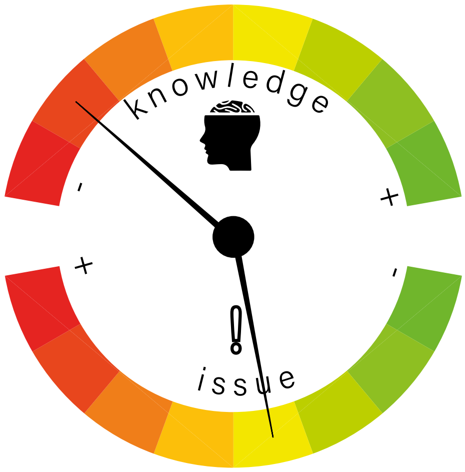
Can floating offshore wind farms pose a risk of entanglement and injury to marine megafauna?

Bulletin n°9
July 2023

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 "an intermediate issue and for which the current state of knowledge is considered low in particular as concerns the behaviour of marine megafauna within floating offshore wind farms"

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Introduction

Over the past decades, the technology boom associated with offshore renewable energy has led to the development of floating offshore wind farms in waters previously considered too deep for bottom-fixed wind farms (for example the floating wind farm Hywind Scotland commissioned in 2017).

In France, several floating wind farm projects are scheduled to be brought into operation during the 2020s off the Atlantic and Mediterranean coasts. This technological change has consequences for electric power transmission systems and wind turbine moorings. It generates new environmental concerns with power cables now suspended in the sea and mooring lines extending through the entire water column. Some of the main environmental concerns are the risks of collision and entanglement of certain large species (referred to collectively here as "marine megafauna") with these structures.

After defining the notion of **entanglement** applied to marine megafauna, the experts involved in this bulletin laid the groundwork for a **risk assessment** by:

- identifying the **potential pressure** sources associated with floating wind power liable to generate **effects** on **marine megafauna**;
- defining the main **biological characteristics** of marine megafauna. The **potential impacts** at individual scale are also addressed. There is currently little feedback from experience in relation to floating wind farms in Europe. The experts have put forward a series of recommendations aimed at improving knowledge of the potential effects of floating wind farms on the environment, and more specifically on marine megafauna.

Mooring lines of a floating structure

Definitions

Marine megafauna

Fauna generally refers to all animal species living in a given habitat and/or geographical area. When preceded by the prefix "mega" (which means "large" in Greek), **megafauna** literally includes all large animal species. In this bulletin, the notion of **marine megafauna** refers to all large mobile vertebrates living in the marine environment: marine mammals (cetaceans, seals, etc.), sea turtles and large pelagic fish (tuna, sharks, rays, etc.).

Anthropogenic 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 or biological characteristics of the environment[1]. The area of influence of this pressure is the geographical zone within which this pressure is exerted. It is dependent on the environmental compartment affected.

Effect

Objective consequence of the introduction of one or more pressures liable to generate impact on the marine environment. An **effect** may or may not generate an impact on the different compartments of the marine ecosystem according to their **sensitivity** (capacity to tolerate changes to the environment – **resistance**, and the time required to recover following these changes – **resilience**)[1].

Risk

Probability of an adverse and/or undesirable phenomenon occurring to a species, or group of species, a habitat or even an entire ecosystem, resulting in its direct or indirect exposure to one or more types of pressure[1].

Population

Populations are often defined as a group of individuals of the same species, living in the same geographical area and liable to interbreed. Considerable caution should be taken when applying this type of definition to mobile species with complex social structures, as is the case of marine megafauna. Thus, 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.

Community

An assemblage of species occurring in the same space or time, often linked by biotic interactions such as predation[2].

Management unit (MU)

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.

Collision

A **collision** results from an impact between two objects, at least one of which is in motion. In this bulletin, the term collision refers to an unintentional impact between a stationary object (for instance a mooring line) and a moving animal. This collision may be a result of a lack of detection, which may be specific to the species (hunting behaviour, morphological or sensory inability, etc.) or may be due to a deterioration of its detection capacities caused by an external factor (turbidity, noise emissions, etc.).

[1] Adapted from definitions given by the working group on cumulated effects (GT ECUME) 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

[2] Based on the definition of the Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-being. Synthesis. Island Press, Washington, DC. 155p.

What is entanglement?

In its literal sense, **entanglement** refers to a set of elements twisted together into a disorderly mass. When associated with the development of offshore renewable energies (ORE), the term "entanglement" is commonly used to specifically describe animals being caught in ropes, lines, cables or any other man-made linear structure causing the inadvertent capture or restraint of marine animals without the possibility of escaping (Benjamins *et al.*, 2014; Garavelli, 2020).

The notion of entanglement should be differentiated from the notion of **bycatch** which will be reserved for cases in which animals are inadvertently caught in fishing gear (nets, longlines, etc.), whether active (being actively used for fishing) or derelict (abandoned, lost or otherwise discarded).

What causes entanglement?

In the marine environment, there are **many possible causes** of entanglement, related to different human activities which use linear structures made of flexible materials, such as fishing (fishing gear, nets, etc.), aquaculture (mooring lines, nets, etc.), shipping and pleasure boating (anchoring lines, moorings, etc.), grid connections (telecommunications cables, etc.) and floating wind farms (mooring lines, power cables) (Benjamins *et al.*, 2014).

