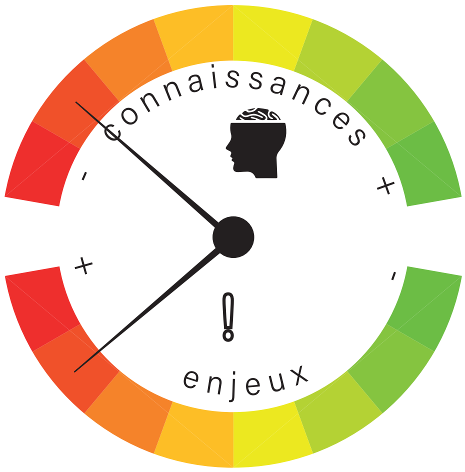
What are the potential effects of offshore wind farms on coastal fish and their essential habitats?

Bulletin n°10
March 2024

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 by the experts to be "a major issue for which the current state of knowledge is considered low with regard to the diverse life history strategies of coastal fish, and the lack of knowledge on their behaviour and sensitivity at certain key life stages".

Scientific experts

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Introduction

As is the case for the majority of human activities in coastal zones, the development of offshore wind farms can lead to effects on the environment and on marine species. This bulletin focuses in particular on the potential effects of the presence of offshore wind farms on fish that inhabit inshore waters for all or part of their life cycle.

In France, plans to install offshore wind farms currently only concern coastal waters. It is difficult to assess the impact of offshore wind farms (or indeed any other human activity) on the fish found in these shallow waters, given the complexity and diversity of their life cycles. To gain a better understanding of this complexity, a few key concepts inherent to coastal fish biology and their habitats are first presented. The main pressures related to the development of offshore wind farms are also listed, together with their main effects on the life cycle of fish. As all offshore wind farms have different characteristics, a global impact assessment method is put forward.

Seagrass beds are home to large numbers of juvenile fish

Definitions

Pelagic

Relating to the water column. A pelagic organism is an organism that spends all or part of its life cycle swimming (case of many fish) or drifting (case of plankton and many larvae of marine species) near the surface (Fig. 1).

Demersal

In close proximity to the seabed. A demersal organism is an organism that swims in open water and mainly dwells close to the seabed to feed, hide, rest, etc. This is the case of many crustaceans (shrimps, lobsters, etc.) and fish (sea bream, red mullet, hake, etc.) (Fig. 1).

Benthic

Relating to the seabed. A benthic organism is an organism that spends the majority of its life cycle (or even its entire life cycle) on or near the bottom or in the sediment. Such organisms may be sessile (like corals, mussels, etc.) or motile like certain crustaceans (brown crabs, spider crabs, etc.) or flatfish (sole, plaice, etc.) (Fig. 1).

Substrate

In a literal sense, the substrate refers to the supporting surface in or on which an organism lives. In the marine environment, the substrate is generally the seabed. Hard substrates include rocky bottoms, biogenic structures such as coral reefs, and artificial substrates such as wrecks, while soft substrates include sandy and muddy bottoms.

