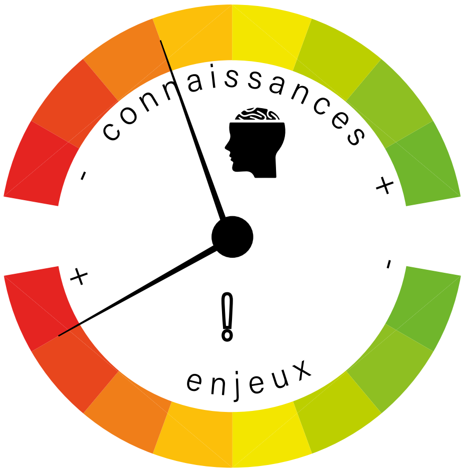
To study the effect on marine ecosystems of noise emitted by offshore wind farms during construction and operation phases, is it relevant to focus on a few species?

Bulletin n°5

September 2022

COME3T

COME3T, a committee of experts for environmental issues related to offshore renewable energies, brings together neutral, independent experts to provide scientific knowledge and recommendations in response to environmental issues associated with offshore renewable energy.



Question deemed

"a major issue for which knowledge remains insufficient in certain areas" by the experts*

**biological compartments, particle motion, etc.*

Scientific experts

Laura Ceyrac - Bioacoustics, relationships between marine mammals and anthropogenic noise (Shom)

Lydie Couturier - Marine ecosystems, interactions between fish populations and ORE (France Energies Marines)

Karine Heerah - Marine ecology, interactions between marine megafauna and the environment (France Energies Marines)

Florent Le Courtois - Acoustics, underwater noise pollution (Shom)

Ludivine Martinez - Marine biology, interactions between human activities and marine fauna (Cohabys)

Coordination, compilation and drafting

Sybill Henry - France Energies Marines

Introduction

Noise emissions generated by human activities can affect marine fauna. For several decades, underwater ambient noise has been increasing, in particular due to the growth of anthropogenic activities. Assessing the effects of these emissions on marine organisms is essential, especially as sound travels far more efficiently in water than in air (speed of around 1500 m/s, i.e. 5 times faster) (Mooney, 2020). This task constitutes a methodological and scientific challenge.

In this bulletin, the experts emphasise the need to consider all species and to tend towards an ecosystem approach (i.e. considering all biological compartments) to assess the effects of noise emitted by anthropogenic activities, and in particular by offshore wind farms during their construction and operation phases. There are gaps in knowledge on the effects of noise emissions on marine fauna, and various recommendations are put forward by the experts at the end of the bulletin to fill these gaps.

Definitions

Pressure

Manifestation of human activities in the environment that may take the form of a change in status, in space or time, of the physical, chemical and/or biological characteristics of the environment[1].

Effect

Objective consequence of the introduction of one or more pressures liable to generate impact on the marine environment[1].

Impact

Transposition of an effect on the different biological compartments of the marine ecosystem taking into account their sensitivity, defined by their capacity to tolerate changes to the environment (resistance), and the time required for them to recover following these changes (resilience).

Fig. 1 *Conceptual diagram of the different terms used to define the impact chain of a pressure on an ecological receptor (a species, habitat or group of species – marine mammals, plankton communities, etc.)*

Sound

Pressure variation generated by an **acoustic wave** (or vibration). A sound is characterised by its frequency (number of acoustic waves emitted per second), its sound level (volume or sound intensity) and its duration. The higher the frequency, the higher the pitch of the sound emitted (high frequency: high-pitched sound; low frequency: low-pitched sound) (Persohn, 2020).

Acoustic wave (Fig. 2)

Physical phenomenon resulting from a mechanical disturbance of a medium (water, air) propagating from place to place. An acoustic wave is characterised by a repeating pattern of **compressions and rarefactions** (decompressions) of the medium at the origin of the **pressure variation** and by the **motion of particles** (composed of several molecules of the medium) (Persohn, 2020).

