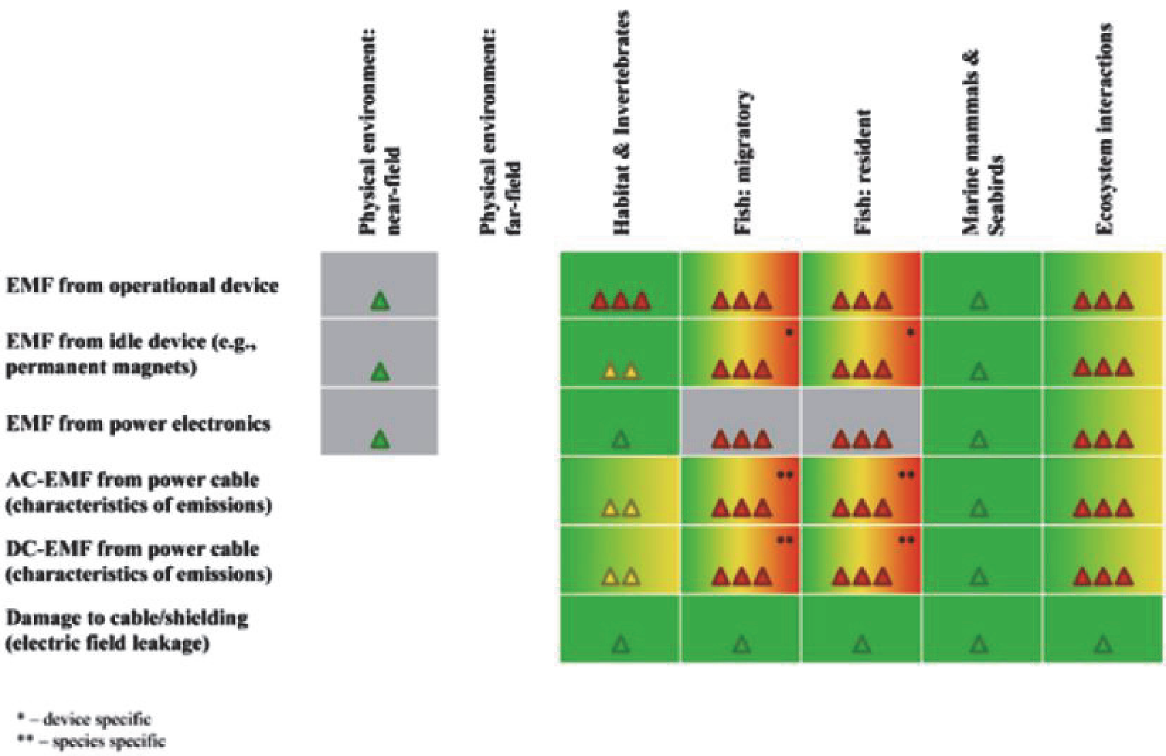


Stressor matrix: Acoustic effects –pilot and commercial-scale deployments.
Source: Polagye et al., 2010.

