A risk-based method to prioritize cumulative impacts assessment on marine biodiversity and research policy for offshore wind farms in France

Jean-Marc Brignon, Morgane Lejart, Maëlle Nexer, Sylvain Michel, Alan Quentric, Léa Thiebaud

A risk-based method to prioritize cumulative impacts assessment on marine biodiversity and research policy for offshore wind farms in France

Jean-Marc Brignon[a,*], Morgane Lejart[b], Maëlle Nexer[b], Sylvain Michel[c], Alan Quentric[d], Léa Thiebaud[d],

[a] *Ineris, Parc Technologique ALATA, BP 2, 60550 Verneuil-en-Halatte, France*

[*] Corresponding author : Tel.: +33 3 44 55 6129, e-mail address: Jean-Marc.Brignon@ineris.fr.

[b] *France Energies Marines SAS bâtiment Cap Océan, 525 avenue Alexis de Rochon, 29280 Plouzané, France*

[c] *Office Français de la Biodiversité, 16 quai de la Douane, 29229 Brest cedex 2, France*

[d]*Cerema, Technopôle Brest Iroise, 155 rue Pierre Bouguer BP5, 29280 Plouzané, France*

Abstract

This study developed the "ECUME" risk-based approach to identify and prioritize critical impact pathways to be considered in cumulative impact assessment of offshore windfarms, and for future research. The prioritization framework has been tested on two offshore windfarms projects located in the French part of the English Channel off the coast of Normandy, those of Fécamp and Courseulles-sur-Mer. The approach is based on a complete inventory of impact pathways, prioritizing those for which an impact assessment will be carried out. The aim was to avoid a "quantification bias" and elaborate a systemic vision. The novelty of the study is to apply a combination of expert judgement, consensus building, and a scoring system, to prioritize the pairs of pressures and receptors of the marine environment to work on. The scoring system is based on the ecological importance of receptors, the degree of knowledge on the effect of a pressure on a receptor and the sensitivity of each receptor to pressures. Priorities for research were also determined during the same process. Bringing together a large set of specialized marine environnement scientists, the initial challenge was to build a common vocabulary, and a shared understanding of the risk-based prioritization approach. This required significant time and effort but secured foundations for further work. This study confirms the increasingly shared view that adopting a risk-based approach considering adverse effects on receptors is an efficient way to assess cumulative impacts, to focus on critical impact pathways, and manage the scientific complexity and the significant uncertainties.

Keywords : Marine ecosystem, cumulative impact assessment, offshore wind energy, risk-based approach, prioritization, anthropogenic pressures, impact pathways .

Highlights :

- We prioritize issues in cumulative impact assessment of offshore windfarms
- Prioritization combines risk-based expert judgement and a scoring system
- It is also used to identify priority research areas for the future
- It was tested on two French offshore windfarm projects
- Such a risk-based approach allows to manage scientific complexity and uncertainties

Table of contents

1 INTRODUCTION

1.1 GENERAL BACKGROUND

Marine ecosystems are subject to pressures (e.g. seafloor habitats modification or destruction, noise, emission of light, chemical pollution, mortality…) generated by human activities (fishing, dredging, aggregates extraction, marine energies,…). Among these activities, multiple offshore wind farms (OWF) projects are increasingly being implemented in different marine regions (GWEC, 2019). In northern Europe, the North Sea is seeing a high and growing density of wind farms. In France, no OWF is in operation currently, but several are under construction or already planned by the government, with the national objective of an installed capacity of 2,4 GW in 2023 and around 5 GW in 2028 (MTE, 2019).

In 2018, The French Ministry for Ecology considering that this situation required a cumulative impacts assessment of these projects on marine and coastal ecosystems, established the "ECUME" scientific working group (WG) (for "Effets CUMulés des projets Eoliens en Mer" : Cumulative effects of offshore wind projects). The ECUME WG has been tasked with developing a methodological approach to assess the cumulative impacts of French and relevant foreign projects, and to demonstrate its feasibility on two OWF projects located off the coast of Normandy, those of Fécamp and Courseulles-sur-Mer (Eastern Channel) (Figure 1). The Cumulative Impacts Assessment (CIA) should also include other anthropogenic activities that will increase the pressures from OWFs at the local or wider scale.

The objective of this paper is to describe a method to identify and prioritize the pressures and impact pathways that should be considered in the development of the ECUME CIA method, and its application to the eastern English Channel and southern North Sea. The paper also provides information on the organisation and general methodological approach of the forthcoming development of the CIA itself.

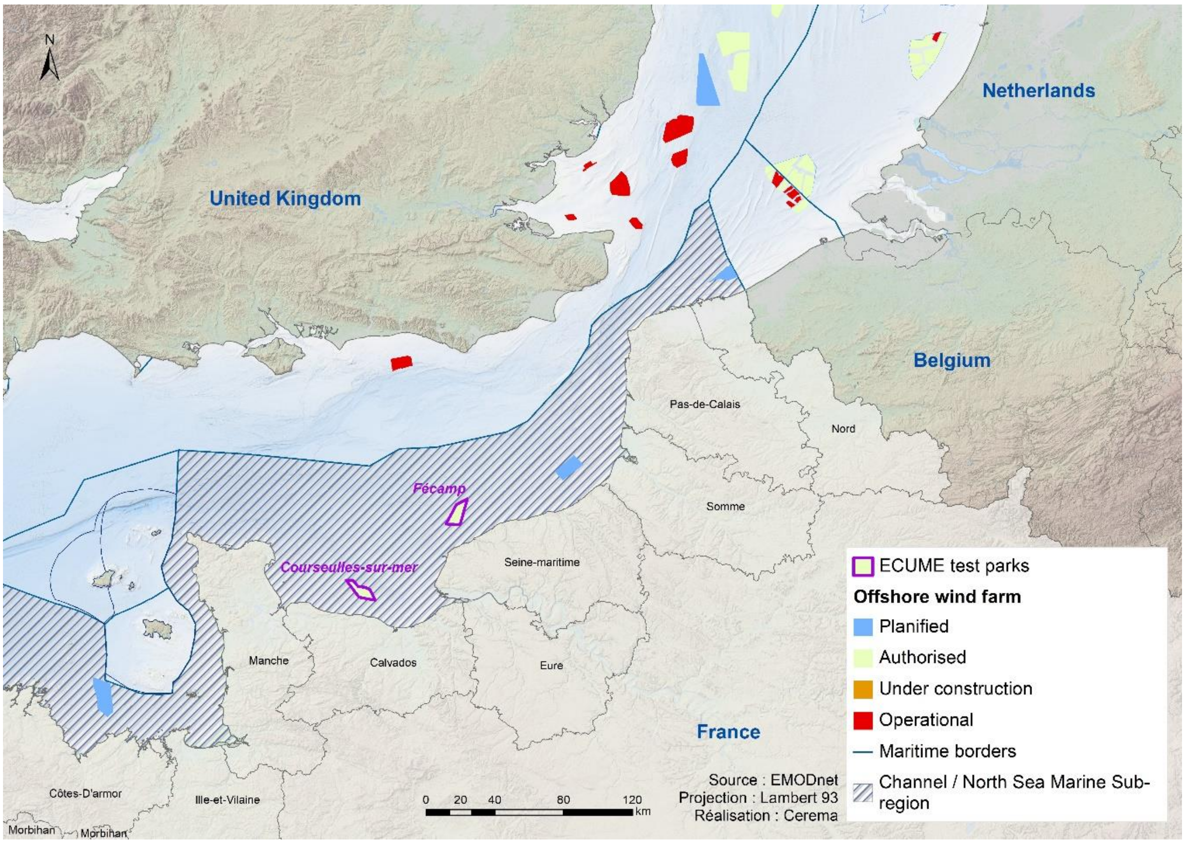

Figure 1: Map of the two OWFs of Fécamp and Courseulles-sur-Mer, and other windfarms in the eastern English Channel and southern North Sea.

1.2 Brief outlook of scientific approaches for marine cumulative impacts

With the growth of human activities at sea, intense research focuses on CIA on marine ecosystems, building on previous broader knowledge and practice of CIA in other fields. CIA has long been considered as part of Environmental Impact Assessment (EIA) (European Communities, 1999), and should as a first requirement follow EIA principles. Several published guidance from both the public and private sectors address the cumulative impacts (European Communities, 1999; IFC, 2013), several being specific to the marine environment (European Commission, 2013; Renewables UK, 2013; MTES, 2017). The European Marine Strategy Framework Directive (MSFD) refers to cumulative effects but restricted to the assessment of ecological state of the marine environment. In the scientific literature, (Willsteed E. et al., 2017; Borja A. et al., 2016; Duinker P. N. et al., 2012; Duinker P. N. & Greig L. A., 2006) underline the importance of following a standardised and rigorous impact assessment method, with transparent and careful formulation of objectives and scenarios definition. Because the outcome of assessments are scale and scope dependant (Lindeboom H. et al., 2015; Rijkswaterstaat, 2019) a fundamental underlying principle of CIA is the need for clarity on these geographical scales and temporal scope. The "before–after–control–impact" (BACI) method to monitor the effects of OWFs considers that scenarios representing the marine environment respectively with and without the offshore project should be compared (Methratta E. T., 2020). There are many variations in the denominations and concepts of CIA frameworks used in the marine environment (Tamis J.E. et al 2016). However, it is becoming a shared view at a theoretical level (Judd A.D. et al., 2015; Hodgson E. et al., 2019) and in practical applications (Singh G. et al., 2020; Verling E. et al., 2021), that given the high uncertainties in the impact causality chains, it is advisable to adopt a risk-based (rather than fully deterministic) approach in marine CIA. Risk-based assessment, that relies on describing the probability of adverse effects, is useful when high uncertainty and lack of knowledge make predictions difficult and poorly reliable and informative. It also helps in such contexts to design preventive action before projects, and adaptative surveillance and mitigation of impacts during the life of projects.

In the ECUME WG, such a risk-based approach will be used for CIA and has already been applied in the work reported here to prioritize impact pathways and research priorities. The need to consider all stressors and all potentially impacted receptors (Willsteed E.A. et al., 2018; (Borja A. et al., 2016) increases complexity and uncertainties (with associated data and scientific challenges) (Piet G.J. et al., 2015; Dannheim J. et al., 2019). Therefore, prioritization methods to decrease the number of pressures, habitats and species (hence impact pathways) to be assessed has already been used for OWF, especially applied to seabirds (Bradbury G. et al, 2014; Furness R. et al., 2013; Desholm M., 2009; Garthe S. et al., 2009). A more comprehensive prioritization process is described in (Tamis J.E. et al., 2016) and our work builds on this latter approach, also adding an explicit scoring system to the expert judgement. We apply this framework to identify priority pressures and receptors for the development of the ECUME CIA, and also to prioritize the main scientific knowledge gaps that need to be addressed in the future course of the ECUME WG and at international level in the North Sea region.

Section 2 of this article describes the general CIA approach in ECUME (2.1 and 2.2) and in more detail the risk-based prioritization of pressures and receptors for developing the CIA framework (2.3) and for future research (2.4). Section 3 presents and discusses results from the risk-based prioritization applied to the test area in the English Channel, then discusses its limits and possible improvements.

2 MATERIALS AND METHODS

2.1 PROJECT ORGANIZATION AND INTEGRATION OF SCIENTIFIC EXPERTISE

The ECUME WG involves several types of actors, the role of each being explained in this section and in the organization chart (Figure 2). Public administration is involved in: i) in setting the objectives and in the validation of the deliverables of the WG to ensure its compliance with national regulations and guidance, and ii) financing and organising the technical and scientific support.

Several French public or semi-public research institutes and agencies (Ineris, France Energies Marines, Cerema, and OFB) oversee the technical work, and the scientific management of experts in the WG. Around 30 scientific experts participating directly in ECUME bring knowledge of the marine ecosystem and their understanding of uncertainties in how these ecosystems are impacted by anthropogenic activities. They are academics or public researchers and were selected as specialists of each of the components of the marine ecosystem (birds, mammals, fish, benthic communities, etc.) and of pressures (noise, chemical pollution, modifications of physical habitats, etc.). Moreover, they are connected to their wider scientific communities who hence indirectly contribute to the ECUME WG.

