Renewables Grid Initiative

A REVIEW OF BIODIVERSITY DATA NEEDS AND MONITORING PROTOCOLS

for the Offshore Wind Energy Sector in the Baltic Sea and North Sea

Renewables Grid Initiative

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About RGI:
The Renewables Grid Initiative is a unique collaboration of environmental NGOs and Transmission System Operators from across Europe. We promote transparent, environmentally sensitive grid development to enable the further steady growth of renewable energy and the energy transition.

More information:
www.renewables-grid.eu

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Abbreviations and Acronyms

ASCOBANS	Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas
AUV	autonomous underwater vehicle
BACI	before-after-control-impact (survey design)
BAG	before-after gradient (survey design)
BfN	Bundesamt für Naturschutz (German Federal Agency for Nature Conservation)
BRUV	baited remote underwater video
EC	European Commission
sDNA	environmental DNA
EIA	environmental impact assessment
EMF	electromagnetic fields
EMODnet	European Marine Observation and Data Network
ESAS	European Seabirds at Sea
EU	European Union
EurOBIS	European Ocean Biodiversity Information System
GBIF	Global Biodiversity Information Facility
HELCOM	Helsinki Commission
IAS	invasive alien species
ICES	International Council for the Exploration of the Sea
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee (UK)
KBA	Key Biodiversity Area
NGO	non-governmental organisation
OBIS	Ocean Biodiversity Information System
OWE	offshore wind energy
OWF	offshore wind farm
PAM	passive acoustic monitoring
PTT	platform terminal transmitter (for telemetry)
RGI	Renewables Grid Initiative
ROV	remotely operated vehicle
SEA	strategic environmental assessment
TSO	transmission system operator
UAV	unmanned aerial vehicle (drone)
UN	United Nations

Executive Summary

Offshore renewable energy, in particular wind power, is central to global efforts to reduce greenhouse gas emissions and tackle climate change, yet wind farms and their associated submarine power cables and grid infrastructure have potential impacts on biodiversity. It is essential that the marine fauna and flora around offshore wind energy (OWE) sites and grids is surveyed during the planning phase of development and that the monitoring of species and the pressures they face is continued throughout the operational lifetime of the infrastructure.

This report provides the results of a review undertaken in April-June 2021 into current biodiversity monitoring needs and practices in two European seas with intense and growing wind energy development, the Baltic Sea and the North Sea. A literature review and interviews with selected experts led to the identification of the main pressures and impacts placed on biodiversity by OWE and associated grids and the main monitoring methods and protocols used. Methods and protocols were then assessed to identify recommendations for the minimum biodiversity monitoring required.

The review found that the pressures placed by OWE and associated grids on biodiversity are commonly agreed but differ between taxa, as well as between the design or type of technology used (e.g. bottom-fixed versus floating turbines; meshed versus radial grid connections). Existing monitoring efforts focus primarily on marine mammals and marine birds, and to some extent on benthic fauna and flora, and are adapted depending on the phase of OWE development. Indicators are not always clearly defined or identical, hampering comparisons and data aggregation.

There are numerous methods available to monitor marine biodiversity around OWE and associated grids but guidance and protocols for applying each method are inconsistent and not always easy to find. Each method has a suite of pros and cons, and many are biased towards certain taxa, but there is little clear guidance on how to prioritise their use or which ones to favour for a given monitoring need. Many existing monitoring protocols have been developed using consultative processes but international, regional-level consultation and methods harmonisation remains weak. Threat monitoring focuses almost entirely on the impulsive noise generated by pile driving during construction, and bird collisions with turbines during operations. Pollution such as oil spills and the noise from vessels, turbines and submarine power cables are largely neglected.

While several national, regional and global data sources are of use in some OWE site assessments or monitoring schemes, data sharing is not systematic for marine biodiversity in general and for the OWE sector in particular. Many data collected around OWE sites and grids are kept in reports, many of which are not shared or are difficult to access. While systems exist for standardising data collection so as to facilitate data sharing, these are not yet used widely.

Recommendations are made on developing a more integrated, multi-species, multi-method approach to biodiversity monitoring in the OWE sector that, while allowing flexibility in the choice of methods to use, encourages the use of those methods in a more standardised way to monitor common indicators. This will facilitate comparisons between sites, data aggregation and sharing across regions, the study of cumulative impacts, and more informed results-based decision-making.

The main recommendations focus on the need for the OWE sector to develop and adopt:

- a set of common state and pressure indicators for use around all sites and grids;
- more focused and targeted use of key monitoring methods, with standardised protocols;

- a set of principles and practices to ensure effective monitoring (including following best practices for indicator development, choosing methods based on indicators and monitoring questions, defining the appropriate spatial and temporal scale, engaging key actors in monitoring design and implementation, designing fit-for-purpose monitoring programmes, and collating data in standard formats linked to regional and global databases to facilitate data sharing);
- enhanced regional and sectoral collaboration, cooperation and data sharing.

Future monitoring efforts should focus on threatened species and habitats and those taxa most impacted by OWE and grids, and on collecting data against a small set of common indicators focused on answering key questions on species populations and their threats. While precise survey and monitoring needs at an OWE site and around submarine power cables, as well as the methods used, will depend on local environmental conditions and legal frameworks, at a minimum, all OWE developments and associated grid infrastructure should measure:

- the distribution, diversity and abundance of marine birds, bats, seals and small cetaceans using aerial surveys and static passive acoustic monitoring, complemented by targeted telemetry (to understand habitat use) and vessel-based surveys (for behaviour data where needed).
- the distribution, diversity and abundance of fish, benthic invertebrates and plants, as well as the extent and quality of natural habitats, using methods such as grab sampling and underwater video surveys for habitats and benthic species, and fyke-net sampling for fish, complemented when necessary by scuba diving for all species, telemetry and baited remote underwater video for fish, and acoustic mapping of seabed habitats
- the extent of key pressures, with priorities being noise pollution, oil spills, invasive alien species, and collisions with turbines and vessels, using a variety of methods from remote sensing to scuba diver surveys and hull inspections.

Whilst a diversity of methods are recommended to monitor key indicators for key taxa based on this review, and examples of protocols are presented, the final choice of methods and protocols to standardise and roll out across the sector will need to be discussed and agreed by key stakeholders.

Two key challenges were encountered during the review. Firstly, there is still inadequate information on the impacts of OWE and submarine power cables on certain taxa and habitats, mostly notably bats, marine turtles and benthic invertebrates, and the extent and scale of some impacts (e.g., how electromagnetic fields affect fish). Information is most sparse on the impacts of submarine power cables on all taxa. Secondly, many of the monitoring methods and protocols that are best developed and most widely applied pre-date recent technological advances in remote sensing that allow more efficient and cost-effective collection of larger volumes of data. In turn, many of the newer methods are still in their infancy and protocols have yet to be developed or widely tested for some of them.

Therefore, recommendations are also made on the research and development required to improve our knowledge of key pressures and impacts that may need to be monitored and to integrate new technologies into monitoring systems. Priority research topics include:

- the collision risk of bats, and the adverse effects of OWE and submarine power cables on marine turtles;
- the impacts on marine biodiversity of electromagnetic fields (especially from submarine power cables) and pollution such as oil spills from vessels involved in construction, maintenance and decommissioning;

- the potential for new tools to be integrated into monitoring systems, especially environmental DNA techniques for assessing species diversity and relative abundance, baited remote underwater video for fish and crustaceans, light traps for benthic invertebrates, and acoustic soundscapes for fish and crustaceans.

An abundance of effort and resources is already invested in researching and monitoring marine biodiversity around OWE and grids. If stakeholders could enhance the level of collaboration and coordination across borders and sites to identify common indicators and standardise methods and data collection formats, the availability and use of data for decision-making in the OWE sector in the Baltic Sea and North Sea would be greatly enhanced, and cumulative impacts better understood. Such collaboration and adoption of more standardised approaches would improve results-based management and ultimately reduce the impacts of offshore wind farms and grids on biodiversity, enhancing the sustainability of energy production.

1. Introduction

1.1 Offshore Renewable Energy and Biodiversity

Renewable energy is central to the global effort to reduce greenhouse gas emissions and tackle climate change. Since the early 1990s, Europe has led the way in offshore renewables, especially wind energy, with the Baltic Sea and the North Sea being the two main hubs of development.

While offshore wind energy (OWE) offers immense potential for clean, green sources of power, there are some environmental impacts associated with the development of the infrastructure involved – the turbines and their towers, and the associated submarine power cables that connect the turbines to onshore electricity substations and grids. While the precise environmental footprint of an offshore wind farm (OWF) will depend on its location in relation to threatened habitats, bird migration routes, and other natural features, there are several potential impacts on biodiversity. Particular attention has been paid to the potential for birds and bats to collide with the turbines, but there are also concerns about, for example, habitat loss and degradation caused by construction, and the effects on wildlife of construction and operation noise, pollution from construction and maintenance vessels, and electromagnetic fields generated by submarine power cables (Gill, 2005; Boehlert & Gill, 2010; Perrow, 2019a). Turbines are usually clustered in wind farms, and if OWFs are placed close together they can lead to cumulative impacts on biodiversity, multiplying effects as well as compounding other anthropogenic pressures (King et al., 2015; Nogues et al., 2021).

1.2 Monitoring Biodiversity and the Pressures on Biodiversity

OWE operators are obliged to conduct environmental impact assessments (EIAs) or strategic environmental assessments (SEAs), which usually advocate ongoing biodiversity monitoring through the first few years of construction and operation. However, the methods used to collect data vary between sites and countries and it is often difficult to access available information (Copping et al., 2017; Methratta & Dardick, 2019).

The problems faced in collecting data around OWE are further compounded by the challenges that the offshore environment poses for monitoring biodiversity, including the following.

- Most species found at sea live underwater or spend some of their life submerged underwater, making detection (and species identification) difficult.
- Marine conditions reduce visibility and species detection, especially during inclement weather and high seas.

- Related to their aquatic existence, less is known about marine biodiversity than terrestrial biodiversity, with limited data available on the distribution and conservation status of species.
- With the exception of some mammals, fish and birds, many marine species have small body size or are nocturnal, furthering hampering detection and identification.
- Other factors besides the presence of a wind farm can affect the behaviour and distribution of species, including tides, weather and seasons.
- Many offshore wind farms are in remote locations and difficult to access; while this may encourage remote sensing, such techniques also have their logistical challenges in marine environments and produce large volumes of data to store and analyse.

The challenges with biodiversity monitoring need to be overcome if data are to inform marine spatial planning and the development and operation of offshore wind farms and associated grid infrastructure.

1.3 Rationale and Aim of the Review

The Renewables Grid Initiative (RGI) is a unique collaboration of European non-governmental organisations (NGOs) and transmission system operators (TSOs) which promotes fair, transparent, sustainable grid development to enable the growth of renewables to achieve full decarbonisation. In the context of its Marine Grid Declaration of 2019 (RGI, 2019), RGI members and other partners support the use of marine spatial planning for marine grid activities, in accordance with the EU Maritime Spatial Planning Directive (EU, 2014). The declaration highlights the need for enabling maritime spatial planning activities in EU Member States to collect the needed data, develop the needed spatial management measures, and have in place a system of monitoring and enforcement of the plan. The declaration also encourages knowledge generation and sharing. In addition, actors need to adhere to, and monitor, commitments to regional seas conventions and multilateral environment agreements, as well as to the Offshore Coalition for Energy and Nature. Therefore, the RGI would like to standardise the way in which biodiversity data are collected.

The purpose of this work was to conduct a review of biodiversity data needs in the offshore renewable energy sector, focusing on wind energy and associated submarine power grids, using the Baltic Sea and North Sea as case studies. The aim was to identify monitoring priorities and assess data collection methods and protocols and make recommendations for a more standardised approach across the sector which would allow data to be collected in a replicable and comparable manner and aggregated at multiple levels. The review focused on OWE infrastructure and the associated submarine power cables (hereafter also referred to as grids or grid infrastructure), and excluded onshore infrastructure such as substations and other onshore and offshore electricity generation sources. It is hoped this effort will lead to the improved collection and sharing of data on marine biodiversity and enhanced results-based decision-making and planning in the offshore renewables sector in the Baltic Sea and North Sea. This should ultimately lead to enhanced sustainability of renewable energy in the target seascapes, with lessons that could be replicable in other ocean basins.

The project output is this report, which assesses the biodiversity data needs for the OWE sector in the Baltic Sea and North Sea, and recommends which indicators and monitoring protocols should be adopted more widely and how they should be used. The project outcome is expected to be the development of a system for collecting, sharing and aggregating marine biodiversity data that enhances the availability and use of data for decision-making in the OWE sector in the Baltic Sea and North Sea, using approaches and protocols that are transferable to other ocean basins.

1.4 Methods Used

Between April and June 2021, the consultant conducted a desk-top literature review to assess the current biodiversity data requirements, monitoring systems and protocols in the offshore renewables sector, focusing on wind energy generation and associated submarine grid infrastructure. Documents were identified through online search engines, such as Google and Google Scholar. A snowballing technique was used to source other literature from that uncovered.

