

# Offshore wind energy and migratory species

## Assessing the evidence for impacts of offshore wind energy on underwater marine migratory species



Figure 1: A harbour porpoise, one of the highly mobile marine migratory species. Source: Jack Lucas, Marine Scotland, © Crown copyright.

### Key messages

- A review of sixty-eight studies found that offshore wind energy developments have more negative than positive effects on underwater marine migratory species (a group that excludes birds and bats).
- Most of the negative impacts that were identified occurred during the construction and operation phases of fixed offshore wind energy infrastructure.
- The most common negative impact involved eliciting a behavioural response from a species. Such responses included species avoiding the area and changing their swimming patterns. It also included acoustic responses, such as changes in vocal patterns.
- There are significant gaps in information on this subject. For example, there is a bias in published studies towards European waters, with relatively limited information on other regions. Evidence is also scarce for species listed as Critically Endangered, Endangered or Vulnerable in the IUCN Red List, particularly in non-mammalian taxa such as fish and turtles.
- More data are needed on the impacts of the pre-construction and decommissioning phases of offshore wind energy development and for new technologies such as floating offshore wind.
- There is a need to utilize existing data and tools to better understand the impacts of offshore wind energy developments in new regions with planned offshore wind expansion.
- There is a need to improve data sharing and accessibility by strengthening data infrastructure and supporting collaboration between stakeholders.
- By planning, designing and operating offshore wind energy projects with biodiversity in mind, potential negative impacts can be minimized and positive impacts enhanced. In this way, offshore wind developments can help mitigate climate change while achieving additional positive outcomes for nature.

# Offshore wind energy and underwater marine migratory species

## **Offshore wind energy developments are predicted to rapidly expand globally**

Urgent action is needed to limit the devastating impacts that a warming climate will have on the planet (IPCC 2023). Renewable energy developments are expanding worldwide to meet growing demands for clean, reliable and affordable energy. Harnessing the ocean's abundant renewable energy potential can play a decisive role in meeting climate targets (Appiott et al., 2014; IRENA, 2020). Offshore wind energy is a particularly promising source of renewable energy and already well developed (IRENA 2020). Aided by technological advances and declining production costs, offshore wind energy capacity has grown considerably over the past decade. In 2022, wind turbines globally reached a total capacity of 64.3 Gigawatts (GW) across nineteen countries (Hoeser et al. 2022; Williams et al. 2022). Offshore wind energy developments are currently concentrated in Europe, the East and South China Seas. In the next decade, offshore wind energy developments will expand into new regions. The sector's capacity is expected to increase over six-fold to 370 GW by 2030 (Williams et al. 2022).

## **Offshore wind energy can jointly tackle the climate and biodiversity crises**

Climate change and biodiversity loss are inextricably connected and cannot be tackled in isolation (Pörtner et al. 2021). Climate change is a major threat to biodiversity. Therefore, actions to mitigate climate change, including renewable energy, are also critical for biodiversity. However, the expansion of offshore wind energy has the potential to come at the cost of marine life and damage the benefits that this life provides to society (IRENA 2020). By planning, designing and operating offshore wind energy projects with biodiversity in mind, potential negative impacts can be minimized and positive impacts enhanced. In this way, offshore wind energy

projects can help mitigate climate change while achieving positive outcomes for nature.

## **There is a strong business case for mitigating the impacts of offshore wind energy on biodiversity**

Developing offshore wind energy projects that support the conservation and restoration of marine ecosystems is not only good for ocean health but also good for business. By mitigating biodiversity impacts, companies can avoid key biodiversity-related risks including financial, regulatory and reputational risks (OECD 2019). As funders, shareholders, policy makers, consumers and civil society become more biodiversity-conscious, there will be increasing pressure on the offshore wind energy sector to demonstrate contributions to biodiversity. This means that having a history of taking biodiversity into consideration is likely to become increasingly important in the selection process for offshore wind energy projects (Gualandi 2023; Rodrigues and Packroff 2022).

Recognizing the importance and advantages of integrating biodiversity into operations, several energy companies are leading the way by setting their own biodiversity ambitions. Ørsted, and Iberdrola, for example, have committed to achieving a net-positive impact for biodiversity by 2030 (Iberdrola 2022; Ørsted 2023).

## **Marine migratory species are vulnerable to potential impacts from offshore wind energy**

Marine migratory species are particularly vulnerable to offshore wind energy developments. These highly mobile animals travel across the ocean following annual or seasonal cycles. Their movement and migratory routes can be hindered by infrastructure such as offshore wind energy developments. Developments can also degrade the habitats on which they depend for breeding, feeding and resting (Bishop et al. 2017).

**Box 1: How does the Convention on Migratory Species (CMS) impact the offshore renewable energy sector?**

International policy instruments are needed to conserve migratory species across their entire range. CMS is the global treaty of the UN that addresses the conservation and management of migratory species. 132 countries and the EU are Parties to CMS and have committed, inter alia, to conserve and, where feasible and appropriate, restore migratory species' habitats and to prevent, remove, compensate for or minimise activities or obstacles that might impede their movements. The national implementation of the CMS has some implications for the private sector:

- CMS Parties are urged to ensure that **Environmental Impact Assessments (EIAs)** consider impacts on migratory species. Guidelines have been developed on EIAs for marine activities, including wind turbine construction, which the private sector has been invited to use.\*
- Governments may establish protected areas and/or implement other measures to conserve migratory species, which could then create **legal requirements** for private companies.
- Companies can **engage with CMS in a voluntary manner** by forming partnerships with CMS, that align their internal environmental policies with CMS goals, and joining the CMS Energy Task Force (ETF). The CMS ETF is a platform that brings together diverse stakeholders to help reconcile renewable energy development and migratory species conservation.

The specific requirements and implications of CMS, and other frameworks for the conservation of migratory species, will vary across regions and will depend on the nature of the company's activities.

\* These guidelines support the implementation of resolutions under the CMS and the collection of Agreements and Memoranda of

Offshore wind energy development should carefully assess and mitigate potential threats to marine migratory species to safeguard their important ecological and socio-economic roles. Marine migratory species help support ecological connectivity, which is essential for healthy and resilient marine ecosystems. Through their movements, migratory species link distant areas of the ocean by, for example, transferring nutrients between environments (Jonsson & Jonsson 2003). Moreover, migratory species, such as tuna, are important sources of food for local communities and commercial fisheries (McKinney et al. 2020; Schmitz et al. 2023).

**More evidence is needed to fully understand the impacts of offshore wind energy on underwater migratory species**

Marine migratory species are a diverse group of animals including birds, cetaceans (whales, dolphins and porpoises), pinnipeds (seals and walrus), sea turtles, cartilaginous fish (sharks, skates and rays), bony fish, cephalopods (squid, octopus and cuttlefish) and crustaceans (shrimps, crabs and lobsters). There remain significant gaps in our understanding of the range of species impacted by offshore wind

energy and the consequences for their health and wider ecosystem functioning.