The scientific expertise is key in the WG and covers as far as possible all aspects of the marine environment, including the functioning of the whole ecosystem. As underlined by (Lindeboom H. et al., 2015; Tamis J.E. et al., 2016; Borja A. et al., 2016) it is crucial to add ecosystem modelling and expertise to this framework to represent indirect / synergistic and trophic effects. Scientific experts are managed to ensure their engagement, and therefore strengthen the scientific quality of the results. Inclusion of expertise was organized through a participatory approach, with regular seminars held to build consensus regarding scientific issues.

Finally, the ECUME WG integrates “socio-professional observers” from stakeholder organisations representing professional activities of the marine environment: National Fisheries Committee (CNPMEM), Federation of Wind Energy and the Renewable Energies Union (FEE and SER), electricity network manager (RTE). Stakeholders from environmental NGOs (France Nature Environnement, the French committee of IUCN) are also present at important milestones.

Figure 2: Organisation and governance of the ECUME WG

2.2 Cumulative Impact assessment framework

Cumulative impacts relate to the multiplicity of human activities and projects that generate various pressures that accumulate and affect receptors in the marine ecosystem and this ecosystem as a whole (in a linear or non-linear way, at the same or distinct periods, at the same or distinct locations, through multiple direct and indirect pathways with synergistic and antagonistic effects). To address this complexity, the ECUME WG decided to follow and adapt to the OWF context the EIA method and formulate it in a risk-based setting (Figure 3).

The ECUME WG reviewed the literature on EIA methods, and international experience of their application. A scientific seminar concluded that the best approach was, in the context of limited scientific understanding of impacts, to combine "impact pathways", risk-based approaches, and ecosystem modelling. The standard impact assessment methodology common to most frameworks can be summarized in five steps: Goal and Scope definition, Preliminary Analysis, Scenarios definition (Baseline, Project, Alternatives), Scenarios Impact Assessment, Interpretation. Accordingly, ECUME WG decided to base its methodology on this comparative assessment framework.

The paper concentrates on the "Objective and Scope" and "Preliminary Analysis" steps, that is the inventory and prioritization of the objects subject to the CIA. This work is based on the notion of "impact chain" or "impact pathway", connecting activities to receptors through pressures. It has commonly been used in health and environmental assessment and in the context of CIA in the marine environment (Bailey H., 2014; Robinson L.A., 2014; Menegon S., 2018; Dannheim J. et al., 2019). Identifying impact chains is a first step to understand the potential impacts, and enables the assessment of the response of receptors to changes in activities, all along the DAPSI(W)R(M)framework (Driver – Activities – Pressure – State – Impact – (Welfare) – Response– (Measures)), also currently used for marine ecosystem assessment (Smith J.C. et al., 2016; Elliott M. et al., 2017; Rijkswaterstaat, 2019). There are few available models to predict these responses, especially for some environmental compartments (for example, few models exist concerning the benthic compartment). To avoid fundamental biases if focussing only on impacts chains for which models are available, the ECUME WG started with an exhaustive inventory of impact pathways, prioritizing those for which an impact assessment would be carried out, using modelling if available, or any other quantitative and qualitative method scientifically validated by ECUME experts (exposure or risk indicators maps, expert judgement). The aim is to build a pragmatic, manageable but holistic vision of the risks incurred by the marine environment and to avoid the "quantification bias".

However, impact pathways approach alone cannot capture cumulative impacts from ecosystem interactions and dynamics effects. A systemic vision will further be built with ecosystem modelling, including physical and intertidal effects modelling where relevant, and the development of indicators of state change, but this is beyond the scope of the present paper.

The ECUME WG intends to apply for testing purposes the methodology outlined in this section to two OWFs projects located off the coast of Normandy, those of Fécamp and Courseulles-sur-Mer (Figure 1), and surrounding OWFs in the same marine region, that will be considered relevant in terms of cumulative impacts, in particular for the mobile megafauna.

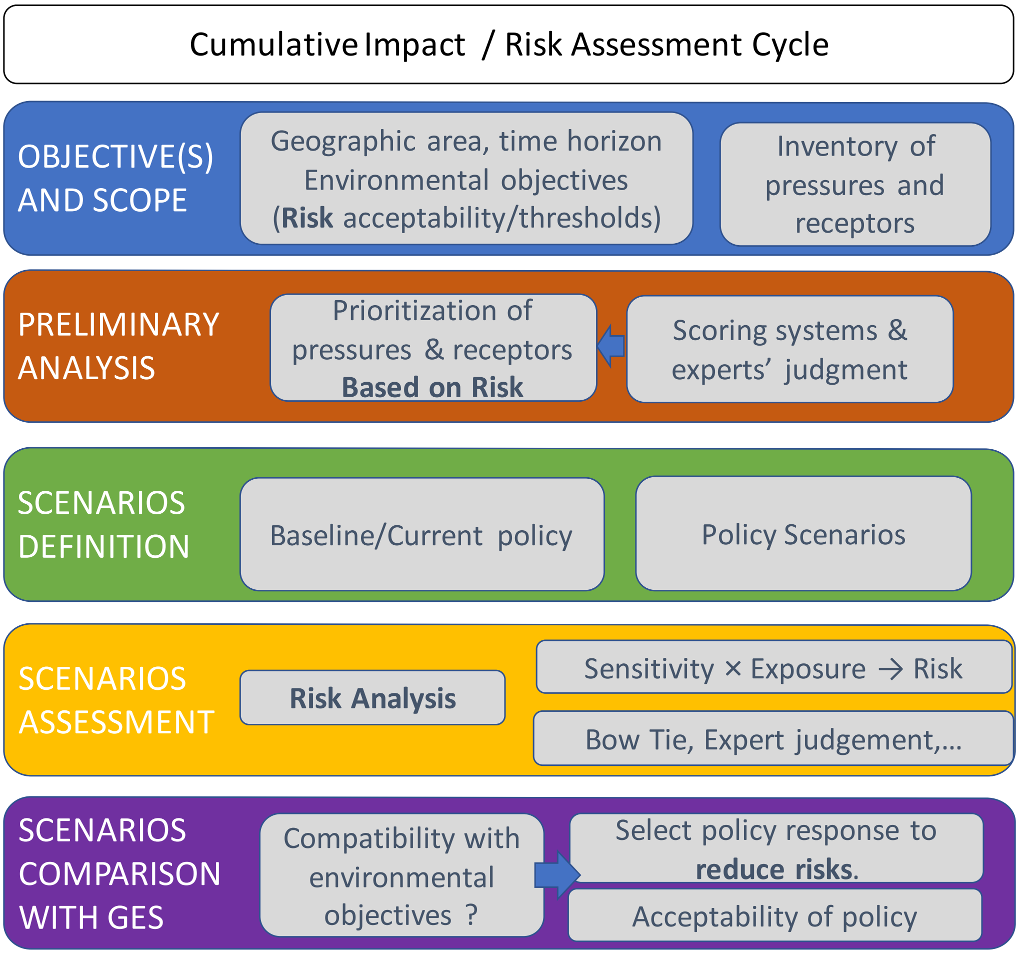

Figure 3: Impact/Risk Assessment methodology in the context of the ECUME WG

2.3 Inventory and selection of priority pressures and receptors

This section describes the inventory and prioritization of impact pathways of the "Objective and Scope" and "Preliminary Analysis" stages in Figure 3.

The ECUME WG carried out an inventory of all activities related to OWFs and the pressures they generate. These activities were identified for each stage of their lifecycle (construction, operation, decommissioning). The list of anthropogenic pressures is based on the MSFD typology, adapted following the works from (La Rivière M. et al, 2015) for physical pressures on benthic habitats and (Quemmerais F. et al, 2020) for other physical, chemical and biological pressures.

The list of biological receptors (habitat types, individual species, …) potentially impacted by pressures from OWF was built from the 2 OWFs environmental impact studies and complemented during experts workshops. Their high number would give rise to an unmanageable number of more than 5 000 impact chains. Therefore, it was decided to carry out an initial screening and grouping step based on expert scientific knowledge before applying a more structured prioritization method on a still large but manageable starting list.

This process was carried out in four steps (Figure 4):

- inventory of pressures and receptors
- initial screening of relevant receptors, activities and relevant pressure/receptor pairs
- systematic ranking of all relevant pressure/receptor pairs by a scoring system underpinned by expert scientific knowledge, described hereafter in detail (see “Systematic ranking of all pairs of pressures and receptors”)
- selection of final most relevant priorities by collective and transdisciplinary expert judgement during workshops

.

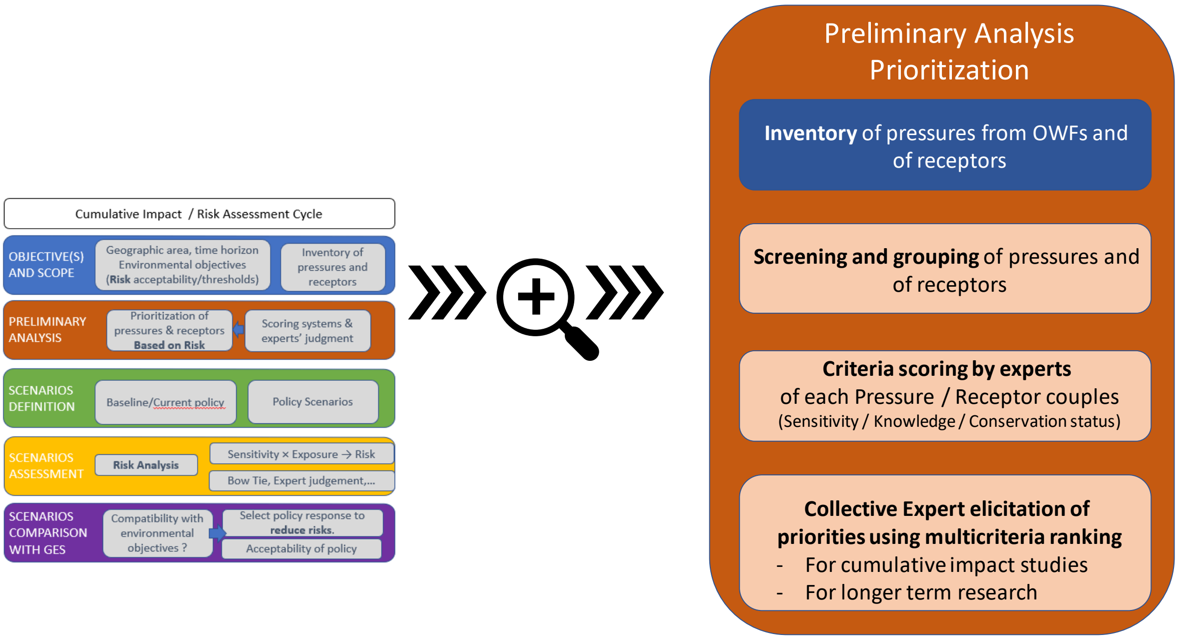

Figure 4: The ECUME prioritization process and its relation to the whole CIA methodology

Initial screening and grouping of most relevant activities and receptors

The screening was performed to retain only pressures generated within an OWF project, but only in normal conditions (i.e. excluding all kinds of accidental events, such as leakages, ship collisions, unforeseen maintenance operations, etc.). Some pressures that might be generated by OWFs but to a negligible extent compared to other sources of this pressure, in the eastern English Channel and southern North Sea region, were discarded during this screening, such as water temperature increase. All types of fixed foundations OWF were considered (monopiles, jackets and gravity-based structures), but not floating OWF as this technology is only emerging worldwide and will not be implemented commercially in France before 2027. The pressures associated with pre-construction activities (environmental, ecological and geophysical surveys, seafloor sampling and drilling) were considered as part of the construction phase.