Material reviewed included not only scientific papers in books and peer-reviewed journals, but also regulatory policies and frameworks, regional strategies and monitoring plans, general and sector-specific guidelines, reports, reviews, indicator sets, data sets and other documents and websites identified as relevant to the identification and use of indicators and data.

In addition, the consultant held several informal interviews with thematic experts to seek their input and benchmark findings. He also participated in a BirdLife International webinar of invited experts on monitoring seabirds around offshore wind farms. See Annex 1 for a list of people who helped.

Pros and cons of different methods and approaches were determined and priorities established. The analysis of pros and cons and resultant recommendations on indicators and monitoring protocols were based on criteria such as: accuracy; reliability (if they can be consistently repeated with minimal variation in results); relative cost-effectiveness; feasibility of use and wider adoption; appropriateness (relevance for measuring priority indicators); level of precision (to measure the change monitored and to signal any relevant thresholds identified); and the value of the information generated for planning and decision-making.

The findings of the review are presented in this report. Feedback received on the draft report from RGI and other people consulted was taken into account in this final version.

2. Strategies and Agreements Relevant to Offshore Wind Energy and Biodiversity in Europe

2.1 European Union

There are several European Union (EU) strategies, directives and agreements that influence how biodiversity is dealt with in the context of offshore wind energy. The following are of particular relevance to the development of OWE.

- The EU Biodiversity Strategy (EC, 2020a) recognises the importance of marine resources and the need to ensure creation of protected areas, restoration of ecosystems, reduction of pollution and alien invasive species, and no deterioration in threatened species and habitats.
- The EU Habitats Directive, adopted in 1992 (EC, 1992), and the EU Birds Directive, adopted in 1979 and amended in 2009 (EC, 2009), promote the establishment and conservation of Natura 2000 protected areas.
- The Marine Strategy Framework Directive (EU, 2008) and the Marine Spatial Planning Framework (EU, 2014) both advocate member states establish characteristics that define “good environmental status” and establish monitoring and evaluation systems with consistent and standardised methods, for the aggregation of data to the level of marine region. Evidence-based decision-making is

key and the Marine Spatial Planning Framework includes provision for “use of the best available data”, and for the sharing of environmental data.

- The EU Strategy to Harness the Potential of Offshore Renewable Energy (EC, 2020b) underlines the importance of minimising the impact of offshore energy on biodiversity by following relevant environmental legislation and appropriate marine spatial planning. It also promotes systematic in-depth analyses and data exchange through the Copernicus Marine Environment Monitoring Service and the European Marine Observation and Data Network (EMODnet).

2.2 The HELCOM Baltic Sea Action Plan

The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM) – is an intergovernmental organisation and a regional sea convention in the Baltic Sea. A regional platform for environmental policy making, HELCOM was established in 1974 to protect the marine environment of the Baltic Sea from all sources of pollution. HELCOM has ten contracting parties: Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

The HELCOM Baltic Sea Action Plan (HELCOM, 2007) aims to reach favourable conservation status of biodiversity. In accordance with the Convention on Biological Diversity, HELCOM’s overall goal of a

favourable conservation status of Baltic Sea biodiversity through ecological objectives covers topics relating to:

- thriving and balanced communities of plants and animals;
- viable populations of species;
- sea floor integrity;
- the distribution, abundance and quality of habitats;
- water quality.

Commitments to achieve these objectives include actions to establish protected areas and to reduce the impacts of maritime activities such as pollution from ships, pollution and other threats from offshore platforms, and invasive alien species (IAS).

2.3 The North-East Atlantic Environment Strategy (OSPAR)

OSPAR (named after the original Oslo and Paris Conventions) is the mechanism by which fifteen governments and the EU cooperate to protect the marine environment of the North-East Atlantic. The fifteen governments are Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. OSPAR started in 1972 with the Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, and was broadened to cover land-based sources of marine pollution and the offshore industry by the Paris Convention of 1974. These two conventions were unified, up-dated and extended by the 1992 OSPAR Convention. The new annex on biodiversity and ecosystems was adopted in 1998 to cover non-polluting human activities that can adversely affect the sea.

The Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020 (OSPAR Commission, 2010) sets out a goal and objectives for a clean, healthy and biologically diverse North-East Atlantic. The goal is to conserve marine ecosystems and safeguard human health and, when practicable, restore marine areas which have been adversely affected in the North-East Atlantic by preventing and eliminating pollution and by protecting the maritime area against the adverse effects of human activities.

Objectives that will require data to monitor progress focus on:

- the status of threatened and/or declining species and habitats, in particular of those on the OSPAR List (see section 3.2);
- ecologically coherent and well managed marine protected areas;
- the impacts of human pressures;
- marine litter;
- energy, including underwater noise;
- non-indigenous species (i.e., alien invasives).

2.4 Implications for Biodiversity Monitoring around Offshore Wind Energy

Given the strategies and agreements in place in the region, wherever possible the monitoring of marine biodiversity and the pressures it faces around OWE and grid development should factor in and prioritise:

- species and habitats listed as important by EU directives;
- regional species priorities identified in the Baltic Sea and North Sea action plans;
- actions to minimise pressures, especially noise, pollution and invasive alien species;
- the sharing of data with EU-supported databases like EMODnet, as well as national databases.

3. Identifying What to Monitor

The recently published IUCN Guidelines for Planning and Monitoring Corporate Biodiversity Performance (Stephenson & Carbone, 2021) advocate for monitoring to focus on indicators that are directly relevant to the goals and biodiversity priorities defined by assessing environmental pressures and impacts. Therefore, the priorities for biodiversity monitoring in the offshore renewable energy sector should be related to the sector-specific environmental pressures and impacts, and the species and habitats these affect. For the Baltic Sea and North Sea, special attention should also be paid to biodiversity indicators used to monitor delivery of regional plans.

HELCOM monitoring programmes are compiled in the HELCOM Monitoring Manual (HELCOM, 2021a) and are the source of data for indicator-based assessments of the state of, and pressures on, the marine environment, as well as the analysis of long-term trends. The data are used for periodic assessment reports (e.g., HELCOM, 2009, 2012). Current monitoring and assessment activities are guided by the HELCOM Monitoring and Assessment Strategy (HELCOM, 2013a), which outlines a series of common indicators to be used across the Baltic (see below).

The OSPAR Commission has a Coordinated Environmental Monitoring Programme (OSPAR Commission, 2016a), which also has a suite of indicators which are explained by a series of guidelines (e.g., OSPAR Commission, 2016b, 2018, 2019). The data collected are then used for periodic assessments (e.g., OSPAR Commission, 2010b, 2021).

Indicators used by HELCOM and OSPAR are considered in the sections below and taken into account as priority indicators are identified.

3.1 Key Biodiversity Pressures and Impacts to Consider for Offshore Wind Energy

The construction, operation and decommissioning of OWE and associated grid infrastructure causes a range of pressures[1] on biodiversity which in turn lead to impacts[2] on species and ecosystems.

The main environmental impacts associated with OWE are risk of collision mortality, displacement due to disturbance (including noise), barrier effects restricting movement and habitat loss, as well as indirect ecosystem effects (OSPAR Commission, 2008a; Boehlert & Gill, 2010; Perrow, 2019a; Bennun et al., 2021). A number of positive impacts of OWE have also been noted, including introduction of new habitat, artificial reef effects and a fishery reserve effect, where marine fauna can aggregate due to the exclusion of human activity, especially fishing (e.g., Bergstrom et al., 2013; Hammar et al., 2016). It has been suggested that, in some cases, "wind farms may even be more efficient means of conservation than ordinary marine protected areas" (Hammar et al., 2016).

Bennun et al. (2021) provide a detailed breakdown and identify fourteen key environmental impacts of OWE:

1) Bird and bat collision with wind turbines and onshore transmission lines;
2) Seabed habitat loss, degradation and transformation;
3) Hydrodynamic change;
4) Habitat creation;
5) Trophic cascades;
6) Barrier effects or displacement effects due to presence of wind farm;
7) Bird mortality through electrocution on associated onshore distribution lines;
8) Mortality, injury and behavioural effects associated with vessels;
9) Mortality, injury and behavioural effects associated with underwater noise;
10) Behavioural effects associated with electromagnetic fields (EMF) of submarine cables;
11) Pollution (e.g., dust, light, solid/liquid waste);
12) Indirect impacts offsite due to increased economic activity and displaced activities, such as fishing;
13) Associated ecosystem service impacts;
14) Introduction of invasive alien species.

Impacts are caused by a variety of pressures which vary between different phases of OWE development. Some pressures such as mortality caused by seabed habitat loss or underwater noise are greatest during construction; others, like bird and bat mortality from collisions, are more prevalent during the operational phase. The first offshore wind farm was established in 1991 and only in recent years have any farms been decommissioned (Topham & McMillan, 2017). Therefore, our knowledge of the impacts and monitoring needs of this

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[1] A pressure as defined here is an anthropogenic threat caused by OWE that has an impact on biodiversity and ecosystem processes

[2] An impact as defined here is the effect the OWE has on the environment.

phase are still poorly understood, as are the correct approaches to minimise impacts and the appropriateness and effectiveness of turbine-to-reef programmes (sensu Reggio, 1987, and Macreadie et al., 2011).

While most attention focuses on the turbines, the commissioning of submarine power cables can also have a number of negative environmental impacts, including habitat damage or loss, noise, heat and electromagnetic field emissions, introduction of artificial substrates, and the creation of reserve effects (Taormina et al., 2018; Copping & Hemery, 2020; Copping et al., 2020; Gill & Desender, 2020). Of these impacts, electromagnetic fields (EMF) are a specific concern for power cables. Although it has been widely demonstrated that fish and other benthic organisms could be influenced by EMF (e.g., Bergstrom et al., 2013; Taormina et al. 2018), there remains limited evidence that the levels around submarine power cables are adequate to elicit an effect (NIRAS, 2015; Gill & Desender, 2020). Similarly, noise associated with the operation of submarine power cables is thought to be insignificant (Starmore et al., 2020). The potential impact of localised temperature increases caused by submarine power cables on infauna communities is an aspect of environmental effects on benthic organisms that has not been addressed much yet (Taormina et al. 2018). While the environmental impacts of submarine power cables are generally relatively weak, small scale and short term, uncertainties remain that need to be investigated, especially as their impact has been studied much less than the pressures caused by OWE infrastructure (Taormina et al., 2018).

The location, design and type of technology used in an OWF and its associated grid infrastructure can also affect the impacts on biodiversity. For example, floating turbines will have less of a footprint on the seabed then bottom-fixed turbines, although mooring cables (especially nylon-containing catenary moorings) may increase the risks of marine mammal entanglement (Benjamins et al., 2014; Bennun et al., 2021). Meshed grids require less power cable than radial grids (Cole et al., 2014) and so are expected to have less environmental impact.

While this review considers the main pressures and impacts identified to date with OWE and grids, it does not compare them with other human uses of the Baltic Sea and North Sea. In that context it is worth noting that, as well as reducing greenhouse gas emissions and the resultant climate change, OWE is generally thought to have lower levels of anthropogenic impacts on many taxa than other commercial activities, such as shipping, oil and gas exploitation, and fishing (Starmore et al., 2020).

It is also important to note that many of the known pressures on biodiversity can be addressed through a variety of mitigation strategies that either reduce the magnitude of the pressure or its impact on species and habitats. Examples include: shutdown on demand approaches that stop turbines when there is imminent risk of bird collisions (e.g. de Lucas et al., 2012; Tomé et al., 2017); bubble curtains, acoustic deterrents and the use of low-noise foundations that can mitigate the effects of pile driving noise on marine mammals (Koschinski & Lüdemann, 2020). While the effectiveness of mitigation measures will need to be evaluated regularly to ensure they are working (by measuring noise levels and the presence and abundance of sensitive species), in general the use of such measures should reduce the amount of monitoring required as it will allow some assumptions to be made about the impacts on biodiversity.

3.2 Biodiversity Priorities for Monitoring in the Baltic Sea and North Sea

Bennun et al. (2021) note the following biodiversity as most at risk from the pressures from offshore wind energy:

- seabirds;
- migratory shorebirds and waterfowl;
- bats;
- marine mammals;

- marine turtles;
- fish;
- habitats - a variety of offshore and coastal habitat types, such as sandbanks, coral reefs, seagrasses, mangroves, salt marshes, oyster beds and wetlands.

While the habitats named by Bennun et al. (2021) include various invertebrates, the infauna, epifauna, algae and seagrasses within those habitats are more explicitly named as potential priorities by other authors (e.g., Dahlgren et al., 2019). Both HELCOM and the OSPAR Commission have identified priority taxa for conservation in the Baltic Sea and North Seas that include most of these taxa (see the following sections).

Other international conventions also influence habitats and species that need to be conserved (see Soria-Rodríguez, 2020, for a review). These include species identified in the EU Birds and Habitats Directives (see above) and species identified by the Convention on Migratory Species and its associated agreements on small cetaceans (ASCOBANS: Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas), seals (WSSA: Agreement on the Conservation of Seals in the Wadden Sea), bats (EUROBATS: Agreement on the Conservation of Populations of European Bats) and waterbirds (AEWA: Agreement on the Conservation of African–Eurasian Migratory Waterbirds), as well as wetland sites of international importance identified by the Ramsar Convention.