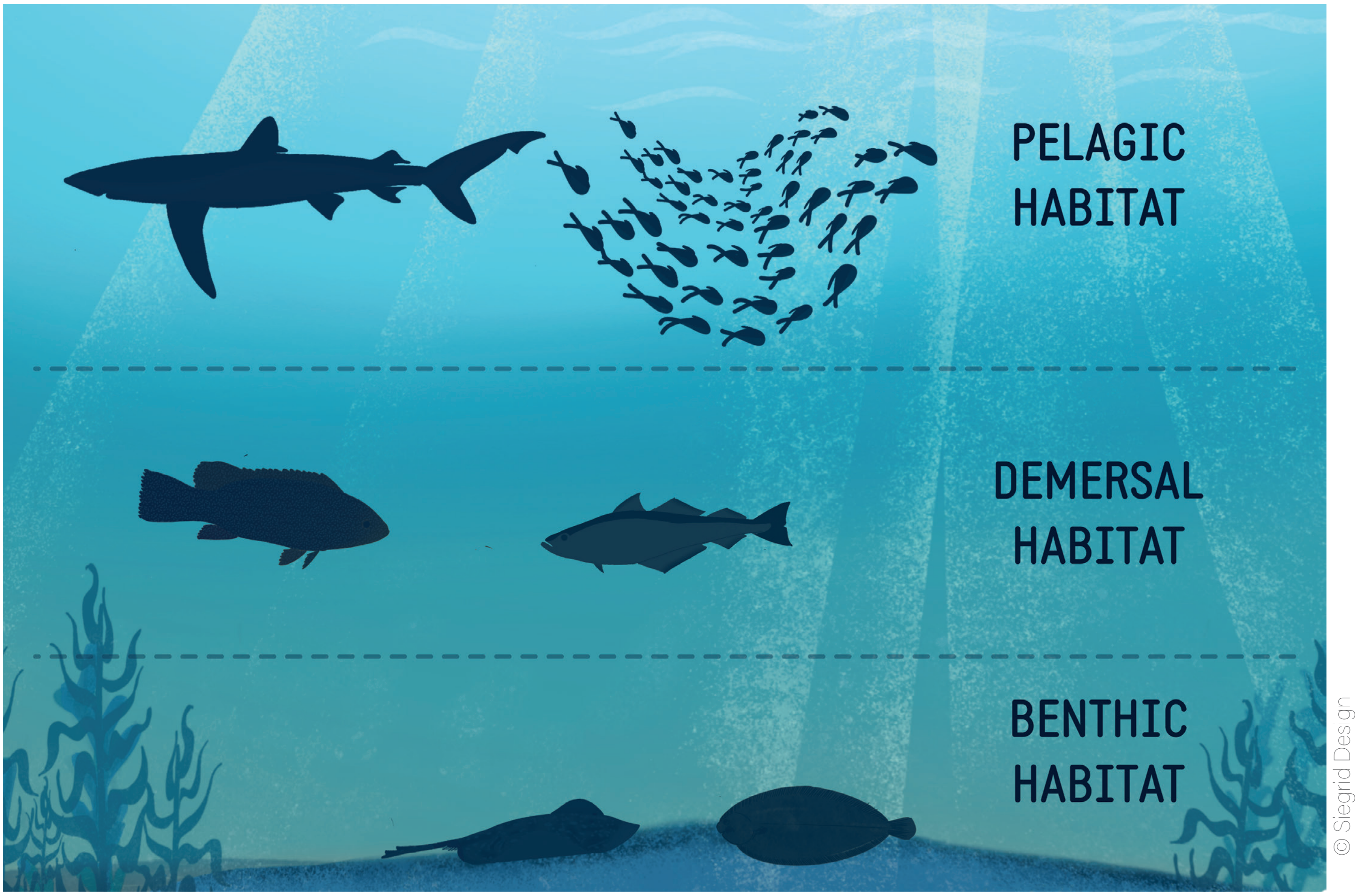


Fig. 1 *Diagram illustrating the vertical distribution of the three main habitats (pelagic, demersal and benthic) of coastal fish.*

Recruitment

Process by which new individuals are added to the population of a species. Recruitment is considered effective when young individuals survive and later integrate the adult population at reproductive age.

Ecophase

The stage in the life cycle of an organism that is characterised by adaptation to specific ecological conditions. During the larval ecophase, the habitat and ecophysiology can be radically different from those of the corresponding adult ecophase, for instance[1].

Anthropogenic pressure

Manifestation of human activities in the marine environment that may take the form of a change in status, either in space or time, of the physical, chemical or biological characteristics of the environment[2]. 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 (Fig. 2).

Effect

Objective consequence of the introduction of one or more pressures liable to generate impact on the marine living 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 for it to recover following these changes – resilience)[2] (Fig. 2).

Stratification

Phenomenon that occurs when water masses with different properties (salinity, oxygen level, temperature, etc.) form layers that prevent the water from mixing.

Fig. 2 *Conceptual diagram of the different terms used to define the impact chain of a pressure on an ecological receptor (a species or group of species – marine mammals, plankton communities, etc.), in this case a fish species*

[1] Based on the definition given in P. Triplet (2020): Dictionnaire de la diversité biologique et de la conservation de la nature, 1216 p.

[2] 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

Key concepts

Life cycle

The **life cycle** of a species (also known as the "biological cycle") is a sequence of all the biological processes involved in the development of an individual throughout its lifetime. Coastal fish have a complex life cycle that can be divided into three main stages[3]:

- The **larval stage** which comprises the "**egg**" and "**larva**" life stages;
- The **juvenile stage** which comprises the "**fry**" and "**juvenile**" life stages;
- The **adult phase**.

The transition from one life stage to another is marked by a **major biological event**, which generally involves a change in behaviour (feeding, movement, etc.) and/or habitat. **Hatching** marks the transition from the egg stage to the larva stage. This is followed by **metamorphosis**, which marks the transition from the larval stage to the fry stage, and involves major physical, behavioural and physiological changes (colour, body shape, diet, swimming ability, etc.). The juvenile stage is characterised by the gradual acquisition of the morphological, ecophysiological and behavioural characteristics of adults. However, the transition to the adult stage is not complete until sexual maturity is reached (defined by the presence of functional male or female reproductive organs). Finally, **reproduction** marks the end of the cycle and the start of a new one.

Figure 3 below is a simplified illustration of the life cycle of most coastal fish species (Fig. 3). Depending on the species, the different life stages can last from a few days to several years.

