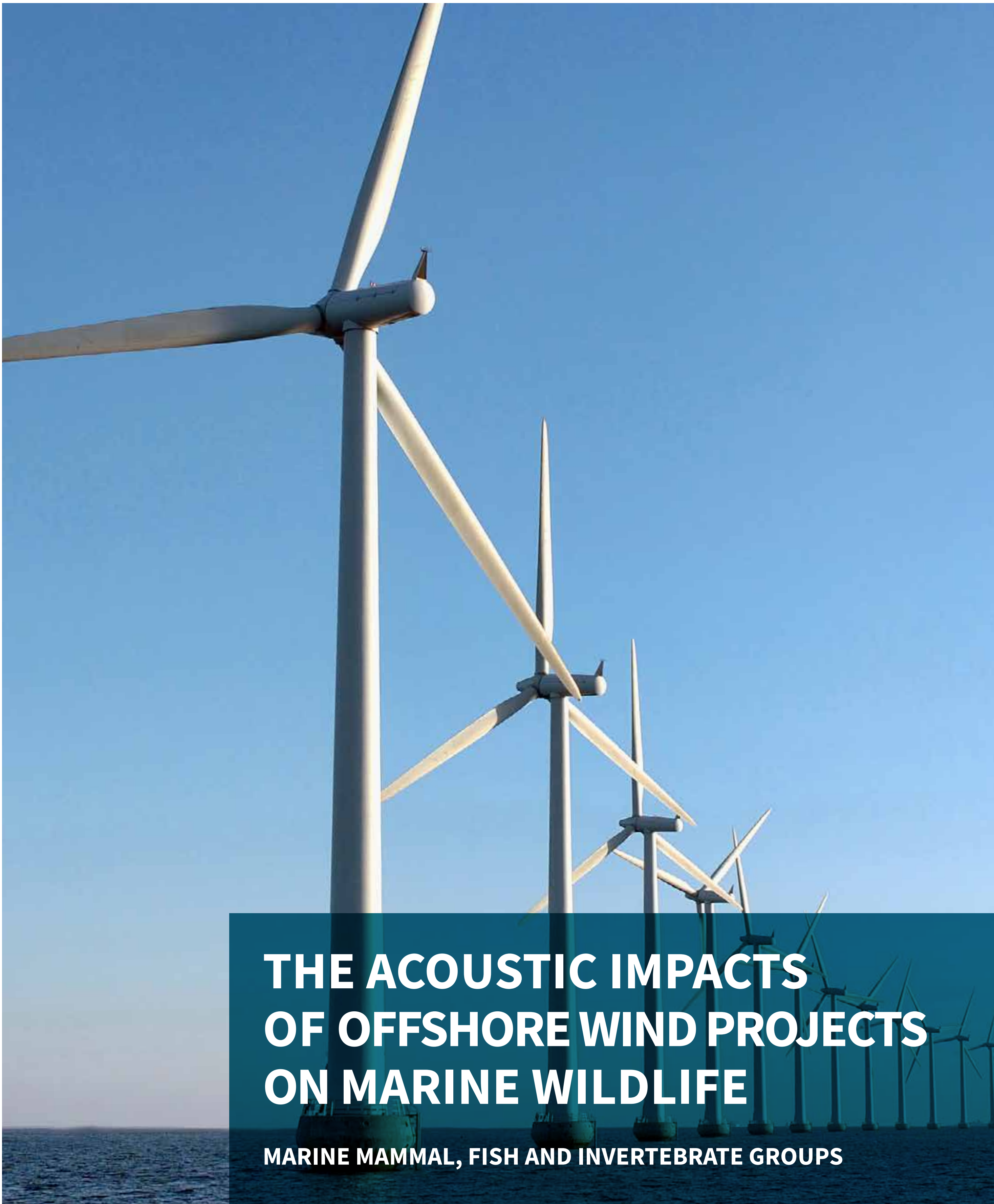
RÉPUBLIQUE
FRANÇAISE
Liberté
Égalité
Fraternité

cnrs



THE ACOUSTIC IMPACTS OF OFFSHORE WIND PROJECTS ON MARINE WILDLIFE

MARINE MAMMAL, FISH AND INVERTEBRATE GROUPS

Synthesis of the collective expert report - November 2021

Download the full report
(in French)

The development of offshore wind energy is currently the subject of much debate. Noise pollution's potentially negative effects on marine life are legitimate sources of concern for civil society, industry and political authorities alike.