Priority species for monitoring are identified in sections 4-6 of this report. While marine turtles may be adversely affected by OWE and associated grids, especially EMF, noise or the reef effect (Bennun et al., 2021; Hernandez et al., 2021), they are not commonly encountered in the Baltic Sea and North Sea. Only the leatherback turtle (Dermochelys coriacea) is named as a regional priority (OSPAR Commission, 2008b), but the species is not monitored systematically in any of the North Sea countries. Therefore, it is not included in this review.

4. Monitoring Marine Birds and Bats

This section reviews the monitoring of volant species affected by OWE, birds and bats, since many of the threats they face are the same and some of the monitoring methods are the same or similar.

4.1 Priority Pressures and Impacts

Most impacts on birds are during the operational phase of offshore wind farms. Bennun et al. (2021) note the main impacts as collision of seabirds, especially gulls, and barrier or displacement effects (especially on divers, gannets and guillemots) when wind farms present an obstacle to movement. The presence of the turbines, and associated maintenance vessel traffic, may also discourage birds from using the OWF site. On the other hand, some taxa (e.g., great cormorant, black-backed gull) are attracted by turbines, which is likely linked to increased fish abundance caused by the reef and reserve effects of the infrastructure. Some birds may also be attracted to lights on wind farms, increasing the risk of collision. Migratory species of shorebirds and waterfowl appear to avoid OWFs (Hüppop et al., 2019). Some migratory land birds may be at risk, especially those attracted to light (and migrating passerines are the main taxa killed on offshore platforms and rigs; Molis et al., 2019), so major crossing routes need to be avoided when developing OWE.

Bats sometimes collide with onshore turbines but the impacts of OWE on bats is less well understood (Thaxter et al., 2017). One study recorded 11 species of bat flying out to sea over the Baltic, with animals hunting for insects around turbines, and even sometimes landing on the infrastructure (Ahlen et al., 2009). Another study off the Netherlands in the North Sea also found bats (2 species) around wind farms (Lagerveld et al., 2014). Recent studies in Germany using acoustic monitoring (BFN, 2021) confirmed that bats regularly migrate across both the Baltic Sea and the North Sea and were recorded at almost all the offshore sites fitted with recording devices. Such studies suggest bats may be at risk from collisions with turbines and need to be monitored.

4.2 Priority Species

Marine birds are defined as those that regularly use the marine environment (Thaxter & Perrow, 2019), which include seabirds, waterbirds and migratory waterfowl and waders.

Priority taxa, based on Bennun et al. (2021), HELCOM (2021b) and OSPAR Commission (2008b) are:

- Seabirds: petrels and shearwaters (Procellariiformes); gannets and cormorants (Pelecaniformes); skuas, gulls, terns and auks (Charadriiformes).
- Shorebirds in the order Charadriiformes, waterfowl in the order Anseriformes (ducks, geese and swans). divers (Gaviiformes) and grebes (Podicipediformes).

Species named as priorities in the two target seas are presented in **Table 4A**. BirdLife International identified common scoter, greater scaup, lesser black-backed gull, herring gull, black-throated divers, and red-throated divers as priority high-risk species for the Baltic Sea and northern gannets, lesser black-backed gulls as priority high-risk species for the North Sea (Piggott et al., 2021). BirdLife International (Piggott et al., 2021) also flagged the following species as of potentially high concern, based on expert opinion: seaducks in general, white-tailed eagles, short-tailed owls, hen harriers and migrating species such as grey herons, white egret and cranes in the Baltic; and migrating passerines in the North Sea.

While no bats have been identified as priorities for protection or monitoring in relation to the target seas, 51 species are listed under the EUROBATS agreement as requiring protection (UNEP EUROBATS 2021; including all of those recorded near OWE in the Baltic), so efforts should be made to reduce collision risk among all bat species found close to OWE.

Table 4A. Bird species listed as conservation priorities in the Baltic Sea (HELCOM, 2021b), and Greater North Sea (OSPAR Commission, 2008b), and their global conservation status as defined by the IUCN Red List of Threatened Species (IUCN, 2021a). Also listed are species identified on the EU Birds Directive (EC, 2009) as regional priorities, and species identified by BirdLife international as at high or very high risk of collision or displacement effects (Piggott et al., 2021). Some birds are also identified by the Common Environmental Assessment Framework (SEANSE, 2019) as species to monitor to assess cumulative impacts of OWE.

English common name	Scientific name	IUCN Red List	HELCOM	OSPAR Commission	Also proposed for monitoring
Balearic shearwater	Puffinus mauretanicus	CR	-	Yes	
Black-legged kittiwake	Rissa tridactyla	VU	Breeding EN Wintering VU	Yes	BirdLife for North Sea; SEANSE (for collisions)
Roseate tern	Sterna dougallii	LC	-	Yes	

English common name	Scientific name	IUCN Red List	HELCOM	OSPAR Commission	Also proposed for monitoring
Common gull-billed tern	Gelochelidon nilotica	LC	RE	-	
Black-throated diver (or Arctic loon)	Gavia arctica (wintering population)	LC	CR	-	BirdLife for Baltic Sea & North Sea
Red-throated diver	Gavia stellata (wintering population)	LC	CR	-	
Kentish plover	Charadrius alexandrinus	LC	CR	-	
Bean goose	Anser fabalis fables (wintering population)	LC	EN		
Dunlin	Calidris alpina schinzii	LC	EN	-	
Long-tailed duck	Clangula hyemalis (wintering population)	VU	EN	-	BirdLife for Baltic Sea
Mediterranean gull	Larus melanocephalus	LC	EN	-	EU Birds Annex 1
Common scoter	Melanitta nigra (wintering population)	LC	EN	-	BirdLife for Baltic Sea & North Sea
Red-necked grebe	Podiceps grisegena (wintering population)	LC	EN	-	
Steller's eider	Polysticta stelleri (wintering population)	VU	EN	-	
Terek sandpiper	Xenus cinereus	LC	EN	-	
Velvet scoter	Melanitta fusca (breeding/wintering)	VU	VU/EN	-	BirdLife for Baltic Sea
Common eider	Somateria mollissima (breeding/wintering)	NT	VU/EN	-	BirdLife for Baltic Sea
Lesser black-backed gull	Larus fuscus fiscus	LC	VU	-	
Red-breasted merganser	Mergus serrator (wintering population)	LC	VU	-	

English common name	Scientific name	IUCN Red List	HELCOM	OSPAR Commission	Also proposed for monitoring
Ruff	Philomachus pugnax	LC	VU	-	
Horned grebe	Podiceps auritus (breeding/wintering)	VU	VU/NT	-	
Ruddy turnstone	Arenaria interpres	LC	VU	-	
Greater scaup	Aythya marila	LC	VU	-	BirdLife for Baltic Sea & North Sea
Black guillemot	Cepphus grylle grylle/Cepphus grylle arcticus	LC	LC-VU	-	
Caspian tern	Hydroprogne caspia	LC	VU	-	BirdLife for Baltic Sea; EU Birds Annex 1
Barnacle goose	Branta leucopsis	LC	-	-	EU Birds Annex 1
White-billed diver	Gavia adamsii	LC	-	-	BirdLife for North Sea
Sandwich tern	Thalasseus sandvicensis	LC	-	-	BirdLife for North Sea; EU Birds Annex 1
Northern gannet	Moras bassanus	LC	-	-	BirdLife for North Sea
Razorbill	Alca torda	NT	-	-	BirdLife for North Sea
Common guillemot	Uria aalge	LC	-	-	BirdLife for North Sea; SEANSE (for habitat loss)
Common goldeneye	Bucephala clangula	LC	-	-	BirdLife for Baltic Sea & North Sea
Goosander	Mergus merganser	LC	-	-	BirdLife for Baltic Sea & North Sea
Glaucous gull	Larus hyperboreus	LC	-	-	BirdLife for North Sea
Iceland gull	Larus glaucoides	LC	-	-	BirdLife for North Sea

English common name	Scientific name	IUCN Red List	HELCOM	OSPAR Commission	Also proposed for monitoring
Sabine's gull	Xema sabini	LC	-	-	BirdLife for North Sea
European herring gull	Larus argentatus	LC	-	-	BirdLife for Baltic Sea & North Sea
Great black-backed gull	Larus marinus	LC	-	-	BirdLife for Baltic Sea & North Sea
Black-headed gull	Larus ridibundus	LC	-	-	BirdLife for Baltic Sea & North Sea
Mediterranean gull	Larus melanocephalus	LC	-	-	BirdLife for Baltic Sea & North Sea
Common gull	Larus canus	LC	-	-	BirdLife for Baltic Sea & North Sea
Little gull	Hydrocoloeus minutus	LC	-	-	BirdLife for Baltic Sea & North Sea
Pied avocet	Recurvirostra avosetta	LC	-	-	EU Birds Annex 1
Common tern	Sterna hirundo	LC	-	-	EU Birds Annex 1
Little tern	Sternula albifrons	LC	-	-	EU Birds Annex 1
Arctic tern	Sterna paradisaea	LC	-	-	EU Birds Annex 1

4.3 Current Monitoring Programmes

The regional seas action plans have a small set of indicators focused on marine bird abundance and breeding success (**Table 4B**), although most of them are not used to monitor birds at sea. However, guidelines for marine bird monitoring around OWE (e.g., Jackson & Whitfield, 2011; Camphuysen et al., 2004; Hüppop et al., 2019; Webb & Nehls, 2019) propose methods to collect data for a larger array of indicators including:

- abundance or relative abundance;
- distribution;
- breeding success;
- behaviour (foraging, travelling, loafing);
- flight patterns (height, speed, avoidance);
- collisions.

Table 4B. Regional marine bird Indicators adopted by HELCOM and the OSPAR Commission.

Indicator	Regional indicator	Notes
Marine bird abundance	OSPAR B1 marine bird abundance	Currently not used for birds at sea
	HELCOM abundance of waterbirds in the breeding season	For coastal area only - not used for birds at sea
	HELCOM abundance of waterbirds in the wintering season	For coastal area only - not used for birds at sea
Marine bird breeding success	OSPAR B3 marine bird breeding success/ failure (number of chicks fledged annually)	Under development; for surface feeders and water column feeders; could be useful indicator of how OWE has affected fish stocks as well as the birds that feed on them

Table 4C. A detailed example of the types of monitoring questions that need to be addressed by bird surveys around offshore energy installations to establish an initial baseline during development and after consent. Adapted from Jackson & Whitfield (2011).

Baseline conditions question	Post-consent monitoring question
Which species occur in the survey area (i.e., the site and its vicinity)?	Does species composition significantly change following construction /operation?
HELCOM abundance of waterbirds in the breeding season	For coastal area only - not used for birds at sea
What is the abundance of the species?	Does abundance of species significantly change following construction /operation?
How does abundance vary spatially across the survey area?	Does spatial distribution of species significantly change following construction /operation?
How does abundance vary temporally (seasonally especially, time of day and state of tide may also be relevant)?	Does temporal patterns of occurrence of species significantly change following construction /operation?
Which habitats do birds use, (surface, mid-water, seabed, air-space etc)?	Does habitat selection at a development site significantly change following construction /operation?
Why do birds use a survey area and at which lifecycle stages are they present (i.e., what is their behaviour and purpose for being there)?	Do species significantly change their behaviour or reasons for using the site following construction / operation?
What are the origins of birds using the study area (where do they breed, what other areas do they use, i.e., connectivity)?	Do any populations stop using the site – or do other populations start using the site – after construction?
What human activities occur in the study area and how do birds respond to them (e.g., vessel traffic, fishing)?	How do human activities at the site change following construction/operation (be they associated with the development or not), and what behavioural changes occur in response?

Baseline conditions question	Post-consent monitoring question
Does a study area have any habitat features that appear to be particularly important to birds (e.g., tide races, skerries, sheltered bays, nest sites)?	Do features identified in baseline surveys as important continue to be so?
Not relevant	Do species initially affected by displacement show habituation to the development with time?
Not relevant	For breeding species potentially affected by a development, are there changes in breeding numbers or productivity at corresponding breeding sites (e.g., nearby colonies), and if so, is there evidence that these are caused by the development?
Not relevant	If death or injury from collision risk has been identified as a potentially serious issue for a species, what is the magnitude of the actual effect?

The large array of questions that need to be answered by such monitoring is demonstrated in **Table 4C**.

HELCOM collates data from member states on the abundance of waterbirds in the breeding season and in the wintering season, and publishes periodic reports showing trends (e.g., HELCOM, 2018a). Likewise, OSPAR monitors marine bird abundance as per its own indicator, with data aggregated from national systems, most countries monitoring a sample of their colonies. Data collection focuses on breeding seabird colonies and breeding waterbirds nesting close to the coast, as well as wintering and migrating waterbirds. The latest results were shared as part of the intermediary Assessment of 2017 (OSPAR Commission, 2021).

Bird data are not collected in co-ordinated regional programmes, but at national level, sometimes in partnership. For example, the UK has several national seabird-related counting mechanisms (RSPB, 2012) and it also works with Germany to conduct at-sea monitoring of marine birds, based on ship-based and aerial transect surveys. The European Seabirds at Sea (ESAS) Partnership led by the British Joint Nature Conservation Committee (JNCC) also collates data on opportunistic seabird sightings at sea for an ESAS database. Standardised ESAS monitoring protocols are used (Lewis & Dunn, 2020).