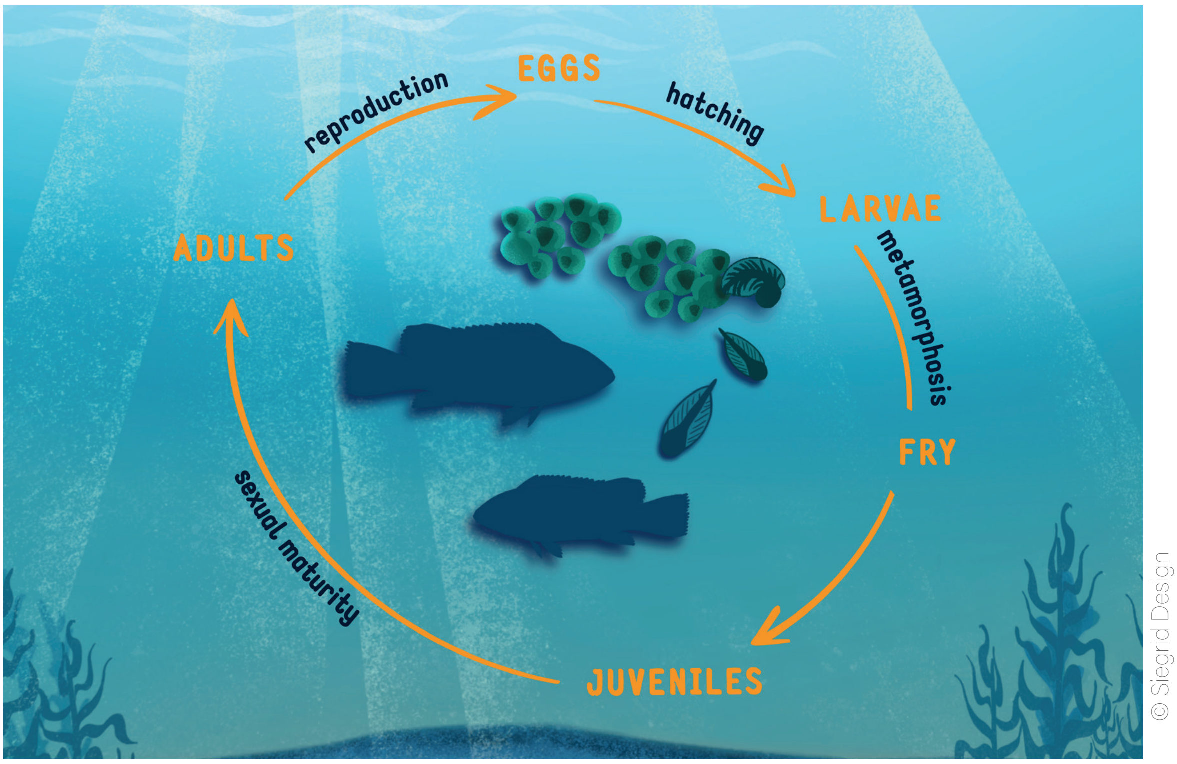


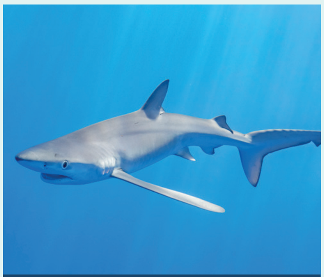
Fig. 3 *Simplified diagram of the life cycle of most coastal fish. This diagram does not cover specific modes of reproduction used by certain species (hermaphroditism, viviparity, etc.).*

[3] Koeck B., (2012): Rôle des récifs artificiels dans l'écologie des poissons : application aux récifs artificiels de Leucate – Le Barcarès (Golfe du Lion, Mer Méditerranée). Evolution [q-bio.PE]. Ecole Pratique des Hautes Études - EPHE Paris, 2012. In French.

Did you know?

Coastal fish use a wide variety of modes of reproduction.

Some species, such as the blue shark (left-hand photo), are **viviparous** : the embryo produced by fertilisation develops inside the mother, who gives birth to live juveniles. Others are **hermaphrodites**, meaning that they change sex during their life cycle. This is the case, for example, of the gilt-head bream (right-hand photo), which initially develop as males then change sex when they reach 30-40 cm (at around 2-3 years of age) to finish their life cycle as females.



Blue shark

© Diego Delso

Gilt-head bream

© Tylwyth-Eldar

Ecological functions

To ensure its survival, a fish must perform three main **ecological functions** at each stage in its life cycle[4]. It must:

- **feed** to support its growth and good health;
- **protect itself** against predators and environmental factors (currents, turbidity, temperature, etc.);
- **reproduce** to ensure the survival of the species.

These three ecological functions can be associated with one or more life cycle stages. For instance, **feeding** is vital for survival at all life stages, whereas **reproduction** only takes place during the adult stage. These ecological functions are often associated with more or less extensive movements, depending on the species, with small-scale daily movements and/or large-scale seasonal migrations, in order to reproduce, spawn, find food or shelter, etc.

A simplified illustration of the three main ecological functions for a typical coastal fish species is given below (Fig. 4).