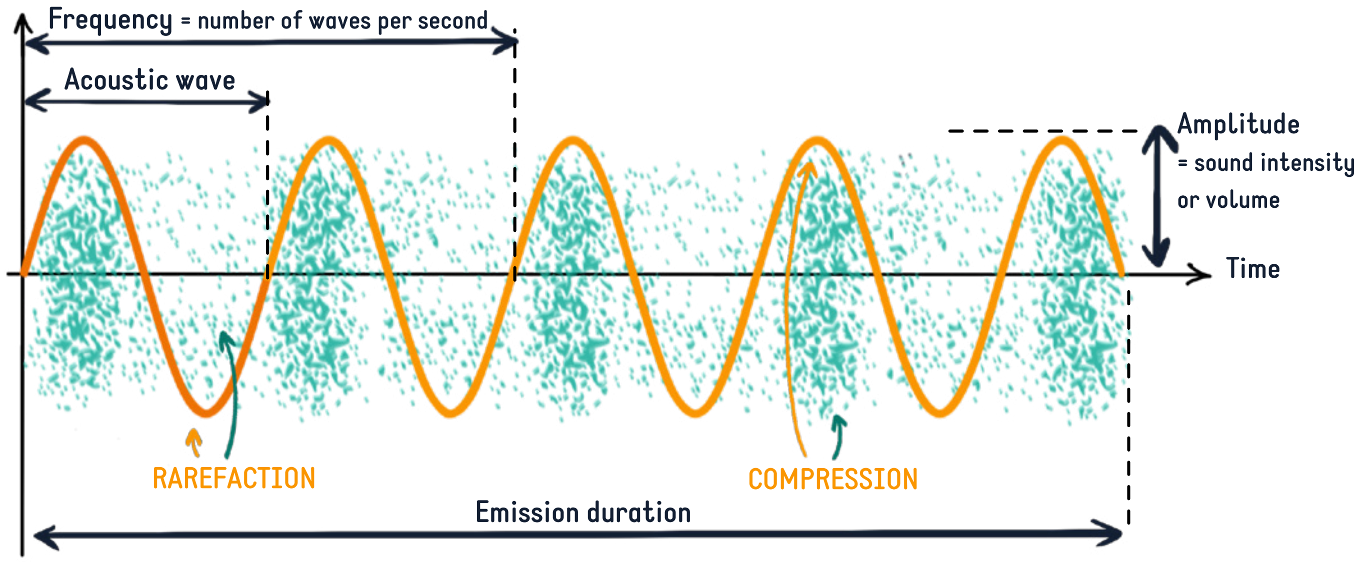


Fig. 2 *Diagram of an acoustic wave and its main characteristics (in orange, the direction of travel of the sound; in green, a representation of the movement of associated particles)*

Pressure variation

Also known as "acoustic pressure", pressure variation can be used to describe the amplitude of the acoustic wave in relation to the static pressure (or hydrostatic pressure in water) of the surrounding medium (Persohn, 2020).

Particle motion

This corresponds to the movement of molecules in the medium (water molecules, gas molecules, etc.) generated by an acoustic wave. The larger the amplitude of particle motion, the louder the sound (or the higher the sound intensity).

Ambient noise

This corresponds to the global noise received at a given point and for a set time period (Fig. 3). Ambient noise includes all sources of noise emissions in the marine environment, which can be divided into three components:

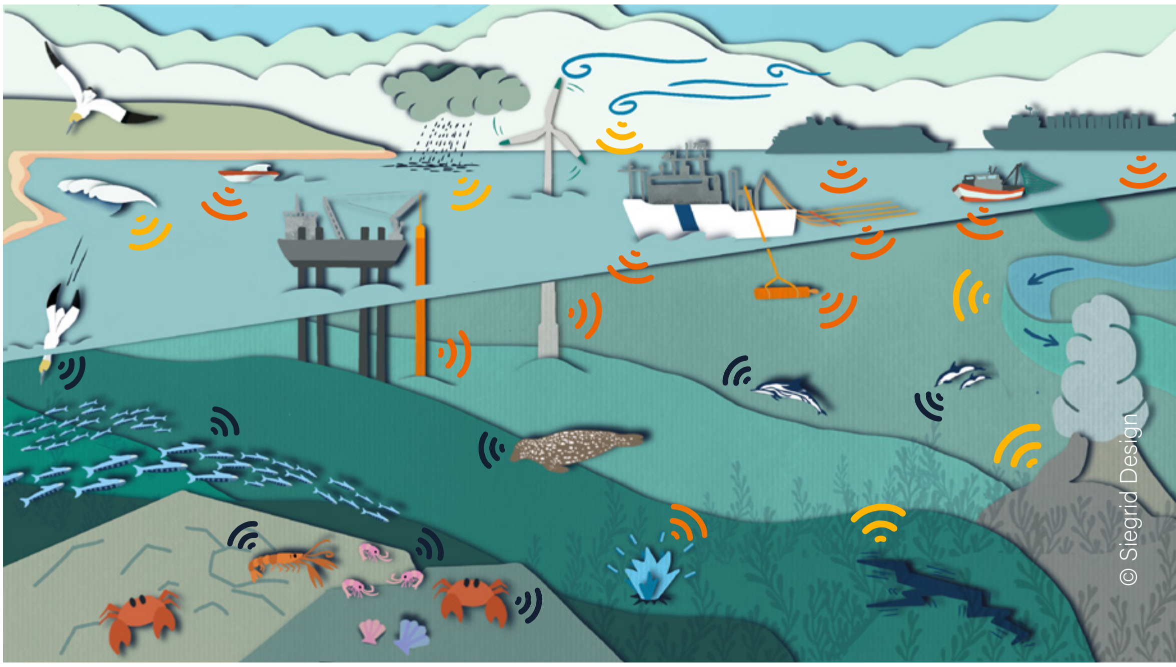


Fig. 3 *Overview of different sources of noise in the marine environment contributing to ambient noise or the underwater soundscape*