To date, the impacts on migratory seabirds, e.g. through collisions with wind turbines, have received the most attention (Abramic et al. 2022; Croll et al. 2022; Leemans & Collier 2022; Piggott et al. 2021). Research has also considered impacts on cetaceans from underwater noise, and to a lesser degree, vessel activity (Bennun et al. 2021). There is also evidence for positive impacts to marine migratory species through the creation of artificial habitats and refugia and the exclusion of harmful activities like fishing (Abramic et al. 2022). However, the full magnitude of the impacts, both positive and negative, on underwater (i.e. excluding birds and bats) marine migratory species remains unclear (Miller et al., 2013; Piggott et al., 2021). Filling this gap will strengthen the evidence-base needed to inform the deployment of renewable energy that results in no net loss or, ideally, net gains in biodiversity (Vallejo et al., 2017).

**A stronger understanding of offshore wind energy's impacts on migratory species can support policy goals**

Businesses are increasingly expected to demonstrate their contributions to biodiversity policy objectives. Many countries with operational and planned offshore wind energy developments are parties to international treaties and agreements aiming to conserve and effectively manage marine migratory species. Among these are the Convention on the Conservation of Migratory Species of Wild Animals (CMS) (**Box 1**) and the Convention on Biological Diversity (CBD). The Kunming-Montreal Global Biodiversity Framework, adopted by the 196 countries that are parties to the CBD, sets out a plan to address the biodiversity crisis (CBD 2022; CMS 2017).

As action for nature grows at all scales, policy and regulatory frameworks to mitigate the biodiversity impacts of marine activities are expected to strengthen. Offshore wind energy developers must therefore not only consider the current biodiversity-related assessment and monitoring requirements, but also anticipate and react to future changes. There are regional variations in policies and laws and as such consideration must be given to the context in which the development is taking place.

In the European Union (EU), several Directives, including the Marine Spatial Planning Directive (2014/89/EU) and Marine Strategy Framework Directive (2008/56/CE), need to be considered by offshore wind energy developments to ensure that 'Good Environmental Status' is maintained and that impacts to protected sites are assessed (deCastro, Costoya et al. 2019; deCastro, Salvador et al. 2019). Moreover, the EU has proposed a new Nature Restoration Law, which may have implications for renewable energy developments (EC 2022). While the adoption of the law remains uncertain, it would require that EU Member States consider areas for renewable energy development in "National Restoration Plans" and outline the potential contributions of renewable energy towards restoration objectives (General Secretariat of the Council 2022).

In China, wind energy regulations are less specific and are enacted through short-term policies rather than laws (Chang & Wang 2017). In the USA, marine spatial planning initiatives are currently being developed at regional and state levels to facilitate expansion of offshore wind

energy in the coming years (deCastro, Salvador et al. 2019).

In many countries, offshore wind energy operators are required to carry out Environmental Impact Assessments (EIAs) or Strategic Environmental Assessments (SEAs) to assess the impacts of proposed offshore wind energy projects on the marine environment and society (Salvador & Ribeiro 2023). However, the specific environmental aspects to be included in these assessments are often vague and differ across sites and countries (Abramic et al. 2022b). As a result, important environmental impacts, including impacts on marine migratory species, may not be required and may be overlooked.



Figure 2 Middelgrunden Offshore Wind Farm, Copenhagen, Denmark. Source: [Pål Espen Bondestad, Flickr](#) CC BY 2.0.

**This brief synthesises the current state of knowledge on the impacts of offshore wind energy on marine migratory species**

An improved understanding of the impacts of offshore wind energy developments on underwater marine migratory species is urgently needed to ensure that potential risks are adequately assessed and mitigated so that the sector's expansion does not compromise ocean health.

As far as the authors are aware, no previous studies have assessed current evidence for the impacts of offshore wind energy developments

across all underwater marine migratory species. This brief aims to fill this gap by:

- Providing an **overview of the current state of knowledge** on the impacts of offshore wind energy developments on underwater marine migratory species.
- Suggesting **future directions** to support Proteus Partners and other actors in the

renewable energy sector in considering and managing these impacts.

This brief builds on another Proteus technical brief on [migratory connectivity in the ocean](#) released in March 2023.

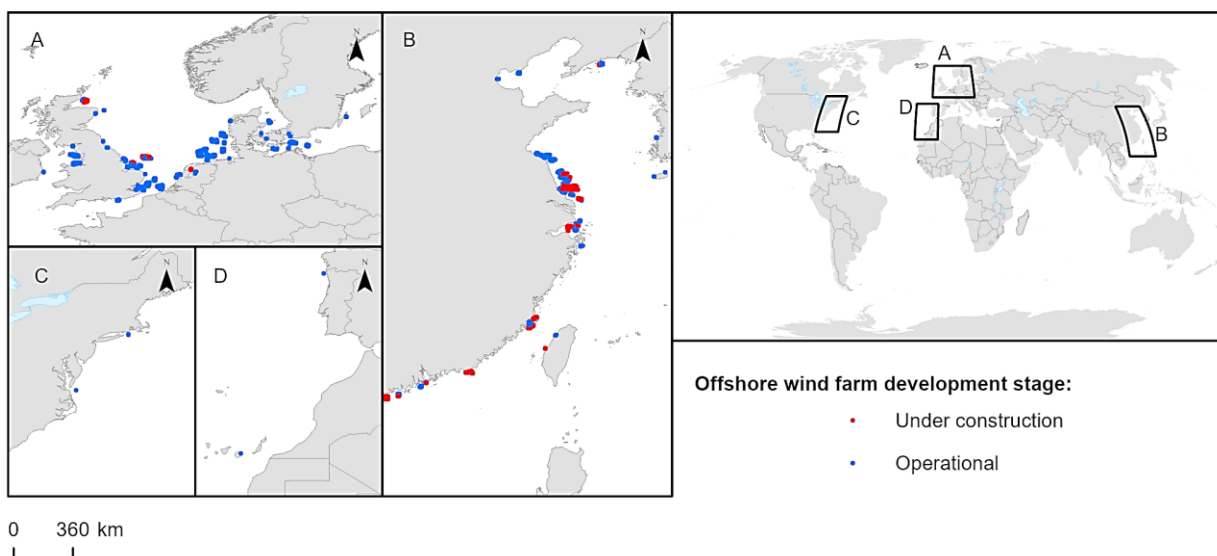
# The state of knowledge on the impacts of offshore wind energy on migratory species

Evidence exists for a range of impacts, both negative and positive, that offshore wind developments have on migratory species, but critical knowledge gaps remain

A systematic review was conducted to evaluate the impact of offshore wind energy developments on marine migratory species. Seabirds were excluded as other studies have recently reviewed the impacts of offshore wind energy developments on birds (Croll et al. 2022; Leemans & Collier 2022; Piggott et al. 2021). Sixty-eight peer-reviewed publications and grey literature reports were identified. For each, the geographical location, wind energy type, wind farm life cycle stage and the focal pressure were

recorded. Moreover, the impacted species or habitat type, type of impact and whether this impact was negative, positive or had no response, was also determined.