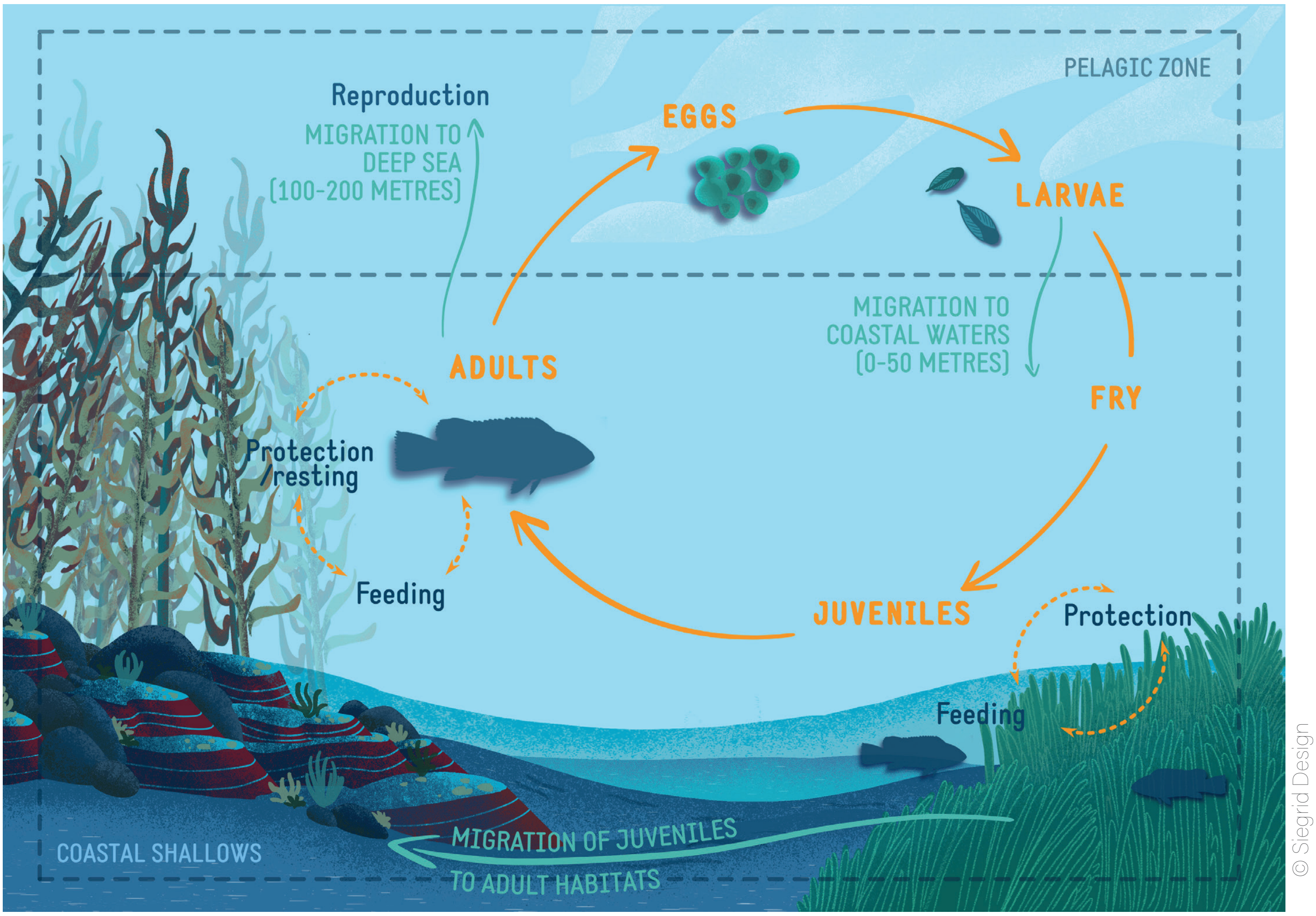


Fig. 4 *Simplified diagram of the ecological functions during the life cycle of a typical coastal fish species and the associated movements.*

[4] Lévêque C., (1995): L'habitat : être au bon endroit au bon moment ? Bull. Fr Pêche Piscic. 337/338/339 : 9-20

Essential habitats

The term "**habitat**" refers to a specific environment characterised by particular conditions (temperature, depth, flora and fauna present, etc.) in which an organism, population or community can survive and develop. Each habitat corresponds to a geographical or physical area, however its location is dynamic, meaning that it can change over time. Fish may change habitats over the course of their life cycle in order to seek a suitable environment to perform all the **ecological functions** that are essential for their survival. The **essential habitats** for each species are those considered **indispensable** for performing at least one of their ecological functions at each stage in their life cycle (Fig. 5). According to the ecological functions they perform in these habitats and the life stages during which they are present, essential habitats may take on different names. For example, the term "nursery" is used to describe habitats used by juveniles for protection and feeding, and "spawning grounds" refers to areas where adults reproduce.