The 2017 OSPAR Commission bird status report disaggregated data by functional group, which refers to the feeding category of the birds (waders, surface feeders, water column feeders, benthic feeders and grazing feeders). The HELCOM indicator on waterbird abundance in the breeding season also dis-aggregates data by feeding group. This appears to be done to help assess any change in trophic guild.

4.3.1 Pros and cons of the main methods used for monitoring marine birds and bats

There are a range of well-established methods and protocols for surveying marine birds in general (e.g., Tasker et al., 1984; Komdeur et al., 1992; Walsh et al., 1995; Gilbert et al., 1998) and in the specific context of OWE (e.g., Jackson & Whitfield, 2011; Camphuysen et al., 2004; Hüppop et al., 2019; Webb & Nehls, 2019).

The main methods for measuring marine bird populations around OWE (Webb & Nehls, 2019) are vessel-based or aerial line transect surveys, with increasing use of aerial digital surveys (using still and moving images and, sometimes, species identification software). Aerial surveys have the advantage of covering larger areas and detecting species sensitive to vessels. However, vessel-based surveys allow the collection of a wider diversity of data; bird behaviour and flight height can be monitored, and other species such as mammals can be surveyed from the same vessel (also fish through the use of hydroacoustics; Masse, 1996; Krägefsky, 2014). Furthermore, data on water salinity, temperature and other environmental parameters can be collected. Vessel and aerial surveys are increasingly being complemented by digital aerial surveys, using high-definition camera technology to collect still and moving images (Webb et al., 2017; Zydelis et al., 2019). These digital aerial surveys can usually identify species as effectively as human observers on boats (Johnstone et al., 2015). In some cases, cameras are deployed with drones or unmanned aerial vehicles (UAVs), especially for colony counts (Wich & Koh, 2018; Raoult et al., 2020).

For vessel-based surveys, standard ESAS protocols are often used (Webb & Durinck, 1992; Camphuysen & Garthe, 2004; Lewis & Dunn, 2020), using two observers on board to monitor distribution and abundance and also record behaviour (Camphuysen et al., 2004). An explanation of this long-used approach is described in Box 4.1.

Box 4.1: An example of vessel-based survey methods. Adapted from Batty (2008).

Vessel-based bird surveys involve the simultaneous operation of three separate, but linked, methodologies.

1) Surveying a 90° scan area, from bow to beam, on one side of the vessel (the side chosen is based on observation conditions). All birds seen at any time within this area are recorded. This data can be used to give indications of abundance and distribution, and allows for the recording of scarce and unusual species which are unlikely to appear in transect.
2) Surveying a band transect. A 300 m wide transect, ahead of the vessel within the 90° survey area is operated. This strip is further divided into four sub-bands (A-D, band E>300 m). Birds recorded on the water (or making contact with the water, e.g., feeding), at any point within this 300 m area are recorded as being ‘in transect’.
3) A ‘snapshot’ method is operated for flying birds. The area ahead of the ship, within the band transect, is surveyed instantaneously at set intervals (depending on vessels speed) for flying birds. For example, if the vessel travels 300m per minute, the snapshot area will be 300 m ahead, and an instantaneous count of flying birds will be made every minute. Birds recorded within the snapshot are recorded as being ‘in transect’.

Counts of birds ‘in transect’ (methods 2 & 3) allow for the determination of densities and distributions of seabirds. There was no surveying during the stationary periods, while shooting or hauling nets, or when trawling. Weather limitation is usually taken to be sea state 6 or over but these conditions were not experienced on the survey. (Note that recent studies have shown that radial rather than box snapshots avoid underestimating the densities of some species; see Webb & Nehls, 2019).

Surveying is usually performed using the naked eye, with binoculars used to check identifications or other details. Binoculars are also occasionally used to scan ahead of the vessel as an observers ‘self check’ on observational efficiency during the survey. In certain areas, where species such as divers and sea-duck are present, binoculars must be used with more regularity in order to detect these birds at distance, ahead of the vessel, before they fly off.

Vessel surveys generally need to be conducted in favourable conditions, although the precise definition varies. For example, Vanermen et al. (2015) conducted seabird surveys only in good visibility, a calm to moderate wind force (<6 Bft) and a significant wave height of less than 2 m. BSH (2013) suggest surveys can be carried out in winds of up to 7 Bft and at wave heights of up to 2.5 m.

Bats generally need to be monitored using passive acoustic techniques, though this poses greater challenges at sea (Molis et al., 2019; Sugai et al., 2019; BFN, 2021). The main option is to attach passive acoustic recording devices to OWE infrastructure (BFN, 2021; Noordzeeloket, 2021).

Other monitoring methods for birds include vantage point surveys and telemetry. Telemetry (the tracking of birds by tagging them with various electronic devices) is still the most effective way at gaining an understanding of how an individual bird moves and uses its habitat (e.g., Largey et al., 2021). For OWE monitoring, it can complement aerial and vessel surveys by gaining an understanding of how a species uses habitats in and around a wind farm or subsea power cable corridor. Platform terminal transmitters (PTTs) have provided scope for the detection of emitted radio waves by satellite (Phillips et al., 2007; Griffin et al., 2011). As technology advances, a larger variety of sensors is becoming available that can be attached to birds and, as well as position and speed, some can record a bird's altitude, the time it spends underwater, and the depth dived (Thaxter & Perrow, 2019)). Telemetry can thus help identify foraging areas and barrier effects and be used to understand connectivity between a bird colony and a wind farm, how much birds are exposed to risk from collision, and how much their movement and behaviour changes in response to the farm. The method is therefore useful in all phases of OWE development and operation. During the scoping and planning phase of OWE development, telemetry data can be used to assess the importance of the area for birds, and then later used to see if birds have been displaced or attracted to the area once the OWF goes into operation. The data can be fed into collision risk models, which are especially key in the EIA process to attain consent for OWE development (Band, 2012; Cook & Masden, 2019).

The main threat to birds and bats from OWE is collision with turbines and efforts have been made to monitor birds and bats killed. However, numerous challenges exist, the greatest one being the fact carcasses are usually lost at sea, making precise figures for collision deaths difficult to estimate. Furthermore, bird count and flight height data are generally inadequate to accurately estimate collision risk (Green et al., 2016). Nonetheless, several techniques have been used to try to detect bird and bat interactions and collisions with wind turbines, including radar, active sonar, thermal infrared imagining and acoustic monitoring. A large variety of radar systems and types of antenna have been developed (Molis et al., 2019), but this broad choice complicates the standardisation of protocols. Radar observations often include both a horizontal radar to measure flight paths, and a vertical radar to measure fluxes and flight altitudes (e.g., Krijgsveld et al., 2011). The main challenge, however, is that the spatial resolution provided by radar does not allow detection of collisions. LiDAR systems that emit frequent, short-duration laser pulses have also been used and are increasingly being tested (e.g., Cook et al., 2018), and these offer an option for measuring bird and bat flight height and for assessing micro-avoidance movements. While no ready to use LIDAR products in the field of detecting bats and birds are currently available (Lagerveld et al., 2020), this tool should be explored further. It is also being tested with digital aerial surveys to help add data on flight height. One study (Cook et al., 2018) showed that the height of birds in flight could be measured using LiDAR to an accuracy of within 1 m, which compares favourably to other tools. Thermal imaging has been used to record bird and bat collisions with wind turbines since the 1980s and sensors continue to evolve (see Molis et al., 2019). But multiple cameras are generally needed to provide adequate detection coverage.

Some offshore wind farm operators have used acoustic monitoring to detect the presence of both bird and bats around turbines. Generally, acoustic monitoring is insufficient to monitor the flight activity of birds (Molis et al., 2019) but is undoubtedly the most efficient method for assessing the collision risk of bats (Peterson et al., 2016; Molis et al., 2019).

In recent years, multidetector or multi-sensor systems have been employed in a number of terrestrial and offshore wind farms to maximise the advantages of different remote sensing systems, especially to monitor collisions or collision risk (Skov et al., 2018: Molis et al., 2019; Niemi & Tanttu, 2019; Lagerveld et al., 2020;

Largey et al., 2021; Noordzeeloket, 2021). However, the proliferation of different options makes comparisons and standardised protocols a significant challenge. One advantage of such systems is that they can facilitate shutdown on demand approaches to mitigate impacts on birds with minimal loss of energy production (de Lucas et al., 2012; Tomé et al., 2017; Bennun et al., 2021), so these monitoring systems should continue to be tested.

Common characteristics of current marine bird monitoring around OWFs (as identified by BirdLife International Europe and Central Asia; Piggott et al., 2021) include:

- boat and aerial transect surveys are the most often used monitoring tools; sometimes digital aerial survey of transects or grids;
- baseline field studies are usually conducted for a minimum of 2 years;
- the impact area should comprise the wind farm and a suitable buffer;
- ideally surveys should cover day/night, tidal cycles, weather variation and breeding/non breeding seasons;
- besides recording presence, behaviour (especially flight height) is usually measured.

The pros and cons of the main methods for monitoring birds are summarised in Annex 2. It was often hard to compare cost-effectiveness directly between methods since, besides the direct costs of monitoring (equipment, transport, human resources, etc.), there are many indirect costs that are difficult to gauge (time needed for data processing and analysis, training, etc,), as well as scale issues to assess (e.g. it may cost more per day to fly aircraft transects but they will cover a wider area more quickly than cheaper vessel-based surveys). A recent review of monitoring methods suggested that, “while the costs involved in using technological tools may be declining, challenges remain with the capacity and time needed to store, share and analyse the large volumes of data generated” (Stephenson, 2020). Therefore, while cost is undoubtedly an important factor to consider in choosing methods, other efficiencies need to be considered as well. Probably the biggest challenge to selecting the most appropriate method is that most established protocols are for older methods such as vessel surveys and, while newer technological options are promising, many are still only being tested and there are often no standardised protocols for their use.

Ultimately, it is most important that surveys for particular species are designed around methods that can answer the key monitoring questions and measure priority indicators for priority species and threats, adapted as necessary to local conditions. All methods have their valid uses in certain prevailing conditions, and some continue to be favoured more by some national level marine bird monitoring programmes than others (e.g., aerial digital surveys are becoming more standard across Germany and the UK; vessel-based surveys remain dominant in places like Belgium and the Netherlands).

4.4 Priority Indicators, Methods and Protocols for Monitoring Marine Birds and Bats

Based on the priority species identified, and the pressures they face from OWE. the key questions that marine bird monitoring needs to answer include:

- Which marine birds are present in the area? Is there a breeding colony nearby that might be foraging at the site?
- What is the distribution and abundance of the species that are present?
- Does distribution and abundance change as a result of wind farm construction and operations?

- Is there evidence of behavioural traits that place birds at risk (such as flying at rotor blade height or foraging near farms)?
- Is there any evidence of bird collisions with OWE infrastructure?
- Do mitigation measures affect the animals?

For bats the question most important to answer for the moment is: what is the collision risk of bat species and what mitigation methods are most effective?

Priority indicators for each stage (1. Planning – scoping, pre- and post- consent); 2. Construction; 3. Operation; 4. Decommissioning) are:

- Presence of birds and bats in and around the wind farm to determine the extent of occurrence or distribution of each species and overall species diversity (1-4)
- Presence and size of seabird breeding colonies within an appropriate radius of OWE (1-4)
- Absolute or relative abundance of marine birds (numbers of birds per unit area in and around the wind farm) (1-4
- Behaviour of birds and bats (use of wind farm area for foraging/migration) (1-4)
- Flight height (1-3).

Bird abundance (framed as densities) can also act as a proxy measure of habitat availability (Fox et al., 2006).

Weighing up the various pros and cons and optimising efficiency, comparability across sites and effectiveness, it would seem that:

- Methods to be favoured should include: digital aerial surveys for birds; acoustic monitoring for bats
- Methods to be used for more targeted studies when needed: telemetry; aerial-based and vessel-based observation surveys
- Methods that are generally of less use across OWE sites: vantage point surveys (which are too reliant on close proximity to the coast)
- Methods to be explored and developed further: multi-sensor arrays mounted on turbine jackets to monitor collision risk.

A summary of the main indicators for birds and bats, the monitoring methods used to monitor them, and examples of relevant protocols, are presented in **Table 4D**.

Table 4D. Minimum monitoring requirements for marine birds around offshore wind energy sites and associated grid infrastructure. One method or a combination of methods may be needed for each indicator. Monitoring frequency is presented as guidance but will need to be based on each survey design. While some data may need to be collected monthly in some sites, in others it may prove more effective and efficient to conduct more intense and more widespread surveys less often. Note that these are recommended minimum requirements for every site; each site will also need to monitor additional indicators based on the profile of the site and prevailing legal requirements. Phases of development are: 1. Planning; 2. Construction; 3. Operation; 4. Decommissioning.