As the review only considered observed impacts, studies were limited to existing offshore wind developments. Furthermore, the available literature was found to be biased towards certain geographical locations, taxa and types of impact assessed. Few studies considered the



Hoeser, T. and Kuenzer, C. (2022). DeepOWT: A global offshore wind turbine dataset. Zenodo [DeepOWT.geojson (Dataset)], <https://doi.org/10.5281/zenodo.5933967>.

Base map: United Nations Geospatial, 2023  
Coordinate system: Geographic WGS84

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 3 Global distribution of operational and planned offshore wind turbines Source: Hoeser and Kuenzer, 2022.

cumulative, indirect and long-term impact on species and habitats.

### Studies focused on Europe with evidence lacking for many regions

Most studies assessed the impacts of offshore wind farms in Europe (n = 53), with around three quarters of these in the North Sea (n = 38), followed by the Baltic Sea (n = 10). Europe has historically dominated the offshore wind energy sector. In 2017, 80% of global installed offshore capacity was in Europe (15,780 MW), with instalments in the North Sea accounting for over 70% of this (GWEC 2017). However, while offshore wind has now expanded into other regions such as the North-west Atlantic, North Pacific and East China Sea, only one or two studies were conducted in each of these regions (Figure 3).

In 2022, China (34GW) overtook Europe (30GW) as the largest offshore wind market and Europe's share of installed offshore capacity is projected to decline to 30% in 2027 (IEA 2022). Despite this, no studies investigating the impacts of offshore wind energy on migratory species in China were identified in this review. This knowledge gap has also been identified by others (Russell et al. 2016). Similarly, North America is aiming to deploy an additional 30 GW of offshore wind energy by 2030 and are aiming for over 110 GW by 2050, yet only three studies were identified looking at how these might impact migratory species (Wiser et al. 2015).

### Offshore wind energy impacts many migratory species, but our knowledge is limited

There are significant taxonomic gaps in the evidence available for the impacts of offshore wind energy on marine migratory species. For example, only 8% of marine migratory species listed under CMS were covered in the reviewed studies.<sup>1</sup> Almost half of the reviewed studies investigated the impact of offshore wind energy on the harbour porpoise (*Phocoena phocoena*)

(n=32), with the harbour seal (n=10; *Phoca vitulina*), the grey seal (n=8; *Halichoerus grypus*) and Atlantic cod (n=9; *Gadus morhua*) the next most studied (Figure 4).

The harbour porpoise is the most common cetacean in the North Sea and is protected under several instruments including the EU Habitats Directive, CMS and the CMS "Agreement on the Conservation of Small Cetaceans of the Baltic, Northeast Atlantic, Irish and North Seas". However, little attention has been paid to other common and protected migratory species in the area, such as the bottlenose dolphin (*Tursiops truncatus*) that was only examined by three studies.

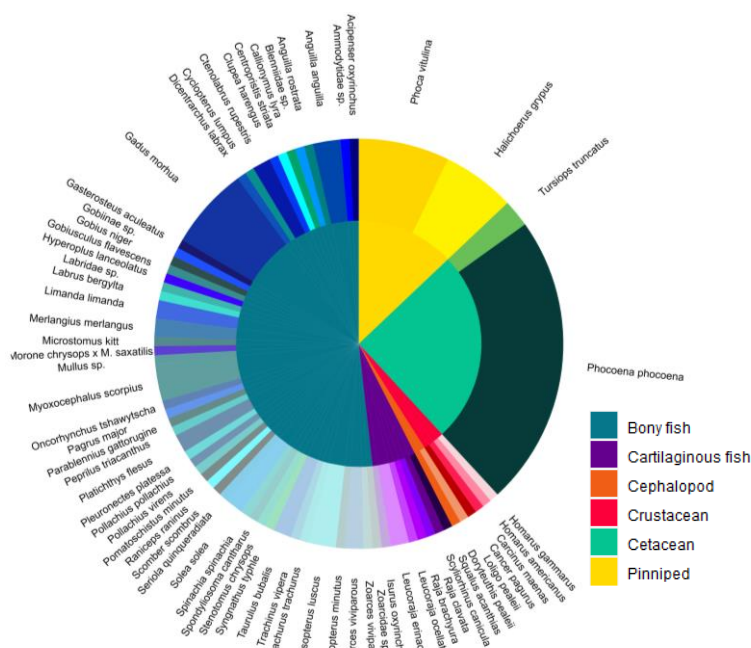
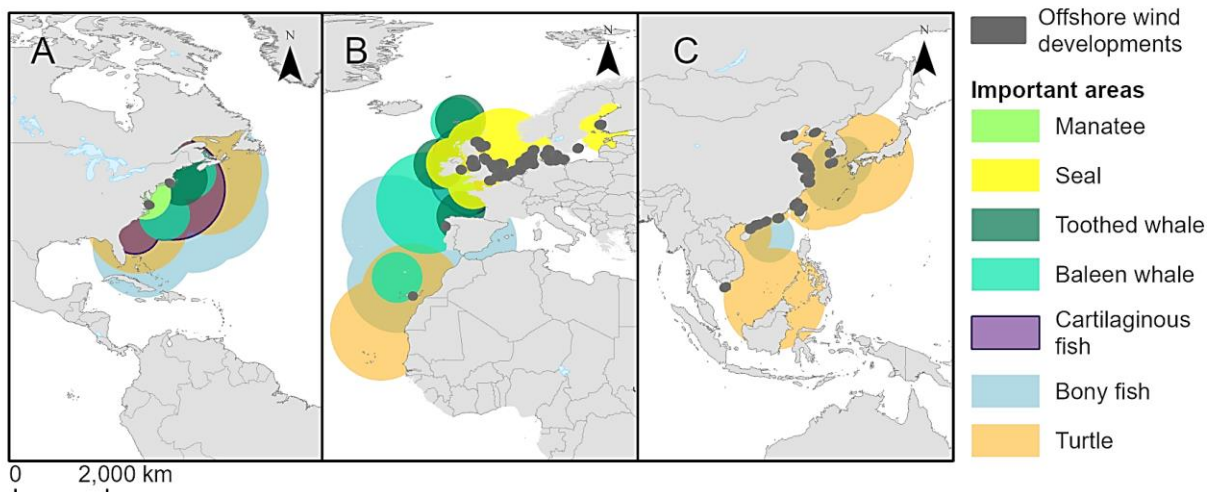


Figure 4 Number of studies assessing impacts of offshore wind energy on each migratory species. Source: UNEP-WCMC own elaboration

Within studies on bony fish (n = 19), there is unequal coverage among species, with most studies looking at commercially important species such as the Atlantic cod (*Gadus morhua*) (n = 9). The few studies on offshore wind energy and cartilaginous fish (n = 4) found mixed evidence for impacts depending on the species. There were a limited number of studies on migratory invertebrates (n = 6), with evidence of negative impact responses such as stress and changes in swimming patterns by cephalopods

<sup>1</sup>This percentage is expected to increase when considering species not currently listed under CMS.