The environmental stressor: ***Electromagnetic effects***

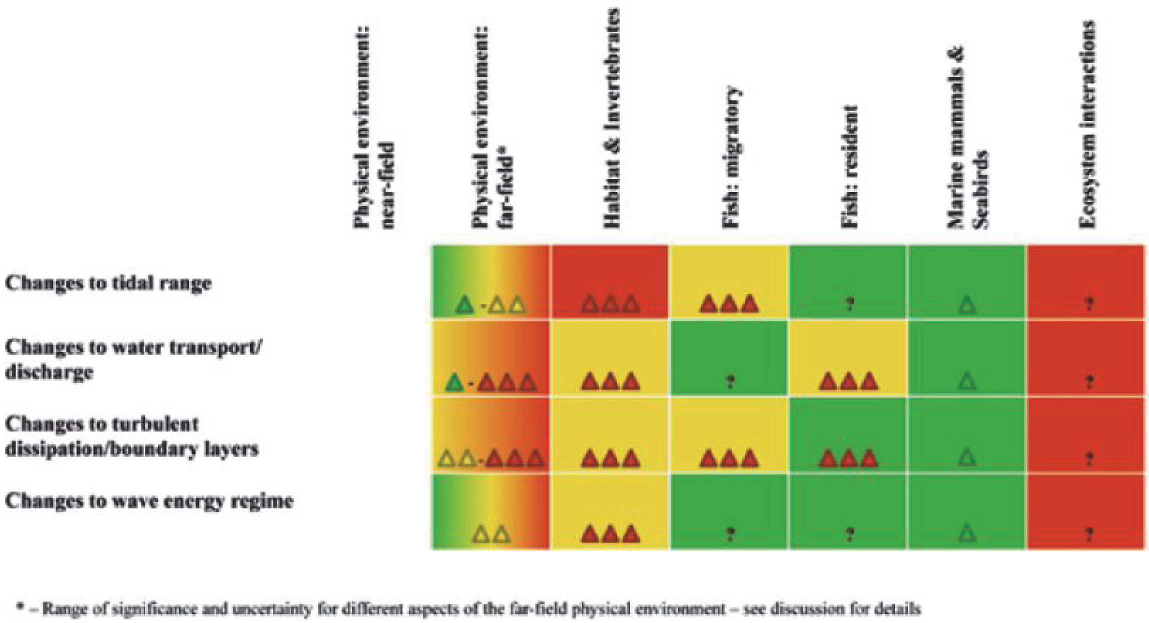


Stressor matrix: Electromagnetic effects: pilot-scale deployments.
Source: Polagye et al., 2010.

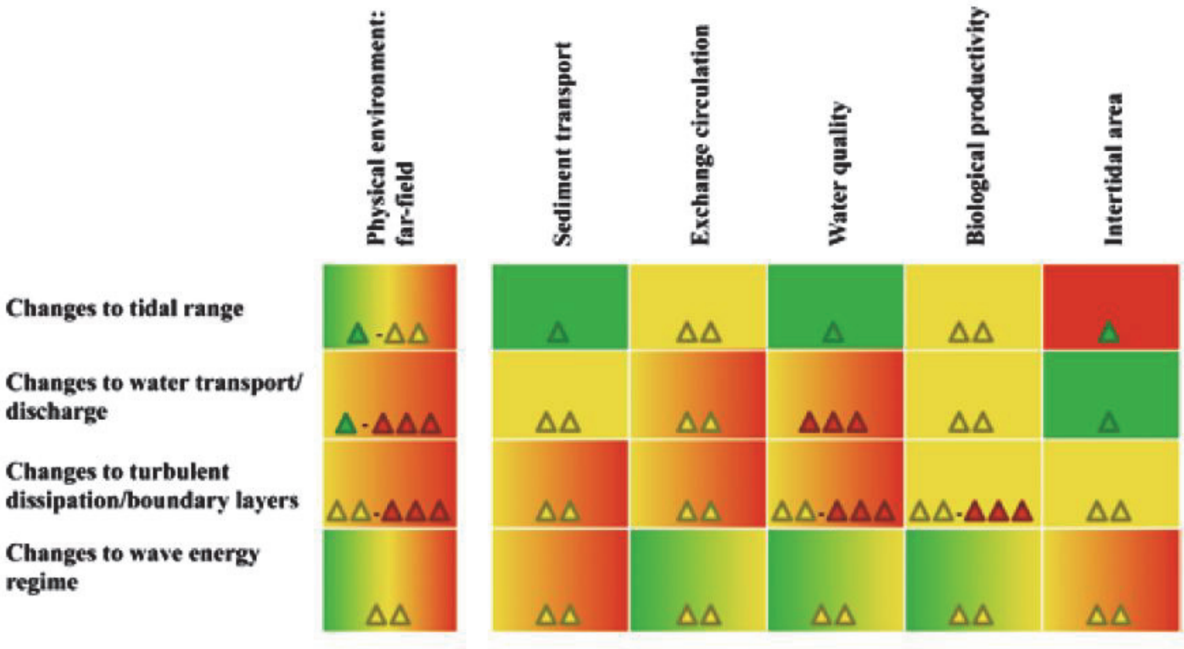


Stressor matrix: Electromagnetic effects –commercial-scale deployments.
Source: Polagye et al., 2010.