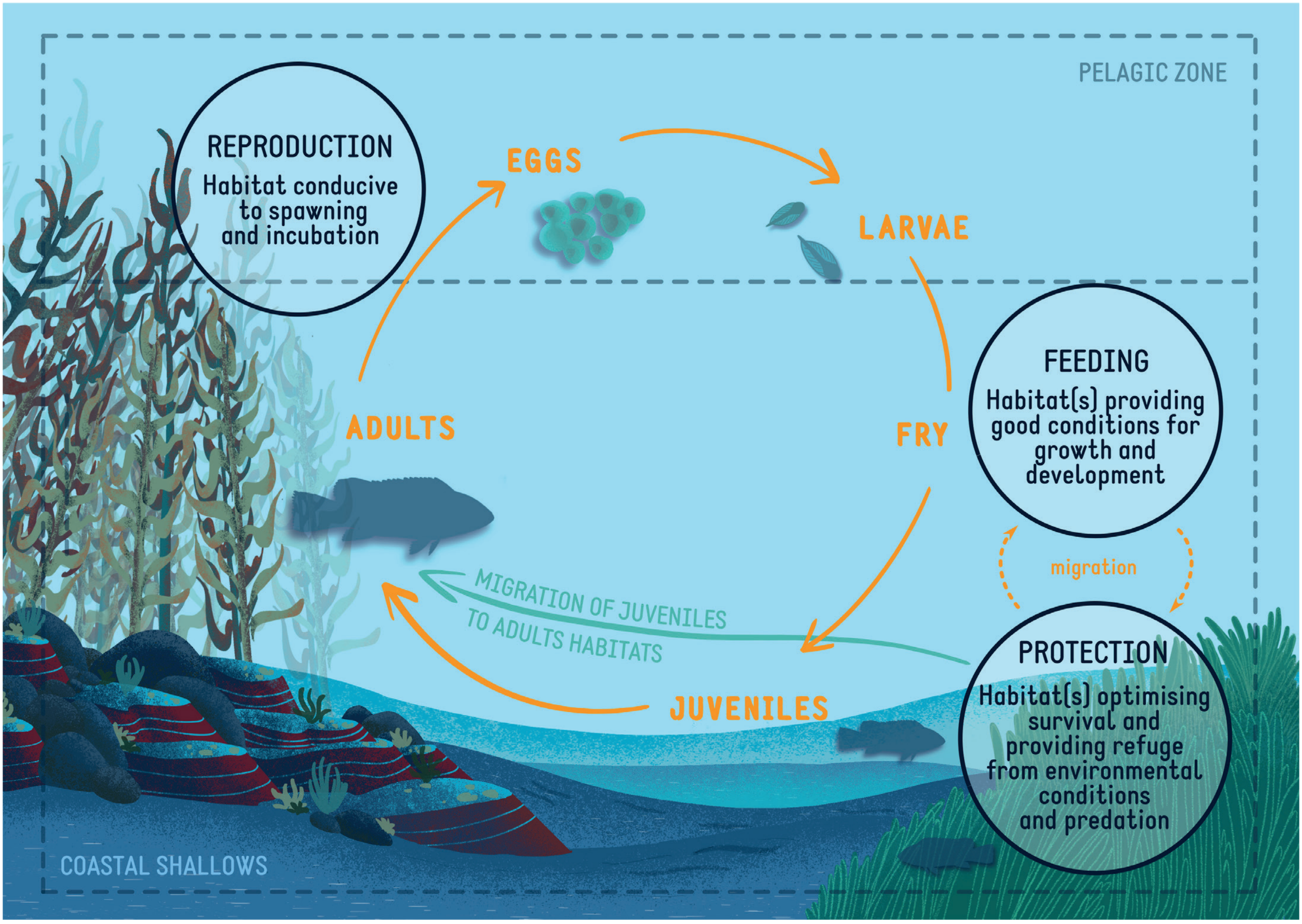


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Fig. 5 *Diagram illustrating the essential habitats of the "juvenile" and "adult" stages of the life cycle of a coastal fish. The essential habitats and the ecological functions performed there are indicated in simplified form.*

Essential habitats are a complex concept. They vary according to the species, the life stage and the various biological events that occur during the life cycle of the fish. Each species may also have one or more essential habitats for a single life stage. These essential habitats can have very different characteristics and are all interconnected by the different species that use them. A predatory species, for example, may be indirectly affected by the degradation of a habitat that is essential to the life cycle of one of its preys. Furthermore, individuals of the same species may use the same habitat at different stages in their life cycle, which does not necessarily mean that the habitat is essential for all of these stages.

Fish and offshore wind farms

Coastal fish may be affected by the temporary or permanent degradation of marine habitats caused by offshore wind farm development. In this bulletin, only the operational phase of offshore wind farms is considered, given its estimated duration of 25-30 years.

Kelp forest near Molène

Impact assessment method

With almost 743 marine fish species recorded in French waters[5] and as many life cycles, it is not currently feasible to assess the impact of offshore wind farms on all coastal fish. In addition, the complexity of this assessment is exacerbated by the fact that every wind farm has its own specific characteristics: number of turbines, type of foundations, type of technology, nature of the substrate, etc. The presence of wind farms in coastal waters is likely to lead to the modification or loss of essential habitats, while other habitats could in fact benefit from certain effects caused by the introduction of these man-made structures to the environment. The complexity of the effects (direct and/or indirect)[6], the lack of information on the life cycle and the sensitivity of species and their essential habitats complicate the impact assessment process.

Given this context, a risk-based approach is therefore applied to assess the potential impacts of offshore wind farms on coastal fish. With this approach, we overcome the issue of the specificities of each species and are able to identify the life stages that are potentially most affected by the different pressures. Depending on the technology used and the characteristics of the species chosen to assess the potential effects, different scenarios can be put forward. This risk-based approach offers an overview of the pressures and their potential effects on the life cycle of fish, and makes it possible to assemble a profile of the most sensitive species. It is divided into a number of key stages:

(1) Identify the **pressures** generated by wind farms;

(2) Identify the potential **effects** of these pressures for:

   a. each main habitat type in the fish life cycle (pelagic, demersal and benthic, hard or soft bottom) and

   b. assign them an intensity ranking (high, moderate, low, nil, unknown);

(3) Pair up the identified **effects** with the **ecophases**, i.e. match the key life cycle stages (larval, juvenile and adult) to the habitat occupied (pelagic, hard-bottom bentho-demersal and soft-bottom bentho-demersal).

(4) For each "**effect/ecophase**" pair (e.g. *"habitat destruction"* combined with *"hard-bottom bentho-demersal juvenile"*), assess the level of impact (high, moderate, low, nil, unknown) for each ecological function (feeding, protection, reproduction)

Given the gaps in knowledge of the biology of many coastal fish and the sensitivity of their life stages, only some of the conclusions drawn from this approach are presented below. While it was possible to identify the pressures induced by the farms and their effects on fish habitats (points 1 and 2 below), it was more difficult to estimate their impacts on each ecophase. Only the main expected impacts are

[5] INPN, (2019): La biodiversité en France, 100 chiffres expliqués sur les espèces. UMS Patrinat (AFB-CNRS-MNHN), Paris, 48p

[6] Direct effects, such as habitat loss; or indirect effects, such as the repercussions of the loss of a fish species' habitat on its predator.

therefore illustrated below (point 3). Their assessment is based on existing observations of the response of several coastal fish species to certain environmental effects, which cannot, however, be generalised to all coastal fish.

1. What pressures induced by offshore wind farms are relevant to fish?

The pressures induced by offshore wind farms will depend on the type of wind turbines deployed (bottom-fixed or floating), as well as on the type of foundation/mooring, the materials used and, most importantly, the type of substrate on which the farms are built (sand, rock, etc.). Six types of pressure should be considered for fish:

- **Added substrate** (1): Introduction of hard substrates (foundations/floats, cable protection systems and scour protection systems[7], dynamic cables, mooring lines) to the marine environment.
- **Habitat destruction** (2): Clear, localised marine habitat destruction due to the introduction of man-made structures (foundations, cable protection systems and scour protection systems[7], moorings and mooring lines) into the marine environment.
- **Noise emissions** (3): Noise associated with the resonance of blade movements on the mast and foundations and with the movements of the floats and mooring lines.
- **Electromagnetic emissions** (4): Electromagnetic fields emitted by the cables
- **Hydrodynamic conditions** (5): Disturbance of hydrodynamic conditions (current speed and direction) by the introduction of man-made structures into the marine environment (foundations/floats, cable protection systems and scouring protection systems[7], dynamic cables, mooring lines).
- **Chemical pollution** (6): Spills and/or metal release by cathodic protection systems (corrosion protection systems).