Type of indicator and phase of development	Method and frequency	Examples of monitoring protocol options
Minimum		
Occurrence/area of occupancy (distribution) (1-4) and Species diversity (1-4) and Absolute or relative abundance (1-4) and Flight height (1-4)	Digital aerial surveys (8-10 p.a.)	Aerial surveys of seabirds (Buckland et al., 2012). Remote sensing image data and automated analysis to describe marine bird distributions and abundances (Groom et al., 2013). High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols (Thaxter & Burton 2009). StUK4 protocols (BSH, 2013): carried out with suitable methods in co-ordination with the BSH (linked to Groom et al. 2013, and Buckland et al. 2012).
	Vessel-based surveys (monthly)	ESAS Seabirds at Sea Survey Methods (Camphuysen & Garthe, 2004; Lewis & Dunn 2020). Towards standardised seabirds at sea census techniques (Camphuysen et al, 2004) with adaptations made by MacLean et al. (2009). Counting seabirds at sea from ships (Tasker et al 1984). StUK4 methods (BSH, 2013), including Garthe et al. (2002) instructions for the detection of seabirds at sea of ships. Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 4. Birds (Jackson & Whitfield, 2011).
When necessary (e.g., in proximity to Natura 2000 sites or when high collision risks expected)		
Connectivity between breeding colonies or migration routes and site (1-3)	Telemetry	Methods used for PTTs and other sensors (e.g., Phillips et al., 2007; Griffin et al., 2011).
Collision risk (2,3)	Multiple sensors (including cameras and radar) or multi-sensor arrays (constant)	Best practice guidance for the use of remote techniques for a) ornithological monitoring (Walls et al. 2009) b) behaviour (Desholm et al., 2004). Guidance on bird and bat collision risk monitoring using multiple sensors (Lagerveld et al., 2020). SOSS Band model for calculating collision risk (Band, 2012).
Breeding colony counts (1-3)	Digital aerial (as needed)	For aerial use see above. For application of drones see Wich & Koh (2018) and Raoult et al. (2020)
	Observer colony counts (in breeding season)	Breeding bird monitoring methods (Gilbert et al., 1998) Seabird monitoring handbook (Walsh et al., 1995) Waterbird counts (Wetlands International, 2010)

Guidance across taxa and across methods that includes protocols for marine bird monitoring in Europe is also provided by the German Federal Maritime and Hydrographic Agency (BSH, 2013), the Scottish government (Jackson & Whitfield, 2011), the government of Ireland's Department of Communications, Climate Action and Environment (2018a,b), and in other publications (e.g., Komdeur et al., 1992; Johansen et al., 2012; Kemper et al., 2016). There are also some examples available from North America (e.g., Moulton & MacTavish, 2004). Various methodology tests and reviews provide further insights into choosing appropriate protocols (e.g. Mellor & Maher, 2008; Maclean et al., 2009; Williams et al., 2015). Many existing protocols have been developed using consultative processes (e.g., Thaxter & Burton 2009) but international, regional-level consultation seem to remain weak.

4.5 Research Needed to Improve Monitoring of Marine Birds and Bats

As with other taxa, most of the methods and protocols most widely for monitoring birds and bats used were developed more than 15 years ago. There is inadequate testing of standard protocols for newer tools.

Research needed includes:

- Further testing and harmonisation of approaches to monitor birds and bats with other technologies, such as radar, sonar and infrared imaging (that may work in poor weather or at night).
- Testing combinations of methods to optimise monitoring of multiple taxa using complementary tools.
- Better understanding of migration corridors and how they vary over time, and a better understanding of the relevant buffer zone around OWFs and related submarine power cables that should be monitored.
- Collison risk studies, looking into, for example, flight heights and micro-scale behaviours inside OWE sites, especially for migrating seaducks and especially telemetry studies.
- Better understanding of barrier effects, and the use and effectiveness of corridors created within and between OWFs.
- Understanding how prey distribution and density affects bird use of OWFs.
- Understanding the impacts of OWF decommissioning on birds and bats to identify any additional indicators that need to be monitored during this phase.
- BirdLife International lists the following bird species as a priority focus for future research into OWE impacts (Piggott et al., 2021):
    - Long-tailed duck (Clangula hyemalis)
    - Common goldeneye (Bucephala clangula)
    - Greater scaup (Aythya marila)
    - Velvet scoter (Melanitta fusca)
    - Common eider (Somateria mollissima)
    - Caspian tern (Hydroprogne caspia)
    - Roseate tern (Sterna dougallii)
    - Sandwich tern (Thalasseus sandvicensis)
    - Arctic jaeger (Stercorarius parasiticus)
    - Storm petrel species (Hydrobatidae spp.)
    - Shearwater species (Procellariidae spp.)
    - Grebe species (Podicipedidae spp.).

5. Monitoring Marine Mammals

Marine mammals occur in probably every OWE site worldwide (Nehls et al., 2019). Taxa of concern in the Baltic Sea and North Sea are cetaceans (whales and, in particular, dolphins and porpoises) and pinnipeds (seals).

5.1 Priority Pressures and Impacts

The largest impact of OWE on marine mammals is likely caused by the strong impulsive noise generated by pile driving during the construction phase, with harbour porpoises especially sensitive (Russell et al., 2016; Nehls et al., 2019; Starmore et al., 2020). Some marine mammals can be displaced several kilometres. For example, harbour porpoises may have a displacement distance of more than 20 km during OWE construction (Scheidat & Porter, 2019). Non-impulsive noise from vessel engines and construction may also affect some species. For example, some cetaceans may be sensitive to the underwater noise generated by vessels tens of kilometres away (Halliday et al., 2017). Other pressures on marine mammals include collisions with vessels involved in survey, construction, maintenance and decommissioning (Sparling et al., 2011). Entanglement with the mooring cables of floating turbines may pose a threat to some larger species, such as baleen whales (Benjamins et al., 2014). Pollution from vessels and the release of anti-fouling chemicals is also potentially harmful (Dolman & Simmonds, 2010). Creation of refuges through the reserve effect and the resultant increase in fish abundance may cause some species to frequent offshore wind farms.

5.2 Priority Species

Regional priority marine mammal species are shown in **Table 5A**.

Table 5A. Species listed as conservation priorities in the Baltic Sea (HELCOM, 2021b) and Greater North Sea (OSPAR Commission, 2008b), and their global conservation status as defined by the IUCN Red List of Threatened Species (IUCN, 2021a). The harbour porpoise is also identified by the Common Environmental Assessment Framework (SEANSE, 2019) as a species to monitor in the North Sea to assess the cumulative impact by the underwater sound generated by pile driving. Note that ASCOBANS prioritises all small cetaceans.

Common name	Scientific name	IUCN Red List	Baltic Sea	North Sea	Proposed for monitoring by
Blue whale	Balaenoptera musculus	EN	-	Yes	-
Northern right whalel	Eubalaena glacialis	CR	-	Yes	-
Harbour porpoise	Phocoena phocenin	LC	CR/VU	Yes	HELCOM OSPAR Commission SEANSE
Eastern Atlantic harbour seal	Phoca vitulina vituline	LC	VU/LC	No	HELCOM
Baltic (ringed) seal	Pusa (Phoca) hispida botnica	LC	VU	-	HELCOM
Grey seal	Halichoerus grypus	LC	LC	No	HELCOM OSPAR Commission

All three of the pinnipeds found in the region are considered priorities. While only three species of cetacean are singled out for special attention, 36 species have been recorded in the Greater North Sea region alone (see below) and all cetaceans found in and around an OWE site should be surveyed. The harbour porpoise, however, is the most commonly encountered species and may be especially susceptible to construction noise. The large baleen whales (Mysticeti), such as the blue and northern right, are less common and less likely to be regular visitors to an OWF, so will probably not need regular monitoring. However, the harbour porpoise and any other toothed whales and porpoises (Odonticeti) found around a site will need to be monitored closely. The Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas (ASCOBANS, 2021) promotes international cooperation to achieve and maintain a favourable conservation status for small cetaceans throughout the region. It defines "small cetaceans" as any species, subspecies or population of toothed whales (Odontoceti), except the sperm whale (Physeter macrocephalus). It names the 20 most commonly recorded species but notes that the convention covers all small cetaceans.

5.3 Current Monitoring Programmes

The regional seas action plans have a small set of indicators focused on marine mammal abundance and seal health and breeding success (**Table 5B**) that monitor:

- abundance or relative abundance;
- distribution;
- reproduction (pup production in seals);
- health status (reproductive and dietary status in Baltic seals; causes of death).

Table 5B. Regional marine mammal Indicators adopted by HELCOM and the OSPAR Commission.

Indicator	Regional indicator	Notes
Cetacean abundance	OSPAR M4 cetacean abundance and distribution	Currently not used for birds at sea
Distribution of impulsive noise	OSPAR Distribution of reported impulsive sounds	Data are available for a limited number of countries and sound sources. E.g., Data for 2015 were provided by Belgium, Denmark, Germany, the Netherlands, Sweden and the UK for four sound sources (seismic surveys, pile driving, explosions, and sonar and acoustic deterrents). (OSPAR Commission, 2021).
Seal distribution	OSPAR M3 seal abundance and distribution	
	HELCOM distribution of Baltic seals	
Seal abundance	OSPAR M3 seal abundance and distribution	
	HELCOM population trends and abundance of seals	
Grey seal pup production	OSPAR M5 grey seal pup production	Under development; would be hard to link change with OWE
Seal population health	HELCOM	

As apex predators, marine mammal abundance and distribution are key indicators of broader environmental status, including ecosystem function and food web integrity. The OSPAR Commission also has an indicator for the distribution of impulsive noise, which has relevance to marine mammals. However, data are available for only a limited number of countries and sound sources. For example, data for 2015 were provided by Belgium, Denmark, Germany, the Netherlands, Sweden and the UK for four sound sources (seismic surveys, pile driving, explosions, and sonar and acoustic deterrents) (OSPAR Commission, 2021).

The EU Habitats Directive requires member states to monitor and maintain at favourable conservation status those species identified to be in need of protection, including all cetaceans. The Directive (EC, 1992) defines favourable conservation status as when population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and there is, and will probably continue to be, a sufficiently large habitat to maintain its population on a long-term basis. This suggests member states need to monitor not only population levels, but broader population dynamics as well as habitats. However, there are no regionally-coordinated marine mammal monitoring programmes in the Baltic Sea or North Sea; indeed, HELCOM does not yet even have a functional cetacean indicator. Data against regional indicators are collated from national survey programmes, examples of which include the Joint Cetacean Protocol in the UK (Paxton et al., 2016).

One regional cetacean monitoring effort - the SAMBAH project (Static acoustic monitoring of the Baltic harbour porpoise; Kolmårdens Djurpark AB, 2017) - produced information on harbour porpoise distribution and abundance in the Baltic using static PAM through an extensive network of C-PODs. The results are planned for use in designing coordinated harbour porpoise monitoring programmes. HELCOM thematic assessments (e.g., HELCOM, 2018b) have, however, collated national data to provide some level of overview on marine mammal abundance, especially for seals.

Thirty-six species of cetacean have been recorded in recent history within the Greater North Sea, Celtic Seas, and Bay of Biscay and Iberian coast (OSPAR Commission, 2021). Aerial and vessel-based cetacean surveys (named SCANS I, II and III and CODA) have been conducted in Atlantic waters by Denmark, Germany, Portugal, Spain, Sweden and the UK (Hammond et al., 2013, 2017; Paxton et al., 2016). The OSPAR Commission has an indicator for cetacean abundance and distribution, and the cetacean status report in the intermediary assessment of 2017 (OSPAR Commission, 2021) used data collected from national programmes to provide an update on trends. The report concluded that cetaceans are widely distributed and abundant in the OSPAR Maritime Area but they are challenging to monitor. There was no evidence of changes in abundance for white-beaked dolphin, minke whale and harbour porpoise since 1994 but insufficient evidence to determine trends for other species. The distribution of harbour porpoise and minke whale has shifted southward in the Greater North Sea. While larger cetaceans should be monitored where necessary around the North Sea, in general monitoring for OWE will need to focus on the smaller, toothed cetaceans (dolphins and porpoises) since these are likely to be the most common and the ones most likely to be impacted.

For pinnipeds, OSPAR monitors both species present in its North Sea waters, the harbour seal and the grey seal, even though the grey seal is not on its list of threatened and declining species (OSPAR Commission, 2008b). HELCOM monitors all three seal species present in its waters and listed on its Red List (HELCOM, 2021b), the harbour seal, grey seal and Baltic ringed seal. Seal species have also been flagged as important taxa to monitor around offshore renewable installations (e.g., Sparling et al., 2011; Bennun et al., 2021), due to the risk of impacts, especially from noise.

5.3.1 Pros and cons of the main methods used for monitoring marine mammals

There are a range of well-established methods for surveying marine mammals (e.g., Garner et al., 1999; Evans & Hammond, 2004; Diederichs et al. 2008; Boyd et al., 2010; TCE, 2010; Macleod et al., 2011; Paxton et al., 2016).

The main methods for measuring marine mammal populations around OWE installations are line transect surveys, acoustic surveys and telemetry (Scheidat & Porter, 2019). Tools used include vessel-based surveys, aerial surveys, digital aerial surveys, satellite imagery surveys, passive acoustic monitoring surveys using towed arrays or static devices, telemetry, and haul-out counts (for seals that are breeding or moulting).