While there is little knowledge of how marine megafauna become entangled in floating wind farm structures, the majority of observations concern the entanglement of animals in fishing gear (nets, cables used to attach floats to lobster and crab traps, etc.) and aquaculture gear (anti-predator nets) (Kropp, 2013).

Several decades ago, cases of entanglement in communication cables were observed, but they mainly concerned sperm whales entangled as a result of excessive slack in cables in deep waters or poor cable design (Kropp, 2013; Garavelli, 2020). Sperm whales are particularly at risk because they hunt close to the bottom in low light conditions, with their mouths open wide to engulf their prey. Since the 1960s, the fact that no cases of entanglement have been observed with this type of cable is thanks to technological progress (burial and protection techniques, etc.) and advances in cable design, with new cables being less susceptible to coiling and forming loops (especially through the use of optical fibres) (Kropp, 2013).

The development of floating wind farms (and offshore renewable energy in general) off the French coast will mean in an increase in the number of man-made linear structures crossing through the water column. This raises questions within the scientific community about the risks of entanglement for marine megafauna.

How can floating wind farms pose an entanglement risk?

Main sources of pressure within floating wind farms

Within floating wind farms, the potential sources of entanglement are:

(1) **mooring lines** (in red in the figure) which hold structures in place;

(2) **cables** (in orange in the figure) used to transport the electricity generated during the operational phase (Fig. 1).

Two main categories of cables are used in offshore wind farms: **inter-array cables**, which carry the electricity generated by the wind turbines to the offshore substation; and **export cables**, which carry the electricity generated at sea to the onshore electricity grid. The potential sources of entanglement will therefore exist throughout the **operational phase** of offshore wind farms, which lasts an estimated 25 to 30 years on average.

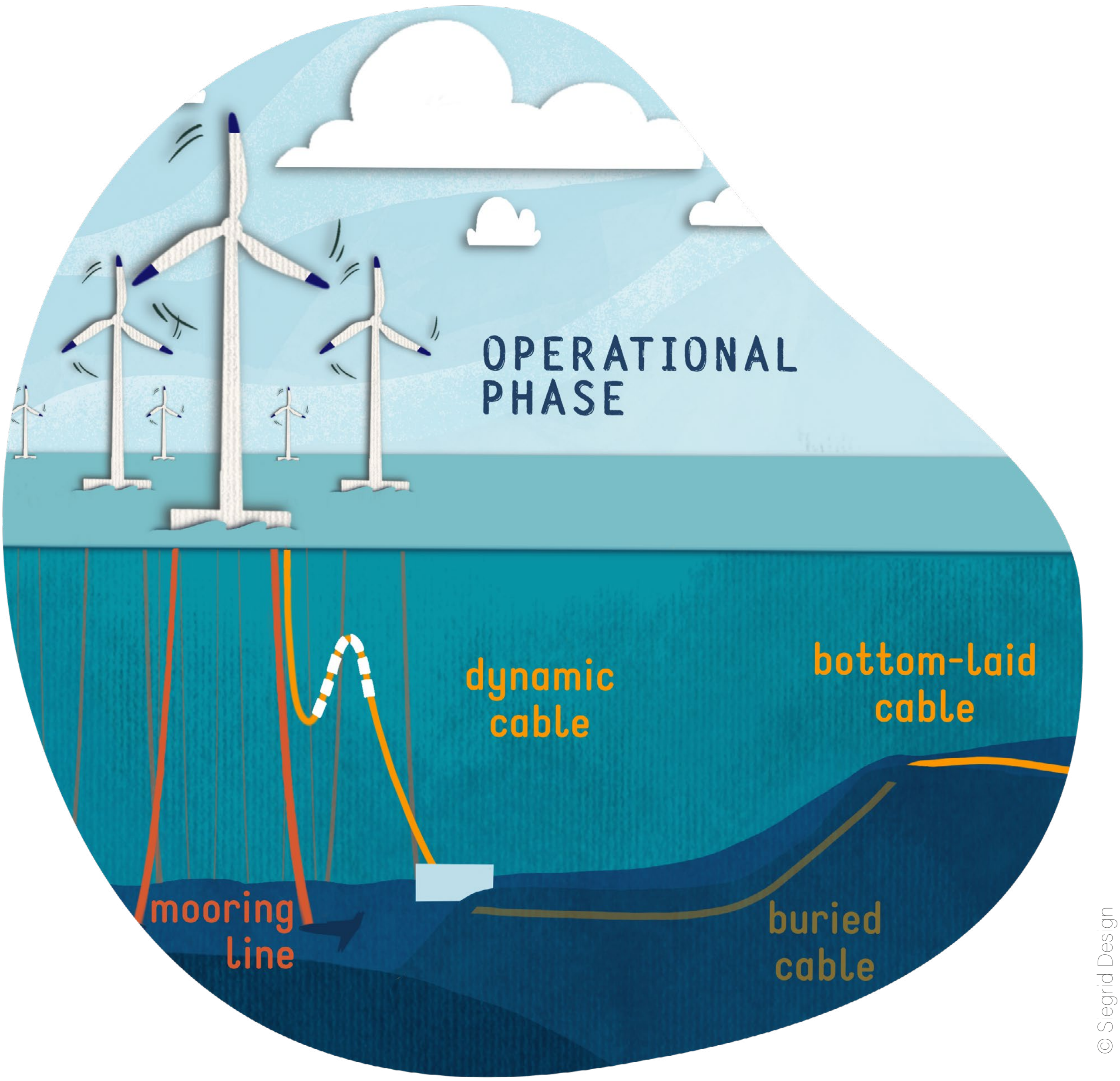


Fig. 1 *Overview of the main sources of entanglement created by floating wind farms. In red, mooring lines. In orange, inter-array cables and export cables. Cables protected by riprap or specific concrete structures are not shown here as they do not pose an entanglement risk.*

Wind farm characteristics liable to affect pressure sources

A number of characteristics specific to cables and mooring lines can affect the probability of entanglement (Tab. 1).