- **Biophony** (natural sounds of biological origin, emitted intentionally (vocalisations, clicks, etc.) or incidentally (movements, etc.) by marine fauna);
- **Geophony** (natural sounds of non-biological origin: sound of waves, wind, marine currents, submarine volcanoes, earthquakes, etc.);
- **Anthropophony** (sounds emitted by human activities: maritime traffic, cruise ships, professional and leisure fishing, watersports, acoustic deterrent devices, seismic exploration and sonar, offshore renewable energy, marine aggregate extraction, dredging, sediment disposal, etc.) (Persohn, 2020).

Population

Historically, populations are often defined as a group of individuals of the same species, living in the same geographical area and capable of interbreeding. Considerable caution should be taken when applying this type of definition to marine mammals. For example, individuals of the same species do not all have the same chances of interbreeding. This can give rise to the existence of groups of individuals of the same species that are more or less isolated from each other, and yet can be present in the same place.

Management unit

A group of individuals of the same species that experience the same pressure and are sufficiently isolated from other groups of this same species to require specific management.

[1] Definition taken from the work of the working group on cumulated effects under the French Ministry in charge of the environment and derived from the French order of 17 December 2012 relating to the definition of good ecological status.

Noise emitted by offshore wind farms and potential effects on marine fauna

Throughout their life cycle, offshore wind farms and their connections, whether they be bottom-fixed or floating turbines, generate different types of noise emissions which may affect marine fauna.

1. The different sources of noise emissions from offshore wind farms and their nature

The life cycle of wind farms can be broken down into four main phases: development (preliminary studies), construction, operation and decommissioning. Each of these phases involves different activities which generate noise emissions that vary in nature, intensity, duration, etc. However two main types of noise can be distinguished: **impulse noise** and **continuous noise**.

Impulse (or impulsive) noise is characterised by a short-duration noise impulse due to a sudden, transient increase in acoustic pressure. This is the type of noise generated by a hammer striking a pile during pile-driving operations (bottom-fixed turbines) (Persohn, 2020) or by tensioning mooring chains (floating turbines). The frequency of noise generated by pile-driving with a hydraulic hammer, for example, ranges between 10 Hz and 20 kHz, with a duration of a few milliseconds,

> **DID YOU KNOW?**
>
> The **sound level** is the intensity of sound exerted on a species or group of species. It is expressed in decibels (dB) referenced (re) to an acoustic pressure of 1 microPascal (µPa), the standard reference in underwater acoustics.