Vessel and aerial surveys use onboard observers to count animals following a distance sampling approach. Technological solutions continue to evolve and estimates of relative density of harbour porpoises from digital and acoustic surveys have been demonstrated to be strongly correlated to estimates from visual surveys (Williamson et al., 2016), suggesting remote sensing methods offer viable and cost-effective options. They are now the favoured method in some countries (e.g., BSH, 2013). In some cases, cameras are deployed with drones or UAVs, especially for haul-out counts of pinnipeds (Wich & Koh, 2018; Raoult et al., 2020), although the sensitivity of species to drone noise, especially during the breeding season, needs to be taken into account (Palomino-González et al., 2021).

Static acoustic devices, such as C-PODs and their predecessors, T-PODs (which operate passively at sea to detect click trains), are widely used static PAM devices for recording the presence and activity of cetaceans around OWFs (Haelters 2009; Macleod et al., 2011; Scheidat et al., 2011; Williamson et al., 2016). Acoustic monitoring glider systems have also been tested (e.g., Kowarski et al., 2020) and offer an alternative as a towed array.

Vantage point surveys are an additional option in some locations (Sparling et al., 2011), although the expending size of OWFs and their distance offshore means it can only be used in a small proportion of cases. Some cetacean populations are monitored using photographic identification of individuals to allow mark-recapture population estimates (Urian et al., 2015). This can also be used to answer questions pertaining to population size and the presence of individuals from a Natura 2000 population within or near to the development site (Macleod et al., 2011).

The use of radar, active sonar and thermal infrared have also been tested but are not yet widely used, though they should be explored further (Verfuss et al., 2018). For example, there is potential for using a vessel-mounted infrared imaging system to detect marine mammals in real-time (Smith et al., 2020). Increasing evidence suggests environmental DNA (eDNA) may be a useful tool to detect mammal species when large enough volumes of water can be analysed (e.g., Foote et al., 2012). Satellite-based remote sensing can be an option for monitoring whales (Pettorelli et al., 2014).

Cumulative impacts also need to be assessed, and two models have been applied in the North Sea (Nehls et al., 2019): the interim Population Consequences of Disturbance framework (King et al., 2015; Booth et al., 2017, 2020); and the DEPONS model (Nabe-Nielsen et al 2018; DHI, 2019) (see also Nabe-Nielsen & Harwood, 2016).

The main pressure that is monitored in relation to mammals is underwater noise, which can be recorded using hydrophones (e.g., Bailey et al., 2010; Dekeling et al. 2014). Systems deploying static PAM devices, as used, for example, by NOAA in US waters (Haver et al., 2018), could also help monitor both anthropogenic and biological noise over time. Marine mammal observers are also used to determine the presence of animals close to installations during pile driving, or to avoid collisions with vessels.

Marine mammals pose specific challenges for monitoring. They spend all, or large periods, of their time at sea, covering large areas, often submerged, making sightings and species identification difficult. As with all taxa, the long timelines involved in monitoring pose challenges to identifying and keeping on research team members and the relevant equipment and vessels. Monitoring teams also need to be flexible to account for unexpected delays (e.g., equipment faults can lead to pauses of weeks in phases such as pile driving).

Annex 3 describes the pros and cons of the main methods used for monitoring marine mammals. As with the methods used for other taxa (sections 4 and 6), it was often hard to compare cost-effectiveness directly between methods, given the difficulty in comparing other indirect costs.

Ultimately, it is most important that surveys for particular species are designed around methods that can answer the key monitoring questions and measure priority indicators for priority species and threats, adapted as necessary to local conditions. All methods have their valid uses in certain prevailing conditions, and some continue to be favoured by some national level monitoring programmes than others (e.g., aerial digital surveys are becoming more standard across Germany and the UK; vessel-based surveys remain dominant in places like Belgium and the Netherlands).

5.4 Priority Indicators, Methods and Protocols for Monitoring Marine Mammals

Based on the priority species identified, and the pressures they face from OWE, the key questions that marine mammal monitoring needs to answer include:

- Which marine mammals are present in the area? Is there a seal colony nearby that might be foraging at the site? Are there any Special Areas of Conservation close to the site?
- What is the distribution and abundance of species that are present?
- Does distribution and abundance change as a result of wind farm construction and operations (and later decommissioning)?
- Is the noise of construction, operations and decommissioning within acoustic thresholds?
- Do mitigation measures affect the animals?

Priority indicators for each stage (1. Planning; 2. Construction; 3. Operation; 4. Decommissioning) are:

- presence of cetaceans and pinnipeds to determine the extent of occurrence or distribution of each species and overall species diversity (1-4);
- presence and size of seal breeding colonies within an appropriate radius[3] of the OWE site (1-4);
- absolute or relative abundance of cetaceans and pinnipeds (1-4);
- habitat use by cetaceans and pinnipeds (1-4);
- anthropogenic noise levels (2-4).

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[3] The radius needs to be determined based on the known ecology and range of the target species. For example, studies suggest grey seals travel up to 40 km from a haul-out site to forage (McConnell et al., 1999).

Weighing up the various pros and cons and optimising efficiency and comparability across sites, it would seem that:

- Methods to be favoured should include: digital aerial surveys; static PAM.
- Methods to be used for more targeted studies when needed: telemetry; aerial-based and vessel-based observation surveys; towed PAM.
- Methods that are generally of less use across OWE sites: vantage point surveys (which are too reliant on close proximity to the coast).
- Methods to be explored and developed further: eDNA, satellite-based remote sensing (for larger cetaceans and potentially seal colonies at haul-out sites).

A summary of the main indicators for marine mammals, the monitoring methods used to monitor them, and examples of relevant protocols, are presented in **Table 5C**. Guidance across taxa and across methods that includes protocols for marine mammal monitoring in Europe is also provided by the German Federal Maritime and Hydrographic Agency (BSH, 2013), the Scottish government (Macleod et al., 2011), the government of Ireland's Department of Communications, Climate Action and Environment (2018a,b), and in various other publications (e.g., Johansen et al., 2012; Kemper et al., 2016). There are also some examples available from North America (e.g., Moulton & MacTavish, 2004).

Table 5C. Minimum monitoring requirements for marine mammals (cetaceans and pinnipeds) around offshore wind energy sites and associated grid infrastructure. One method or a combination of methods may be needed for each indicator. Monitoring frequency is presented as guidance but will need to be based on each survey design. While some data may need to be collected monthly in some sites, in others it may prove more effective and efficient to conduct more intense and more widespread surveys less often. Note that these are recommended minimum requirements for every site; each site will also need to monitor additional indicators based on the profile of the site and prevailing legal requirements. Phases of development are: 1. Planning; 2. Construction; 3. Operation; 4. Decommissioning.

Type of indicator and phase of development	Method and frequency	Examples of monitoring protocol options	Notes
Minimum			
Presence (extent of occurrence/distribution) (1-4) and species diversity (1-4) and relative or absolute abundance (1-4)	Digital aerial surveys (ideally every 1-2 months); if necessary, surveys of seal haul-out sites in breeding and moulting seasons)	German protocols (BSH, 2013). High-definition imagery for surveying seabirds and marine mammals: a review of recent trials and development of protocols (Thaxter & Burton 2009). Monitoring seabirds and marine mammals by georeferenced aerial photography (Kemper et al., 2016). Methods for monitoring marine mammals at marine renewable energy development (Thompson et al., 2014).	See birds (**Table 4D**).
	Static PAM using C-PODs Continuous	Methods for monitoring marine mammals at marine renewable energy development (Thompson et al., 2014). For porpoise monitoring in the Netherlands (van Polanen Petel et al., 2012).	
	Vessel surveys with towed PAM arrays As needed (every 1-2 months if digital aerial surveys not feasible)	Double-platform line transect methodology used in the SCANS (Small Cetacean Abundance in the North Sea) surveys (Borchers et al., 1998; Hammond et al., 2002, 2017; Laake & Borchers, 2004). Scottish PAM protocols (Sparling et al., 2011).	Also, methods for monitoring marine mammals at marine renewable energy development (Thompson et al., 2014).
Habitat use (1-4) (and/or connectivity to breeding colonies)	Telemetry	Scottish protocols (Sparling et al., 2011).	C-PODs can add data for this indicator.
Noise levels - (2-4)	Hydrophones	Hydrophones, as per Bailey et al. (2010) and BSH guidelines (2011) and EU monitoring guidance for underwater noise (Dekeling et al. 2014).	
When necessary (e.g., in proximity to Natura 2000 sites)			
Seal breeding colony counts	Digital aerial survey (breeding season)	See above for aerial	Drones may also be useful: see Wich & Koh (1998) and Raoult et al. (2020).

As part of the review, an analysis was conducted into guidelines on cetacean monitoring provided by three governments: Ireland, Germany and the UK (Annex 4). Although Ireland is not in the Baltic Sea or North Sea, the government provided similar levels of guidance in relation to OWE as the other two case studies chosen. The analysis demonstrates several trends found across the review in relation to the wide variability in methods proposed and the level of detail provided. These trends in marine mammal monitoring include:

- Most schemes use a wide variety of methods even for one taxon.
- The degree of specificity on how methods should be applied varies greatly, as does the amount of cross-referencing of source references for those methods.
- There are some similarities in approach and survey design (such as ways of conducting vessel-based surveys) but also many differences (such as whether or not to encourage a before-after control-impact design or a Before-After-Gradient design or assessing impacts; see section 9.3.5).
- Monthly surveys are recommended 2-3 years before construction and 3-5 years after operations begin.
- No agreement exists on the precise geographic scope of surveys, and how wide the buffer zone should be.

5.5 Research Needed to Improve Monitoring of Marine Mammals

In spite of a wide body of research on the impacts of OWE on marine mammals, further research is needed to better understand pressures and impacts and define monitoring needs and tools.

Research needed includes:

- Further testing and harmonisation of approaches to monitor marine mammals, especially radar, sonar and infrared imaging.
- Testing combinations of methods to optimise monitoring of multiple taxa using complementary tools.
- A better understanding of the impact of the noise and pollution generated by vessels, and the noise and hear from submarine power cables, on marine mammals and their prey, and how this needs to influence the choice of buffer zone around OWFs that should be monitored.
- Understanding how prey distribution and density affects marine mammal use of OWE sites, and the potential benefits of OWE sites to marine mammals due to reef and reserve effects.
- Testing and validating assessment tools that can be used to predict OWE impacts on the conservation status of marine mammals.
- Understanding the impacts of OWE decommissioning on marine mammals to identify any additional indicators that need to be monitored during this phase.

6. Monitoring Fish and Seabed Communities

Other than air-breathing organisms such as mammals and birds, the marine biodiversity that is potentially impacted by the development of OWE and associated grid infrastructure includes the organisms in the sediment (infauna) and on the sediment or submarine structures (epifauna, algae and seagrasses), the habitats they form, and the demersal (bottom-dwelling) and pelagic (open water) fish. Most of this underwater biodiversity is subject to similar pressures and are monitored from vessels using similar methods, so are treated here together. Organisms living in the water column such as plankton may also be affected, especially by pollution, though are not generally considered at risk from OWE and are not dealt with here.

6.1 Priority Pressures and Impacts

The main threat to underwater biodiversity is during the construction of the OWE towers and turbines and the placement of submarine power cables, when benthic species can be killed or displaced and habitats lost under the infrastructure (Boehlert & Gill, 2010; Perrow, 2019a; Bennun et al., 2021; Taormina et al., 2018). The type of turbine will affect the area impacted, with floating turbines expected to cause less disturbance to the seabed than bottom-fixed turbines. The area lost is usually relatively small and, if the project is properly planned, sensitive or threatened habitats can be avoided. However, other pressures are also associated with construction and operation. These include increased turbidity or suspended sediments caused by vessels, construction activity, or the wake from turbine towers which can cause the smothering of habitats, harming species such as corals and seagrasses. Sediment plumes can travel tens of kilometres (Taormina et al.., 2018). Hydrodynamic effects can also alter the demersal habitat or change water column conditions. Pollution or oil spills from construction activities or vessels can also threaten species and habitats (Saunders et al., 2011), as can invasive alien species brought into the area by vessels.

Underwater noise (especially from pile driving and other construction activity) is primarily a concern for marine mammals but may also put pressure on fish and benthic communities. For fish, noise can especially affect benthic species and those species that are hearing specialists, such as herring or cod (Bennun et al., 2021). The seismic pressure from sound waves can reduce survival of some species (Dahlgren et al., 2019). The EMF from submarine cables can also affect fish species with electroreceptors (sharks, rays, sturgeons and lampreys) and those that migrate (such as salmon and eels), although the effect may not be significant (Dahlgren et al., 2019; Taormina et al., 2018). Overall, there may be no large-scale effects of OWE and associated grid infrastructure on the diversity and abundance of demersal fish communities, although smaller scale changes in densities may occur (Bergstrom et al., 2013; Stenberg et al., 2015). Data are far scarcer on the potential impacts on benthic invertebrates (Taormina et al., 2018). Heat generated by submarine power cables is another potential pressure but has been studied very little.