<table>
<tr><th colspan="2">Characteristics common to all man-made linear structures</th></tr>
<tr><td colspan="2">Behaviour of the linear structure in the water column and in particular its tendency to coil and form loops</td></tr>
<tr><td colspan="2">Degree of flexibility and rigidity</td></tr>
<tr><td colspan="2">Lifetime
(in the case of floating offshore wind farms, this corresponds to their average operational lifetime)</td></tr>
<tr><td colspan="2">Depth of installation
(in the case of floating offshore wind farms, the depth is estimated at between 50 and 100 metres* in mainland France)
*Estimated average depth of installation for the technologies used in 2023.</td></tr>
<tr><td colspan="2">Local density in the water column
(in the case of offshore wind farms, this corresponds to the number of cables and mooring lines within a single wind farm)</td></tr>
<tr><td colspan="2">Technical characteristics
(diameter, length, mass, associated buoyancy/protection systems, etc.)</td></tr>
<tr><th>Characteristics specific to the cables used in off-shore wind farms</th><th>Characteristics specific to the mooring lines used in offshore wind farms</th></tr>
<tr><td>Electromagnetic emissions
from power cables</td><td>Configuration
(mooring lines can have different levels of tension – taut, semi-taut, etc.).</td></tr>
<tr><td>Installation method
(buried, bottom-laid, etc.)</td><td>Type of material
(mooring chains can be composed of a series of links made of steel and/or synthetic nylon or polyester fibres)</td></tr>
<tr><td></td><td>Level of mechanical tension
(depends on the capacity of the materials to absorb the shock waves generated by the movement of floating structures in response to the movement of swell and surface currents)</td></tr>
<tr><td></td><td>Noise emissions
created by the movements of mooring lines according to metocean conditions</td></tr>
</table>

Tab. 1 *Table summarising the characteristics of man-made linear structures used in floating wind farms.*

The main differences between the sources of pressure generated by offshore wind farms and other activities liable to pose an entanglement risk (fishing, pleasure boat moorings, etc.) lie in the **technical characteristics** of the cables and mooring lines. The dimensions of these linear structures (size, diameter, mass, length) are not comparable with the buoy lines associated with fishing traps or mooring buoys. They are considerably larger (22 cm in diameter in the case of the nylon mooring lines used for the FLOATGEN[3] floating wind turbine, compared to an average of a few centimetres for buoy ropes associated with fishing traps). The flexibility of the cables and mooring lines is also different. The cables and mooring lines are designed so that they are not exposed to excessive torsional stress and are sufficiently rigid so that they will not form loops.

[3] The FLOATGEN floating wind turbine is installed at the SEM-REV test site off Le Croisic. Further information is available on the FLOATGEN website: https://floatgen.eu/

What is the difference between primary and secondary entanglement?

Primary entanglement

Direct entanglement (or "**primary entanglement**") of marine animals in the cables or mooring lines used in floating wind farms is unlikely due to the technical characteristics and very low level of flexibility of these structures. Under normal conditions of use, the risk of buried cables being uncovered is limited thanks to current cable burial and/or protection techniques. Direct interaction between cables or mooring lines and marine megafauna would be more likely to be caused by a **collision** due to detection difficulties by the animal than by primary entanglement. The more cables and mooring lines there are within a single wind farm (whose surface area will depend on the scale of the project), the greater the density of linear structures passing through the water column. This density will depend on the characteristics of the technologies used (type of float, number of mooring lines, etc.) and of the farms (layout of structures in relation to each other, distances between structures, etc.). This density of linear structures within a limited surface area could lead to a "**barrier effect**", This barrier effect impedes the free movement of marine megafauna, which can lead to abandonment or avoidance of the area (Fig. 2).