The complete list of receptors included prior to screening around 452 species and habitats and was based on the full lists of habitats and species presented in the regulatory impact assessment reports of the Fécamp and Courseulles-sur-Mer windfarms projects.

The species and habitats have been classified in four groups:

- benthic habitats and communities (initial number of 300 species)
- ichthyofauna and planktonic communities (initial number of 101 species)
- marine mammals and turtles (initial number of 9 species)
- flying fauna (initial number of 36 bird species and 6 bat species)

For each group, the following specific scientific literature and rationale were used by ECUME experts:

For benthic habitats and communities, the number of receptors was reduced by grouping habitat types to the EUNIS 5 level, and to only consider the subtidal habitats.

For ichthyofauna, ECUME experts grouped the species by categories according to their habitats and phylogenetic supergroups (i.e. Actinopterigians, Elasmobranches and Cephalopods). Habitats and species were classified according to their position in the water column (benthic, demersal, pelagic), dependence to freshwaters (amphihaline or not), type of seabed (rocky, muddy, sandy, mixed) and location (on the shore, offshore). Trophic position of species was also considered, in case trophic models would be used for impact assessment. For instance, rays were distinguished from other benthic fishes.

For marine mammals and sea turtles, experts selected the most common species based on their knowledge of observation data in the study area. They selected turtles that can be, even at low numbers, regularly observed in the English Channel / North Sea area, but not those that are only occasionally observed (in exceptional circumstances for only one or a few individuals), which led to discard the green turtle, based on (Nivière M. et al., 2018). The harbour porpoise is the most common marine mammal species in the study area. Bottlenose dolphins, grey seals and harbour seals are also frequently observed. These species were then considered separately from cetaceans and from pinnipeds.

Experts identified “indicator” bird species representing the different families of seabirds relevant and most at risk for the area. The collision and displacement risk indicators provided by (Furness S. et al., 2013) and (Bradbury G. et al, 2014) were used as an additional guideline. These indicators are based on observations in the British part of the North Sea which is close to but distinct from our study area, and these studies partly rely on extrapolated data. Furthermore, the indicators are estimated for wind turbines 150m high, while those for French projects will reach 180 to 220 m, and they do not consider the differences between sites, colonies or populations, nor differences between nesting and wintering periods, and they cannot be used for migration periods. Experts were therefore the main source of information to design a species list adapted to the ECUME context. A category of passerine birds was added to take account of terrestrial birds which are exposed to collision risk with OWFs during their migrations.

A summary of structured groupings made can be found in first columns in Tables 2 to 5.

Systematic ranking of all pairs of pressures and receptors

Our approach relies on identifying the major risks of adverse and cumulative effects, as advocated by (Rijkswaterstaat, 2019). We focus on species that are the most sensitive, most at stake for the ecosystem, and for which at least a qualitative assessment (possibly based on expert judgement) of cumulative impacts is feasible with an acceptable level of uncertainty. It was agreed by experts that the acceptable level of uncertainty was defined on a case-by-case basis through discussion, based on their knowledge of the amount and quality of scientific evidence available regarding the sensitivity of the receptor to the pressure.

This prioritization will also allow to identify pressure-receptors pairs for which it is currently not possible to assess the impacts due to too severe gaps in scientific knowledge, or too high uncertainties. The aim of the ECUME WG is in this respect to inform on priorities for scientific research to improve CIAs in the future.

Each pressure-receptor pair was quoted based on the following scoring system:

- A first score (1 to 10), reflects the level of sensitivity (S) of the receptor to the pressure, within a realistic range of its intensity in the real-life marine environment but regardless of its actual value (the actual value of pressures is taken into account during the impact assessment phase). This score includes an appreciation of how severe the consequence of exposure might be at individual level for the receptor, for instance whether survival can be at stake,

- A second score (1 to 10) reflects the level of scientific knowledge (K) on the interaction between the pressure and the receptor. This score is an appreciation by experts regarding how much the pressure-receptor relationship is proven (in terms of the amount and quality of available scientific evidence) and can be at least qualitatively assessed meaningfully (so that the results are reliable enough to modify the design or even reconsider the OWF projects for instance).
- A third score (1 to 10) representing the conservation status (St) of the receptor. This St score is inspired by the "focal" species concept (i.e. important from either the perspective of ecosystem conservation or ecosystem services) advocated in several impact assessments of human activities on marine ecosystems (Link J.S., 2011; Zacharias M.A. et al., 2001). The St score also includes qualitative consideration of the socio-economic importance of the species (economic and/or patrimonial value). The St-scores were attributed transcribing on a numerical scale previous expert evaluation carried out within the framework of the implementation of the MSFD and the MSPD[1] in the marine region of concern (MTES and AFB, 2019). These evaluations included the species conservation statutes at the French national or European level published by the IUCN (IUCN French committee, 2013, 2015, 2016 and 2017). When different scores were attributed to different sectors of the East Channel and North Sea subregion, the maximum score was retained.

These score need to be balanced against each other, and therefore they are combined in a multiplicative way (S x K x St), so that the pressure/receptor pairs being subject to a more critical (S and St) and more scientifically established (K) potential adverse effect are in priority included further in the CIA. The precautionary principle was applied throughout the process by the ECUME scientific team and experts, using a "realistic worst case" approach for setting the values for the scores, similar to the one adopted in the Dutch KEC framework for cumulative effects (Rijkswaterstaat, 2019). In practice the realistic worst case approach consisted for example, if an interval of sensitivity scores were considered possible by the expert group, to not retain the absolute maximum sensitivity possible according to a single expert (that would be "worst case") but a value representing the maximum that the whole group agreed on.

The numerical values of K and S scores where first proposed by the ECUME project team, then consolidated by the experts during a full one-day seminar. The experts worked first in subgroups for each environmental compartment (Benthic habitats and communities, Ichthyofauna and plankton, Marine mammals and turtles, Birds and chiropters), and then shared their work to improve the consistency of quotations between subgroups.

To guide experts involvement, we followed and adapted the general features of the "Investigate," "Discuss," "Estimate" and "Aggregate" IDEA procedure for expert elicitation (Hemming V. et al., 2018). The pre-elicitation phase was fully carried out, but in some cases the personal investigation ahead of expert meetings was prepared by only some of them, leading to more importance put on the discussion and post-elicitation phase during expert workshops. There were no predefined criteria to guide experts in using the 1 to 10 scale. Experts were invited ahead of workshop discussions to prepare their individual scoring based on literature and their own judgement. Each expert own recourse to literature and own judgement was not precisely traced, and variation between experts in terms of their own working methodology can be a source of uncertainty and lack of robustness in the whole prioritization.

Selection of final priorities by experts

Based on the quotations by experts, we prepared the rankings of all pairs of pressures and related receptors, grouping them into the four ecological compartments (benthic habitats and communities, ichthyofauna and planktonic communities, marine mammals and turtles, and flying fauna). Prior to presentation to experts, the team merged certain pairs that obviously would be assessed together, and also suggested to discard some pairs for which it was evident that the current unavailability of data, or time and resources constraints of the ECUME WG would make any assessment impossible.

[1] Respectively 2008/56/CE and 2014/89/EU directives

However, such discarded pairs would automatically be identified as potential scientific research priorities. Examples of such discarded pairs (but systematically considered for being a research priority) are, for each compartment, the following : Introduction of non-native species for all benthic communities species, Underwater collision for cetaceans, Obstacle to movements, feeding and rest for amphialine fishes, and Disturbance in the aerial environment by human presence for ducks (scoters). We also proposed to cut the list at a point where all remaining pairs appeared to not cause any significant impact.

All lists and suggestions (groupings and discarding) were thoroughly reviewed and discussed by the scientific experts during a second one-day seminar, again with work in subgroups followed by harmonization between groups results. Experts were free to integrate pairs that they felt, independently of their previous quotations and of rankings, would finally be important for the CIA. It was made clear that a low Knowledge score should not necessarily lead to the exclusion of pressure/receptor pairs, and that final collective expert judgment had to prevail over the systematic ranking obtained through the scoring system.

Even if an ecosystemic approach will also be implemented in ECUME at a later stage, experts were invited to take already into account during this exercise the possible cumulative and combination effects (synergistic or antagonistic) between pressures, and the interactions between receptors. Overall, the experts found the prioritization quite helpful in keeping the scientific discussion and the exercise manageable. Discussions during the seminar lead to some additional groupings, and some significant changes to the proposed pre-prioritization.

2.4 INVENTORY AND SELECTION OF PRIORITY RESEARCH AREAS

A second aim of the ECUME WG is to prepare a research agenda for the CIA of OWFs on the marine environment. The above process was also used to identify research priorities with the group of experts. The same scores were combined in a different way (S x (1/K) x St), so that the pairs reflecting a more critical but less scientifically established issue clearly move up in the research priority hierarchy, to be eventually included in CIAs as soon as acquired knowledge allows to confirm or not the potential concern. A preliminary list of research priorities based on these scores was first analysed by the project team. Finally, this list was further discussed during a third workshop with experts to establish 4 to 6 research priorities by component of the marine ecosystem.

.

3 RESULTS AND DISCUSSION

In this section we describe and discuss results from the prioritization of impact pathways, applying the methodology outlined in section 2.3.

3.1 INITIAL SCREENING OF MOST RELEVANT RECEPTORS

The complete initial list of receptors for the Courseulles-sur-Mer and Fécamp wind farms included a total of 452 species that was finally reduced to 41 species or groups of species and habitats, for both OWFs. A challenge was to ensure the same understanding among different experts of when the presence of a habitat or a species in the study area was significant enough to justify its inclusion. Some experts might unintentionally tend to focus more on the ecosystem component they are specialized in and consider it should be integrated in the scoping phase, which could bias the selection process. This issue was resolved by strong adhesion of experts to the objectives and consensus building, to finally agree on priority species and habitats (Table 1).

This list contains 6 benthic habitats types (EUNIS level 5) which are the most prevalent ones in the subtidal part of the study area. Ichtyofauna is represented through 12 groups of species, divided into 3 groups for benthic rays, 1 group for benthic cephalopods and 8 groups for Actinopterigians (i.e. bonny fish): 1 diadromous, 2 benthic, 3 demersal, 1 bentho-pelagic and 1 pelagic fish groups. Two receptors are also introduced to describe the pelagic communities: phytoplankton (i.e. micro-algae) and zooplankton (including ichtyofauna larvae). The marine mammals species are much less numerous than fish species, thus individual species were retained, focusing on the most common species in the study area: 2 small cetaceans species and 2 pinnipeds species. Marine turtles are considered by selecting the 2 species which are occasionally found in the English Channel. Seabirds are considered through 11 species which are representative of wider species groups. Scoters are retained to represent the group of sea ducks, Eurasian curlew to represent shorebirds, and Passerines to represent all terrestrial migratory birds which may cross seasonally the study area. Ultimately, chiropterans species are synthetized by selecting 6 species which are considered by the experts as potentially present at sea in the study area, either during their migratory flights or for feeding during their reproduction period.