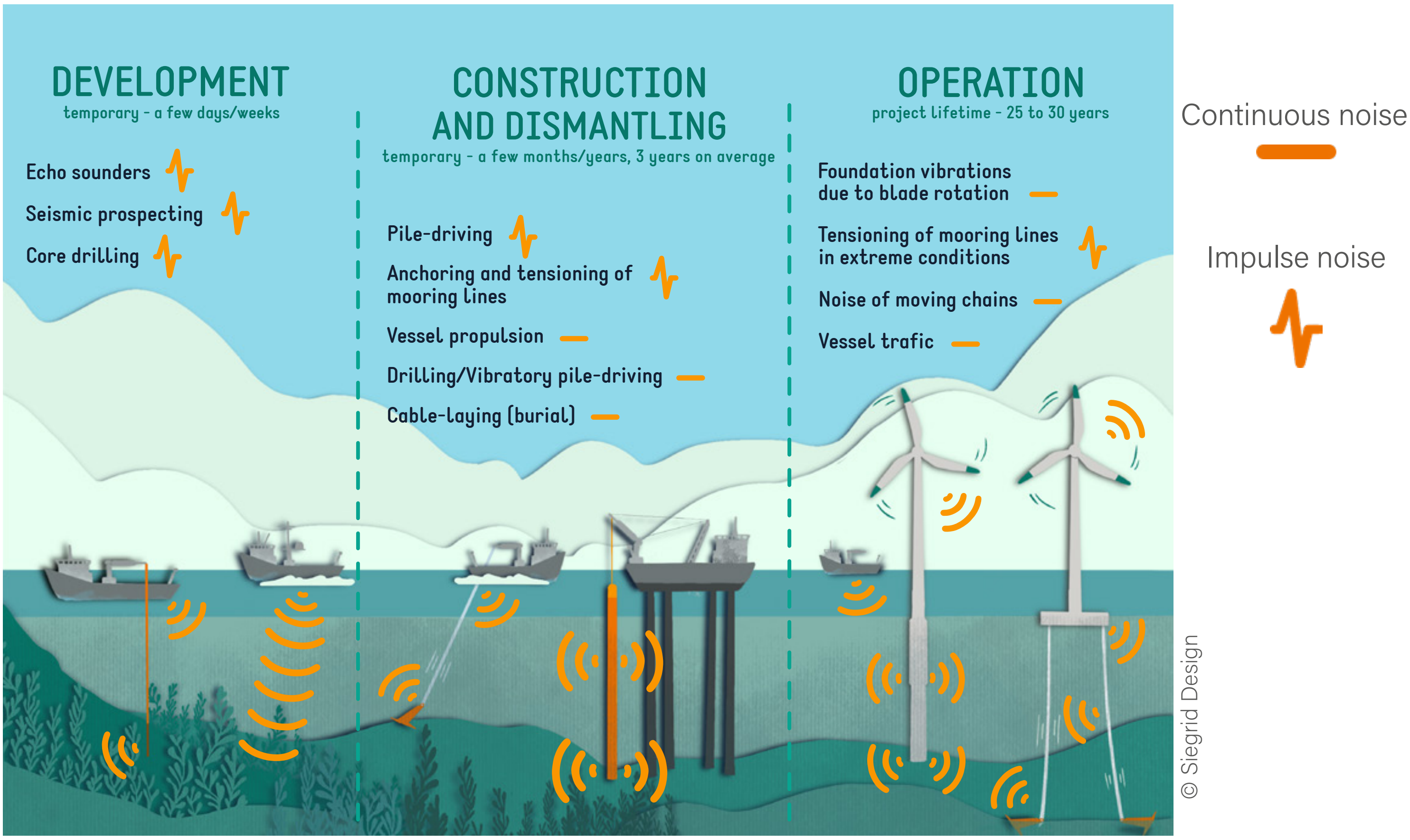


Fig. 4 *Overview of the main sources of noise emissions associated with all the phases of the life cycle of an offshore wind farm (from site selection through to decommissioning) according to the type of turbine (bottom-fixed or floating) and activity (prospecting, vessel traffic, etc.). The types of sounds emitted are indicated by the orange lines. The acoustic energy of the different sources of emissions according to distance, noise type, etc. is not represented here (modified after Popper & al., 2022).*

and depends on numerous factors (pile diameter, type of substrate, bathymetry, etc.). The associated sound level (expressing the sound intensity) is estimated at between 200 and 250 dB re 1 μPa. A noise described as continuous remains stable and constant over a given period of time (Persohn, 2020). This is the type of noise generated by a passing vessel or by a wind turbine in operation. The frequency emitted by maintenance vessels, for example, is estimated at between 1 Hz and 20 kHz according to their power, speed, etc., with an intensity ranging between 150 and 180 dB re 1 μPa; the noise generated by a bottom-fixed wind turbine in operation is estimated at between 50 Hz and 2 kHz, and is dependent in particular on the type of foundation and the wind speed, with an intensity estimated at between 120 and 150 dB re 1 μPa (Persohn, 2020). These two types of noise can be emitted, either simultaneously or separately, at all stages in the life cycle of offshore wind farms (Fig. 4).

2. Potential effects of noise emissions

Sound is capable of travelling quickly over long distances in water and is used by marine animals to obtain information about their environment and to interact with each other. The auditory ability and perceptions of different underwater noise emissions vary from one species to another and all species react differently (SEER, 2021).

The effects of noise emissions on marine fauna can be arranged into several zones of influence (Fig. 5) and will vary according to the species and its sensitivity, the sound intensity and duration (Mooney, 2020):

- Closest to the noise source, the **permanent lesions** zone. Injuries may be physical and/or physiological and may lead to mortality;
- The **depreciation** zone where physical and/physiological lesions are temporary. They do not cause direct mortality, however they may induce hearing loss which may be temporary and may lead to a reduction in reproductive capacity and in survival rate, with possible consequences for the whole management unit;
- The **behavioural changes** and **masking** zones where biologically important sounds that are necessary for communication or environmental perception are masked/disturbed;
- The **audibility** or tolerance zone where noise emissions can be perceived by animals without them having an apparent effect on their physical integrity or behaviour.