Dunn, D. C., et al. 2019. The importance of migratory connectivity for global ocean policy. *Proceedings of the Royal Society B: Biological Sciences* 286:20191472.

Hoeser, T. and Kuenzer, C. (2022). DeepOWT: A global offshore wind turbine dataset. Zenodo [DeepOWT.geojson (Dataset)], <https://doi.org/10.5281/zenodo.5933967>.

Base map: United Nations Geospatial, 2023

Coordinate system: Geographic WGS84

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**Figure 6 Important areas (e.g. breeding, feeding, nesting and migrating grounds) for marine migratory species available on the Migratory Connectivity of the Ocean (MiCO) system.** Source: Dunn et al., 2019, that intersect with the impact area around operational and under construction wind farms in 2021 Source: Hoeser and Kuenzer, 2022. The impact area was defined as a 70 km buffer around each wind turbine as this was the largest zone of impact identified through the systematic review Source: Fernandez-Betelu et al., 2021; Leopold & Camphuysen, 2008.

(n = 2). Similarly, there is limited evidence for impacts on crustaceans, although a few studies point to potential positive effects from increased habitat from artificial reef creation in foundations (n = 4).

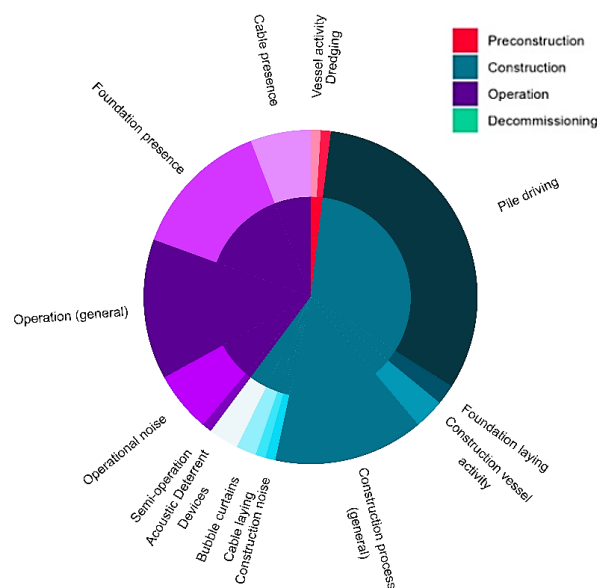
There were no studies on marine turtles, likely due to the geographic bias of the studies as none reside in the North Sea. However, studies suggest that activities, such as dredging, might influence turtle swimming behaviour (Whittock et al. 2017).

Overlaying known feeding, breeding, nesting and migrating routes of turtles, manatees, baleen whales, toothed whales, bony fish and cartilaginous fish, shows several areas with spatial overlap between these important areas and offshore wind developments (Figure 5). This strongly suggests that the taxonomic bias in the literature is due to an absence of evidence rather than confirmation of no impact upon these groups. The gaps are identified for species where tracking data is available but there may be many more species impacted which lack spatial data.

**Little is known about the impacts of pre-construction and decommissioning phases**

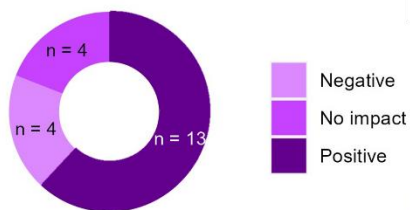
Broadly speaking, the offshore wind energy lifecycle can be split into four stages: pre-

construction, construction, operation and decommissioning (Hooper et al. 2004). Each of these stages involves activities that can impact different marine migratory species in different ways (Miller et al. 2013). Only one study assessed impacts at the preconstruction stage (e.g. increased vessel traffic) with most focused on construction (n = 41) and operation (n = 37) (Figure 6).

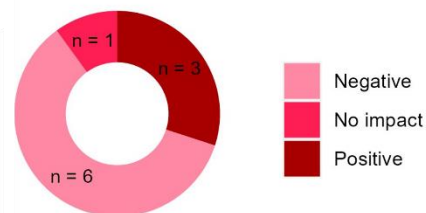


**Figure 5 Number of studies assessing the impacts of pressures on marine migratory species associated with** Source: UNEP-WCMC own elaboration

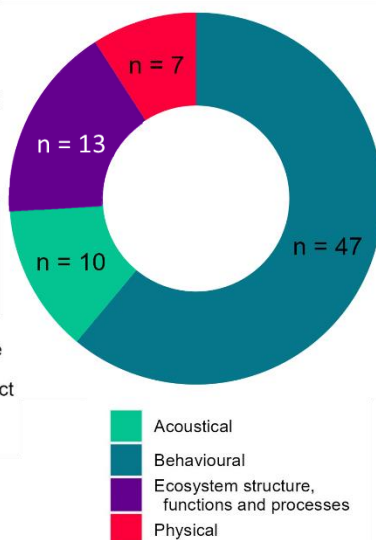
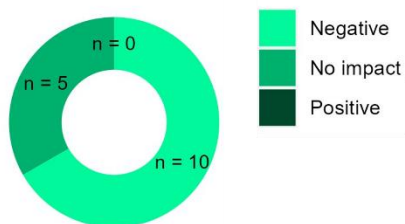
Ecosystem structure, functions and processes



Physical



Acoustical



Behavioural

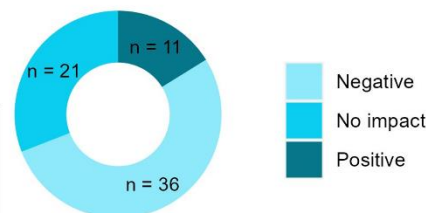


Figure 7 Number of impacts observed in each response group. Source: UNEP-WCMC own elaboration.

There were no studies assessing the impacts of the decommissioning stage. The potential impacts of the decommissioning phase on migratory species are unknown, largely because very few offshore wind farms have reached the end of their operational lifetime which on average lasts for 25 years (Hall et al. 2020). Several activities that take place during the decommissioning phase, such as removing or refurbishing structures, vessel activity and noise, could have impacts on marine migratory species (Miller et al. 2013). Moreover, full removal might lead to more damage by removing structures that were providing artificial habitats and supporting species connectivity (Glarou et al. 2020).

**Pile-driving was the most studied pressure**

Pile driving is the process of repeatedly pounding a hydraulic hammer on the top of steel or concrete pipes into the ocean floor. At a rate of one hammer strike per second, it takes several hours to drive one pile into the floor. Pile driving produces high sound levels and has a vast range of up to 1000km. Within 10m these have been recorded to produce up to 220 underwater dB ((Madsen et al. 2006). Most studies assessing the impacts of the construction process focused on pile driving noise (n = 33) (Teilmann & Carstensen 2012). Few papers assessed the impacts of mitigation measures such as acoustic deterrent devices (n = 3) and bubble curtains (n =

2). Studies on the impacts of the operation period focused on the impact of the operation process in general (n = 14) and the foundation presence on marine migratory species (n = 14) while others examined operational noise (n = 6) and changes in electromagnetic fields due to the presence of cables (n = 6).