Benthic communities and habitats	**Ichthyofauna**	**Marine mammals and sea turtles**	**Flying fauna**
Ophiures Banks Ophiothrix fragilis (EUNIS A5.445), *Population of heterogeneous circalittoral sediments (EUNIS A5.44),* *Branchiostoma lanceolatum in coarse sand-gravelly circalittoral sediment (Eunis A5. 145),* *Mediomastus fragilis, Lumbrineris spp. and venerid bivalves in coarse sand or circalittoral gravel (EUNIS A5.142),* *Coarse sediment with circalittoral gravel (Eunis A5.14),* *Spirobranchus triqueter (formerly Pomatoceros triqueter), barnacles and encrusting bryozoans on circalittoral unstable pebbles and gravel A5.141)*	*Benthic rays - mixed bottoms - coastal* *Benthic rays - soft bottoms - offshore* *Benthic rays -soft bottoms - coastal* *Cephalopods - soft bottoms - coastal* *Diadromous* *Benthic Actinopterygians - soft bottoms* *Benthic Actinopterygians - rocky bottoms - coastal* *Bentho-pelagic Actinopterygians - sandy bottoms* *Demersal Actinopterygians - soft bottoms - coastal* *Demersal Actinopterygians - mixed bottoms* *Demersal Actinopterygians - rocky bottoms* *Pelagic Actinopterygians*	Marine mammals *Gray seal* *Harbor Seal* *Harbor porpoise* *Bottlenose dolphin* Sea turtles *Leatherback turtle Dermochelys coriacea* *Loggerhead turtle Caretta caretta*	Birds *Northern gannet* *Northern fulmar* *Red-throated loon* *Black-legged kittiwake* *Common guillemot* *Herring gull* *European Shag* *Lesser Black-backedgull* *Balearic shearwater* *Sand wich Tern* *Little gull* *Ducks (scoters)* *Eurasian curlew* *passerines (meadow pipit, skylark)* Bats *Common Pipistrelle* *Serotine bat* *Nathusius' s bat* *Noctule bat* *Lesser noctule of* *Parti-coloured bat*

Table 1 : List of priority species and habitat types for the assessment of cumulative impacts of OWFs

3.2 PRIORITIZATION OF MAJOR PRESSURES AND RECEPTORS

Relevant pressures for impact pathways related to OWFs where first identified through building a correspondence matrix between activities related to OWFs lifecycle, and pressures. 18 relevant pressures were identified during the construction phase, 16 pressures during the exploitation phase and 13 during the decommissioning phase. All the pressures potentially generated during decommissioning are also generated during construction, as the nature of activities as similar for these two phases.

	Groups	Species family or habitat type	Loss of underwater habitat	Loss of aerial habitat	Underwater habitat change	Change of aerial habitat	Substrate extraction	Physical action on the bottom (without material deposition and extraction)	Material deposition	Modification of hydrodynamic conditions	Modification of particle load	Temperature change	Underwater sound emissions	Airborne sound emissions	Electromagnetic emissions	Light emission	Synthetic and non-synthetic metals	Organic and non-synthetic compounds	Other chemicals (solids, liquids, gases)	Organic enrichment	Hypoxia	Introduction of individuals genetically different from native species	Introduction or spread of non-native species	Underwater collisions	Air collisions	Obstacle to movement, feeding, rest, moulting in an underwater environment (leading to loss of functional habitat)	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	Human attendance underwater environment (disturbance, sound disturbances excepted)	Human attendance in the air environment (disturbance, sound disturbances excepted)
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14)	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Spirobranchus triqueter (formerly Pomatoceros triqueter), encrusting barnacle	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Mediomastus fragilis, Lumbrineris spp. and venerid bivalves in coarse sand or c	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Branchiostoma lanceolatum in coarse sand-gravelly circalittoral sediment (Euni	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Stand of heterogeneous circalittoral sediments (EUNIS A5.44)	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)	10		9		6	5	4	3	3	2	2		2		6	6	6	3	6	7	7						
		Benthic crustaceans	10		5		6	6	3	2	3		4		4		4	4	4	3	10	1	1			3			
Marine mammals	Pinnipeds	Gray seal	4		4		1	1	1				6	1	1	1	5	7	3	1				8		6		5	1
		Seal calf marine	5		5		2	1	2				6	1	1	1	5	7	3	1				8		6		5	1
	Cetaceans	Harbor porpoise	4		4		1	1	2				7		1	1	5	7	3	1				8		5		4	
		Bottlenose dolphin	5		5		2	1	2				7		1	1	5	7	3	1				8		5		4	
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea	4		1					5		1	7		10	8	3	3	3					10		4		8	
		loggerhead turtle Caretta caretta	5		2					7		6	7		10	8	3	3	3					10		4		8	
Pelagic communities	Phytoplankton	Phytoplankton	1		5		5			7	7	5	1		1	5	3	3	3	3	5	1	5						
	Zooplankton	Zooplankton	1		5					5	5	5	1		1	5	3	3	3	3	5	1	5						
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	5		1				1		1		1		1	1	1	1	1	1	1		1			2		5	
		Benthic-loose rays - offshore			1						1		1		1					1									
		Benthic-loose rays - coastal	10		10		10	5	5		1		1		1	1	1	1	1	1	1		1			5		5	
	Cephalopods	Coastal benthics - soft bottoms			1		1	1		1	1		1			1	1	1	1	1	5		1			2			
	Actinopterygii	Amphihalins	1		1		1	1			1		5		1	5	1	1	1	1	1		1			10			
		Benthic - soft bottoms	10		10		10	1	5	1	1		3			1	1	1	1	1			1			5		1	
		Coastal benthic - rocky bottoms	1		1		1	1	1	1	1		1			1	1	1	1	1	5		1			2		1	
		Bentho-pelagic - sandy bottoms	5		5		10	1	1	1	5		5			5	1	1	1	1	5		1			2		10	
		Demersals - movable funds	7		5		10	1	5	1	1		3			3	1	1	1	1	5		1			5		10	
		Coastal demersals - mixed bottoms	3		1		5	1	1	1	1		1			3	1	1	1	1			1			2		10	
		Demersals - mixed funds	3		1		1	1	1	1	1		1			3	1	1	1	1						2		10	
		Pelagic	1		1		1			1	5		5			5	1	1	1	1						2		10	
Birds		Gannet	7	7	6	6							3	3		5	2		2					6	6	7	7	3	3
		Northern fulmar	1	4	1	3							1	3		8	2		2					1	3	1	7	1	3
		Red-throated Loon	4	4	7	7							4	4		3	3		3					5	5	6	6	8	8
		Kittiwake	1	1	1	4							1	3		5	2		2					1	7	1	3	1	3
		Common Guillemot	3	3	6	6							3	3		3	3		3					3	3	5	5	5	5
		Herring gull	1	2	1	3							1	3		5	2		2					1	9	1	3	1	3
		Crested cormorant	2	2	7	7							3	3		3	2		2					5	5	1	3	5	5
		Brown gull	1	2	1	3							1	3		5	2		3					1	9	1	3	1	3
		Balearic Shearwater	1	6	1	6							1	3		8	2		3					1	3	6	6	1	6
		Caugek Tern	1	3	1	5							1	3		3	2		2					1	5	1	4	1	4
		Pygmy seagull	1	4	1	4							1	3		3	2		2					1	6	1	4	1	4
		Ducks (scoter)	1	4	1	7							1	4		3	3		3					1	5	1	4	1	8
		Curlew	1	1	1	1							1	4		3	1		1					1	5	1	2	1	1
		Sparrows (farlouse pipit, skylark)		1		1							1	2		8	1		1						7		2		1
Bats		Common pipistrelle		3										1		5									5		3		
		Common serotin		3										1		5									5		3		
		Pipistrelle of Nathusius		3										1		5									5		3		
		Common noctule		3										1		5									5		3		
		Leiler's Noctule		3										1		5									5		3		
		Two-tone serotin		3										1		5									5		3		

Table 2:"sensitivity index" (S) for each pair of pressure (columns) and receptor (lines).

This matrix was used to quote relations between each pressure and each receptor in terms of sensitivity of the receptor to the pressure, from 1 to 10, 10 corresponding to a maximum level across all the pressures and receptors preselected in ECUME (Table 2). Blank cells correspond to cases in which no significant potential relationship exists between the pressure and the receptor (in the context of OWFs). For instance, the sensitivity of benthic habitats to "physical habitat loss" was scored 10, as this pressure produces a total and permanent loss of any marine habitat. Conversely, the sensitivity of plankton communities to the "introduction of individuals genetically different from local populations" was set to 1, as the interaction appears to have potential low adverse effect. Relations between pressures and receptors were also rated in terms of "Knowledge" of the previous level of sensitivity, again from 1 to 10 (Table 3).

	Groups	Species family or habitat type	Loss of underwater habitat	Loss of aerial habitat	Underwater habitat change	Change of aerial habitat	Substrate extraction	Physical action on the bottom (without material deposition and extraction)	Material deposition	Modification of hydrodynamic conditions	Modification of particle load	Temperature change	Underwater sound emissions	Airborne sound emissions	Electromagnetic emissions
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14)	8		6		5	4	5	4	3	4	1		1
		Spirobranchus triqueter (formerly Pomatoceros triqueter), encrusting barnacle	8		6		5	4	5	4	3	4	1		1
		Mediomastus fragilis, Lumbrineris spp. and venerid bivalves in coarse sand or c	8		6		5	4	5	4	3	4	1		1
		Branchiostoma lanceolatum in coarse sand-gravelly circalittoral sediment (Euni	8		6		5	4	5	4	3	4	1		1
		Stand of heterogeneous circalittoral sediments (EUNIS A5.44)	8		6		5	4	5	4	3	4	1		1
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)	8		6		5	4	5	4	3	4	1		1
		Benthic crustaceans	10		5		5	5	3	4	4		1		3
Marine mammals	Pinnipeds	Gray seal	10		3		3	3	3				7	1	1
		Seal calf marine	10		3		3	3	3				7	1	1
	Cetaceans	Harbor porpoise	10		2		2	2	2				7		1
		Bottlenose dolphin	10		2		2	2	2				7		1
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea	10		1					5		3	2		4
		loggerhead turtle Caretta caretta	10		2					5		3	2		7
Pelagic communities	Phytoplankton	Phytoplankton	1		5		3			5	5	5	1		1
	Zooplankton	Zooplankton	1		5					3	3	5	1		1
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	10		6				4		2		5		4
		Benthic-loose rays - offshore			6						2		5		4
		Benthic-loose rays - coastal	10		6		5	4	4		2		5		4
	Cephalopods	Coastal benthics - soft bottoms			6		5	4		2	2		5		
	Actinopterygii	Amphihalins	10		6		5	4			2		5		2
		Benthic - soft bottoms	10		6		5	4	4	2	2		5		
		Coastal benthic - rocky bottoms	10		6		5	4	4	2	2		5		
		Bentho-pelagic - sandy bottoms	10		6		5	4	2	2	2		5		
		Demersals - movable funds	10		6		5	4	2	3	2		5		
		Coastal demersals - mixed bottoms	10		6		5	4	2	3	2		5		
		Demersals - mixed funds	10		6		5	4	2	3	2		5		
		Pelagic	10		6		5			3	2		5		
Birds		Gannet	6	6	3	3							2	2	
		Northern fulmar	5	5	3	3							2	2	
		Red-throated Loon	4	4	3	3							2	2	
		Kittiwake	8	8	3	3							2	2	
		Common Guillemot	7	7	3	3							3	3	
		Herring gull	8	8	3	3							2	2	
		Crested cormorant	4	4	3	3							2	2	
		Brown gull	8	8	3	3							2	2	
		Balearic Shearwater	2	2	3	3							2	2	
		Caugek Tern	4	4	3	3							2	2	
		Pygmy seagull	5	5	3	3							2	2	
		Ducks (scoter)	10	10	3	3							2	2	
		Curlew	1	1	1	1							2	2	
		Sparrows (farlouse pipit, skylark)		4		1							2	2	
Bats		Common pipistrelle		4										1	
		Common serotin		4										1	
		Pipistrelle of Nathusius		4										1	
		Common noctule		4										1	
		Leiler's Noctule		4										1	
		Two-tone serotin		4										1	