The environmental stressor: ***Energy removal effects***



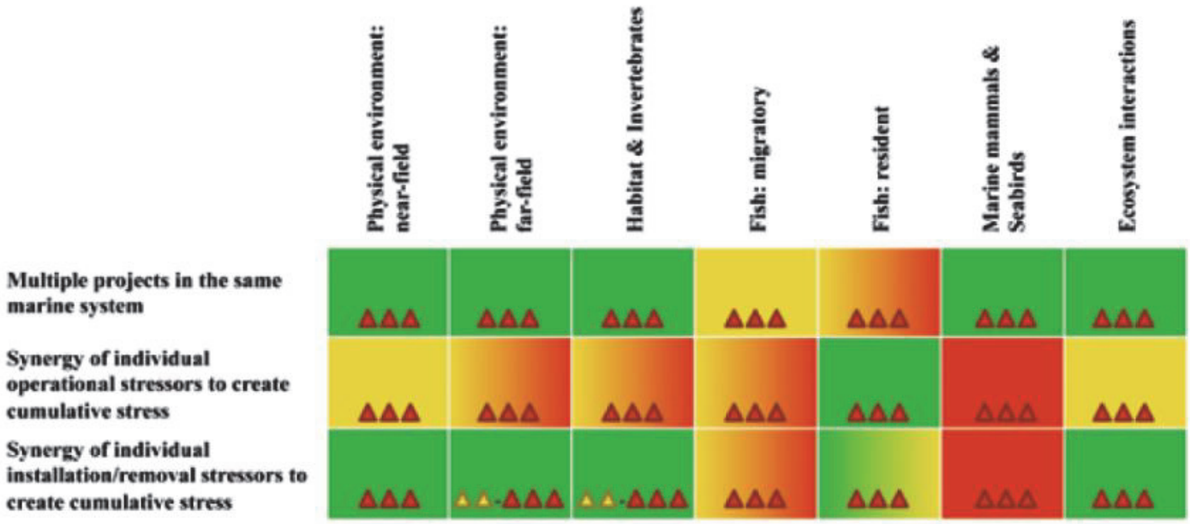
Stressor matrix: Energy removal - commercial-scale deployments.
Source: Polagye et al., 2010.



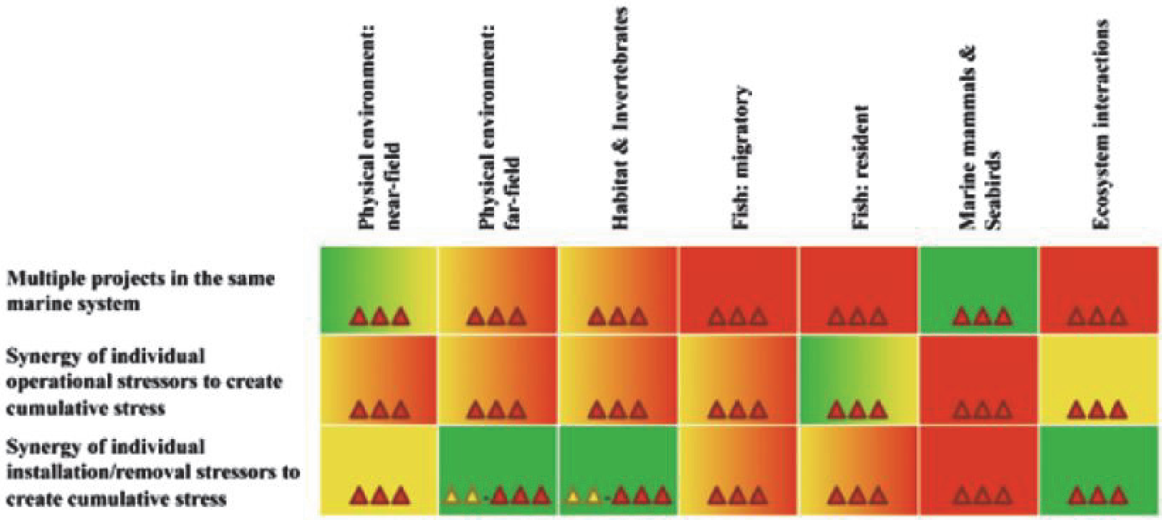
F

ar-field environment detail for energy removal stressor
Source: Polagye et al., 2010.