[7] Scour refers to the erosion phenomenon that can be seen at the foot of man-made structures caused by changes to water circulation and currents.

2. What are their main effects on fish habitats?

These pressures lead to three main effects: habitat loss, modification and degradation (Fig. 6).

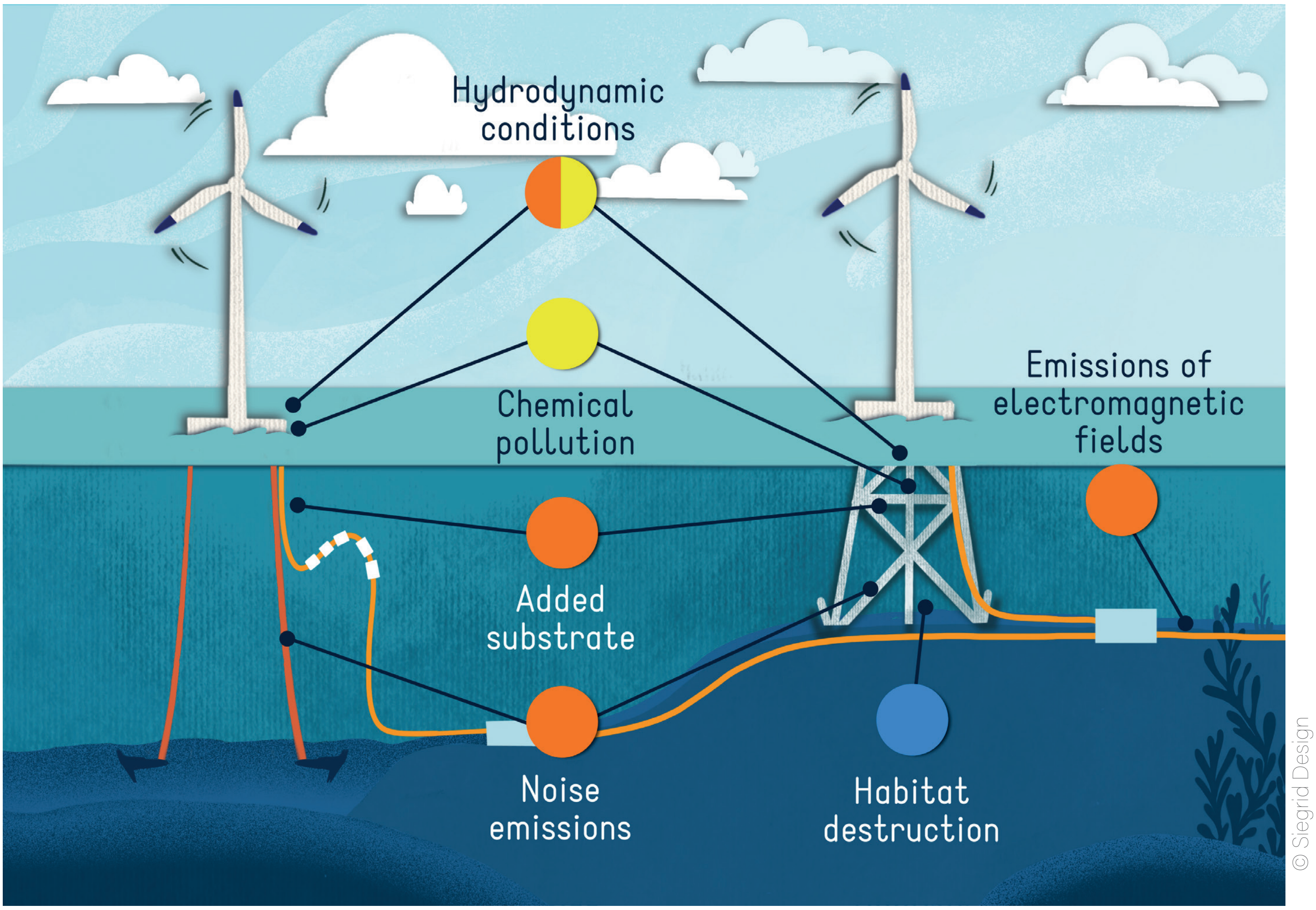

Fig. 6 *Summary of the six main pressures generated by offshore wind farms that affect coastal fish. Their main induced effects are also presented: habitat loss (blue circle), modification (orange circle) and degradation (yellow circle). Different types of floats and foundations exist, but for the sake of clarity, only semi-submersible floats for floating wind turbines and jacket foundations for bottom-fixed wind turbines are shown here.*

Habitat destruction (2) results in permanent or temporary habitat loss, mainly affecting benthic habitats. The main effect induced by the pressures created by added substrate (1), noise emissions (3), electromagnetic emissions (4) and hydrodynamic conditions (5) will be to modify the habitats, whether benthic, demersal or pelagic (see definitions). An added substrate (1) will provide a new surface for colonisation or protection, which could lead to an attraction phenomenon for certain species (reef effect[8]). Noise emissions (3) and electromagnetic emissions (4) will lead to changes to the natural acoustic and electromagnetic landscape. Disturbances to hydrodynamic conditions (5) can lead to (i) local changes to currents, stratification of the water column and hydro-sedimentary processes in bottom-fixed wind farms and (ii) increased surface turbulence and stratification of the water column in floating wind farms. Finally, chemical pollution (6), whether chronic or accidental[9], can reduce the quality of marine habitats and make them potentially harmful to the development of marine flora and fauna, as can a local increase in turbidity caused by a local disturbance to hydrodynamic conditions (5) on the bottom.