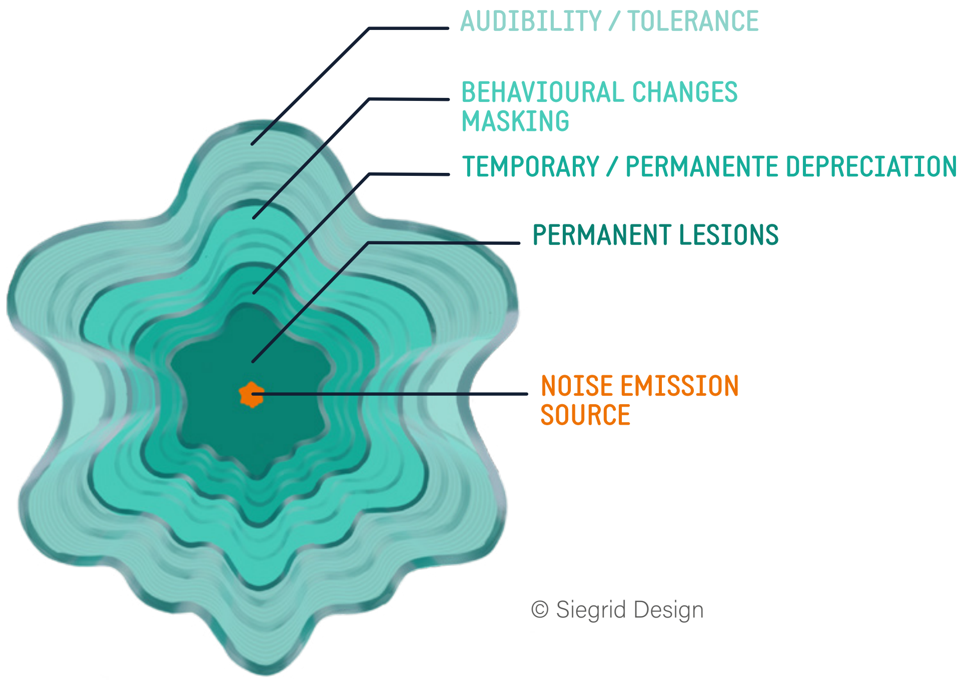


Fig. 5 *Zones of influence of noise emissions on marine fauna (modified after Mooney & al., 2020 / Richardons & al., 1995)*

Like all anthropogenic activities, the development of offshore wind farms is a source of noise emissions that can have impacts on the ecosystem's different biological compartments. The auditory sensitivity of marine mammals is well known and ranges between 10 Hz and 200 kHz, with a sensitivity threshold estimated at around 50 dB re 1 μPa. Turtles are reportedly able to perceive sounds between 30 Hz and 2000 Hz and fish between 50 and 300 Hz, or even up to several thousand hertz for certain species with swim bladders (Persohn, 2020). The emission of impulse noise, for example, can cause physical and physiological injury to an individual, even if the sound emitted is outside its range of audibility. High intensity impulse noise emissions can also lead to physical injury, such as damage to certain organs that are particularly sensitive to pressure variations (lungs of marine mammals, swim bladders of fish, etc.). Continuous noise can lead to changes in behaviour or physiological functioning through increased stress. The list of examples associated with each of these categories and of the long-term consequences of these effects presented here is not exhaustive (Fig. 6)

DID YOU KNOW?

The swim bladder is a gas-filled organ that contributes to the ability of certain fish to control their buoyancy and thus stay at a specific depth. In certain species, the swim bladder can function as a resonating chamber to produce or receive sound.