	Groups	Species family or habitat type	Light emission	Synthetic and non-synthetic metals	Organic and non-synthetic compounds	Other chemicals (solids, liquids, gases)	Organic enrichment	Hypoxia	Introduction of individuals genetically different from native species	Introduction or spread of non-native species	Underwater collisions	Air collisions	Obstacle to movement, feeding, rest, moulting in an underwater environment (leading to loss of functional habitat)	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	Human attendance underwater environment (disturbance, sound disturbances excepted)	Human attendance in the air environment (disturbance, sound disturbances excepted)
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14)		5	5	5	5	5	5	5						
		Spirobranchus triqueter (formerly Pomatoceros triqueter), encrusting barnacle		5	5	5	5	5	5	5						
		Mediomastus fragilis, Lumbrineris spp. and venerid bivalves in coarse sand or c		5	5	5	5	5	5	5						
		Branchiostoma lanceolatum in coarse sand-gravelly circalittoral sediment (Euni		5	5	5	5	5	5	5						
		Stand of heterogeneous circalittoral sediments (EUNIS A5.44)		5	5	5	5	5	5	5						
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)		5	5	5	5	5	5	5						
		Benthic crustaceans		4	4	4	5	10	1	1			5			
Marine mammals	Pinnipeds	Gray seal	1	4	6	1	1				7		5		7	1
		Seal calf marine	1	4	6	1	1				7		5		7	1
	Cetaceans	Harbor porpoise	1	4	6	1	1				7		5		7	
		Bottlenose dolphin	1	4	6	1	1				7		5		7	
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea	5	4	4	4					10		2		2	
		loggerhead turtle Caretta caretta	8	7	7	7					10		2		2	
Pelagic communities	Phytoplankton	Phytoplankton	3	3	2	2	3	5	1	2						
	Zooplankton	Zooplankton	3	3	2	2	3	5	1	4						
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	3	4	3	3	3	6		7			10		3	
		Benthic-loose rays - offshore					3									
		Benthic-loose rays - coastal	3	4	3	3	3	6		7			10		3	
	Cephalopods	Coastal benthics - soft bottoms	3	4	3	3	3	6		7			10			
	Actinopterygii	Amphihalins	3	4	3	3	2	6		7			10			
		Benthic - soft bottoms	3	4	3	3	3			7			10		3	
		Coastal benthic - rocky bottoms	3	4	3	3	3	6		7			10		3	
		Bentho-pelagic - sandy bottoms	3	4	3	3	2	6		7			10		2	
		Demersals - movable funds	3	4	3	3	2	6		7			10		2	
		Coastal demersals - mixed bottoms	3	4	3	3	2			7			10		2	
		Demersals - mixed funds	3	4	3	3	2						10		2	
		Pelagic	3	4	3	3	2						10		2	
Birds		Gannet	2	2		4					6	6	5	5	4	4
		Northern fulmar	5	2		4					4	4	4	4	4	4
		Red-throated Loon	1	2		4					5	5	3	3	4	4
		Kittiwake	4	4		4					6	6	3	3	4	4
		Common Guillemot	2	2		4					5	5	3	3	4	4
		Herring gull	4	3		4					8	8	4	4	4	4
		Crested cormorant	2	2		4					3	3	3	3	4	4
		Brown gull	4	3		4					8	8	4	4	4	4
		Balearic Shearwater	5	2		4					2	2	2	2	4	4
		Caugek Tern	3	2		4					5	5	3	3	4	4
		Pygmy seagull	3	2		4					6	6	3	3	4	4
		Ducks (scoter)	2	2		4					8	8	5	5	8	8
		Curlew	2	2		4					2	2	2	2	4	4
		Sparrows (farlouse pipit, skylark)	8	2		4						6		2		4
Bats		Common pipistrelle	4									4		1		
		Common serotin	4									4		1		
		Pipistrelle of Nathusius	4									7		1		
		Common noctule	4									4		1		
		Leiler's Noctule	4									4		1		
		Two-tone serotin	4									4		1		

Table 3: "knowledge index" (K) for each pair composed of pressure (columns) and receptor (lines).

Another matrix was used to record "conservation status" (St), established according to the procedure described in section 2 (Table 4).

			Ecological stake levels					Ecological issue notes						
	Groups	Species family or habitat type	Sector 1: South North Sea and Strait of Pas de Calais	Sector 2: Picardy estuaries and the Opal Sea	Sector 3: Coastal river - seino-marine littoral	Sector 4: Eastern Channel	Sector 5: Bay of Seine	Sector 1: South North Sea and Strait of Pas de Calais	Sector 2: Picardy estuaries and the Opal Sea	Sector 3: Coastal river - seino-marine littoral	Sector 4: Eastern Channel	Sector 5: Bay of Seine	Middle facade Channel-East North Sea	Maximum Channel-East facade North Sea
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14)	nd (gravel, gravel)	low (coarse sediment)	low (A5.1)	strong (coarse sediment)	medium (A5.1)	5	4	4	8	6	**5,4**	**8**
		Spirobranchus triqueter (formerly Pomatoceros triqueter), encrusting barnacle	nd (gravel, gravel)	low (coarse sediment)	low (A5.1)	strong (coarse sediment)	medium (A5.1)	5	4	4	8	6	**5,4**	**8**
		Mediomastus fragilis, Lumbrineris spp. and venerid bivalves in coarse sand or c	nd (gravel, gravel)	low (coarse sediment)	low (A5.1)	strong (coarse sediment)	medium (A5.1)	5	4	4	8	6	**5,4**	**8**
		Branchiostoma lanceolatum in coarse sand-gravelly circalittoral sediment (Euni	fort (hydraulic dunes)	fort (hydraulic dunes)	low (A5.1)	strong (coarse sediment)	medium (A5.1)	8	8	4	8	6	**6,8**	**8**
		Stand of heterogeneous circalittoral sediments (EUNIS A5.44)	way	way	nd (A5.4)		major (A5.4)	6	6	5	2	10	**5,8**	**10**
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)	strong (medium sands)	strong (fine and medium sa	nd (A5.4)		major (A5.4)	8	8	5	2	10	**6,6**	**10**
		Benthic crustaceans	strong	low	strong	way	low	8	3	7	6	4	**5,6**	**8**
Marine mammals	Pinnipeds	Gray seal	major	strong	way		low	10	8	6	2	4	**6,0**	**10**
		Seal calf marine	way	major	way		strong	6	10	6	2	8	**6,4**	**10**
	Cetaceans	Harbor porpoise	strong	strong	strong (in winter)	strong (in winter)	medium (in summer)	8	8	8	8	6	**7,6**	**8**
		Bottlenose dolphin			low		strong	2	2	4	2	8	**3,6**	**8**
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea						2	2	2	2	2	**2,0**	**2**
		loggerhead turtle Caretta caretta						2	2	2	2	2	**2,0**	**2**
Pelagic communities	Phytoplankton	Phytoplankton	nd	strong	strong		nd	5	8	8	2	5	**5,6**	**8**
	Zooplankton	Zooplankton	strong	strong	strong		strong	8	8	8	2	8	**6,8**	**8**
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	strong (curly ray)	strong (curly ray)	strong (curly ray)	strong (curly ray)	strong (curly ray)	8	8	8	8	8	**8,0**	**8**
		Benthic-loose rays - offshore	strong (soft stripe)	strong (soft stripe)	strong (soft stripe)	strong (soft stripe)		8	8	8	8	2	**6,8**	**8**
		Benthic-loose rays - coastal	strong (brunette ray)	strong (brunette ray)	strong (brunette ray)	strong (brunette stingrays, stingrays)		8	8	8	8	2	**6,8**	**8**
	Cephalopods	Coastal benthics - soft bottoms		strong (cuttlefish spawning grounds)			strong (cuttlefish)	2	8	2	2	8	**4,4**	**8**
	Actinopterygii	Amphihalins			medium-strong		medium-strong	2	2	8	2	8	**4,4**	**8**
		Benthic - soft bottoms	strong (callionyms, spawnin	strong (callionyms, nurseries plaice, sole)			strong (callionyma, commo	8	8	2	2	8	**5,6**	**8**
		Coastal benthic - rocky bottoms		strong (gobies, shrimps)			strong (paganel goby)	2	8	2	2	8	**4,4**	**8**
		Bentho-pelagic - sandy bottoms		strong (let's launch)		nd (gobies), strong (spawni	strong (let's launch)	2	8	2	8	8	**5,6**	**8**
		Demersals - movable funds	strong (whiting nurseries)	strong (bar nurseries, whiting)			strong (whiting)	8	8	2	2	8	**5,6**	**8**
		Coastal demersals - mixed bottoms			strong (gray sea bream)		strong (gray sea bream, pou	2	2	8	2	8	**4,4**	**8**
		Demersals - mixed funds	strong (red mullet spawning	strong (red mullet spawning grounds)		strong (spawning mullet, ga	strong (bar)	8	8	2	8	8	**6,8**	**8**
		Pelagic	strong (herring spawning gr	strong (herring spawning gr	strong (horse mackerel, herring)		strong (sprat, griset, macker	8	8	8	2	8	**6,8**	**8**
Birds		Gannet	migratory?	weak (migratory)	migratory?	strong (wintering, migrator	migratory?	2	4	2	8	2	**3,6**	**8**
		Northern fulmar	medium (breeder)	migratory?	strong (breeder)		strong (breeder)	6	2	8	2	8	**5,2**	**8**
		Red-throated Loon	migratory?	strong (wintering)	medium (in wintering)	strong (wintering, migrator	weak (overwintering)	2	8	6	8	4	**5,6**	**8**
		Kittiwake	major (breeder)	migratory?	medium (breeder)	migratory?	strong (breeder)	10	2	6	2	8	**5,6**	**10**
		Common Guillemot	migratory?	migratory?	weak (breeder)	migratory?	migratory?	2	2	4	2	2	**2,4**	**4**
		Herring gull	migratory?	migratory?	strong (breeder)	migratory?	strong (breeder)	2	2	8	2	8	**4,4**	**8**
		Crested cormorant	migratory?	migratory?	migratory?	migratory?	medium (breeder)	2	2	2	2	6	**2,8**	**6**
		Brown gull	migratory?	migratory?	migratory?	migratory?	migratory?	2	2	2	2	2	**2,0**	**2**
		Balearic Shearwater	migratory?	migratory?	migratory?	migratory?	migratory?	2	2	2	2	2	**2,0**	**2**
		Caugek Tern	medium (breeder)	weak (migratory)	migratory?	migratory?	migratory?	6	4	2	2	2	**3,2**	**6**
		Pygmy seagull	migratory?	migratory?	weak (breeder)	migratory?	migratory?	2	2	4	2	2	**2,4**	**4**
		Ducks (scoter)		strong (wintering)			strong (wintering)	2	8	2	2	8	**4,4**	**8**
		Curlew	medium (large plover)	strong (large plover)			medium (ring-necked plove	6	8	2	2	6	**4,8**	**8**
		Sparrows (farlouse pipit, skylark)	nd	nd	nd	nd	nd	5	5	5	5	5	**5,0**	**5**
Bats		Common pipistrelle	minor concern	minor concern	minor concern	minor concern	minor concern	1	1	1	1	1	**1,0**	**1**
		Common serotin	minor concern	minor concern	minor concern	minor concern	minor concern	1	1	1	1	1	**1,0**	**1**
		Pipistrelle of Nathusius	near-threatened	near-threatened	near-threatened	near-threatened	near-threatened	4	4	4	4	4	**4,0**	**4**
		Common noctule	near-threatened	near-threatened	near-threatened	near-threatened	near-threatened	4	4	4	4	4	**4,0**	**4**
		Leiler's Noctule	near-threatened	near-threatened	near-threatened	near-threatened	near-threatened	4	4	4	4	4	**4,0**	**4**
		Two-tone serotin	insufficient data	insufficient data	insufficient data	insufficient data	insufficient data	5	5	5	5	5	**5,0**	**5**

Ecological issues DCSMM - 2nd cycle	major	10
	strong	8
	way	6
	low	4
	undefined	5
	no stake	2
IUCN France Red List Statutes	critically endangered	10
	vulnerable	7
	near-threatened	4
	minor concern	1
	insufficient data	5

Table 4: "regional conservation status index" (St) for each receptor (lines) and for different sectors within the French part of the Eastern Channel and North Sea.