Three French Ministries: 1) Ecological Transition, 2) the Sea, 3) Higher Education, Research and Innovation mandated the CNRS to carry out a collective expert review to provide proven scientific elements and thus more in-depth knowledge about the complex issue of the acoustic impact of marine renewable energy projects on marine fauna. The aim of this review of the scientific knowledge that is currently available on the subject of the acoustic impact of wind projects is to help guide public decision-making on the installation and management of offshore wind farms.

Alain Schuhl, the CNRS Deputy CEO for Science led this scientific expert review involving a group of scientists from different disciplines who are recognised as experts in this area. They were asked to provide an overview of the most recent knowledge through collective, critical and neutral analysis of worldwide scientific literature on the mechanisms of underwater sound propagation, the multiple impacts of anthropophony on various marine species, the noise produced by wind projects particularly during their construction and the methods that enable such noise to be reduced.

The collective expert report highlights the species most likely to be impacted by offshore wind projects, the form and severity of such impacts and the effects of mitigation strategies that can be implemented. It also highlights the fact that current knowledge remains incomplete and stresses the need to find out more in this area, particularly about several species and sound sources.

I hope that ongoing research will soon enable impact studies to be extended to all marine ecosystems while taking all sources of both transient and chronic noise fully into account.

With the present expert review, the CNRS – a research organisation that covers multiple disciplinary fields – wishes to contribute science's views on this question to support decision-makers and enhance public debate about a topical issue for society as a whole.

Antoine Petit,
Chairman and CEO

SYNTHESIS

This collective expert report takes stock of scientific knowledge about the acoustic impact of offshore wind projects on marine wildlife in a context of planned development of marine renewable energy (MRE) projects. It focuses on the impact of noise from offshore wind turbine construction projects and on three marine fauna groups – marine mammals, fish and invertebrates as few studies are available for seabirds or sea turtles. For the purposes of comparison, this study also concentrates on operational marine renewable energy projects along with other anthropogenic (man-made) noise emissions.

The first part of the collective expert report summarises the knowledge about signal processing, underwater acoustics and bioacoustics required to effectively study the impact of MRE projects and the sounds they generate. A sound wave can be described in terms of several physical quantities, notably sound pressure and particle velocity. MRE projects cause various types of both transient (impulsive or not) and continuous noise. This means a distinction needs to be made between the construction phase – particularly drilling and pile-driving work – and the operational and decommissioning stages. The noise generated by MRE projects also needs to be situated as much as possible in the overall context of oceanographic soundscapes taking into account the natural and human sounds which are already present.

It is difficult to model the propagation of these sounds in the marine environment. A realistic acoustic prediction requires precise knowledge and study of bathymetry (the topography of the ocean floor), spatial variations in the speed of sound in the water column and the geoacoustic parameters of the sea floor and sediment strata. The latter parameters remain mainly unknown. In practice, current knowledge is based on laboratory experiments and *in situ* observations.

The environmental parameters that animals use to perceive sound vary according to the auditory system involved. Some are sensitive to pressure variations, others to particle acceleration and/or substrate vibration. Three groups from the animal kingdom, namely marine mammals, fish and invertebrates (pelagic and benthic), are the main subjects of study but the quantity of available knowledge varies between the three groups with much more being known in this area about vertebrates than invertebrates.

The second part of the collective expert report presents feedback from different MRE projects regarding their impact on wildlife. This section concentrates on a set of international studies thanks to which we are beginning to identify and understand the effects of underwater sound generated by offshore wind projects on marine fauna.

Numerous *in situ* studies have been carried out since the 2000s in the North and Baltic Seas, focusing particularly on pile-driving work carried out during the construction phase. More recently, *in situ* monitoring of the operational phase has been implemented. However, currently no *in situ* observational studies are available for floating wind turbines. The decommissioning phase has been relatively unstudied and was thus not taken into account herein.

Few studies of **floating wind turbines** have been carried out.