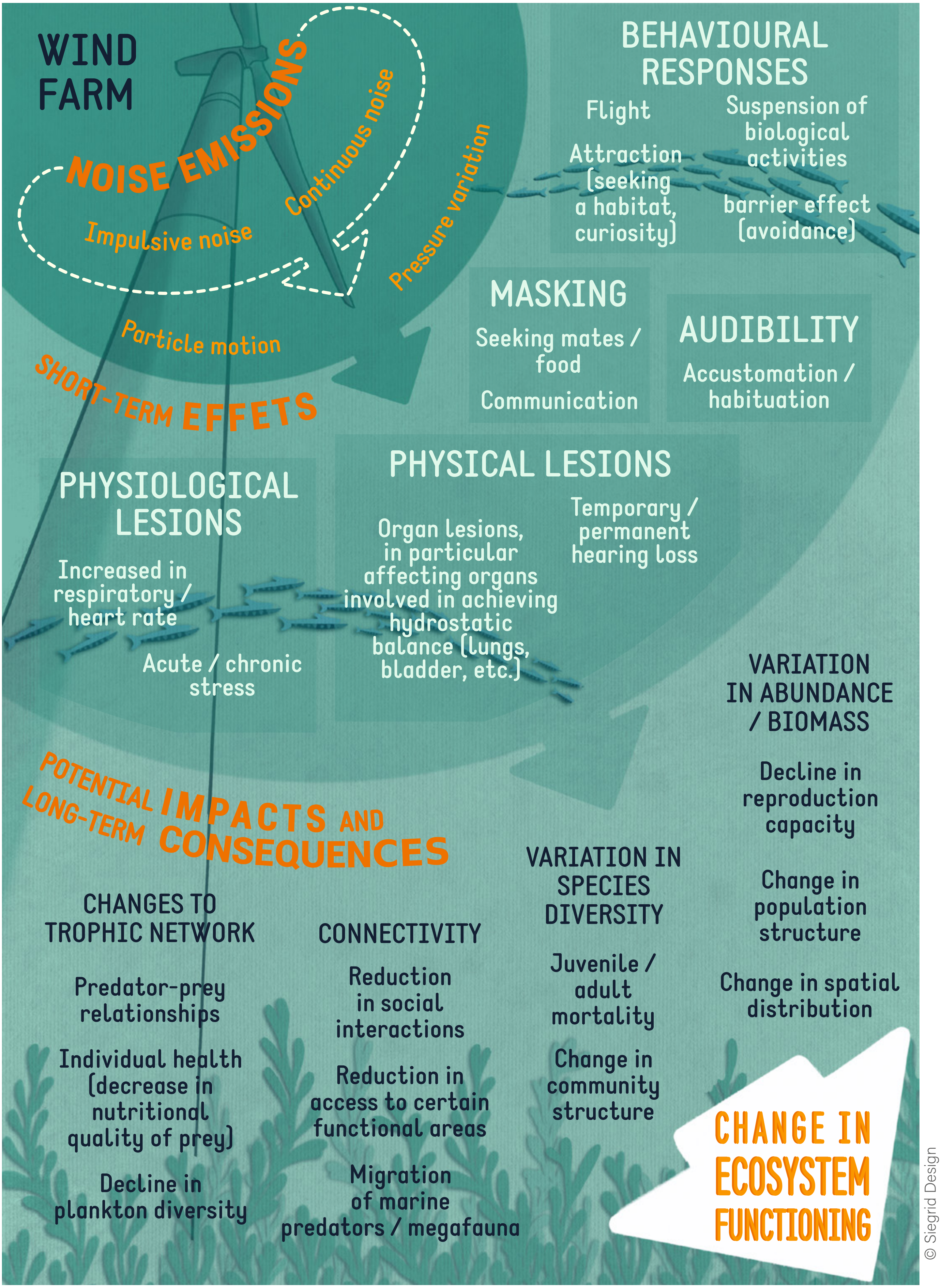


Fig. 6 *Potential effects and impacts of noise emissions from offshore wind farms (bottom-fixed and floating) on marine fauna. For each effect and impact, the list of examples provided is not exhaustive.*

Impacts of noise emissions at ecosystem level

The long-term consequences of noise emissions on an ecosystem are illustrated here, by way of example, at the scale of a wind farm (Fig. 7). It is important to note that the notions illustrated in this figure are not specific to the type of turbine shown. The consequences presented here as examples are not specific to the biological compartment described but can be applied to all biological compartments within the ecosystem (cetaceans, turtles, fish, invertebrates, plankton communities, etc.).

[1] Changes to trophic network

Here, the changes to the food web are illustrated by the existing inter-connection between all of the ecosystem's biological compartments. For example, the stress exerted on plankton communities due to noise emissions can disrupt the growth and development of certain species.

[2] Changes to plankton development

Through a cascade effect, the decrease in the survival rate of certain plankton species can have an impact on the entire food web.

[3] Changes in connectivity

Connectivity refers to all existing connections between different natural environments which, given their characteristics (biological, functional, etc.), contribute to the proper functioning of an ecosystem. Here, the changes in connectivity are illustrated by the barrier effect that can be induced by noise emissions. The presence of a noisy area between two functional areas (shelter, breeding, feeding, etc.) can destabilise the connectivity of a population or community by isolating individuals from each other and preventing them from using certain functional areas.

[4] Changes in diversity

The changes in diversity are illustrated here by the attraction/repulsion effect that noise emissions can have on certain benthic invertebrate larvae. The noise emissions emitted by foundation vibrations due to blade movements at the surface may promote the development of certain species that are particularly sensitive to this attraction effect (such as the blue mussel, *Mytilus edulis*), to the detriment of other species, and can lead to a reduction in species diversity.

[5] Changes in abundance and/or biomass

Abundance (number) and biomass (mass or weight) relate to the quantity of individuals of one or more species in an environment of interest. Changes in abundance/biomass are represented here by the variation in the number of individuals (here, an increase) resulting from the attraction/repulsion phenomenon (here, an attraction phenomenon) generated by noise emissions that may have an impact on the structure of fish populations/communities.

It should be noted that several different sources of sound pressure (e.g. vessel traffic + chain movement on the seabed + foundation vibration) can be cumulative. Based on current knowledge, it is not always possible to differentiate between the specific effects of noise emissions by wind farms and those generated by other anthropogenic activities. We therefore talk about **cumulative effects**.