The environmental stressor: ***Cumulative effects***



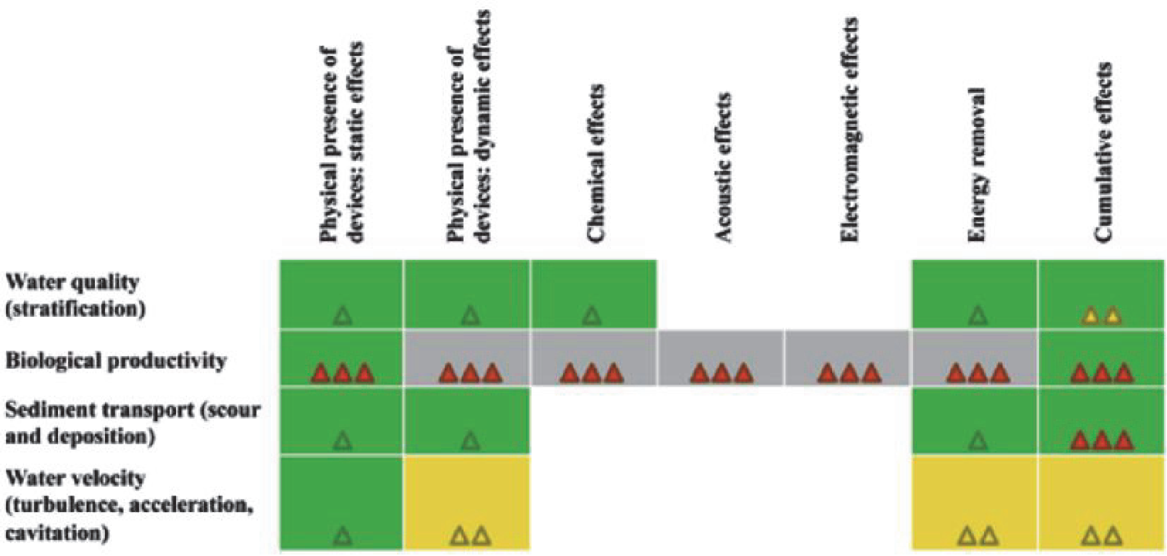
Stressor matrix: Cumulative effects: pilot-scale deployments.
Source: Polagye et al., 2010.



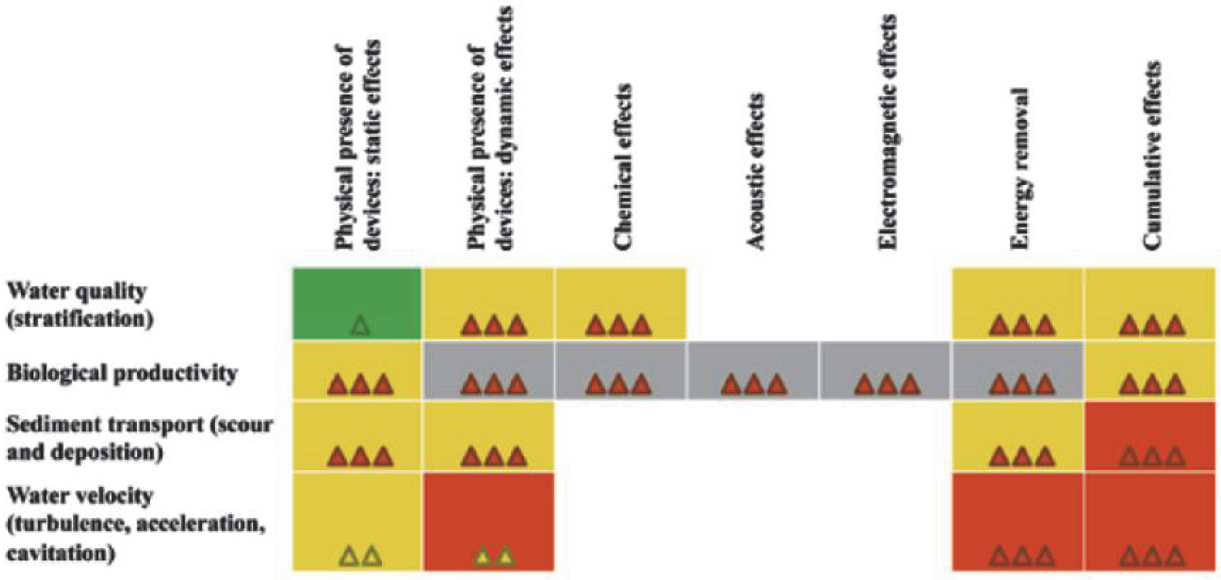
Stressor matrix: Cumulative effects –commercial-scale deployments.
Source: Polagye et al., 2010.