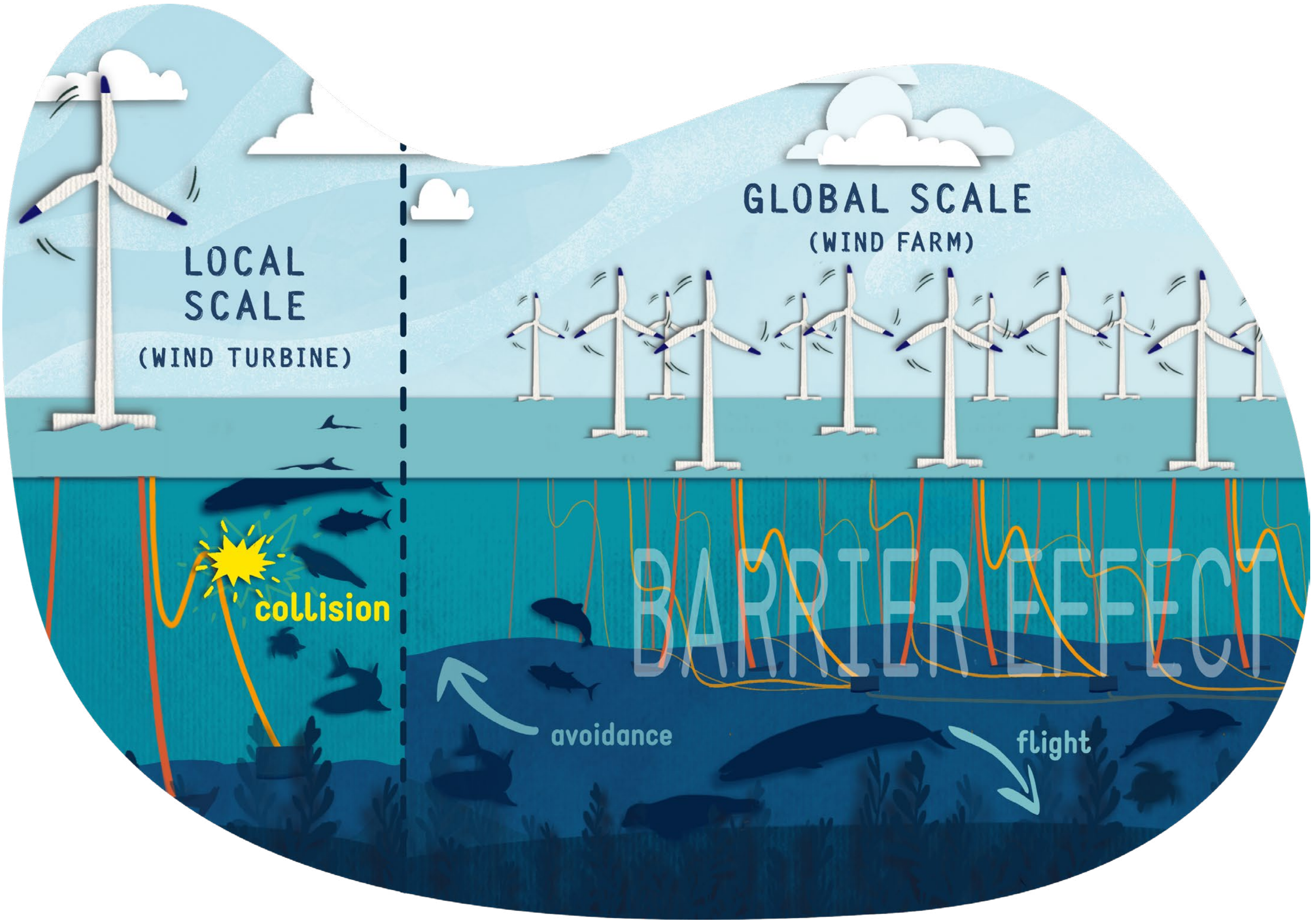


Fig. 2 *Illustration of the potential direct effects of floating wind farms on marine megafauna. Note that the species, man-made structures (wind turbines, cables, mooring lines) and layout of the floating wind farm are not to scale. They are shown here for illustrative purposes.*

Secondary entanglement

Indirect entanglement is known as "**secondary entanglement**". The risk of secondary entanglement of marine megafauna due to the presence of cables or mooring lines would appear to be more likely and depends mainly on the frequency at which debris becomes ensnared in these structures. A floating wind farm located in an estuary plume, for example, is likely to be more exposed to debris accumulation than one located in an offshore area less exposed to pollution from land-based sources.

In the marine environment, there are many sources of debris that are liable to pose a risk of secondary entanglement: agriculture (tarpaulins, sacks used to transport fruit and vegetables, etc.), trade and industry (plastic bags, packaging nets, etc.), fishing and aquaculture (lost or abandoned nets, etc.) and shipping (plastic bags, etc.). When such debris reaches the sea, it can become snagged on linear structures in the water column and can lead to the **entanglement** of marine megafauna, in a similar way to the existing phenomenon of bycatches.

The presence of debris entangled around cables or mooring lines can also lead to a risk of **physical lesions** (wounds, cuts, etc.) through direct contact of the animal with solid debris (hard plastic residues, pieces of metal, etc.) tangled up with softer debris (nets, bags, ropes, etc.). Accumulated debris can also be colonised by small living organisms and attract a community of fish, which in turn can lead to the **attraction** of certain predatory species (tuna, sharks, etc.) drawn to this potential food source. Finally, the degree of debris accumulation within a floating wind farm can strengthen the **barrier effect** by increasing the amount of man-made material within a limited surface area (Fig. 3).