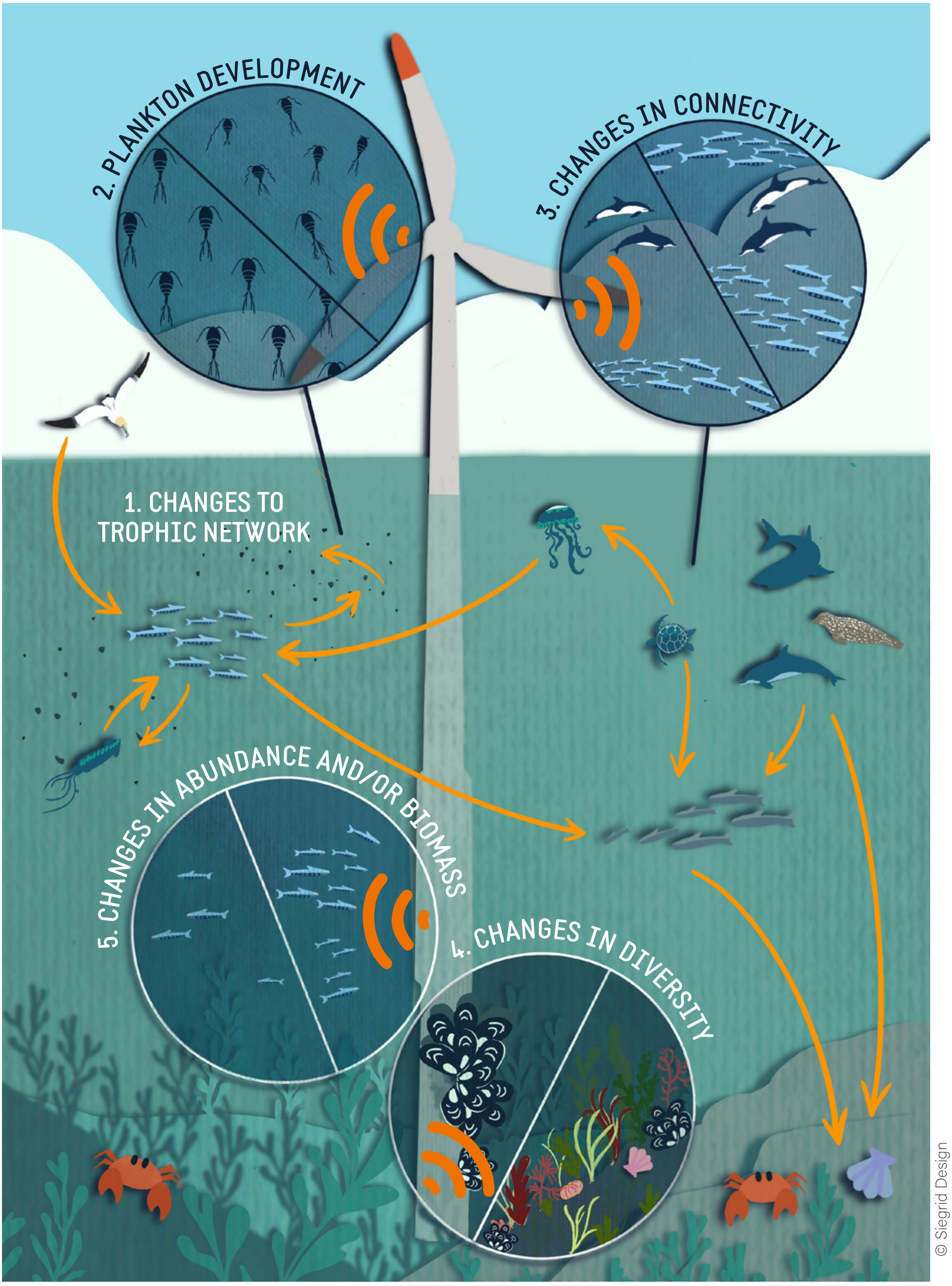


Fig. 7 *Illustration showing the consequences of the different potential effects generated by noise emissions at ecosystem level (non-exhaustive list)*

Limits and research focuses

Limits

The level of information available on the impacts of noise emissions varies from one species to another. Current research into assessing the effects and impacts has certain limits:

- It mainly focuses on marine mammals. Knowledge gaps remain in relation to the impacts of noise emissions on other marine species (fish, invertebrates, plankton, etc.);
- It mainly concerns physical and physiological impacts by studying auditory thresholds, which are fairly widely agreed upon within the scientific community for marine mammals but not for all biological compartments. Impact thresholds for behavioural changes or stress are currently lacking because they are difficult to study (methodological limitations);
- It does not include the study of particle motion, which can have more impact on individuals than pressure variations, particularly for fish and invertebrates. According to Popper and Hawkins (2018), the sensory organs used for sound detection by certain species of fish and invertebrates are, given their physical characteristics, sensitive to particle motion rather than to pressure variations (Popper, 2018);
- It is based on impact assessment methods that are not standardised and whose protocols generally focus on studying a single effect on one (or a few) species of interest;
- It is composed of short-term studies (investigating direct impacts) at individual level and does not include a long-term approach at population level;
- It is time-limited, with monitoring generally carried out over a few years (3 years on average and not always continuously) and for periods which do not correspond to the biological cycles of all species;
- They focus on the construction and operation phases of wind farms, although all phases generate noise emissions and are therefore important to consider.