- *Operational phase:* The sound levels measured during the test phases led to the conclusion that there is likely to be no physiological impact on any species of marine mammals or fish during these phases. The maximum radius of the observed zone of behavioural change is 450 metres for marine mammals and 15 metres for fish.
- *Construction phase:* The construction of floating offshore wind farms does not involve pile driving. However the noise characteristics of the installation of floating offshore wind farms (installing riprap, burying cables, anchoring) are close to the noise generated by ships. Studies have found a reduction in the number of marine mammals (porpoises and seals) around these projects which can be explained by the noise made by the increased ship traffic on the site.

Studies of **installed wind turbines** shed light on the impact of construction work and their operation on several marine mammal species that are abundant in the North Sea and the Baltic Sea (harbour porpoises, grey seals and harbour seals), fish and invertebrates.

Harbour porpoises: Scientists have managed to identify the actual effects of the installation and operation of various offshore wind farms on harbour porpoises through *in situ* studies featuring passive acoustic and visual monitoring (aerial and ship-based observations).

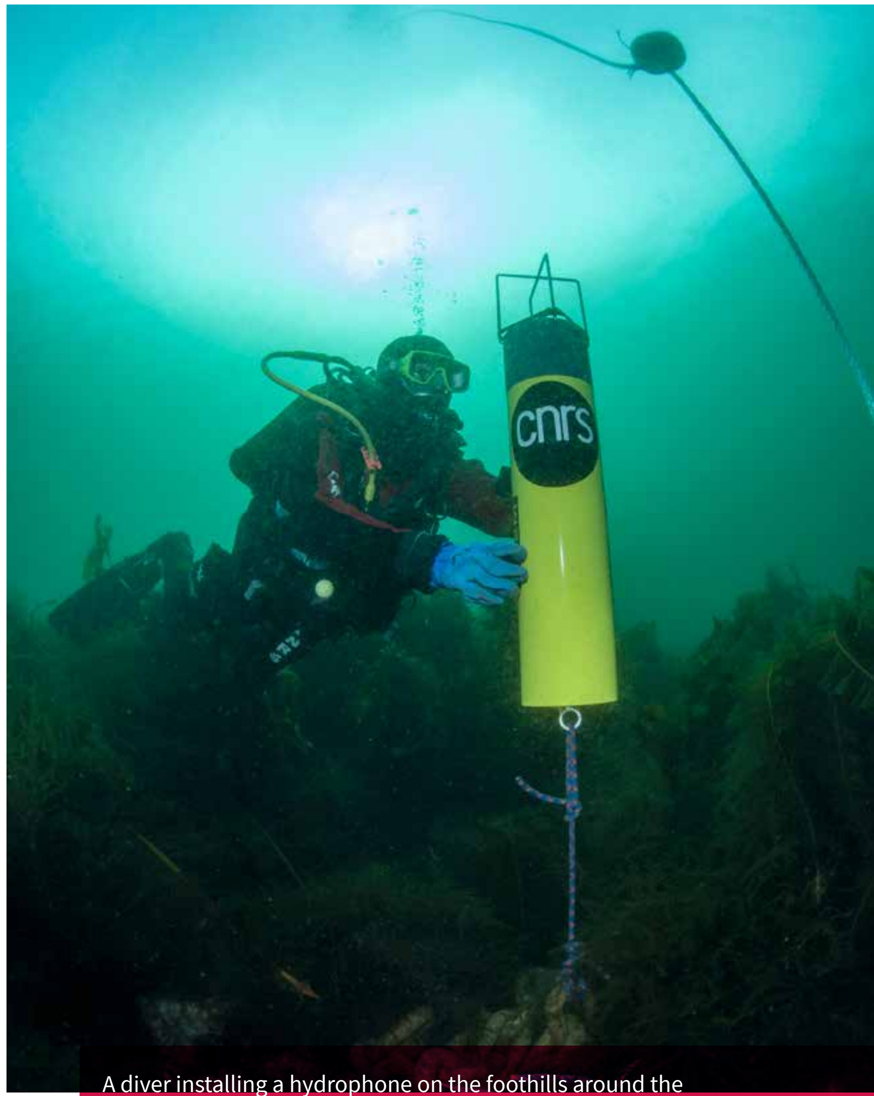
- *Construction phase:* Significant differences in the extent and importance of the construction phase's effects on harbour porpoises have been observed at different offshore wind farm sites. However almost all such studies report a short-term impact beginning with a significant reduction in acoustic activity and a temporary displacement of individuals close to the site before or from the start of work. This was found to be followed by a return to a normal situation in terms of acoustic activity and abundance up to 3 days after operations. The studies reported few long-term effects.
- *Operational phase:* Monitoring work carried out several years after the construction of offshore wind farms enabled scientists to assess their effects in the operational phase with no significant effects reported to date.