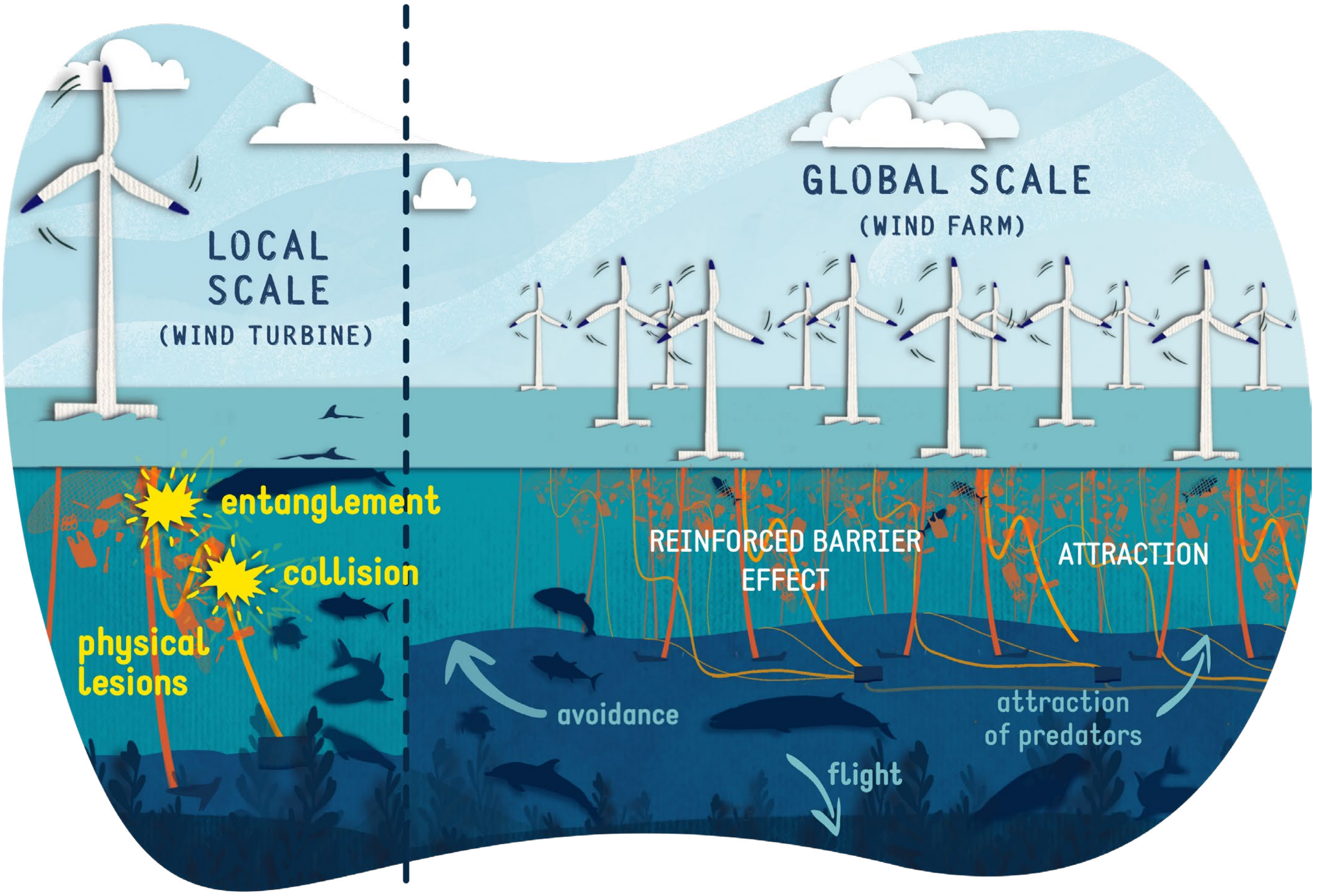


Fig. 3 *Illustration of the potential indirect effects of floating wind farms on marine megafauna. Note that the species, man-made structures (wind turbines, cables, mooring lines) and layout of the floating wind farm are not to scale. They are shown here for illustrative purposes.*

What criteria determine the sensitivity of marine megafauna to the risk of entanglement?

There are three types of behavioural response by marine animals to a cable or mooring line:

- **Attraction**. The presence of a new man-made linear structure will arouse the animal's interest either directly (curiosity) or indirectly (the structure generates an effect, for example a reef effect[4] which will attract a new community of fish);
- **Neutrality**. The presence of a new man-made linear structure does not provoke any reaction from the animal, whose behaviour does not change;
- **Repulsion**. The presence of a new man-made linear structure will trigger avoidance or even evasion behaviour by the animal, which will distance itself from the structure in a more or less marked manner (change in behaviour may vary in its abruptness and rapidity) and with a varying degree of anticipation (at a greater or lesser distance from the structure).

Depending on the species and their individual characteristics, the **sensitivity** of individuals to man-made linear structures will vary along this "attraction > neutrality > repulsion" gradient. It will depend on a range of characteristics liable to influence the animals' ability to detect and avoid the cables or mooring lines. These characteristics vary depending on the species (or even the individual) and can be divided into two categories (Fig. 4):

- **Biological characteristics** (in blue), i.e. which are specific to the species' morpho-biological characteristics and which determine the animals' ability to detect and avoid linear structures;
- **Environmental characteristics** (in white), i.e. which will influence the animals' ability to detect linear structures, and are all closely interlinked.