After application of the prioritization procedure outlined in section 2.3, the final scoring of pairs of pressures and receptors was the following (Table 5, in which higher scores denote higher priority). Tables 6 to 8 summarize the reduced number of final priorities after grouping and selection by experts, for each ecological compartment. For Ichtyofauna, experts faced difficulty to establish priorities because of the critical lack of knowledge regarding the sensitivity of species to pressures. The priority for this compartment is to acquire more knowledge regarding sensitivity of species. Therefore, this compartment has not been addressed in terms of CIA studies to be launched but in terms of setting research priorities (see section 3.1)

	Groups	*Species family or habitat type*	Loss of underwater habitat	Loss of aerial habitat	Underwater habitat change	Change of aerial habitat	Substrate extraction	Physical action on the bottom (without material deposition and extraction)	Material deposition	Modification of hydrodynamic conditions	Modification of particle load	Temperature change	Underwater sound emissions	Airborne sound emissions	Electromagnetic emissions	Light emission	Synthetic and non-synthetic metals	Organic and non-synthetic compounds	Other chemicals (solids, liquids, gases)	Organic enrichment	Hypoxia	Introduction of individuals genetically different from native species	Introduction or spread of non-native species	Underwater collisions	Air collisions	Obstacle to movement, feeding, rest, moulting in an underwater environment (leading to loss of functional habitat)	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	Human attendance underwater environment (disturbance, sound disturbances excepted)	Human attendance in the air environment (disturbance, sound disturbances excepted)
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14	640		432		240	160	160	96	72	64	16		16		240	240	240	120	240	280	280						
		Spirobranchus triqueter (formerly Pomatoceros trique	640		432		240	160	160	96	72	64	16		16		240	240	240	120	240	280	280						
		Mediomastus fragilis, Lumbrineris spp. and venerid bi	640		432		240	160	160	96	72	64	16		16		240	240	240	120	240	280	280						
		Branchiostoma lanceolatum in coarse sand-gravelly ci	640		432		240	160	160	96	72	64	16		16		240	240	240	120	240	280	280						
		Stand of heterogeneous circalittoral sediments (EUNIS	800		540		300	200	200	120	90	80	20		20		300	300	300	150	300	350	350						
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)	800		540		300	200	200	120	90	80	20		20		300	300	300	150	300	350	350						
		Benthic crustaceans	800		200		240	240	72				32		96		128	128	128	120									
Marine mammals	Pinnipeds	Gray seal	400		120		30	30	30				420	10	10	10	200	420	30	10				560		300		350	10
		Seal calf marine	500		150		60	30	60				420	10	10	10	200	420	30	10				560		300		350	10
	Cetaceans	Harbor porpoise	320		64		16	16	32				392		8	8	160	336	24	8				448		200		224	
		Bottlenose dolphin	400		80		32	16	32				392		8	8	160	336	24	8				448		200		224	
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea	80		2					50		6	28		80	80	24	24	24					200		16		32	
		loggerhead turtle Caretta caretta	100		8					70		36	28		140	128	42	42	42					200		16		32	
Pelagic communities	Phytoplankton	Phytoplankton	8		200		120			280	280	200	8		8	120	72	48	48	72	200	8	80						
	Zooplankton	Zooplankton	8		200					120	120	200	8		8	120	72	48	48	72	200	8	160						
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	400		48				32		16		40		32	24	32	24	24	24	48		56			160		120	
		Benthic-loose rays - offshore			48						16		40		32					24									
		Benthic-loose rays - coastal	800		480		400	160	160		16		40		32	24	32	24	24	24	48		56			400		120	
	Cephalopods	Coastal benthics - soft bottoms			48		40	32		16	16		40			24	32	24	24	24	240		56			160			
	Actinopterygii	Amphihalins	80		48		40	32			16		200		16	120	32	24	24	16	48		56			800			
		Benthic - soft bottoms	800		480		400	32	160	16	16		120			24	32	24	24	24			56			400		24	
		Coastal benthic - rocky bottoms	80		48		40	32	32	16	16		40			24	32	24	24	24	240		56			160		24	
		Bentho-pelagic - sandy bottoms	400		240		400	32	16	16	80		200			120	32	24	24	16	240		56			160		160	
		Demersals - movable funds	560		240		400	32	80	24	16		120			72	32	24	24	16	240		56			400		160	
		Coastal demersals - mixed bottoms	240		48		200	32	16	24	16		40			72	32	24	24	16			56			160		160	
		Demersals - mixed funds	240		48		40	32	16	24	16		40			72	32	24	24	16						160		160	
		Pelagic	80		48		40			24	80		200			120	32	24	24	16						160		160	
Birds		Gannet	336	336	144	144							48	48		80	32		64					288	288	280	280	96	96
		Northern fulmar	40	160	24	72							16	48		320	32		64					32	96	32	224	32	96
		Red-throated Loon	128	128	168	168							64	64		24	48		96					200	200	144	144	256	256
		Kittiwake	80	80	30	120							20	60		200	80		80						420	30	90	40	120
		Common Guillemot	84	84	72	72							36	36		24	24		48					60	60	60	60	80	80
		Herring gull	64	128	24	72							16	48		160	48		64						576	32	96	32	96
		Crested cormorant	48	48	126	126							36	36		36	24		48					90	90	18	54	120	120
		Brown gull	16	32	6	18							4	12		40	12		24						144	8	24	8	24
		Balearic Shearwater	4	24	6	36							4	12		80	8		24					4	12	24	24	8	48
		Caugek Tern	24	72	18	90							12	36		54	24		48						150	18	72	24	96
		Pygmy seagull	20	80	12	48							8	24		36	16		32						144	12	48	16	64
		Ducks (scoter)	80	320	24	168							16	64		48	48		96						320	40	160	64	512
		Curlew	8	8	8	8							16	64		48	16		32						80	16	32	32	32
		Sparrows (farlouse pipit, skylark)		20		5							10	20		320	10		20						210		20		
Bats		Common pipistrelle		12										1		20									20		3		
		Common serotin		12										1		20									20		3		
		Pipistrelle of Nathusius		48										4		80									140		12		
		Common noctule		48										4		80									80		12		
		Leiler's Noctule		48										4		80									80		12		
		Two-tone serotin		60										5		100									100		15		

Table 5: "cumulative impact priority index" (P) for each pair of pressure (columns) and receptor (lines).

For benthic habitats and communities (Table 6), the experts concluded that all six selected habitat types should be considered together, and they only prioritized the pressures which affect them as a whole.

Pressure	Priority
Loss of underwater habitat	1
Modification of hydrodynamic conditions	1
Underwater habitat change, Physical action on the seafloor (without deposition and extraction), Material deposition, Substrate extraction	2
Synthetic and non-synthetic metals	2
Change in suspended particle load	3
Introduction of individuals genetically different from native species and Introduction or spread of non-native species	3
Organic enrichment	3

Table 6: Priority pressures and receptors among Benthic Habitats and their Communities

For the Harbor porpoise, the Bottlenose dolphin, the Loggerhead turtle *Caretta caretta*, and the Leatherback turtle *Dermochelys coriacea*, experts concluded based on scientific evidence (Panigada, S. et al., 2006 ; IWC, 2018) and their own considerations of precaution that underwater collision risk increases rapidly when vessel speed in the area can be above 12 knots(case of maintenance ships, during the operation phase only). Collision risk with high speed ships appears to be the only pressure which may cause direct mortality to these species in the context of an OWF project. For both cetaceans and pinnipeds species, habitat change (mainly from the wind turbines foundations) and underwater noise (mainly during the construction phase) were identified as top priority pressures (Table 7).

Receptor	Pressure	Priority
Gray seal, Sea calf seal	Underwater habitat change	1
Harbor porpoise, Bottlenose dolphin	Underwater habitat change	1
Gray seal, Sea calf seal	Underwater sound emissions	1
Harbor porpoise, Bottlenose dolphin	Underwater sound emissions	1
Harbor porpoise, Bottlenose dolphin	Underwater collisions	1
Loggerhead turtle Caretta caretta, Leatherback turtle Dermochelys coriacea	Underwater collisions	1
Gray seal, Sea calf seal	Human attendance underwater environment (disturbance, sound disturbances excepted)	2
Harbor porpoise, Bottlenose dolphin	Human attendance underwater environment (disturbance, sound disturbances excepted)	2
Gray seal, Sea calf seal	Synthetic and non-synthetic metals	3
Harbor porpoise, Bottlenose dolphin	Synthetic and non-synthetic metals	3
Loggerhead turtle Caretta caretta, Leatherback turtle Dermochelys coriacea	Electromagnetic emissions	3
Loggerhead turtle Caretta caretta, Leatherback turtle Dermochelys coriacea	Light emission	3

Table 7: Priority pressures and receptors among Marine Mammals and Turtles

For most seabird species, similarly to cetaceans and turtles, collision is the most prominent pressure in terms of potential cumulative impacts (Table 8). Several other pressures are ranked as intermediary priority for certain species: obstacle to movement (i.e. “barrier effect”), human disturbance and loss of underwater habitat. Other pressures are associated of lower priority, but still significant: light emission and underwater habitat change.

Receptors	Pressures	Priority
Northern Gannet, Northern Fulmar, Herring Gull, Black-backed Gull, Pygmy Gull, Black-legged Kittiwake, Pool Tern	Air collisions	1
Ducks (Scoter), Red-throated Loon	Air collisions	1
Black-legged Kittiwake, Herring Gull	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	2
Curlew	Air collisions	2
Ducks (scoter)	Human attendance in the air environment (disturbance, sound disturbances excepted)	2
Northern Gannet, Red-throated Plongean	Loss of underwater habitat	2
Northern Gannet, Northern Fulmar	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	2
Red-throated Loon	Human attendance in underwater and air environments (disturbance, sound disturbances excepted)	2
Sparrows (farlouse pipit, skylark)	Air collisions	2
Ducks (Scoter), Red-throated Loon	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	2
Nathusius' pipistrelle, Bicoloured serotin	Air collisions	2
Northern Fulmar, Black-legged Kittiwake, Herring Gull	Light emission	3
Sparrows (farlouse pipit, skylark)	Light emission	3
Red-throated Loon, Crested Cormorant	Underwater habitat change	3
Gannet	Underwater habitat change	3
Common Guillemot	Underwater habitat change	3
Ducks (scoter)	Underwater habitat change	3

Table 8 : Priority pressures and receptors for the Avifauna

3.3 PRIORITIZATION OF RESEARCH AREAS

The application of the methodology described in section 2.4 produced the scores presented in Table 9, and the research priorities presented in Table 10 for each ecological compartment, with no particular hierarchy among the selected research themes.

The preliminary prioritization index appeared helpful and was followed in general by experts, who however found many possibilities to regroup research themes that the methodology had defined in a too detailed approach. After further elaboration, financing of the research themes will be set through collaboration with research funding organisations and public agencies.

Further to research priorities attached to specific ecological compartments, some transversal research priorities were identified. For instance, experts stressed the need to improve hydraulic and sediment transport modelling, to try overcoming current difficulties of coupling atmospheric and hydraulic models, and large-scale (oceanic) and small-scale (local around windfarms structures) hydraulic models.