Seals: Researchers used visual observations and telemetric monitoring to study the response of seals to activities linked to wind projects.

- *Construction phase:* No long-term effects on seal behaviour were found during the construction phase but a significant short-term reduction in the number of seals present close to the wind farms (abundance at sea and on land) was observed during pile-driving operations. This avoidance response is probably linked to the noise made by the pile-driving operations and the associated mitigation measures and has been observed up to 25 kilometres away from such construction work.
- *Operational phase:* The studies have found wind farms to have no significant effect on seal behaviour (abundance at sea and on land, movements and behaviour at sea) during the operation of wind turbines.

Fish

- *Construction phase:* Numerous experiments in fish pools have highlighted the negative effects on fish species of the noise made by offshore wind farm construction activities. These have enabled scientists to define theoretical noise impact thresholds for different categories of fish and thus simulate the influence of wind farms, taking into account the sound levels emitted, sound propagation and the hearing capacities of fish. There have been few studies of the actual effects of pile driving work on fish species, mainly because of the logistical challenges involved. ➔



A diver installing a hydrophone on the foothills around the Kongsfjorden fjord in Spitsbergen, in Norway's Svalbard Archipelago, to study the acoustic landscape.

- *Operational phase:* Many factors are likely to affect fish populations once offshore wind farms become operational. These include habitat changes, noise disturbance or disturbance caused by the electromagnetic fields created around cables. These factors all have a simultaneous effect which means their relative importance for fish is difficult to define separately and evaluate empirically.

Invertebrates: The rare studies that exist are based on *in situ* observations and noise simulations of operational offshore wind turbines. However, these have not enabled scientists to draw any general conclusions. Some studies find a negligible acoustic impact of noise and vibration on benthic fauna during the operational phase while others report the negative influence of sounds emitted by wind turbines, for example on the fixation of crab larvae which is thought to lead to a delay in their metamorphosis.

The third part of the collective expert report broadens the analysis of acoustic impacts to include other anthropogenic sources of noise for which more knowledge is available. Such impacts can be significant and occur throughout the whole life cycle of marine organisms, with biological responses on individual organisms (physiological and behavioural responses), populations, species and also effects on interactions between species. These responses can vary depending on the developmental stage, age or sex, context, the distance from the source and the sound source's characteristics.

The bibliographical summary provided is based on a broad range of observational studies involving various anthropogenic emissions such as seismic blasts, explosions or maritime traffic. It covers marine mammals (cetaceans with low (LF), medium (MF) and high (HF) frequency hearing, pinnipeds), fish with specialist or generalist hearing according to whether their inner ear is connected to the swim bladder (this can act as a resonance chamber), and finally the impacts on invertebrates' larval, paralarval and juvenile stages. The effects of anthropogenic sound production are classified in five groups – direct mortality, transient or permanent changes in the auditory threshold, other physiological responses, behavioural responses and masking. These responses are not independent and may interact in complex ways.

Regarding **mortality**, there are few direct observations of deaths which are concomitant at the individual or population levels with measurements of the characteristics (frequency, level) of the sound wave causing the disturbance. However events linked to high sound production have been reported for three groups of animals – marine mammals, fish and invertebrates. For marine mammals, mortality essentially corresponds to mass stranding events involving mid-frequency hearing cetaceans (beaked whales) observed in relation to the use of military sonar and seismic shooting. Mortalities have also been observed for fish with generalist hearing within an average radius of 10 metres of the sound source during the use of airguns by seismic vessels and also during pile-driving operations. The studies of invertebrates seem to show a highly variable impact depending on the species and the development stage.

Traumatic effects on the auditory system have been well documented. Animals exposed to sufficiently intense noise have been found to demonstrate an increased hearing threshold or in other terms a reduced sensitivity to sound. The duration of this effect mainly depends on the exposure time and the amplitude and frequency of the sounds involved. In the case of a temporary effect, the hair cells in the animals' inner ear demonstrate the characteristics of a state of fatigue before later returning to their normal form. The hair cells are permanently damaged, eventually necrotizing and disappearing, if exposure to noise exceeds a certain limit or if the temporary hearing loss is chronically induced over a long period of time.