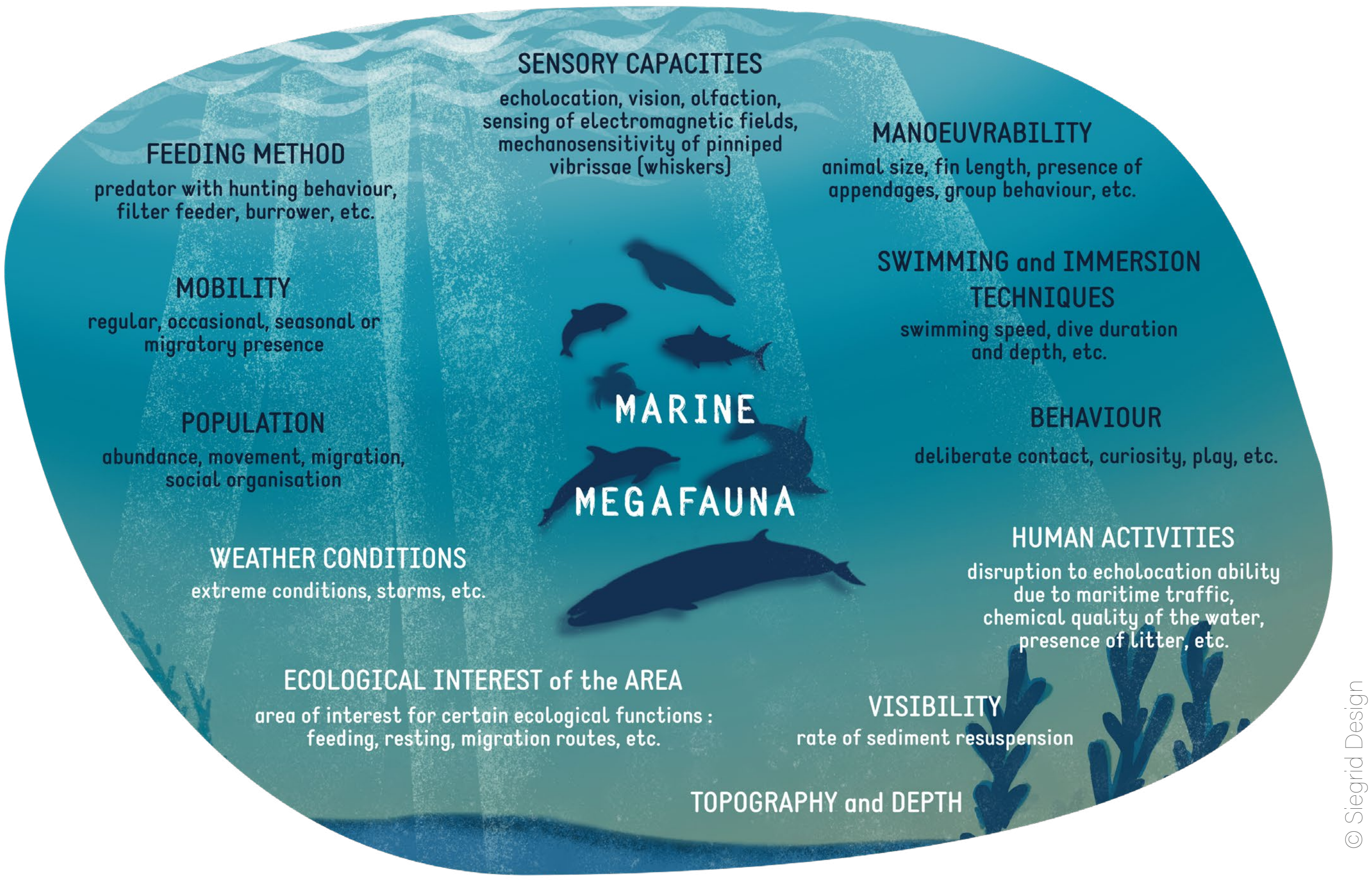


Fig. 4 *Illustration of the biological and environmental characteristics that affect marine megafauna's ability to detect and avoid linear structures.*

The behavioural response may affect the probability of the animals visiting the area and therefore the risk of entanglement. We note that certain environmental characteristics, such as sediment resuspension caused by chain movements on the seabed, can, according to the species and the individual, cause attraction (species that visit turbid environments to feed) or repulsion (species that flee turbid environments due to a lack of visibility). The ecological interest of the area and/or the reef effect[4] resulting from the introduction of a man-made structure into the marine environment (in this case floating, linear structures) can also increase the probability of animals visiting the area. The risk of entanglement for certain species with a limited biological ability to detect cables or mooring lines may therefore be higher, particularly for secondary entanglement. The risk of primary entanglement in cables and mooring lines remains low, due to their technical characteristics.

[4] See COME3T Bulletin n°3 "The reef effect induced by wind farms and their grid connection"

What are the potential impacts of entanglement?

The link between the effects of entanglement (whether primary or secondary) and the potential impact on marine megafauna is difficult for the scientific community to establish. **Risk estimations are often the result of hypotheses made by experts based on observations of similar man-made equipment at an individual scale.**

In the case of a **collision** between cables or mooring lines and an animal, the most likely potential impact would be a physical injury (contusion, oedema, etc.) for which the recovery time will vary depending on the animal's speed of movement. The **barrier effect** generated by the density of linear structures within a restricted surface area can lead to the fragmentation of habitats and management units. Depending on the species, it can also trigger behavioural changes such as abandonment or avoidance of the area. In both cases, the increased energy expenditure involved in circumventing or deserting an area of ecological interest (area for feeding, resting, caring for young, etc.) can lead to a deterioration in the health of the individuals. In the long term, this deterioration in health can have consequences at management unit level (see “Focus” box).

Secondary entanglement in trapped debris can lead to asphyxiation if the animal is unable to free itself. It can also lead to emaciation if the debris restrains the animal. In the long term, this form of restraint can have significant physiological impacts on the individual's general health and metabolic activity, with possible consequences on its growth and reproductive capacity. Finally, **physical lesions** caused by contact with certain types of debris can, depending on their severity, lead to infection, disease or deformities (new bone growth, etc.).