Underwater structures and submarine power cables are usually colonised by hard-substrate benthic species including epifauna (e.g., bivalve molluscs, corals) and mobile macrofauna (e.g., worms, crustaceans). In turn, this reef effect can attract megafauna, such as decapod crustaceans and fishes (Reubens et al., 2014) and some studies suggest that, in general, fish abundance is elevated inside of offshore wind farms (Methratta & Dardick, 2019). The reef effect can be further enhanced by the reserve effect, where limited access to fishing and marine traffic in the OWF or around submarine power cables protects species and further increases numbers.

6.2 Priority Species and Habitats

Priority species can be considered to be those that are threatened, those sensitive to being impacted by OWE, or those that provide ecosystem services.

HELCOM (2021) identifies 55 species of invertebrates from a diverse array of taxa (from crustaceans to molluscs to starfish) that are priorities in the Baltic Sea. The OSPAR Commission (2008b) names only three invertebrate priorities for the North Sea: ocean quahog (Arctica islandica), dog whelk (Nucella lapillus) and flat oyster (Ostrea edulis).

Fish species that are considered regional priorities are listed in **Table 6A**. While it is difficult to mitigate impacts on specific fish species, any monitoring data collected on these species should be a priority for analysis and sharing.

Table 6A. Fish species listed as conservation priorities in the Baltic Sea (HELCOM, 2021b) and Greater North Sea (OSPAR Commission, 2008b), and their global conservation status as defined by the IUCN Red List of Threatened Species (IUCN, 2021a).

Common name	Scientific	IUCN Red List	HELCOM	OSPAR Commission
Common skate	Dipturus batis	CR	Yes	Yes
Gulf sturgeon	Acipenser oxyrinchus	NT	Yes	-
Spiny dogfish	Squalus acanthias	VU	Yes	Yes
Grayling	Thymallus thymallus	LC	Yes	-
European eel	Anguilla anguilla	CR	Yes	Yes
Porbeagle	Lamna nasus	VU	Yes	Yes
Ling	Molva molva	LC	Yes	-
Atlantic wolffish	Anarhichas lupus	DD	Yes	-
Maraene	Coregonus maraena	VU	Yes	-
Sea lamprey	Petromyzon marinus	LC	Yes	Yes
Thornback skate	Raja clavate	NT	Yes	Yes
Atlantic salmon	Salmo salar	LC	Yes	Yes
Atlantic cod	Gadus morhua	VU	Yes	Yes
Tope	Galeorhinus galeus	CR	Yes	-
Whiting	Merlangius merlangus	LC	Yes	-
Atlantic sturgeon	Acipenser sturio	CR	-	Yes
Allis shad	Alosa studio	LC	-	Yes
Portuguese dogfish	Centroscymnus coelolepis	NT	-	Yes
Leafscale gulper shark	Centrophorus squamosus	EN	-	Yes
Basking shark	Cetorhinus maximus	EN	-	Yes
Spotted Ray	Raja montagui	LC	-	Yes
Long-snouted seahorse	Hippocampus guttulatus	DD	-	Yes
Short-snouted seahorse	Hippocampus guttulate	DD	-	Yes
White skate	Rostroraja alba	EN	-	Yes
Angelshark	Squatina squatina	CR	-	Yes

A recent consultation of deep-sea scientists suggested ecosystem monitoring should prioritise large organisms (macro- and megafauna) living in deep waters and in benthic habitats (Danovaro et al., 2020). Species important for fisheries, such as cod, are often a priority for monitoring and research (e.g., Reubens et al., 2014). In the Baltic Sea (HELCOM, 2018b), typical species monitored are perch (Perca fluviatilis), flounder (Platichthys flesus) and cod (Gadus morhua), depending on the sub-basin. Perch is generally the key species in coastal fish communities in the less saline eastern and northern Baltic Sea (Sweden, Finland, Estonia, and Latvia), and in more sheltered coastal areas in Lithuania, Poland and Germany. In the more exposed coastal parts of the central Baltic Sea and in its western parts the abundance of perch is generally lower and flounder is used as the key indicator species. Cod is the representative species in the western and more saline parts of the region. Basking sharks are also often highlighted as priorities, and they can be monitored using methods employed for marine mammals (Macleod et al., 2011; Department of Communications, Climate Action & Environment, 2018).

Many of the habitats created by underwater species communities that are of greatest concern are those that provide ecosystem services, especially fisheries or coastal protection. These habitats include coral reefs, seagrasses, sand banks, salt marshes, oyster beds (or other bivalve mollusc beds), and wetlands (Bennun et al., 2021).

The OSPAR Commission (2008b) priority habitats for the North Sea are:

- coral gardens
- intertidal Mytilus edulis beds on mixed and sandy sediments
- intertidal mudflats
- littoral chalk communities
- Lophelia pertusa reefs
- maerl beds
- Modiolus modiolus beds
- Ostrea edulis beds
- Sabellaria spinulosa reefs
- sea-pen and burrowing megafauna communities
- Zostera beds.

Priority habitats can also be considered those that represent important areas for biodiversity. These include protected areas and community reserves, Natura 2000 sites, World Heritage sites, wetlands of global importance, Key Biodiversity Areas, priority ecoregions, biodiversity hotspots and critical habitats (areas of high biodiversity value with habitats important for threatened species or for endemic or restricted-range species or for unique or threatened ecosystems) (Stephenson & Carbone, 2021).

6.3 Current Monitoring Programmes

The regional seas action plans have a small set of indicators focused on fish, marine habitats and invertebrates that monitor:

- abundance or relative abundance of target taxa;
- presence (extent of occurrence/distribution) of target taxa;
- species communities/diversity;
- distribution or extent of benthic habitats;
- noise levels;
- pollution levels;
- invasive alien species.

The main indicators in use or under development regionally are presented in **Table 6B**. As apex predators, marine mammal abundance and distribution are key indicators of broader environmental status, including ecosystem function and food web integrity.

Table 6B. Regional indicators adopted by HELCOM and OSPAR related to fish and benthic faunal and floral communities. Note that some are still being tested and several other candidate indicators are in development (especially in the North Sea).

Indicator	Regional indicator	Notes
Fish abundance	HELCOM abundance of key coastal fish species	The abundance of typical species of fish, such as perch and flounder, in coastal areas to assess environmental status. Good status is achieved when the abundance is above a set site- and species-specific threshold value.
	HELCOM abundance of coastal fish key functional groups	The abundance of selected functional groups of coastal fish. As a rule, good status is achieved when the abundance of piscivores (i.e., fish that feed on other fish) is above a site-specific threshold value, and the abundance of cyprinids or mesopredators (i.e., mid trophic-level fish) is within an acceptable range for the specific site.
	OSPAR indicators FC1, FC2, FC3 and FW3 on fish and food webs	In early stages of implementation. The objective of the suite of indicators is to characterise fish communities in terms of their biomass, size structure and species composition (including demersal and pelagic communities) in order to link to pressure and food web functioning. Favours trawling data which may not be appropriate for OWE context. Groundfish and beam trawl survey data are loaded into the ICES DATRAS (Database of Trawl Surveys). https://datras.ices.dk/Data_products/Download/Download_Data_public.aspx
Plankton abundance	HELCOM Zooplankton mean size and total stock	Zooplankton community structure to determine whether it reflects good environmental status which is achieved when large-bodied zooplanktons are abundant in the plankton community.
	OSPAR changes in phytoplankton and zooplankton communities	A pilot OSPAR indicator
Habitat extent	HELCOM Distribution or extent of the benthic habitats	Not an official indicator but HELCOM has provided guidance on its measurement (HELCOM, 2015a).

Indicator	Regional indicator	Notes
Habitat condition	OSPAR Condition of benthic habitat communities	OSPAR is measuring habitat condition in certain parts of the North Sea https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/introduction/what-assessed/ Preliminary testing demonstrated that the indicator “is conceptually applicable to several habitat types and is sensitive to various pressure types” (OSPAR Commission, 2018b). The metric is an index of species composition and relative abundance combined with a measure of specific pressures. It complements other planned indicators but does not yet seem to be in active and widespread use.
Distribution of impulsive noise	OSPAR Distribution of reported impulsive sounds	Data are available for a limited number of countries and sound sources.
Presence of invasive alien species	OSPAR Trends in new records of non-indigenous species introduced by humans	Data are collated from records provided by countries.

The OSPAR Commission also collates data on trends in discharges, spills and emissions from offshore oil and gas installations and could presumably expand such an effort to include OWE. Both HELCOM and OSPAR aggregate data from the countries in their regions to assess indicators periodically (HELCOM, 2018b; OSPAR Commission, 2021). Fish data are probably more extensive than for other taxa. Invertebrate data are not considered separately, and tend to be dealt with as part of habitat quality or alien invasive species monitoring.

6.3.1 Pros and cons of the main methods used for monitoring fish and seabed communities

One of the main challenges to assessing marine biodiversity is the lack of consistent monitoring approaches (Przeslawski et al., 2019), and this review found a diverse array of methods that were not all applied in a consistent way, especially for fish and seabed communities. An example of the diversity can be demonstrated by the guidance for OWE monitoring in Germany. BSH (2013) offers the most extensive range of monitoring options for benthic fauna and flora and recommends:

- investigation of the sediment and habitat structure and their dynamics using side scan sonar;
- video survey of epifauna, macrophytes and habitat structure;
- grab sampling survey of infauna;
- beam trawl survey of epifauna;
- installation-based grab sampling survey of infauna;
- investigation of growth and demersal megafauna on the underwater construction structure;
- investigation of benthos and habitat structures in the context of installation of cable routes for connecting offshore wind farms.

Fish

Tools traditionally used to monitor fish presence and diversity include fyke-net fishing, where baited traps are set at a randomly selected series of fishing stations (Thoresson, 1996; Bergstrom et al., 2013; Dahlgren et al., 2019). The nets allow the trapping of live specimens, facilitating capture-mark-recapture studies that can help understand population health and dynamics. They tend to target smaller demersal and benthic species. Gill nets (e.g., demersal multi-mesh gillnets) can also be used (Stenberg et al., 2015), as can cage or pot fishing. In each case, the mesh size and length of net need to be chosen in relation to target species (HELCOM, 2015b).

Direct observation of the seabed fauna including fish can be conducted in some cases, either through scuba divers or through drop-down cameras or cameras attached to remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs) (Saunders et al., 2011; Edgar & Stuart-Smith, 2014; Reef Life Survey, 2019). Direct or camera observations are especially useful for mapping habitat cover, including reefs and mussel beds, as well as alien invasive species. Fish communities can also be monitored through digital video technology, either deployed through scuba divers (Goetze et al., 2019) or through baited remote underwater video or BRUV (Langlois et al., 2010; Santana-Garcon et al., 2014; Bouchet et al., 2018). BRUVs have been used successfully in some OWF systems (e.g. Griffin et al., 2016) and need to be more widely tested in temperate climates. Pelagic fish are also sometimes monitored with hydroacoustic methods, i.e., active acoustic monitoring (Hvidt et al., 2006; Krägefsky, 2014; Berger et al., 2020). Telemetry can be used to monitor the movement and behaviour of some fish species (Hussey et al., 2015), and has been used on larger species like cod around OWFs (Reubens et al., 2014; Dahlgren et al., 2019).

Invertebrates

There are several well-established methods for surveying and monitoring marine invertebrates (New, 1998) and broader benthic communities (BSH, 2013; HELCOM, 2015a). However, data on invertebrates is generally much less abundant than for vertebrates, especially in the marine environment. Reasons include: basic science on invertebrates is scarce and underfunded; most species are undescribed; the distribution and abundance of described species is mostly unknown; and species ways of life and sensitivities to habitat change are largely unknown (Cardoso et al., 2011).

Monitoring of invertebrates on the seabed around OWE will help increase data on the presence and abundance of poorly known species. Furthermore, studies over the last three decades have demonstrated that benthic organisms can be useful indicators of environmental status, as they respond predictably to various natural and human-induced disturbances (Thouzeau et al, 1991; Dauer, 1993; Ritter & Montagna, 1999; Muniz et al., 2005).

Benthic invertebrates can be sampled with a variety of grabs, mechanical devices that scoop up samples of the sea bed (Dahlgren et al., 2019; Box 6.1).

› Box 6.1: Benthic grab sampling.

Two examples: descriptions of grab sampling techniques provided by Scottish guidelines for the North Sea (Saunders et al., 2011) and HELCOM guidelines for the Baltic (HELCOM, 2015a).

USING A GRAB (SAUNDERS ET AL., 2011)

The primary method of establishing the biological community composition of sedimentary habitats is by recovering sediment samples using a grab. Grabs are lowered to the seabed from a stationary vessel and a sample is usually obtained by automatically or manually operating some form of mechanism that closes the jaws of the grab. A wide range of grabs have been developed with varying capabilities in terms of recovery of different sediment types, penetration depth, volume reproducibility and reliability. It is beyond the scope of this document to discuss the relative merits of each grab type and a more detailed review can be found in Eleftheriou and McIntyre (2005). The devices most frequently used for UK marine survey work are the van Veen grab, the Day grab and the Hamon grab. The van Veen grab is acknowledged as a good all-round option and has been adopted as the standard by some organisations, notably for benthic surveys in the Baltic Sea. It is simple and quick to deploy and its long lever arms provide a substantial jaw closing force, but they also make it cumbersome to manoeuvre on a ship's deck and will sometimes cause it to be pulled onto its side before closing if the vessel is drifting.