Other **physiological responses or lesions** have been observed which may have an impact on other tissues than those related to the auditory system and to metabolic conditions (stress-related or not).

- In **marine mammals**, these responses may take the form of an increase in respiratory activity or stress levels and even neurological and immune changes. In some marine mammals, there can be lesions such as dislocation of middle ear bones, bleeding, and haemorrhages in the fat or oil, mainly in melon or lower jaw. Such lesions reduce or prevent the transmission of sound to the inner ear.

- In **fish**, anthropogenic sounds generally induce a stress metabolism characterised by an increase in cardiac output and ventilation or cortisol secretion. Most studies of this subject have shown the negative effects of high sound levels (e.g. pile driving) on physiological processes. Tissue damage may also occur. These responses vary according to the hearing ability and way of life of the species concerned.

- The physiological responses observed in **invertebrates** to exposure to anthropogenic noise are mostly linked to an increase in biochemical stress markers:
  – it is impossible to draw overall conclusions for **crustaceans** but studies have shown varied physiological responses depending on the species. These include an increase in the expression of stress proteins and oxygen consumption, a decrease in growth and reproduction rates and the modification of immunological capacities;
  – there have been very few studies of acoustic impacts on the physiology of **endofauna molluscs**.

During anthropogenic sound emissions, the **behavioural reactions** observed in mammals or fish are comparable and mostly involve fleeing to avoid the source of sound. According to the studies, these reactions can be noticed at highly varied distances depending on the sound source, the group of animals studied and even the species. However, in some cases the animals studied were found not to be disturbed by the noise produced with some animals even attracted to the sound source.

- The studies of **marine mammals** have revealed a wide range of behavioural changes in response to anthropogenic noise. These include swimming faster or diving deeper to avoid the sound source, social groups pulling closer or a reduction in resting time or in the time spent searching for food. The nature of the effects and their levels of severity vary from one species to another depending on the distance from the sound source and its characteristics. For example, researchers have found that the behavioural response of beaked whale species to sonar emissions can be particularly severe, even leading to these species being stranded in the worst cases. Also, a sonar emission can cause a similar level of stress to that observed when there is an immediate danger of predation. The impact of pile-driving has been observed up to 30 kilometres from the focus of the sound in the cases of "high frequency" cetaceans and some seals. In the case of ship noise, the animals' behaviour can vary according to the size and type of ship but some creatures become used to regular ship passages and show a decrease in escape responses.

- **Fish** with generalist and specialist hearing demonstrate panic and escape responses to the sound source with faster swimming, schools breaking up and vertical rather than horizontal dispersion. The radius of the impact of pile driving varies from 300 metres to 1.4 kilometres for generalist fish but is limited to 4 metres for noise from operational offshore wind turbines for all fish. Noise from ships can also cause fish to find it harder to detect and capture their prey and conversely to exhibit reduced awareness of the presence of predators. Finally, various anthropogenic noises disturb the mating behaviour of many species.

- Numerous behavioural responses have been observed in **invertebrates** to exposure to a sound source like pile-driving, boat noise and substrate vibrations. In the case of crustaceans, this may include changes to burrowing and displacement behaviour, feeding behaviour, sound production and responses to predators. The different studies of invertebrates have revealed complex effects on the biological interactions between benthic species without there being any major impact in terms of direct mortality. The behavioural responses of some cephalopods involve severe and abrupt changes in swimming and the production of ink jets during the first few seconds of exposure to pile-driving and seismic sounds although long-term effects have yet to be proven. Increased tolerance to noise may also alter the ability to escape from predators. In bivalves, exposure to noise seems to affect valve activity which may go as far as the complete closure of valves, resulting in filtering activity stopping. This also reduces their ability to mix the sediment surface during their movements.

Sound has also been found to impact the **larval development and recruitment of invertebrates.** Such impacts may occur throughout the life cycle of marine invertebrates – particularly at the larval, paralarval and juvenile stages – and they have long been studied. However, the case of development noise has only rarely been examined. For example, studies have shown the high vulnerability of some cephalopods in laboratory experiments, major impacts on zooplankton (with mass mortality for krill larvae) after seismic surveys. Impacts on the rate of larval settlement and changes in metamorphosis dynamics have also been found. The latter can be either delayed or accelerated depending on the species of benthic fauna involved.