While it is possible to form hypotheses at the level of individuals, it is difficult to extrapolate them to a group of individuals. Functional interactions within a group are complex and depend on a large number of parameters (species, number of individuals, study area, etc.). This is particularly the case for marine megafauna, which comprises species with a long life expectancy and a low reproduction rate. In order to estimate impacts at management unit level, we must determine the point at which individual impacts will affect a sufficient number of individuals to have an impact on the viability of the group as a whole (see “Focus” box).

FOCUS

While the risk of direct entanglement in cables or mooring lines is deemed to be of low probability, the same cannot be said for marine debris (nets, ropes, etc.). This type of debris, when lost or abandoned at sea, is liable to accumulate in floating wind farms, posing a risk of indirect or secondary entanglement.

The impact of floating lines used for fishing traps and pots

When individual impacts affect too many animals or primarily affect animals that are essential to maintaining the structure of the management unit (reproductively active females, for example), the consequences in terms of group viability may lead to a reduction in the number of individuals. This was highlighted by Moore (2019) in his study on North Atlantic right whale populations (*Eubalaena glacialis*). The results of this study show that the number of mortalities and serious injuries resulting from human activities routinely exceed the threshold value for the maximum number of animals that can be killed by anthropogenic causes each year without affecting the structure of the management unit over time. In view of the traces and marks observed on entangled animals, floating groundlines from trap fisheries have been identified as one of the anthropogenic activities that have led to the decline in the population since 2010 (Moore, 2019).

How can knowledge be improved and risks mitigated?

The species of marine megafauna present in the waters of mainland France are clearly identified and well known to the scientific community. However, there is still a lack of fundamental knowledge on how management units work for species that live in groups (marine mammals, sea turtles, large fish, etc.). The study of potential effects must therefore not be limited to individuals, but should consider groups of individuals that evolve and change over time. It is difficult to improve knowledge of this aspect due to the wide variety of methods and monitoring initiatives that need to be set up to assess these effects.

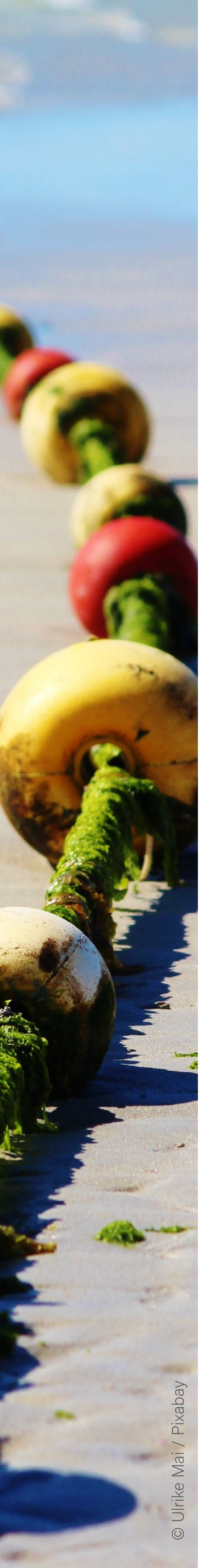
Given this lack of knowledge, it is even more difficult to predict the effects caused by different sources of pressure. This is the case whether they are caused by the development of floating wind farms, other human activities or global change. In the case of floating wind farms, the current lack of feedback on entanglement risks (whether primary or secondary) exacerbates this difficulty.

It is crucial to understand the behaviour of marine megafauna in the presence of cables or mooring lines in order to assess the risks. In the absence of a predefined area and target species, a quantitative assessment of the entanglement risk in floating wind farms for marine megafauna cannot be conducted. However, the first essential steps towards such a risk assessment consist in identifying potential pressure sources liable to pose an entanglement risk, the biological characteristics of the species and the environmental characteristics.

On the basis of the characteristics identified in this bulletin, the experts put forward a number of proposals to determine, prevent, reduce and monitor entanglement risks in floating wind farms:

- **Improve fundamental knowledge** and acquire data on the behaviour of the animals present in floating wind farms. The gained knowledge should be global and consider, for each site, all the species present (frequency of visits to the site, social structures of groups, etc.);
- **Implement preventive measures** to reduce the risks and the probability of secondary entanglement in anthropogenic marine debris. Control, monitoring and clean-up measures can be implemented to limit debris accumulation. In floating wind farms, these monitoring, control and clean-up operations can be combined with on-site maintenance operations. While the best way to reduce marine debris is to implement actions at the source (onshore waste management), protocols for assessing potential sources of debris within wind farms throughout the project's life cycle can help to limit and reduce the amount of debris on site;
- **Mitigate the risk of secondary entanglement** by implementing appropriate repulsion measures. The use of acoustic deterrent devices to repel marine megafauna from floating wind farms and reduce the risk of entanglement is strongly discouraged. Given the lifespan of wind farms, the use of this type of device is liable to result in habituation for certain species and to generate additional continuous pressure in the long term (25 to 30 years, equivalent to the average lifespan of an offshore wind farm). Based on the knowledge and behavioural observations made at floating wind farms using the monitoring measures proposed below, appropriate repulsion measures may be proposed if necessary for certain species;

- **Monitor the potential effects on marine megafauna** by studying their behaviour within floating wind farms. Conventional monitoring (aerial and/or vessel-based observation and monitoring) can only partially meet the knowledge needs. To understand what is happening underwater and what type of behaviour marine megafauna adopt when faced with a series of linear structures in the water column, the most relevant monitoring methods that are best suited to studying animal behaviour must be combined (imaging – video cameras, telemetry, acoustics – echosounders, hydrophones, etc.). These monitoring methods must be innovative and specific to the context of floating wind farms and the cognitive capacities of marine megafauna. The spatial and temporal scale of this monitoring must also be tailored to the species' biological cycle, life expectancy and high mobility. In addition to the monitoring measures implemented for impact studies and those required by regulations, encouraging the development of citizen science also can help to boost knowledge. Based on appropriate, standardised protocols defined in collaboration with scientists, citizen science often offers a key opportunity to gather information. In addition to sea users, this monitoring could be carried out in partnership with professionals operating within and/or in the immediate vicinity of floating wind farms (maintenance operators, fishermen, etc.).