The environmental receptor: ***Physical Environment***

Polagye et al. (2011) had distinguished the near-field physical environment and the far-field physical environment.
The near-field is the aspects of the physical environment in the region in which the specific stressors from tidal energy devices are directly observable (e.g., within the device wake). And the far-field is the aspects beyond the near-field region, where specific stressors from tidal energy devices may affect the environment.



Receptor matrix: Physical environment: Near-field pilot-scale deployments.
Source: Polagye et al., 2010.



Receptor matrix: Physical environment: Far-field pilot-scale deployments.
Source: Polagye et al., 2010.

6. Main environmental issues of offshore Wind Farms, Wilhelmsson et al., (2010)

Degree of **s**everity estimated (-) or benefit (+) effect on assemblages of species in the zone of a wind farm classified as follows:

- Small: Does not influence or has only small impacts on the size or structure of the assemblages
- Moderate: impacts could moderately effect assemblages of species, generally or for particular species
- Grand: impacts could significantly influence the size or the structure of species assemblages, generally or for particular species.

Certainty:

1: literature is based on scientifically based speculation
2: Research is in its infancy and is inconclusive
3: Available literature provides a reasonable basis for evaluations
4: Available literature provides a good basis for evaluations assessments
5: The evidence base is convincing and is relatively strong

Table 3: Key environmental issues of offshore wind energy

Key environmental issues		Level of certainty for predictions/ estimates (1 low to 5 high)	Estimated scale of impact n.a. = Not assessed			Discussed in section in Annexe 1
			Spatial	Temporal	Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area	
FISH	Injuries from sound pulses (construction)	3	Local	n.a.	Small (-)	7.1
	Displacement/habitat loss (construction)	3	Very broad	Short term	(-) *see* 4.2.2	7.3
	Sediment dispersion (construction)	4	Broad	Short term	Small (-)	4
	Disturbance from operational noise	4	Very local	Long term	Small (-)	7.6
	Trawling exclusion	5	Broad	Long term	Large (+) *see* 4.2.3	3.3
	Artificial reef effects	3	Local	Long term	Moderate (+) *see* 4.2.3	3.3
	Electromagnetic fields	2	Local (but *see* migrating fish)	Long term	Small (-) (but *note* level of certainty and *see* migrating fish)	8.1
	Collisions with turbines	2	n.a.	n.a.	Small (-)	3.4
	Noise masking bioacoustics	2	Local	Long term	Small (-) (but *note* level of certainty)	7.9
MARINE MAMMALS	Injuries from sound pulses (construction)	3	Local	n.a.	Small (-) but *see* 4.2.2	7.1
	Displacement/habitat loss (construction)	3	Very broad	Short term	(-) *see* 4.2.2	7.2
	Displacement, disturbance (operation)	3	Very local	Long term	Small (-)	7.7
	Habitat enhancement	1	Broad	Long term	Small (+) (but *note* level of certainty)	3.3
	Migration barriers	2	n.a.	Long term	Small (-) (but *note* level of certainty and extra caution for whales), and *see* 4.2.3	7.9
	Collisions with turbines	2	n.a.	n.a.	Small (-)	3.4
	Noise masking bioacoustics	2	Local	Long term	Small (-) (but *note* level of certainty)	7.9