	Groups	*Species family or habitat type*	Loss of underwater habitat	Loss of aerial habitat	Underwater habitat change	Change of aerial habitat	Substrate extraction	Physical action on the bottom (without material deposition and extraction)	Material deposition	Modification of hydrodynamic conditions	Modification of particle load	Temperature change	Underwater sound emissions	Airborne sound emissions	Electromagnetic emissions	Light emission	Synthetic and non-synthetic metals	Organic and non-synthetic compounds	Other chemicals (solids, liquids, gases)	Organic enrichment	Hypoxia	Introduction of individuals genetically different from native species	Introduction or spread of non-native species	Underwater collisions	Air collisions	Obstacle to movement, feeding, rest, moulting in an underwater environment (leading to loss of functional habitat)	Obstacle to movement, food, rest, moulting in the air (leading to a loss of functional habitat)	Human attendance underwater environment (disturbance, sound disturbances excepted)	Human attendance in the air environment (disturbance, sound disturbances excepted)
Benthic habitats and communities		Coarse sediments with circalittoral gravel (Eunis A5.14	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
		Spirobranchus triqueter (formerly Pomatoceros trique	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
		Mediomastus fragilis, Lumbrineris spp. and venerid bi	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
		Branchiostoma lanceolatum in coarse sand-gravelly ci	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
		Stand of heterogeneous circalittoral sediments (EUNIS	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
		Shoals of Ophiides Ophiothrix fragilis (EUNIS A5.445)	80		54		30	20	20	12	9	8	2		2		30	30	30	15	30	35	35						
Marine mammals	Pinnipeds	Gray seal	40		12		3	3	3				42	1	1	1	20	42	3	1				56		30		35	1
		Seal calf marine	50		15		6	3	6				42	1	1	1	20	42	3	1				56		30		35	1
	Cetaceans	Harbor porpoise	40		8		2	2	4				49		1	1	20	42	3	1				56		25		28	
		Bottlenose dolphin	50		10		4	2	4				49		1	1	20	42	3	1				56		25		28	
Marine reptiles	Sea turtles	Leatherback turtle Dermochelys coriacea	40		1					25		3	14		40	40	12	12	12					100		8		16	
		loggerhead turtle Caretta caretta	50		4					35		18	14		70	64	21	21	21					100		8		16	
Pelagic communities	Phytoplankton	Phytoplankton	1		25		15			35	35	25	1		1	15	9	6	6	9	25	1	10						
	Zooplankton	Zooplankton	1		25					15	15	25	1		1	15	9	6	6	9	25	1	20						
Pisces	Elasmobranchs (rays and sharks)	Benthic rays - mixed bottom - coastal	50		6				4		2		5		4	3	4	3	3	3	6		7			20		15	
		Benthic-loose rays - offshore			6						2		5		4					3									
		Benthic-loose rays - coastal	100		60		50	20	20		2		5		4	3	4	3	3	3	6		7			50		15	
	Cephalopods	Coastal benthics - soft bottoms			6		5	4		2	2		5			3	4	3	3	3	30		7			20			
	Actinopterygii	Amphihalins	10		6		5	4			2		25		2	15	4	3	3	2	6		7			100			
		Benthic - soft bottoms	100		60		50	4	20	2	2		15			3	4	3	3	3			7			50		3	
		Coastal benthic - rocky bottoms	10		6		5	4	4	2	2		5			3	4	3	3	3	30		7			20		3	
		Bentho-pelagic - sandy bottoms	50		30		50	4	2	2	10		25			15	4	3	3	2	30		7			20		20	
		Demersals - movable funds	70		30		50	4	10	3	2		15			9	4	3	3	2	30		7			50		20	
		Coastal demersals - mixed bottoms	30		6		25	4	2	3	2		5			9	4	3	3	2			7			20		20	
		Demersals - mixed funds	30		6		5	4	2	3	2		5			9	4	3	3	2						20		20	
		Pelagic	10		6		5			3	10		25			15	4	3	3	2						20		20	
Birds		Gannet	42	42	18	18							6	6		10	4		8					36	36	35	35	12	12
		Northern fulmar	5	20	3	9							2	6		40	4		8					4	12	4	28	4	12
		Red-throated Loon	16	16	21	21							8	8		3	6		12					25	25	18	18	32	32
		Kittiwake	8	8	3	12							2	6		20	8		8						42	3	9	4	12
		Common Guillemot	21	21	18	18							9	9		6	6		12					15	15	15	15	20	20
		Herring gull	8	16	3	9							2	6		20	6		8						72	4	12	4	12
		Crested cormorant	8	8	21	21							6	6		6	4		8					15	15	3	9	20	20
		Brown gull	8	16	3	9							2	6		20	6		12						72	4	12	4	12
		Balearic Shearwater	2	12	3	18							2	6		40	4		12					2	6	12	12	4	24
		Caugek Tern	4	12	3	15							2	6		9	4		8						25	3	12	4	16
		Pygmy seagull	5	20	3	12							2	6		9	4		8						36	3	12	4	16
		Ducks (scoter)	10	40	3	21							2	8		6	6		12						40	5	20	8	64
		Curlew	1	1	1	1							2	8		6	2		4						10	2	4	4	4
		Sparrows (farlouse pipit, skylark)		4		1							2	4		64	2		4						42		4		
Bats		Common pipistrelle		12										1		20									20		3		
		Common serotin		12										1		20									20		3		
		Pipistrelle of Nathusius		12										1		20									35		3		
		Common noctule		12										1		20									20		3		
		Leiler's Noctule		12										1		20									20		3		
		Two-tone serotin		12										1		20									20		3		

Table 9: "research priority index" (R) for each pair of pressure (columns) and a receptor (lines).

Experts also felt it was not always possible to be specific in terms of species, and research priorities are often more generic (Table 10). In several instances (especially for marine mammals), it was more relevant to express priorities for several pressures as a whole. For instance, the effect of non-native species introduction on benthic communities may be difficult to assess separately from the effect of changes in the physical substratum (e.g. change from a soft sediment to a hard and artificialized bottom). Therefore, the use of ecosystem modelling appears necessary to study and further assess the combined effects of some pressures which interact inextricably.

Receptors	**Pressures**	**Research goals**
Birds	Aerial habitat modification Obstacle to movement, feeding, resting, moulting in an aerial environment (leading to a loss of functional habitat)	Improve understanding of the displacement risk, through: - Gathering information on bird's concentration and functional areas at sea - Determining changes in behaviour and area use due to offshore wind projects and their effects at the scale of a colony, then a population
	Aerial collisions, and pressures at source of population displacement risks	Improve understanding of collision and displacement risks on population dynamics, through: - Developing population dynamics models for selected seabird species - Collecting the demographic data necessary to configure these models and use the models to predict the probable future evolution of colonies located in France and determine whether certain colonies or populations are threatened
Benthic habitats	Chemical contamination (other contaminants and sources than anticorrosion devices)	Improve understanding of the risk of these less studied sources and contaminants, through: - Establishing ecotoxicity threshold values - Estimating the expected concentrations in the different environmental matrices, and characterizing the risk
	Development of non-native species	Set up observation campaigns to monitor colonization on wind turbine infrastructures, on-site and in ports before installation. Develop a multi-scale approach for the identification, evaluation and preventive management of the risks of the introduction of new non-native species.

	Electromagnetic fields (excluding light emissions)	Identify the types and sources of electromagnetic fields generated by OWFs and relevant to benthic organisms, carry out measurement campaigns to collect basic data on EMFs in the marine environment, identify biological models and test their sensitivity to different types and levels of electromagnetic fields Depending on the results in terms of sensitivity, work could be carried out to: - Developing or adapting models for the propagation of EMF to allow exposure estimates - Methodological development and implementation of risk assessment for benthic organisms identified in the first phase (sensitivity x exposure)
	Physical pressures as a whole (habitat loss and change, substrate extraction, material deposition, and physical action on the bottom (without material extraction or deposition))	Observe seasonally over several years in the field the impact on benthic communities of the physical disturbance gradients (setting up several observation stations for reference, minimum to maximum disturbance situations, and before/after windfarm projects). Define risk indicators, risk acceptability thresholds based on ecological resilience and identify communities most at risk based on threshold exceedances. Evaluate the physical modifications on the seabed in terms of intensity and temporality (depending on the characteristics of the parks and wind turbines) Develop and test risk assessment approaches for cumulative impacts at the scale of a marine region.
Ichthyofauna	Emission of light	Observe the effect of different types of light disturbances (aerial beaconing of wind turbine masts, electrical stations lighting) especially for life stages where nychthemeral migrations occur (larval stages).
	Other electromagnetic fields than light	Even if effects of electromagnetic fields on ichthyological communities are in general expected to be moderate, they are still poorly understood and have been identified as one of the research priorities.
	Increased particle load	Although mostly a transient pressure during construction and decommissioning the effect of the increased particulate load in the water column on fish communities is poorly investigated so far and requires basic research.
	Habitat loss and habitat change	The issues that require scientific investigation are the reef effect, impact on fish of benthic non-native species and the connectivity of fish populations.
	Underwater noise	This priority is justified by the intensity of the pressures generated in the wind energy context., during the construction phase of course but also eventually during the

		operating phase. It is also justified by a less extensive knowledge than for other biological compartments, even if publications already exist, in particular on case studies in the Baltic Sea (Hammar L. et al., 2014 for example). The larval life stage will also be studied.
Marine mammals	Habitat change in a wide sense, encompassing following pressures - Substrate extraction; - Physical action on the seabed; - Loss of an underwater habitat; - Deposition of material; - Change of underwater habitat; - Organic enrichment; - Obstacle to movement, food, rest, moulting in an underwater environment (leading to a loss of functional habitat); - Changes in activities linked to the presence of the park (e.g. fishing).	To characterize the evolution of the area and change of habitat. Seals will be predominantly affected by changes in the benthic habitats, while cetaceans predominantly in the pelagic habitats. Subsequently, to identify the change in the use of habitats by those species, based on bibliography, on data acquisition during the lifecycle and after decommissioning of windfarms (through noise data and visual observation for cetaceans, and telemetric monitoring of seals). This research needs to be conducted at the spatial scale of a seafront.
	All relevant pressures in terms of demographic impact, inter alia: noise, fishing, contaminants, habitat change (detailed in the previous line), collisions.	To define populations to be studied, to produce local demographic data (observational and/or modelling) and to assess populational impacts of pressures on populations. This last step should consider several pathways between pressures and demographics, such as mortality of individuals, deterioration in the state of health of individuals, and behavioural changes in individuals. Given uncertainty in populational modelling, developing and applying risk analysis for species taking into account uncertainties could be carried out, in order to define risk mitigation / reduction measures.

Table 10: Summary of priority research areas for OWFs cumulative impacts for each ecosystem compartment.

4 LESSONS LEARNED AND PERSPECTIVES

This study developed the “ECUME” risk-based approach to prioritize impact pathways (i.e. activity – pressure –receptor chains) that should be considered in CIA of OWFs and identify critical research needs. The prioritization framework has been tested on two OWF projects located in the French part of the English Channel. A complete inventory of pressure-receptor pairs was carried out, followed by their prioritization, using a combination of expert judgement, consensus building, and a scoring system. The scoring system was based on the ecological importance of receptors, degree of knowledge on the effect of a pressure on a receptor and the sensitivity of each receptor to pressures. Priorities for research were also assessed during the same process.

Some more general lessons were obtained during this first phase of the ECUME project. First, while gathering a large set of specialized marine biologists and other scientists, an initial difficulty was to build a common vocabulary and a shared understanding of a risk-based approach. This required significant time and effort but enabled to secure the rest of the prioritization and forthcoming work of the ECUME WG. Since collective expertise plays an important role, experts must be prepared ahead of workshops to be able to productively exchange during workshops. Prioritization based on expert judgement allows to deal with scientific uncertainty and lack of knowledge but there is a need to repeat this type of exercise in the same and other areas to check their robustness and improve collectively their conclusions.

Setting priorities for research during the same risk-based process as the one used for impact assessment, was useful not only *per se*, but also to enhance the engagement of the scientific community, who has an interest in contributing to the elaboration of the scientific agenda in marine science. The scoping phase also demonstrated that an exhaustive identification of pressures, and of their future evolutions, is required for a meaningful assessment of OWFs. A significant challenge ahead is to build future scenarios on all marine anthropogenic activities and pressures. The next stage of the ECUME WG will therefore focus on scenario building, identification of available methods and models, and finally CIA *per se*. In parallel to CIA, several research projects have been initiated on identified priority research areas. Risk-based approaches are relatively new in marine environment management. But despite the initial cultural and vocabulary difficulties mentioned, this approach was useful to manage the scientific complexity and the uncertainties, and therefore increased the quality of the ongoing CIA, avoiding “paralysis by analysis”. The risk-based approach is expected to bring the same added value when the ECUME WG will actually assess the consequences for the marine ecosystems of the several OWF projects under its scope, and therefore contribute to the timely and sustainable development of renewable marine energy.