[8] See Bulletin n°3: The artificial reef effect induced by wind farms and their grid connection

[9] Chronic pollution is ongoing pollution resulting from the recurrent or continuous release of a pollutant into the environment. It is generally opposed to accidental pollution, most commonly caused by a spill or an exceptional event.

3. How are coastal fish affected by habitat loss, modification and degradation?

The consequences (or impacts) of the six above-mentioned pressures and their induced effects will vary according to the characteristics of the pressure (duration, intensity, etc.), the location of the induced effect(s), the species or life stages concerned, and the respective sensitivities of each species (and their prey/predators) to each effect (see table below).

Pressure	Main effect	Potential impacts
Added substrate (1)	Habitat modification	The reef effect can have potential consequences on the abundance and composition of fish communities, trophic relationships and/or migration routes, with fish species possibly staying for longer periods or diverting from their initial trajectory.
Habitat destruction (2)	Habitat loss	The loss of a habitat that is essential to one or more life stages of a soft-bottom benthic/demersal species can have a major impact on recruitment success and population maintenance. When an essential habitat is lost, there is a risk of the life cycle not being completed, with significant consequences for the population of the species concerned (and its prey/predators), the abundance and composition of fish communities and/or trophic relationships.
Noise emissions (3)	Habitat modification	Changes to the soundscape can mask signals used by fish for communication and orientation, with potential consequences on population dynamics and individual health. In addition to noise, some fish may be sensitive to particle movements triggered by the sound wave travelling through the water. In the long term, this sensitivity can lead to chronic physiological stress or desertion of the area.
electromagnetic emissions (4)	Habitat modification	Changes to the electromagnetic landscape can disturb sensitive species' perception of the Earth's magnetic field and therefore their hunting behaviour, orientation and/or migration. According to the species and life stages concerned, these disturbances can affect the distribution of individuals, prey/predator relationships and migration trajectories/durations.
Hydrodynamic conditions (5)	Habitat modification	Local changes to currents, water column stratification and surface turbulence can impact the transport of fish eggs and larvae from essential habitats for reproduction (spawning grounds) to essential habitats for protection (nursery area), potentially with non-negligible consequences for recruitment success and local population maintenance.
	Habitat degradation	Habitat degradation due to sediment resuspension can affect species that are sensitive to turbidity. Depending on the species and the intensity of the disturbance, turbidity can trigger a change in hunting/flight behaviour and therefore in prey/predator relationships, partial or total desertion of the affected area and asphyxiation of the most sensitive species due to clogging of the gills, with potential consequences for the abundance of certain fish species, particularly at the juvenile stage.
Chemical pollution (6)	Habitat degradation	Depending on the type of pollutant and its concentration in the marine environment, there may be numerous impacts on fish survival and biology (health, reproductive success, development, etc.). These impacts will vary according to the species' sensitivity and lifestyle. All life stages are potentially vulnerable to chemical pollution, although the strongest impacts are expected for eggs and larvae, given their fragility and their limited (or non-existent) motility. Chemical pollution can have consequences on the abundance and composition of fish communities.

The loss, modification and/or degradation of coastal habitats can have non-negligible consequences for fish at every life stage, affecting their development (growth, etc.), behaviour (search for food and/or mates, prey/predator relationships, orientation, etc.) and/or physiology (reproduction, etc.). The extent of the response of fish to the presence of offshore wind farms will be determined by the intensity of the various pressures, the abundance of the different species present and their characteristics (lifestyle, migrations, etc.) (Fig. 8).

Specific case: the reserve effect

The reserve effect is often mentioned when addressing the potential effects of offshore wind farms on fish and is closely related to the reef effect. However, the reserve effect is not the direct result of pressure induced by the wind farm, but rather of changes in the uses and regulations applied to professional fisheries within the wind farms. For this reason, it is not covered here.