Recommendations

- Increase knowledge of the marine environment in order to:
  - Better understand and characterise the effects of the different components of noise emissions, in particular the effects of particle motion. Particle motion in the marine environment is a phenomenon that remains poorly known and requires prior characterisation (study of the existing links between pressure variation and particle motion resulting from a noise emission, study of the differences between particle motion induced by an impulse sound versus a continuous sound, etc.);
  - Characterise the impacts of noise on species according to season, life cycle stage (larvae, juveniles, adults) and behaviour (reproduction, care of young, foraging, communication);
  - Better understand sound propagation in sediment to assess the effects and impacts of noise emissions on benthic invertebrate communities.
- Given the lack of knowledge and data (especially on the effects of particle motion and of noise emissions on certain marine species - marine invertebrates, etc.), prioritise risk-based approaches (probability of impact or not) by applying the precautionary principle;
- Use a spatio-temporal scale tailored to the biological cycle of the species and their area of distribution to evaluate the effects and impacts at individual and management unit level;
- Develop monitoring methods to assess behavioural changes other than flight and movement (interruption of activities - feeding, care of young, etc., changes in dive duration and frequency, burial in the sediment for certain benthic species, startle reflex, etc.);
- To implement an ecosystem approach, continue to improve knowledge of key species/groups of species to study the impacts of noise emissions, in particular for fish and benthic invertebrates. Focusing on a few key species constitutes a first step in understanding the effects and impacts of noise emissions at ecosystem level.
- Enhance research efforts across all biological compartments in order to shift towards an ecosystem approach.

Conclusion

To understand the impact of noise emissions on the marine ecosystem, it is crucial to have an understanding of the impact on each of its biological compartments. Implementing an ecosystem approach means not focusing simply on the physical impacts of noise emissions (e.g. hearing damage) through the analysis of pressure variations alone. In order to comprehend the effects of noise emissions and their impacts on all species, the effects of particle motion must also be considered, particularly for less mobile species and benthic habitats.

Bibliography

Mooney T.A., Andersson M.H., Stanley J., (2020). Acoustic impacts of offshore wind energy on fishery resources: An evolving source and varied effects across a wind farm's lifetime. In Oceanography 33(4):82-95.

Persohn, C., Helloco, L., Baudinière, E., Martinez, L., (2020). Préconisations pour limiter les impacts des émissions acoustiques en mer d'origine anthropique sur la faune marine. Rapp. Du Ministère de la transition écologique et solidaire, 212p.

Popper A.N., Hawkins A.D., (2018). The importance of particle motion to fishes and invertebrates. In The journal of the Acoustical Society of America 143:470-488.

Popper A.N., Hice-Dunton L., Jenkins E., Higgs D.M., Krebs J., Mooney A., Rice A., Roberts L., Thomsen F., Vigness-Raposa K., Zeddies D., Williams K.A., (2022). Offshore wind energy development: Research priorities for sound and vibration effects on fishes and aquatic invertebrates. In J. Acoust. Soc. Am. 151 (1), 205-2015.

Richardson W.J., Greene C.R., Malme C.I., Thompson D.H., (1995). Marine mammals and noise. Academic press, London and San Diego. 576p.

SEER, (2021). Underwater noise effects on marine life associated with offshore wind farms. Research brief. In. U.S. Offshore Wind Synthesis of Environmental Effects Research, 10p.

Please cite this document as follows:
Henry S., Ceyrac L., Le Courtois F., Martinez L., Couturier L., Heerah K.
To study the effect on marine ecosystems of noise emitted by offshore wind farms during construction and operation phases, is it relevant to focus on a few species?
COME3T Bulletin n°05
Plouzané: France Energies Marines, 2022, 20 pages.
Published: September 2022

Legal deposit upon publication.
Layout: France Energies Marines
Graphic design of figures: Siegrid Design
Traduction: Alba traduction

COME3T

COME3T is an initiative that brings together a panel of national and regional stakeholders (universities, industrial firms, consultants, regions, State services, etc.) within a steering committee that puts forward questions, based on public concerns and key environmental issues identified by the stakeholders, to committees of neutral, independent experts. For each topic, a committee of experts is established following a call for applications and provides information, summaries and recommendations on the environmental issues associated with offshore renewable energy.

https://www.france-energies-marines.org/projets/come3t/

An initiative coordinated by France Energies Marines.

FRANCE ENERGIES MARINES

France Energies Marines is the Institute for Energy Transition dedicated to offshore renewable energies. Its missions: to define, set up and apply the scientific and technical environment required to overcome the obstacles related to the development of ORE technologies while ensuring optimal environmental integration. Built on a public-private partnership, the Institute is at the interface between institutional (local authorities, regions, etc.), academic, scientific and industrial (project developers and leaders) stakeholders.

Bâtiment Cap Océan
Technopôle Brest Iroise
525, Avenue Alexis De Rochon
29280 Plouzané, France
+33 (0)2 98 49 98 69
www.france-energies-marines.org

ISSN 2743-6942