Key environmental issues		Level of certainty for predictions/ estimates (1 low to 5 high)	Estimated scale of impact n.a. = Not assessed			Discussed in section in Annexe 1
			Spatial	Temporal	Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area	
BIRDS	Displacement/habitat loss (construction)	5	Very broad	Short term	(-) *see* 4.2.2	9.3
	Displacement/habitat loss for seabirds (i.e. sea ducks and divers) (operation)	4	Very broad	Long term	(-) *see* 4.2.3	9.3
	Migration barriers (operation) 1. long distance migrators 2. daily commuters	3	n.a.	Long term	1. Small (-) 2. Moderate (-) *see* 4.2.3	9.2
	Collisions with turbines	3	n.a.	Long term	Small (-) but *see* 4.2.3	9.1
BENTHOS	Sediment dispersion (construction)	3	Broad	Short term	Small (-)	4
	Acoustic disturbance (construction)	2	Local	Short term	Small (-) (but *note* level of certainty)	7.4
	Changes in community structure directly due to turbines	4	Local	Long term	Small to Moderate (-) *see* 4.2.3	3.1 & 5
	Electromagnetic fields	2	Very local	Long term	Small (-) (but *note* level of certainty)	8.2
	Anoxia created	4	Very local	Long term	Small (-)	5
	Habitat enhancement (not considering trawling exclusion)	4	Very local	Long term	n.a.	3.1
	Entry point for invasive species	2	Very broad	Long term	n.a.	3.2
	Effects of trawling exclusion	5	Broad	Long term	Large (+) *see* 4.2.3	3.1
HYDROLOGY	Depletion of phytoplankton	4	Local	Long term	Small (-)	5
	Upwelling or downwelling at the perimeter of wind farm	1	Local	Long term	Small (+/-) (but *note* level of certainty)	5
	Toxic substances	4	Local	n.a.	Small (-)	6
	Oil spills (e.g. ship accidents)	-	n.a.	n.a.	(-) *see* 4.2.3	
SEA TURTLES	Displacement/habitat loss (construction)	2	Very broad	Short term	(-) *see* 4.2.2	7.1 & 7.8
	Displacement/habitat loss (operation)	2	Very local	Long term	Small (-) (but *note* level of certainty) *see* 4.2.3	7.8

7. Potential impacts, both positive and negative of wave energy, Pikesley, 2011

Potential negative impacts	Effects
Direct habitat loss during construction & decommissioning	Potential impact to benthic communities - implication for trophic cascades through the marine ecosystem.
Presence of new infrastructure • hard surfaces above & below water, mooring cables	Risk of collision, entanglement & entrapment (internal) for marine mammals, fish & diving birds. Modification of water circulation & currents - potential to reduce water mixing - may increase sedimentation & organic material in the area – implication for trophic cascades. Biofouling on buoys – may slough off or be removed during maintenance - may enhance benthic productivity. Changes to coastal processes through dampening of wave energy. If acting as a Fish Aggregating Device (FAD) then may attract birds to roost or feed or draw predatory species into the area – this may increases collision/entanglement/entrapment risks. Slack-moored systems can increase area of habitat lost or disturbed & increase entanglement risk.
Acoustic disturbance during construction/decommissioning & operation • piling, explosive decommissioning, mechanical movement of devices	Impacts fish, marine mammals & birds – displacement – redirection – auditory damage.
General disturbance • increased boat traffic (*e.g.* construction, maintenance, decommissioning), aerial surveying/monitoring	Impacts fish, marine mammals & birds – displacement – collision.
Sediment mobilisation during construction/decommissioning • increase in turbidity, remobilisation of toxic agents	Potential impact to benthic communities - implication for trophic cascades through the marine ecosystem. Increase in turbidity may increase collision risks.
Electromagnetic Fields (EMF) from cables & generating devices.	Potential to affect fish (particularly elasmobranchs) & marine mammals – use earth's magnetic field to navigate – some use E-fields behaviourally – potential to attract or repel.
Chemical • spills/leaks (oil, hydraulic fluid *etc.*) or continuous release (antifouling paints)	Potential to impact marine ecosystem.
Lighting on surface structures.	Attracts birds - increases collision risk. May change behaviour & migration of birds.
Scale up of project.	Extent, density & duration may bring cumulative effects.
Potential positive impacts	**Effects**
Presence of new infrastructure • hard surfaces above & below water	Artificial reef effect - may increase local biodiversity, species abundance & biomass. FAD – increases abundance of fish & predatory species. May provide roosting sites – potential improvement to foraging opportunities for marine birds.
No-take zone.	Positively enhances abundance of species. Potential for enhanced fisheries in areas adjacent to no-take zone through spill-over effect.

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