Pile driving was disproportionately studied compared to other pressures, whilst vessel traffic, despite being shown to disturb harbour porpoises, was rarely studied (Benhemma-Le Gall et al. 2021). The taxonomic bias of the studies influences the pressures detected, as different species tend to be more vulnerable to certain pressures.

**Avoidance is the most commonly recorded negative impact for migratory species**

This review categorized impacts to migratory species into four response groups – behavioural, environmental, acoustical and physical (Annex Table 1). Most impacts observed were behavioural (n = 47). Across all response groups, most of the recorded impacts were negative (n = 48), followed by no response (n = 27) and positive (n = 26) (Figure 7).

The most common negative impact was avoidance (n = 29). This was seen predominantly in mammals during pile driving (Figure 8). Avoidance can have severe consequences for an

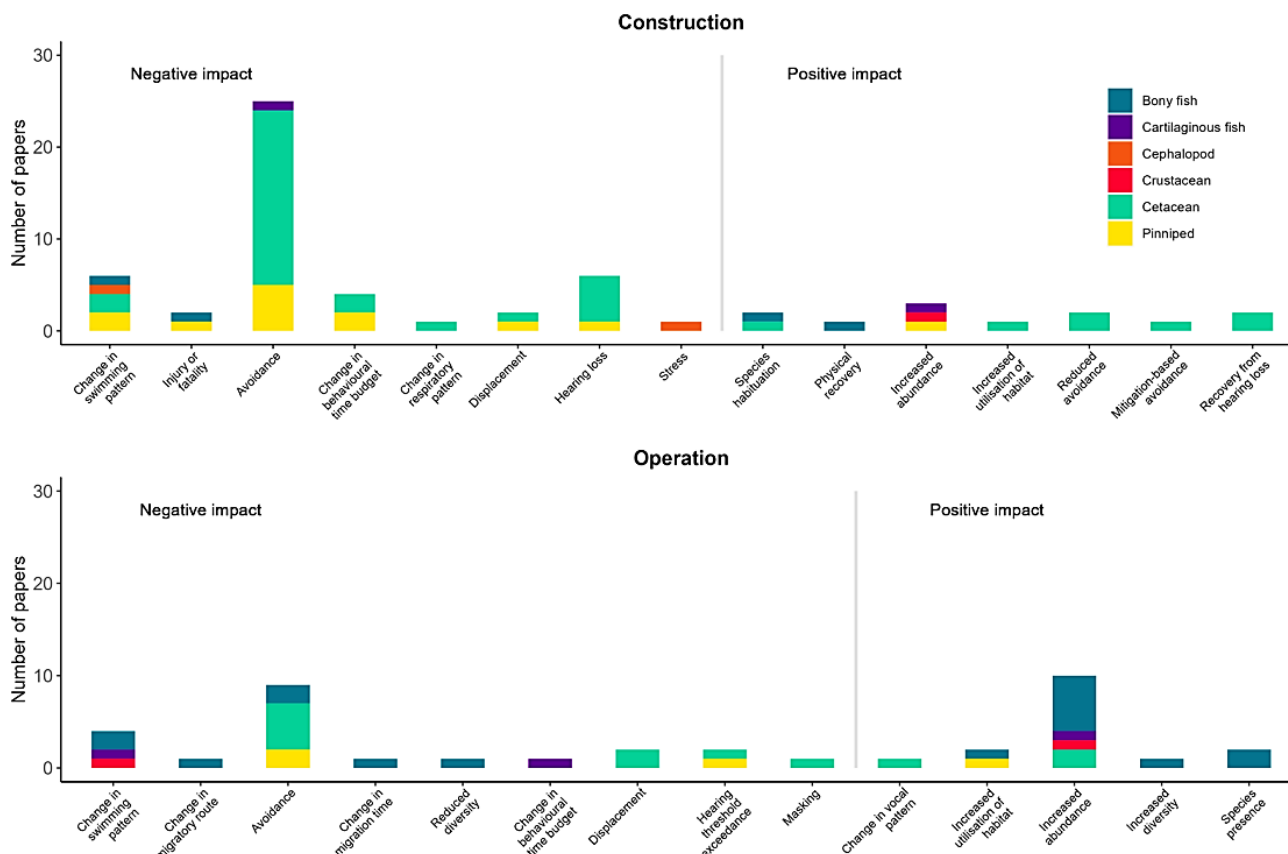


Figure 8 Number of papers by specific response observed by marine migratory species during the construction and operation phases of offshore fixed wind developments. Source: UNEP-WCMC own elaboration.

individual or population avoiding crucial habitat such as calving grounds (Brandt et al. 2018). The most common benefit was increased abundance (n = 11), predominately of bony fish. This benefit was most common during the operation phase, where the foundations of the wind farm provide a habitat for species. Habitat creation can also increase prey availability for migratory species (Kerckhof et al. 2018; Scheidat et al. 2009).

### Impacts of offshore wind energy are likely being missed

The impact of offshore wind energy on species will vary according to its physiology, behaviour and life history. Yet this level of detail is commonly missing in the studies evaluated. For example, wind farms have the potential to impact species with electromagnetic senses, including those that rely on electromagnetic signals to orientate themselves and migrate, are underrepresented in the literature (Normandeau et al. 2011). Cartilaginous fish are electrosensitive and experimental studies suggest that electromagnetic interference from cables influences their swimming behaviour

(Hutchison et al. 2020). Similarly, baleen whales (n=1) use low frequency sounds to communicate and navigate, yet the impact of low frequency noise produced by offshore wind turbines and vessel activity is poorly understood (Erbe et al. 2019; Percival & Edgar 2018).

The lack of evidence describing how the physiology, behaviour and life history of species influences its vulnerability to offshore wind, means the true scale of the impact is not being accounted for (Kraus et al. 2019; Kulkarni & Edwards 2022).

### Knowledge gaps exist for specific techniques, indirect and cumulative impacts

Our review did not consider how impacts vary according to installation techniques, which has been shown to influence the pressures placed upon marine ecosystems and the environmental conditions of the seabed and water column.

Most studies focused on direct and short-term impacts as they are easier to observe. However, positive and negative indirect impacts are predicted by several studies. For example, avoidance might decrease migratory species'

general fitness and long-term survivability as they spend more energy avoiding a specific area (Bergström et al. 2013).

Moreover, few studies measured cumulative impacts on migratory species and ecosystem functions arising from the combination of impacts from offshore wind energy activities alongside other marine activities and background pressures. Understanding and accounting for the cumulative impact of concentrating turbines in certain locations, as well as how the impacts from windfarms interact with pressures from other activities, is vital to developing low impact offshore wind farms and supporting overall ocean health.

### **Only one study looked at the impact of floating offshore wind energy on migratory species**

Offshore wind turbines can be fixed (to the seabed) or floating structures (Figure 9). Only one study assessed the impacts of floating offshore wind farms, reflecting the relative infancy of the floating offshore wind industry.