The impact of sound occurs indirectly when **masking** is involved, namely when a signal of interest cannot be effectively detected or recognised by a receiver. The masking capacity depends on the characteristics of the masking noise (level, frequency band, duration) and the distance involved but studies have shown a reduction in marine mammals' communication and listening spaces in the presence of anthropogenic noise. Also, fish have been found to have difficulties detecting and communicating with their conspecifics.

The fourth part of the collective expert report presents feedback on experiments concerning the use of acoustic impact reduction methods. Several approaches and methods have been developed and tested since the early 2000s to reduce the acoustic impact of pile-driving which is recognised to be a predominant technique. These methods can also be effective in reducing the impact of other types of work like drilling, dredging or riprap and can be classified in three categories.

Sound reduction methods at the source involve modifying pile-driving technique to reduce noise emissions. There are currently no *in situ* measurements of the modification of pile driving characteristics with the only known results coming from simulations. Prolonging the duration of a hammer blow and the duration of contact are known to significantly reduce the noise level and enable maximum energy to be shifted to lower frequencies that have less impact on marine mammals. The solutions being considered consist of installing cushions on the pile or driving the piles by vibration. However the level of maturity of these techniques remains low.

Methods aimed at attenuating sound propagation include installing devices around the pile to reduce the transmitted level.

- The results of *in situ* tests have led to **the bubble curtain method** being recommended. This reduces the noise level during pile driving and minimises the behavioural reactions of harbour porpoises. It consists of injecting compressed air into the water through a ring of perforated pipes surrounding the pile to release air bubbles that modify the water's compressibility and thus the speed of sound propagation. Stimulating gas bubbles at their resonant frequency reduces the amplitude of the sound waves through dispersion and absorption. Interactions between the multitude of bubbles in a curtain further reduce sound levels. To overcome problems linked to currents, one solution that has been suggested is the confined bubble curtain in which the bubble curtain is generated between the wall of a steel tube and the pile itself. ➔

- **Hydro sound dampers (nets with air-filled balloons)** are also used to reduce continuous and impulsive noise. This method serves to control the resonance frequency which is inversely proportional to the diameter of the balloons. This technique is currently less mature than the bubble curtain technique but presents the advantage of not using compressors. Conversely, it should be noted that this system is expensive, depends on there being good weather conditions for implementation while its effectiveness seems to be affected by the tidal current.

- *In situ* tests of **insulating blocks and cofferdams** have shown these to be effective in reducing the sound volume of pile-driving work. This technique consists of surrounding the pile with a steel pipe (insulating block). There are different variants to this – with and without air between the pile and the steel layer, with additional foam layers, for example – and the reflection between the air, steel and water provides sound insulation. However, these devices are difficult to install, particularly because of the weight of the ballast, which has so far restricted their use.

The aim of **species-specific deterrent systems** is to move sensitive species away from the source. Such systems thus limit the impact of sound on marine fauna by causing animals to flee before the sound has an impact on them. Such attempts to avoid noise impact have been made mainly with marine mammals.

- The so-called **"soft-start"** method is mainly used for pile-driving work and consists of gradually starting the work phase to give the mammals the time to move away before the operations reach their full power.

- Acoustic deterrent devices or **acoustic repellents** work by emitting pulses or frequency modulated signals to scare animals away from an area where they might be exposed to high sound levels. The characteristics of such devices (type of signal, frequency, emission level) vary according to the marine mammal species targeted. Two types of repellents which are commonly used to scare marine mammals away from fish farms or fishing nets can also be used to move animals away from pile-driving areas. The effectiveness of such devices has been measured, particularly on harbour porpoises, but the main issue for scientists is the habituation phenomenon. Results are mixed concerning the effectiveness of these devices for dolphins and there are currently no experimental results on the effectiveness of repellents aimed at seals.