Funding: This work was supported by the French Ministry for a Solidary Ecological Transition under grant DRC 18 – 177 311 – 09156 A.

5 REFERENCES

Bailey, H., Brookes, K. L., & Thompson, P. M. (2014). Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystems, 10(1), 8. https://doi.org/10.1186/2046-9063-10-8

Borja A., Elliott M., Andersen J., Berg T., Carstensen J., Halpern B., 7,8, Heiskanen A., Korpinen S., Stewart Lowndes J., Martin G. and Rodriguez-Ezpeleta N., 2016, "Overview of Integrative Assessment of Marine Systems: The Ecosystem Approach in Practice" Frontiers in Marine Science |www.frontiersin.org, March2016 Volume3 Article20 doi: 10.3389/fmars.2016.00020

Bradbury G, Trinder M, Furness B, Banks AN, Caldow RWG, Hume D (2014) Mapping Seabird Sensitivity to Offshore Wind Farms. PLoS ONE 9(9): e106366. https://doi.org/10.1371/journal.pone.0106366

Clarke Murray C., Agbayani S., Ban N.C, 2015, Cumulative effects of planned industrial development and climate change on marine ecosystems, Global Ecology and Conservation 4 (2015) 110–116

Dannheim, J., Bergstro¨m, L., Birchenough, S. N. R., Brzana, R., Boon, A. R., Coolen, J. W. P., Dauvin, J.-C., De Mesel, I., Derweduwen, J., Gill, A. B., Hutchison, Z. L., Jackson, A. C., Janas, U., Martin, G., Raoux, A., Reubens, J., Rostin, L., Vanaverbeke, J., Wilding, T. A., Wilhelmsson, D., and Degraer, S. (2019) Benthic effects of offshore renewables: identification of knowledge gaps and urgently needed research. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsz018.

Desholm M., 2009, " Avian sensitivity to mortality: Prioritizing migratory bird species for assessment at proposed wind farms "Journal of Environmental Management 90 (2009) 2672–2679

Duinker, P. N., Burbidge, E. L., Boardley, S. R., & Greig, L. A. (2013). Scientific dimensions of cumulative effects assessment: toward improvements in guidance for practice. Environmental Reviews, 21(1), 40–52. https://doi.org/10.1139/er-2012-0035

Duinker, P. N., & Greig, L. A. (2005). The Impotence of Cumulative Effects Assessment in Canada: Ailments and Ideas for Redeployment. Environmental Management, 37(2), 153–161. https://doi.org/10.1007/s00267-004-0240-5

Elliott, M., Burdon, D., Atkins, J. P., Borja, A., Cormier, R., de Jonge, V. N., & Turner, R. K. (2017). "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management. In Marine Pollution Bulletin (Vol. 118, Issues 1–2, pp. 27–40). Elsevier BV. https://doi.org/10.1016/j.marpolbul.2017.03.049

European Communities. 1999. Guidelines for the assessment of indirect and cumulative impacts as well as impact interactions. Luxembourg: Office for Official Publications of the European Communities.

European Commission, 2013 "EU Guidance on wind energy development in accordance with the EU nature legislation"

European Union, 2017, "Environmental Impact Assessment of Projects : Guidance on the preparation of the Environmental Impact Assessment Report", https://ec.europa.eu/environment/eia/pdf/EIA_guidance_EIA_report_final.pdf

Furness R. et al., 2013 'Assessing vulnerability of marine bird populations to offshore wind farms', Journal of Environmental Management 119 (2013) 56-66

Garthe S., 2009, Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index, Journal of Applied Ecology 2004 41, 724–734

GWEC (Global Wind Energy Council). 2019. GWEC Global Wind Report 2019, 78 pp., https://gwec.net/global-wind-report-2019/.

HELCOM (2017): The assessment of cumulative impacts using the Baltic Sea Pressure Index and the Baltic Sea Impact Index - supplementary report to the first version of the HELCOM 'State of the Baltic Sea' report 2017. Available at: http://stateofthebalticsea.helcom.fi/about-helcom-and-the-assessment/downloads-and-data/

Heinis F., de Jong C.A.F., 2015, Framework for assessing ecological and cumulative effects of offshore wind farms - Cumulative effects of impulsive underwater sound on marine mammals - TNO Report 2015 R10335-A - https://tethys.pnnl.gov/sites/default/files/publications/TNO-2015.pdf

Hammar, L., Wikström, A., & Molander, S. (2014). Assessing ecological risks of offshore wind power on Kattegat cod. Renewable Energy, 66, 414–424. https://doi.org/10.1016/j.renene.2013.12.024

Hemming, V., Burgman, M.A., Hanea, A.M., McBride, M.F., Wintle, B.C., 2018. Preparing and implementing a structured expert elicitation using the IDEA protocol. Methods Ecol. Evol. 9 (1), 169–180.

Hodgson, E. E., Halpern, B. S., & Essington, T. E. (2019). Moving Beyond Silos in Cumulative Effects Assessment. Frontiers in Ecology and Evolution, 7. https://doi.org/10.3389/fevo.2019.00211

International Finance Corporation (IFC), 2013, "Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets"

IUCN French Committee, « La liste rouge des espèces menacées en France : Requins, raies et chimères de métropole (2013), Reptiles et amphibiens de métropole (2015), Oiseaux de métropole (2016), Mammifères de métropole (2017) » https://uicn.fr/liste-rouge-france/

International Whaling Commission, Report of the Scientific Committee, Bled, Slovenia, IWC/67/Rep01(2018), https://archive.iwc.int/pages/download.php?ref=6940&size=&ext=pdf&k=&alternative=-1&usage=-1&usagecomment=

Judd, A. D., Backhaus, T., & Goodsir, F. (2015). An effective set of principles for practical implementation of marine cumulative effects assessment. Environmental Science & Policy, 54, 254–262. https://doi.org/10.1016/j.envsci.2015.07.008

La Rivière M., Aish A., Gauthier O., Grall J., Guérin L., Janson A.-L., Labrune C., ThibautT. et Thiébaut E., 2015. Méthodologie pour l'évaluation de la sensibilité des habitats benthiques aux pressions anthropiques. Rapport SPN 2015-69. MNHN. Paris, 52pp.

Lindeboom, H., Degraer, S., Dannheim, J., Gill, A.B., and Wilhelmsson, D. (2015) Offshore wind offshore windfarm monitoring programmes, lessons learned and recommendations for the future. Hydrobiologia. 756 (1), 169–180.

Link J.S., 2011, "Translating ecosystem indicators into decision criteria", ICES Journal of Marine Science, 62: 569e576 (2005) doi:10.1016/j.icesjms.2004.12.015

Menegon S et al., 2018, "A modeling framework for MSP-oriented cumulative effects assessment", Ecological Indicators 91 (2018) 171–181

Methratta, E. T., et al., 2020, "Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs." – ICES Journal of Marine Science, 77: 890–900.

MMO (2014) A Strategic Framework for Scoping Cumulative Effects. A report produced for the Marine Management Organisation, pp 224. MMO Project No: 1055. ISBN: 978-1-909452-34-3.

MTE, 2019, Stratégie française pour l'énergie et le Climat, Programmation pluriannuelle de l'énergie 2019-2023 2024-2028

MTES, 2017, Évaluation environnementale – « Premiers éléments méthodologiques sur les effets cumulés en mer » - ISBN : 978-2-11-138758-4

MTES – Ministère de la Transition Ecologique et Solidaire – and AFB - Agence Française de la Biodiversité, 2019, « Stratégie de façade maritime : Document stratégique de la Façade Manche Est-Mer du Nord, Annexe 5 : carte de synthèse des enjeux environnementaux forts et majeurs, Partie b : tableau récapitulatif des enjeux écologiques, Partie c : méthodologie d'identification » http://www.geolittoral.developpement-durable.gouv.fr/strategie-de-facade-maritime-manche-est-mer-du-a1083.html#sommaire_7

Nivière M. et al., 2018, "Activity report 2016-2017 of the Observatoire des Tortues Marines de France Métropolitaine" - PATRINAT Report 2018-114

Panigada, S., Pesante, G., Zanardelli, M., Capoulade, F., Gannier, A., & Weinrich, M. T. (2006). Mediterranean fin whales at risk from fatal ship strikes. In Marine Pollution Bulletin (Vol. 52, Issue 10, pp. 1287–1298). Elsevier BV. https://doi.org/10.1016/j.marpolbul.2006.03.014

Piet, G. J., Jongbloed, R. H., Knights, A. M., Tamis, J. E., Paijmans, A. J., van der Sluis, M. T., de Vries, P., & Robinson, L. A. (2015). Evaluation of ecosystem-based marine management strategies based on risk assessment. Biological Conservation, 186, 158–166. https://doi.org/10.1016/j.biocon.2015.03.011

Quemmerais-Amice F, Barrere J, La Rivière M, Contin G and Bailly D (2020) A Methodology and Tool for Mapping the Risk of Cumulative Effects on Benthic Habitats. Front. Mar. Sci. 7:569205. doi: 10.3389/fmars.2020.569205

Renewables UK, 2013, "Cumulative Assessment Guidelines: Guidance principles for cumulative assessment in offshore wind farms"

Rijkswaterstaat, 2019, "Framework for assessing ecological and cumulative effects for the roll-out of offshore wind energy 2030"

Robinson, L.A., Culhane, F.E., Baulcomb, C., Bloomfield, H., Boehnke-Henrichs, A., Breen, P., Goodsir, F.,Hussain, S.S., Knights, A.M., Piet, G.J., Raakjaer, J., van Tatenhove, J. & Frid, C.L.J. (2014),"Towards delivering ecosystem-based marine management: The ODEMM Approach." Deliverable 17, EC FP7 Project (244273) 'Options for Delivering Ecosystem-based Marine Management'. University of Liverpool. ISBN: 978-0-906370-89-6 : 96 pp.

Singh, G. G., Eddy, I. M. S., Halpern, B. S., Neslo, R., Satterfield, T., & Chan, K. M. A. (2020). Mapping cumulative impacts to coastal ecosystem services in British Columbia. PLOS ONE, 15(5), e0220092. https://doi.org/10.1371/journal.pone.0220092

Smith, C.J., Papadopoulou, K.-N., Barnard, S., Mazik, K., Elliott, M., Patrício, J., et al. (2016) Managing the Marine Environment, Conceptual Models and Assessment Considerations for the European Marine Strategy Framework Directive. Frontiers in Marine Science. 3.

Tamis, J. E., de Vries, P., Jongbloed, R.H., Lagerveld, S., Jak, R.G., Karman, C.C., van der Wal, J.T. Slijkerman, D.M.E. & Klok, C. (2016) Toward a Harmonized Approach for Environmental Assessment of Human Activities in the Marine Environment. Integrated Environmental Assessment and Management, Volume 12, Number 4—pp. 632–642.

Verling, E., Miralles Ricós, R., Bou-Cabo, M., Lara, G., Garagouni, M., Brignon, J.-M., & O'Higgins, T. (2021). Application of a risk-based approach to continuous underwater noise at local and subregional scales for the Marine Strategy Framework Directive. In Marine Policy (Vol. 134, p. 104786). Elsevier BV. https://doi.org/10.1016/j.marpol.2021.104786

Willsteed E.,Gill A.B., Birchenough S.N.R, Jude S., Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground, Science of the Total Environment 577 (2017) 19–32

Willsteed, E. A., Jude, S., Gill, A. B., & Birchenough, S. N. R. (2018). Obligations and aspirations: A critical evaluation of offshore wind farm cumulative impact assessments. Renewable and Sustainable Energy Reviews, 82, 2332–2345. https://doi.org/10.1016/j.rser.2017.08.079

Zacharias M.A. and Roff J.C., 2001, "Use of focal species in marine conservation and management: a review and critique", Aquatic Conserv: Mar. Freshw. Ecosyst. 11: 59–76 (2001)