Interest in expanding floating wind capacity is growing globally. While floating wind and fixed wind structures have common characteristics that will lead to comparable impacts on marine species, some impacts are likely to be unique to floating wind (and potentially more severe). For example, the mooring cables used to stabilize floating wind can create an entanglement hazard for species (Maxwell et al. 2022). In addition, as floating wind farms are typically located further offshore, longer electromagnetic cables are needed, potentially generating greater impacts on electro-sensitive species. In contrast, floating wind might avoid some of the impacts associated with fixed wind structures, such as those associated with pile driving (Bergström et al. 2013).

### **Filling knowledge gaps will become increasingly critical as the offshore wind sector expands**

Offshore wind energy is expected to rapidly expand into new regions, ecosystems and communities. This includes increases in emerging markets such as the USA, Taiwan,

France, the Republic of Korea, Poland and Japan over the next decade. Further expansion is also expected in Norway, India, Spain, Greece, Colombia and Brazil from 2030 onwards (Hoeser et al. 2022).

As the impacts identified in this review are mostly based on research undertaken in the North Sea, their applicability in new regions, with different environmental conditions and ecosystems, is unknown. As such potential impacts in new regions must be carefully assessed with respect to the local environment and the species that reside there (Galparsoro et al. 2022). For example, thirty offshore wind developments are planned for the Mediterranean Sea, with a number of the planned developments occurring within ecologically significant sites including cetacean migration corridors (Lloret et al. 2022). Over a quarter of marine species in the Mediterranean Sea are endemic to the region and may therefore respond differently to offshore wind developments than those in the North Sea. As such, it is important to assess the appropriateness of extrapolating findings to other regions based on the comparability of environmental conditions and species traits. Identifying transferrable findings will help better predict and prevent potential impacts in new regions.

Research on the impacts of floating offshore wind developments on marine migratory species is urgently needed as by 2050, 264 GW is expected to be generated by floating wind, contributing to 15% of all offshore wind energy (DNV 2022). Increased development rates in Japan, the UK, the Republic of Korea, and France will join Norway as the top five leading countries in offshore floating wind (Hoeser et al. 2022) Furthermore, the growth of floating wind technology will make it possible to tap into areas of technical offshore wind potential that are further away from the shore. This raises the possibility of offshore wind development in areas beyond countries' national jurisdictions in the high seas (Elsner & Suarez 2019). The right governance mechanism will need to be

established to ensure that these are developed in socially just ways that safeguard biodiversity in areas beyond national jurisdiction.

Finally, as the marine space becomes more crowded with offshore infrastructure and activities, understanding the potential cumulative impacts of offshore wind energy and other sectors and pressures on marine migratory species will become increasingly important. Future changes in the marine environment,

particularly because of climate change, could influence and exacerbate the impacts of offshore wind on migratory species. For example, a warming climate can lead to changes in the seasonal ranges, migratory paths and behaviours of migratory species. These potential changes should be carefully considered in offshore wind energy development as areas considered low impact in today's conditions may become highly impactful in the future (Albouy et al. 2020).

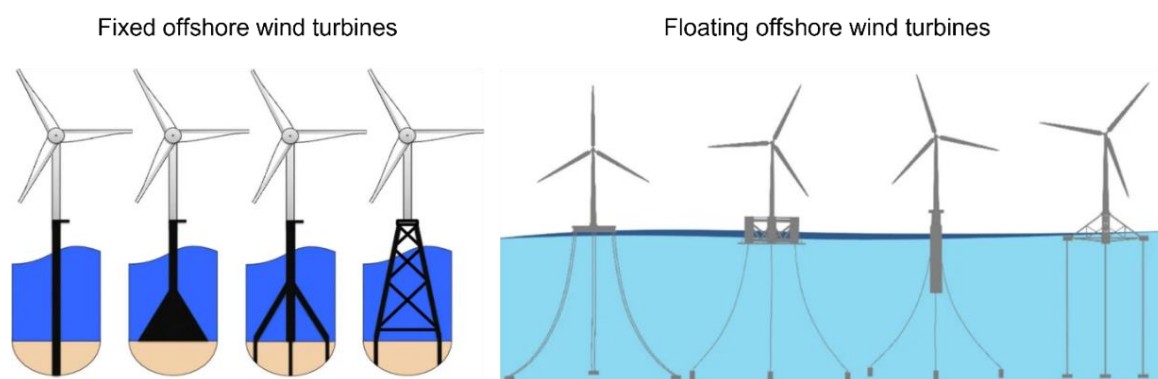


Figure 9 Fixed and floating offshore wind turbine types. Source: DNV, 2022; Ha et al., 2021; Van der Valk, 2014

## Future directions to mitigate the impacts of offshore wind energy on migratory species

Existing data and tools, supplemented by increased data collection, data sharing, advocacy and collaboration are required to avoid and mitigate impacts on marine migratory species

### Existing data sources can be utilised to identify potential impacts on marine migratory species

When direct evidence of impacts is unavailable, data including the distribution, migratory routes and areas of importance for marine migratory species can be used as proxies to estimate where and how species may be at risk, or benefit from, offshore wind developments. Such data can be obtained from multiple sources including fisheries catch, species occurrence and movement records and species distribution models.

Advances in technology to track animals are increasing the availability of spatial data for marine migratory species (Sequeira et al. 2018). For example, the [Migratory Connectivity in the](#)

[Ocean \(MiCO\)](#) system has openly available data on the migratory routes and areas of importance for marine fish, mammal and turtle species (Dunn et al. 2019). More information on how MiCO data can support industry conduct screening and environmental impact assessments can be found in the Proteus technical brief '[Advancing understanding of MiCO](#)'.

As the marine environment is complex and expensive to monitor, information is lacking on the behaviours, travel corridors and areas used by many marine migratory taxa. This is particularly true for invertebrates (Abramic et al. 2022a; Chen, 2021; Kot et al. 2023; Stephenson 2021). As such, proxy information including that obtained from fisheries catch, species occurrence records and species distribution

models can be used to estimate the location and movement patterns of marine species (Palacios-Abrantes et al. 2020). Examples of this proxy information include, the Sea Around Us database, which contains information based upon nationally reported catch and literature, and sources of species occurrence data such as [FishBase](#), [Global Biodiversity Information Facility](#), [Ocean Biogeographic Information System](#) and [International Union for Conservation of Nature \(IUCN\)](#) (Zeller et al. 2016). Species distribution models use environmental and biological data to predict the probability of a species occurring in an area. [AquaMaps](#) have used species distribution models to predict species distributions for over 33,500 species including many marine migrants (Kaschner et al. 2019).

Other datasets have identified areas of importance for marine migratory species using criteria that are relevant to marine migratory species, such as areas important for migration routes, feeding and breeding. These datasets include, [Important Marine Mammal Areas](#), Important Shark and Ray Areas and the upcoming [Important Marine Turtle Areas](#), [Key Biodiversity Areas](#) and [Ecologically or Biologically Significant Marine Areas](#).