The fifth part of the collective expert report deals with the question of the conservation of marine mammal, fish and invertebrate populations subject to anthropogenic noise from the legislative standpoint. The conservation of these populations has been the subject of various legal texts (the 2008 European Marine Strategy Framework Directive or MSFD; the 2012 French Action Plan for the Marine Environment or PAMM) which set out the conditions which need to be respected to protect these species from the impacts of noise. An impact study is required for all MRE work and development projects which have to comply with the objectives of the PAMM. All of this means that knowledge of the acoustic effects on marine species along with the main means of preservation and protection are important issues for the development of MRE projects. Although the regulatory framework is fairly clear, impact studies are hampered by a lack of knowledge about species and their habitats and sensitivity to sound in the marine environment. A project's impact on biodiversity or fishing resources also needs to be taken into account along with the local environmental context including all pre-existing or chronic noise pollution.

The sixth and final part of the collective expert report lists the additional knowledge that is still required to achieve a good level of understanding of the acoustic impact of offshore wind projects on marine fauna. Overall, there is a good level of scientific knowledge about strong impacts of noise emissions on individual marine mammals and fish. However current knowledge is poor to non-existent for the more moderate effects at the individual level (chronic disturbance) which can nevertheless have significant consequences at the population level. There is also a serious lack of knowledge concerning invertebrates.

Progress still needs to made in understanding underwater soundscapes and how sound propagates through them. More specifically the measurement of particle acceleration needs to be improved and also seafloor vibrations that have an impact on benthic species need to be taken into account. Knowledge of the auditory capacities and sound production of marine animals also remains very uneven depending on the species and this needs to be completed for invertebrates, birds and turtles. All of this knowledge is essential if we are to determine the noise thresholds that cause temporary or permanent hearing loss.

To complete knowledge of the impact of wind farms and other offshore developments, a more overall systemic approach to study of the whole marine ecosystem (individuals, species and their interactions) is required which covers migratory patterns and the whole food web. This study could also be extended to the aerial impact of wind projects (noise and collision risks) on all seabird species as has been done for bats.

Experimental systems and conditions also need to improve. Most published studies are carried out in the laboratory in tanks where the complex sound field is rarely quantified. This means it is difficult to compare results from different studies and extrapolate the analysis to the marine environment. There are notably few studies of the exposure of marine invertebrates to a real anthropogenic sound source in the marine environment.

Finally, the regulatory framework of impact studies, mitigation policy and so forth remains incomplete. There is only limited national protection of marine species, particularly invertebrates and plant species. At a time when public debate particularly needs a scientific perspective, regulatory impact studies for MRE projects continue to suffer from a lack of knowledge and well adapted research, with the impact of noise seemingly one of the most difficult impacts to determine.

In conclusion, anthropogenic noise pollution clearly seems to have a significant impact on marine fauna (mammals and fish) but too little information is available to generalise on the response of invertebrates, although there seems to be less impact at this stage.

Where data are available, particularly on marine mammals and fish, research shows that noise can induce transient or permanent trauma to the auditory system, other types of lesions or stress-related disorders and behavioural responses such as avoidance reactions, changes in feeding, response to predators and so forth. These are possibly related to the masking of signals of interest that are no longer effectively detected or recognised. In some extreme cases, the impact of anthropogenic noise can be lethal for these mammals and fish.

However, the nature and severity of acoustic impacts vary greatly from one taxonomic group to another and from one species to another within the same group. Such impacts also vary according to the sound source. Existing studies remain too fragmentary to enable researchers to draw general conclusions.

Concerning the acoustic impact of offshore wind projects, pile-driving operations (construction phase of the installed wind turbines) appear to have a significant and sometimes severe impact over long distances for some of the species studied which means it is important to develop and implement effective mitigation systems. The other operations involved in wind projects such as the construction of floating wind turbines or operating wind turbines seem to have a more moderate acoustic impact but one which varies from one species to another. The current incomplete state of knowledge, particularly concerning invertebrates, benthic life, marine birds and turtles, means general conclusions cannot be put forward yet.

It therefore appears essential to pursue acoustics and bioacoustics research to enhance understanding of the perception systems of marine fauna – particularly invertebrates – and the effects of acoustic stress on the various animal species and therefore on coastal biodiversity. This includes the benthic communities which are of great interest in commercial terms. *In situ* observations also need to be continued over the long term to obtain usable and quantifiable feedback results. The quality of the impact studies associated with marine renewable energy installation works and development projects depends on this.