Conclusion

Solid knowledge is available of the issue of entanglement of marine megafauna in marine debris. Some of the effects observed in cases of entanglement in marine debris can be transposed to the risk of secondary entanglement caused by debris (nets, ropes or other lost or abandoned debris) trapped within floating wind farms. However, given the limited feedback from past experience of floating wind farms, a robust assessment of the risks identified cannot be made. The mechanisms and quantities involved in debris accumulation within floating wind farms remain poorly known. Depending on the observations made on site (debris accumulation rate) and on any measures implemented to reduce the presence of debris within floating wind farms and more widely at sea (waste reduction at source, changes in fishing practices, awareness-raising among professionals and sea users, etc.), the level of concern over the risk of secondary entanglement (greater than that of primary entanglement, which is considered negligible) could possibly be reduced.

IN SHORT

The term "entanglement" describes the inadvertent capture or restraint of marine animals in man-made linear structures (nets, ropes, mooring lines, etc.). There are two types of entanglement. Primary entanglement refers to an animal becoming directly entangled in a linear structure. Secondary entanglement refers to an animal becoming indirectly entangled in debris ensnared in these linear structures.

Floating wind farms are unlikely to be sources of primary entanglement, given the technical characteristics of their cables and mooring lines. However, the risk of secondary entanglement in marine debris generated by human activities at sea (pleasure boating, fishing, aquaculture, shipping, etc.) and on land (agriculture, industry, etc.) is considered non-negligible in light of the impact of marine debris already observed by the scientific community on marine megafauna.

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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 and socio-economic 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 and socio-economic issues associated with offshore renewable energy.

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An initiative coordinated by France Energies Marines.

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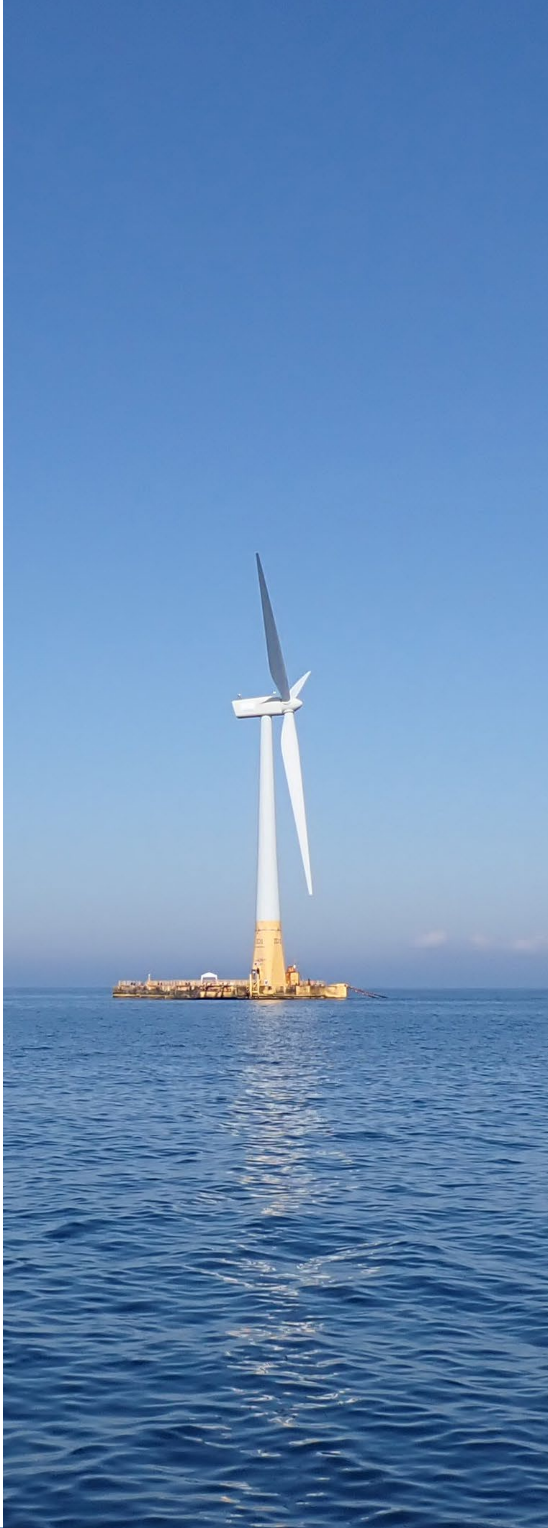
France Energies Marines is the Institute for Energy Transition dedicated to offshore renewable energies. Its missions: to define, set up and apply the scientific and technical environment required to overcome the obstacles related to the development of ORE technologies while ensuring optimal environmental 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.



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