Despite the knowledge gaps, existing data can still help identify key biodiversity risks. For more information on biodiversity data needs and monitoring protocols for offshore wind projects see [Stephenson \(2021\)](#) and [Bennun et al. \(2021\)](#).

### Potential impacts on migratory species can be avoided and mitigated using the 'Mitigation Hierarchy'

The Mitigation Hierarchy is a widely used tool to help manage biodiversity-related impacts at the site-level (Arlidge et al. 2018; CSBI 2015). The Mitigation Hierarchy has four steps: avoid, minimize, restore and offset (Figure 10). It is an interactive process, requiring adaptive management, that can be applied to avoid and mitigate direct, indirect and cumulative impacts during all phases of offshore wind development. A more in-depth look at the Mitigation Hierarchy for offshore wind energy can be found in the [IUCN's guidelines for project developers \(p. 85-151\)](#) (Bennun et al. 2021).

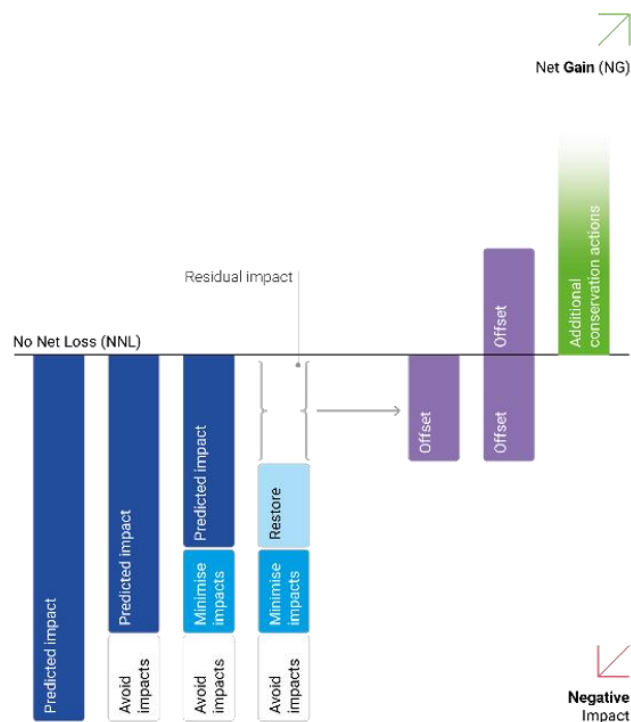


Figure 10 The 'Mitigation Hierarchy' Source: UNEP-WCMC, own elaboration. Source: Hannes Klostermann, Ocean Image Bank.

#### 1. Avoid

'Avoid' involves anticipating and preventing adverse impacts at the outset of a project, often at the screening phase. Preventative measures are the most effective for reducing impacts, from both an economic and ecological perspective, and have the highest mitigation certainty.

- **Site selection:** Some negative impacts on marine migratory species can be avoided at this stage through careful marine spatial planning and sensitivity mapping. For example, when making decisions on potential site locations, sites can be screened out to avoid sensitive areas, such as seasonal migratory routes, feeding and breeding areas, geological features of the landscape that concentrate species movement, Marine Protected Areas and other exclusion zones.
- **Project design:** Once a site is selected, impacts to marine migratory species can be avoided further through careful design of project components. For example, the choice of infrastructure (size, height, turbine type, foundation type, cable design, etc.), layout, construction, mode of operation and the

route taken by cables can all have differing impacts on marine migratory species.

- **Scheduling:** Impacts to marine migratory species can also be avoided by altering the timing and duration of project activities. For example, rescheduling exploration, construction or decommissioning activities to avoid sensitive times of year for migratory species (e.g. breeding seasons).

## 2. Minimize

For biodiversity impacts that cannot be addressed through avoidance, actions can be taken to reduce the duration, intensity and extent of these impacts. Actions to minimize impacts can be taken throughout a project's lifecycle but should start early in the planning process. Minimization actions also rely on reliable knowledge on marine migratory species.

- **Physical controls:** Impacts to marine migratory species can be minimized through altering the physical design of the project's infrastructure and components. For example, components that emit less noise, such as quiet foundations, or reduce the number, intensity and duration of lights might be preferred, as well as technology that allows a turbine to be shut down on demand if marine migratory species are detected near activities.
- **Operational controls:** Project activities can be regulated to minimize impact. For example, limiting the number contractor vessels and the speed at which they operate will reduce the likelihood of collision with marine mammals during surveys, construction, maintenance and decommissioning.
- **Abatement controls:** Actions can reduce the levels of an impact, such as reducing noise, light and chemical pollution. For example, construction methods can adjust pile driver energy or install noise dampening systems.

## 3. Restore

There will always be some environmental degradation that cannot be completely avoided or minimized. In these cases, restoration actions (also known as 'remediation', 'rehabilitation' or

'compensation') at the site can help to repair damage to the environment that impacts marine migratory species. However, even on a small scale, restoration can be costly, and success is not guaranteed. Restoration may not be possible for all biodiversity features, and it will likely require long-term intervention and monitoring.

Restoration requires a good knowledge of the site baseline, including marine migratory species status, prior to the impact or at least to a similar reference site in the vicinity. Restoration activities might include actions to restore species composition, habitats, ecosystem structure and function. For example, the renewables company Ørsted, in collaboration with WWF Denmark, is [introducing 3D printed reefs at the Anholt Offshore Wind Farm](#) to create habitat for cod. The hope is that this will help restore the Kattegat cod population, which has been declining over the past decades, to benefit the entire ecosystem in the area.

## 4. Offset

After restoration, if residual impacts remain, environmental (not monetary) offsets for marine migratory species may be considered.<sup>ii</sup> Offsets are conservation interventions (which may include actions such as restoration) that are applied to areas not impacted by the project but may be related to the residual project impacts. They should have a measurable conservation outcome (often including the final goal of 'no net loss' or 'net gain') and must be equivalent, additional and lasting. Offsets should be treated as a last resort as they are complex and often have uncertain outcomes. Offsets are also costly and may not be appropriate for all residual impacts (e.g. irreplaceable habitats). See the [Business and Biodiversity Offsets Programme \(BBOP\)](#) for guidance on offset design and good practice principles (BBOP 2023). In addition to restoration, marine-based offsets can include "averted loss offsets" which seek to enhance the protection of biodiversity where habitat or species decline is predicted to be imminent (Jacob et al. 2020). Additionally, "Policy-based offsets" support changes in policy or practice to have a positive impact on biodiversity (e.g.

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<sup>ii</sup> In some cases offset and compensation are treated as synonyms

supporting change of fishing practices to reduce bycatch). These may be particularly relevant to marine migratory species as they can cover multiple threats across their range.

#### ***Additional conservation actions***

Additional conservation actions (ACAs) go beyond the mitigation of residual impacts but are often included alongside the Mitigation Hierarchy as an extra step (Figure 10). Like offsets, ACAs include a diverse range of interventions designed to have a positive impact on biodiversity after No Net Loss is achieved. Unlike offsets, ACAs cannot

mitigate project-induced impacts to species and ecosystems affected by the project site and therefore do not contribute measurable gains against project-related losses.