CNRS, *The acoustic impacts of offshore wind projects on marine wildlife*
Marine mammal, fish and invertebrate groups

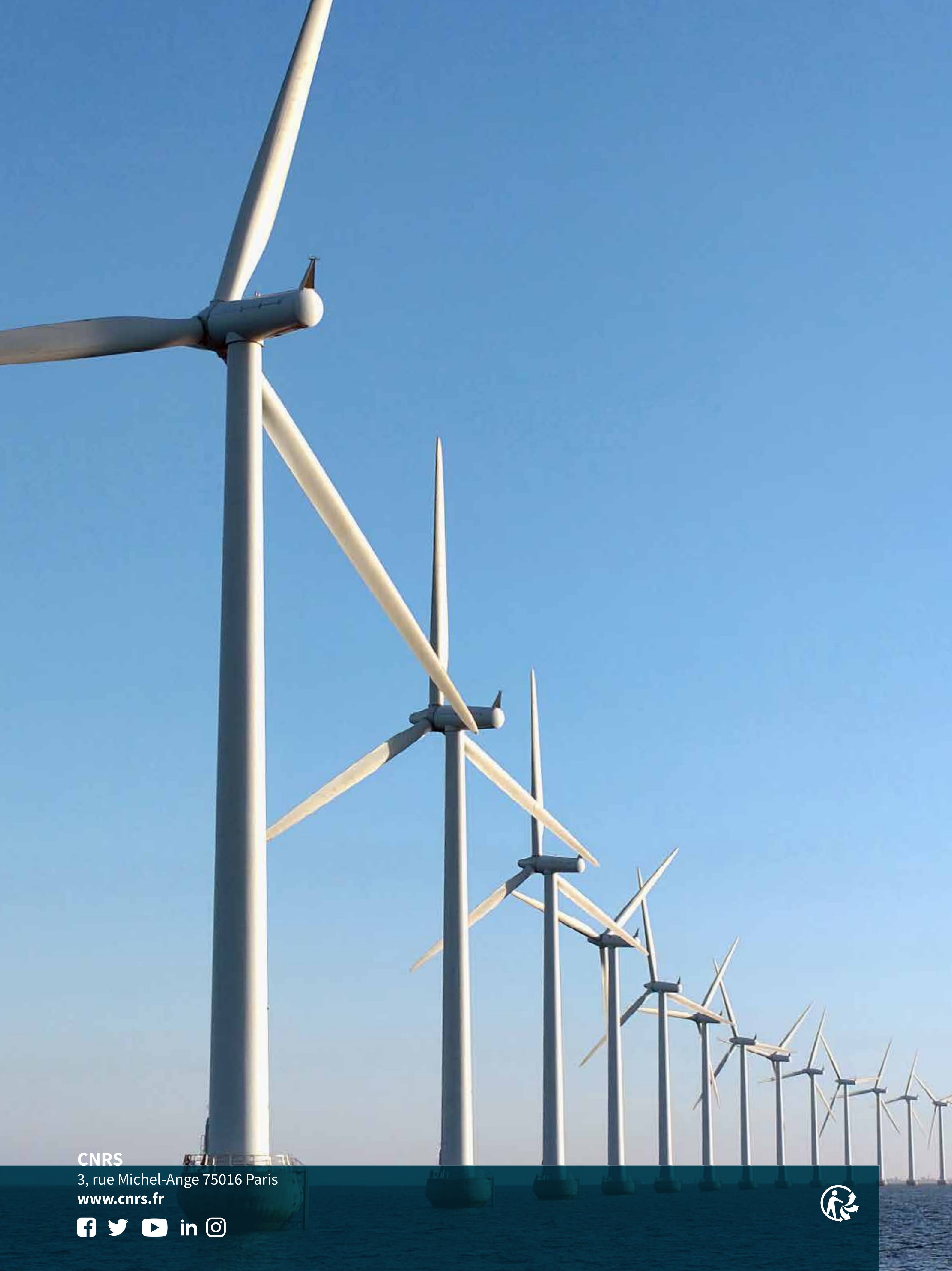
Synthesis of the collective expert report - November 2021

Publisher: Antoine Petit, CNRS Chairman and CEO
Editorial director: Alain Schuhl, CNRS Deputy CEO for Science

Translator: Richard Dickinson (Inist-CNRS)
Proof-reader (English version): Katherine Kean

Brochure produced by the CNRS Communications Department

Printed by IFSeM
September 2022



CNRS
3, rue Michel-Ange 75016 Paris
www.cnrs.fr