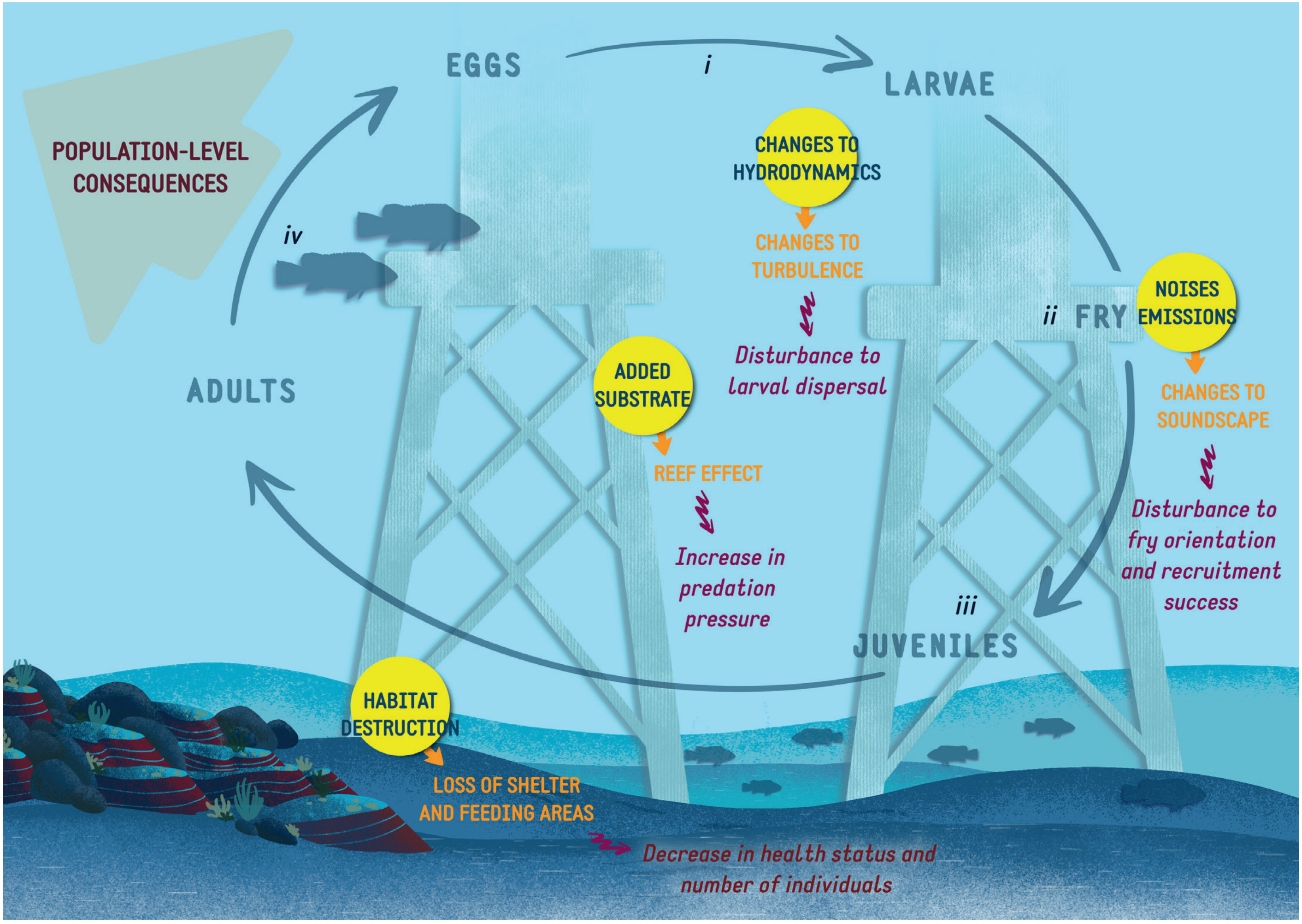

Fig. 7 *Conceptual diagram showing four pressures generated by a wind farm (yellow circles), their effects on the environment (in orange), the potential impacts (in purple) and the consequences at population level (in orange) for a typical species of coastal fish. This diagram is designed to illustrate how different pressures can generate various effects that can impact the same species at different stages in its life cycle. This illustration is not exhaustive. The example given here illustrates the case of a species for which (i) the eggs and pelagic larvae are exposed to passive dispersion in the water column; (ii) the larvae and fry are soft-bottom bentho-demersal and need to find a habitat conducive to their recruitment; (iii) juveniles are benthic and depend on gravel-bottom shallows (essential nursery habitat) which provide them with food and protection for their growth; (iv) adults are bentho-demersal and must travel several kilometres to their offshore breeding grounds.*

Knowledge gaps

For many coastal fish species, it is difficult to know whether a given habitat is essential for one (or more) life cycle stage(s), or whether they can be replaced by other habitats. In order to assess the impact of wind farms (or any other offshore activity) on coastal fish populations, knowledge must first be improved in relation to:

- The biology, physiology and ecology of species throughout their life cycle. It is particularly important to enhance knowledge in this field as it is essential in order to (i) identify essential habitats and (ii) predict species' sensitivity to environmental disturbance;
- The composition of local fish communities and the inter- and intra-species relationships within these communities. In particular, the connections between the different habitats and the position of the species in the food web (prey/predator relationship) require further clarification.

This information could be used to map habitats, identify essential habitats for fish and specify their role in the life cycles of different species and the overall ecosystem functioning. In order to build this knowledge, medium- and long-term fish community and habitat monitoring is required in order to take into account species' renewal times. Such monitoring programmes must be carried out on a large spatial scale in order to consider all the habitats used by these highly mobile species.

Conclusion

Despite gaps in scientific knowledge, it can be concluded that the extent and nature of the potential impacts of offshore wind farms will depend on the fish species (life cycle, life stage, key habitats), but also on numerous environmental parameters (type of substrate, depth, etc.) and wind farm-related technological parameters (type of float/foundation, turbine density, structure size, etc.). Given the interconnections between fish habitats and the interdependence of many marine species (particularly through prey/predator relationships), the only way to reliably assess the impacts for all coastal fish lies in an ecosystem-wide approach. This complex exercise can be simplified by an ecophase-based risk assessment, as presented here. By overcoming the issue of the specificities of each species, this approach offers an overview of the potential impact of each pressure on the life cycle of fish, and makes it possible to assemble a profile of the most sensitive species.

IN SHORT

Predicting the response of coastal fish to anthropogenic pressures is a complex task as there is a wide variety of species that depend on different habitats to perform the biological functions (feeding, protection, reproduction) that are essential to their life cycle. To assess the impacts of offshore wind farms on coastal fish, a risk-based assessment method was defined. This method consists in successively identifying the pressures generated by farms, their induced effects on the environment, and the essential habitats for each life stage (larval, juvenile and adult). Six pressures generated by offshore wind farms were identified as relevant to coastal fish: added substrate, habitat destruction, noise emissions, electromagnetic emissions, hydrodynamic conditions and chemical pollution. These pressures have three major effects on the marine environment (habitat loss, modification or degradation) which, depending on the species, the environmental parameters and the technologies used, will have impacts of varying intensity on coastal fish larvae, juveniles and/or adults, their populations and potentially on the proper functioning of ecosystems.

Further reading

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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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