The effective application of the Mitigation Hierarchy partially depends on the knowledge informing the identification of potential biodiversity risks and actions to manage them. In the absence of knowledge, a precautionary approach should be followed, addressing critical knowledge gaps that will strengthen the mitigation of potential impacts on marine migratory species (Stephenson 2021).



Figure 11 Humpback on the reef, French Polynesia. Source: Hannes Klostermann, Ocean Image Bank.

#### **Opportunities to build knowledge on marine migratory species and offshore wind energy**

Offshore wind sector actors, including developers and environmental managers, can help strengthen knowledge on the impacts of offshore wind energy developments on marine migratory species. For example, investing in research and development can help improve the monitoring and mitigation of the impacts on at-risk marine migratory species. Strengthening established monitoring approaches for at-risk migratory species, alongside testing the application of novel tools (e.g., DNA techniques to measure species diversity, satellite-based remote sensing, and acoustic monitoring), can help improve the availability of data to inform offshore wind energy

development and to study its biodiversity impacts (Stephenson, 2021). Currently, the comparison and aggregation of data on the biodiversity impacts of offshore wind energy is hampered by a lack of standardised monitoring approaches. While monitoring methods need to be adaptable to local needs and contexts, developing more harmonised approaches across the offshore wind energy sector could help ensure migratory species are being consistently monitored using the most effective methods (Stephenson 2021). In the same way, trialling mitigation approaches can help improve the effectiveness of management strategies to address potential negative impacts.

### **Data sharing can improve the knowledge base required to avoid and mitigate impact**

Improving data collection for marine migratory species will only help inform future offshore wind energy expansion if the data are accessible. Data collected to inform the biodiversity management of offshore wind energy developments can be difficult to access. For example, where it is publicly available, data are often fragmented across different platforms making it difficult to access and synthesize. Moreover, some data are associated with publications are not shared via public repositories or are held under restrictive licenses. Promoting the open access to data will help improve understanding of the impacts of offshore wind developments on marine migratory species. This should include the sharing of Environmental Impact Assessments (EIAs), Strategic Environmental Assessments (SEAs), the data and information compiled while undertaking EIAs and SEAs, and ongoing monitoring for offshore wind energy sites, as well as the development of data standards and policies to facilitate data sharing (Stephenson 2021).

### **Industry should advocate for biodiversity-friendly policies and collaborate to enable seascape-level action for nature**

While actors in the renewables sector can take steps to avoid and reduce impacts upon marine migratory species, they are often constrained by

the regulatory environment they operate in. Moreover, mitigating some pressures is beyond their control as migratory species are cumulatively impacted by other marine activities. Therefore, the right enabling policy, regulatory levers and financial levers must be in place to ensure offshore wind energy does not harm migratory species (The Biodiversity Consultancy & WWF 2023). For example, Maritime Spatial Planning can foster collaboration across different sea users to safeguard marine migratory species (WindEurope 2023). Actors in the renewable sector can play a key role in advocating for policies that favour biodiversity-friendly offshore wind developments. For example, the [Offshore Coalition for Energy and Nature \(OCEaN\)](#), bringing together 32 organizations in Europe, is calling for better integration of biodiversity into industry standards, as well as pushing for government policies that further incentivize nature conservation.

Collaboration within the renewables energy sector and across other key stakeholders such as with national and local policy makers, environmental NGOs, local communities and sea users, will be key to ensure cumulative impacts on marine migratory species are adequately addressed. In this way, actors can collectively raise sectoral ambition and joint action on marine migratory species.

## Conclusions

Currently, there is **more evidence for adverse impacts upon cetaceans than on any other underwater marine migratory species group**. They have been shown to alter their swimming patterns, change their vocal behaviours and experience hearing loss due to pile-driving during construction. To a lesser degree, there is evidence for adverse impacts on migratory bony fish and pinnipeds. There is also some early evidence for negative impacts on crustaceans, cephalopods and cartilaginous fish. However, a lack of evidence does not mean there is a lack of impact. Alongside these negatives are some positives. These include the long-term increase in abundance of cetaceans, fish, crustaceans and pinnipeds around turbines, likely due to the creation of artificial habitats.

**Current evidence, data and tools should inform action** to avoid and minimize risks to migratory species from offshore wind energy projects, in line with the Mitigation Hierarchy. Direct evidence for the impacts of offshore wind energy, alongside information to identify potential impacts where there is no direct evidence, should be considered when planning and designing offshore wind projects through processes including early risk screening, EIAs and ongoing monitoring. Crucially, where evidence is limited, a precautionary approach should be followed. Moreover, cumulative and indirect impacts, both on migratory species and connectivity, should be considered. These assessments should include potential future climate change-related impacts. This will **support site-level commitments towards**

**net-positive impacts for nature**. While project-level action to mitigate impacts on marine migratory species needs to be strengthened, these efforts must be supported by **the right legislative, regulatory and financial incentives**.

The **current evidence base on marine migratory species has significant gaps and has largely focused on birds**. So far, studies looking at non-bird taxa have focused on a small number of regions and a small number of species. Evidence is also lacking for the impacts of different stages of the sector, including offshore wind turbine pre-construction and decommissioning. Moreover, there have been very few studies examining the impacts of floating wind as the technology is still rather new. **Filling these gaps is essential as the offshore wind sector grows and expands into new regions**.

**Future research and monitoring to address current knowledge and data gaps** is needed. This can be supported by improved **data sharing and collaboration** within the offshore wind sector and with other sea-users. A more complete evidence-base will help improve the accuracy and certainty surrounding biodiversity-friendly decision-making for offshore wind development. However, evidence gaps should not justify delayed action. Armed with the right knowledge and incentives, the offshore wind sector's expansion can help tackle both the biodiversity and climate crises simultaneously.

## Annex 1: Types of impacts- recorded for marine migratory species

The positive and negative impacts of offshore wind developments on marine migratory species recorded in the literature review.

	Positive Impact	Negative Impact
<b>Acoustical</b>	None recorded.	Masking, change in vocal pattern
<b>Behavioural</b>	Increased utilization of habitat, species habituation, reduced avoidance, mitigation-based avoidance	Displacement (an individual, group or population completely abandons a specific area indefinitely or for an extensive duration of time e.g., one year), avoidance (an individual, group or population abandons a specific area for a limited amount of time e.g., one hour or when noise production is ceased), change in swimming pattern, behavioural time budget, respiratory behaviour, migratory route, migration time
<b>Ecosystem structure, functions and processes</b>	Increased abundance, increased diversity, species presence	Reduced abundance, increased predation, reduced diversity, species absence
<b>Physical</b>	Recovery from hearing loss, physical recovery	Injury or fatality, hearing loss, stress, hearing threshold exceedance
<b>Reproduction and survival</b>	Improved reproductive success, reduced mortality	Reduced reproductive success, increased mortality

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