The pattern of grab deployment and survey design will largely depend on the expected extent and distribution of sediment habitats within the survey area, together with the degree of biological importance attributed to them. This information should be initially supplied by the acoustic mapping and supporting drop-down video data.

A STANDARD SIMPLIFIED METHOD FOR BENTHIC GRAB SAMPLING AS DESCRIBED IN THE HELCOM COMBINE MANUAL (HELCOM, 2015A).

This grab method was first developed for mapping and spatial modelling purposes, when a large number of samples distributed over an area are needed. The purpose is to facilitate collection of large datasets at a minimum cost as well as to sample areas too shallow for large vessels. In that sense the aim is similar to drop-video which is used as a time and cost-effective alternative to diving (where diving is a more exact method, which provides higher taxonomic resolution but also is more expensive and time consuming). The method compared well to the standard (large grab) method along the Swedish south coast and in the Hanö Bight but not in Øresund and Kattegat. The applicability of this method in different areas will depend on species composition and heterogeneity since both sample area and penetration depth are smaller than with the larger grab used in the standard method. The applicability of this method in the actual monitoring area should be tested before it is used in monitoring of the area.

Simplified grab method is based on the use of small Van Veen grab (sample area 0.025 m2) instead of the standard Van Veen grab (sample area 0.1 m2). This method may be performed from small vessels and require a minimum of crew and time. The method has been successfully performed in combination with a drop-video survey from a vessel of six m length and a crew of three people (two is the minimum).

Analyses of samples collected by grab sampling can include comparing the presence or abundance of different species and using different indices. For example, the polychaetes/amphipods ratio has been tested for monitoring major changes in benthic communities in response to a wide variety of different human pressures (oil spills, urban sewage outfalls, enrichment in organic matter, etc.) in estuarine and coastal environments and is used in 23 countries mainly in Europe, based on the fact that polychaetes are more tolerant and opportunistic species and amphipods are sensitive taxa (Dauvin, 2018). Indices like the Marine Biotic Index (Borja et al. 2000; Muniz et al., 2005) and the Benthic Quality Index (Rosenberg et al., 2004) could also be used, though it is essential to narrow down the indices options to identify the most useful and successful (Borja et al., 2009).

Routine assessments of macrobenthic invertebrates have been carried out using almost exclusively morphology-based approaches for species identification. This is a time-consuming and skill-dependent approach, which has resulted in low-throughput in processing biomonitoring samples. However, eDNA metabarcoding offers possibilities to more rapidly and more thoroughly assess the presence of species (Lobo et al., 2017). There is growing evidence that eDNA can be used to assess fish species richness and relative abundance in marine environments (e.g., Afzali et al., 2020; Berger et al., 2020; van Bleijswijk et al., 2020), and the diversity and distribution of other organisms, including bacteria and invertebrates, as well as marine food webs (Goodwin et al., 2017; Taberlet et al., 2018; Leduc et al., 2019; Zhang et al., 2020). However, there is urgent need for more standardisation of sampling protocols (Lacoursière-Roussel et al., 2018) and improvements in DNA reference databases for aquatic species (Weigand et al., 2019).

Ecoacoustics, the use of acoustic monitoring to track the marine soundscape, is also an option to explore further, especially for fish and crustaceans (e.g., Pieretti et al., 2017). Light traps have also shown promise in sampling at least 12 phyla of benthic and planktonic animals, and 13 orders of crustaceans (McLeod & Costello, 2017) and should be explored more in future as well.

› Threats

Invasive alien species are species that are introduced, accidentally or intentionally, outside of their natural geographic range and that become problematic. Marine IAS come from a wide variety of taxa, and may include bivalve molluscs, algae, sea squirts, tunicates, bryozoans, polychaetes, fish and many more forms of life, especially sedentary or sessile invertebrates. The monitoring of species that colonise OWE and grid infrastructure is therefore essential to evaluate the introduction and spread of IAS. Species of particular concern in a given project site that will need to be searched for and monitored can be identified through relevant regional or global databases. Examples include the European Alien Species Information Network (EC, 2021) and the IUCN Global Invasive Species Database (IUCN, 2021b). Many IAS will be detected through the monitoring methods used for the abundance and diversity of species or the area of habitat. However, some additional methods are also useful for certain taxa. Vessels can introduce IAS, and the monitoring of hulls can provide an early warning of invasions (Gewing & Shenkar, 2017), with scrape samples and niche area inspections by divers the most efficient methods to detect species on hulls (Peters et al., 2019), although ROV-mounted cameras can also be used. Settlement plates (made of material such as PVC and suspended in the water) have long been used as a means of studying the species diversity and abundance of sessile IAS (Marraffini et al., 2017). Diver transect or quadrat surveys of potentially affected habitats will also be needed to identify IAS from multiple taxa (Otero et al., 2013), using hand corers to sample benthic infauna as necessary. Environmental DNA techniques can be used to detect the presence of alien invasive species (Mauvisseau et al., 2020; Pearman et al., 2020) and should be further tested in marine environments. Most existing protocols for IAS surveys are based on coastal structures such as harbours and marinas, as applied to some surveys in the North Sea (e.g., Gittenberger et al., 2010; Buschbaum et al., 2012; Rohde et al., 2017). However, some of the methods and protocols adopted jointly by HELCOM and OSPAR for monitoring IAS brought into ports by ballast water (HELCOM/

OSPAR, 2013), as well as the HELCOM protocol for the Baltic Sea (HELCOM, 2013b) could be applied to some OWE and associated grid infrastructure.

Sound and vibrations from OWE construction and operations and the laying and use of submarine power cables may also affect fish and benthic communities and should be monitored for the impacts on these taxa. As discussed under mammals, systems deploying static PAM devices could also help monitor anthropogenic noise. Oil spills can be monitored by direct observation, or by aerial surveys or satellite-based remote sensing (Ferraro et al., 2009; Li et al., 2017).

› Habitat extent and composition

Habitats are usually assessed in the pre-consent planning phase of OWE development during EIAs, but should be monitored periodically. HELCOM (2015a) proposes monitoring habitat extent by using benthic grab sampling, complemented with direct observation through the use of scuba divers and drop-down video, as has been used in several places including Estonia (Martin et al., 2013). Other methods for habitat monitoring include acoustic mapping and cameras deployed on remotely operated vehicles ROVs (Saunders et al., 2011) or on autonomous underwater vehicles (Monk et al., 2018). The main indicator used to monitor habitats is habitat cover (or extent), often combined with some measure of habitat quality (or condition), which may relate to species diversity (see, e.g., Stephenson & Carbone, 2021). The other key aspect of habitat surveys is to identify key habitats, or areas important for biodiversity (see section 6.2). These need to be identified so that they can be avoided or impacts on them mitigated.

Drop-down video or photography is suitable for quickly characterising a large area and the method of choice for ground-truthing acoustic mapping data. Specific types of vessel characteristics are ended to use drop-down video (Holt & Sanderson, 2001). Drop-down video or photography can provide valuable documentation on the presence, abundance and distribution of epibenthic species and presence and extent of habitats, while also supporting other survey tasks such as identifying how sediment and other substrata are distributed, thus contributing to the design and probable effectiveness of, for example, a subsequent grab sampling strategy. A remotely operated vehicle can essentially be considered as a technically complex drop-down system, but with the added ability to navigate to, and examine, specific targets on the seabed. Autonomous underwater vehicles are one step more independent, having no cables attached to the survey vessel.

6.4 Priority Indicators, Methods and Protocols for Monitoring Fish and Seabed Communities

The key questions that need to be answered through the monitoring of fish and seabed communities include:

- Which marine species and habitats occur in the area before and after construction?
- How abundant are the fish populations and how diverse in terms of size and community composition?
- What are the effects of construction activities (and later decommissioning activities) on species and habitats?
- What is the level of noise caused by construction and operations (and later decommissioning activities)?
- What is the distribution and abundance of invasive alien species?

Priority indicators for each stage (1. Planning; 2. Construction; 3. Operation; 4. Decommissioning) are:

- abundance or relative abundance of target taxa (1-4);
- presence of target taxa to determine the extent of occurrence or distribution of each species and overall species diversity (1-4);
- area (distribution or extent) and quality of benthic habitats (1,2,4);
- noise levels (2-4);
- pollution levels (2-4).

Weighing up the various pros and cons of the main methods used for monitoring fish and seabed communities (Annex 5), and optimising efficiency and comparability across sites, it would seem that:

- Methods to be favoured should include: grab sampling and video (drop-down/ROV/AUV) for habitats and benthic species; fyke-net sampling for fish (and possibly BRUVs).
- Methods to be used for more targeted studies when needed: scuba diving for all species as needed; telemetry for fish; acoustic mapping of the seabed habitats.
- Methods that are generally of less use across OWE sites: fishing with more destructive methods, such as beam trawls.
- Methods to be explored and developed further: eDNA and ecoacoustics (for all taxa), BRUVs (for fish and crustaceans), and light traps (benthic invertebrates).

A summary of the main indicators for fish and benthic communities, the monitoring methods used to monitor them, and examples of relevant protocols, are presented in **Table 6C**. Guidance across taxa and across methods that includes protocols for fish and benthic fauna and flora in Europe is also provided by the German Federal Maritime and Hydrographic Agency (BSH, 2013), the Scottish government (Saunders et al., 2011), the government of Ireland’s Department of Communications, Climate Action and Environment (2018a,b), and in various other publications (e.g. Pohle & Thomas, 2001). Use of all types of video methods is reviewed by Mallett & Pelletier (2014). Benthic and pelagic marine monitoring methods are also discussed in detail in Australian reviews and protocols (e.g., Bouchet et al., 2018; Przeslawski & Foster, 2018).

Table 6C. Minimum monitoring requirements for fish and benthic fauna and flora around offshore wind energy sites and associated grid infrastructure. One method or a combination of methods may be needed for each indicator. Monitoring frequency is presented as guidance but will need to be based on each survey design. Note that these are recommended minimum requirements for every site; each site will also need to monitor additional indicators based on the profile of the site and prevailing legal requirements. Phases of development are: 1. Planning; 2. Construction; 3. Operation; 4. Decommissioning.

Type of indicator and phase of development	Method and frequency	Examples of monitoring protocol options	Notes
Minimum			
Presence (extent of occurrence/distribution) (1-4) and species diversity (1-4) and relative or absolute abundance (1-4)	Fyke-net fishing based on catch per unit effort (Annual?)	Take account of HELCOM (2015b) coastal fish monitoring guidance. BSH (2013) proposes beam trawls to survey macro-benthos and demersal fish.	Also consider Swedish guidance on methods for monitoring of coastal fish communities (Thoresson, 1996).
	Fish surveys using BRUVs (Annual?)	Marine sampling field manual for pelagic BRUVS (Bouchet et al., 2018a).	Griffin et al. (2016) used BRUVs for fish and crabs around an OWF.
	Grab sampling (grab to be chosen based on habitat type; Van Veen grab generally favoured) (Annually – in autumn?)	Scottish protocols (Saunders et al 2011), Recommendations and Guidelines for Benthic Habitat Monitoring (HELCOM, 2015a).	Take account of OSPAR (2018b) guidance on monitoring benthic habitat communities; BSH (2013) proposes baseline for infauna survey set in the autumn
	Video (deployed as drop-down or by ROV or AUV) (Annual?)	Field manual for autonomous underwater vehicles (Monk et al., 2018). Scottish protocols for drop down video and ROVs (Saunders et al 2011).	Video survey of epifauna, macrophytes and habitat structure proposed for every autumn by BSH (2013). AUV methods also in Bridge et al. (2011).
	Divers (When and where needed)	Scottish protocols for various diver methods (Saunders et al 2011). Use of stereo video (Goetze et al., 2019) Reef fish survey protocols (Reef Life Survey, 2019)	BSH (2013) proposes divers survey macrophytes, macrobenthos and demersal megafauna growing on underwater OWE structures in 3rd and 5th years of operation,
Habitat extent and quality (1-4)	Grab sampling (Annually)	Scottish protocols (Saunders et al 2011). Recommendations and Guidelines for Benthic Habitat Monitoring (HELCOM, 2015a).	Take account of OSPAR (2018b) guidance on monitoring benthic habitat communities; BSH (2013) proposes baseline for infauna survey set in the autumn

Type of indicator and phase of development	Method and frequency	Examples of monitoring protocol options	Notes
Habitat extent and quality (1-4)	Video (deployed as drop-down or by ROV or AUV); divers can also be used as above. (Annually in summer months - as per Irish standard)	Field manual for autonomous underwater vehicles (Monk et al., 2018). Scottish protocols for drop-down video and ROVs (Saunders et al 2011).	Also see: Identifying biotopes using video recordings (Holt & Sanderson, 2001) and relevant ISO standards on marine habitat sampling (ISO, 2007, 2014).
	Acoustic mapping (Annually if needed)	Hydrographic survey standards (IHO, 2008).	
Invasive alien species (1-4)	Underwater surveys (Annually)	Settlement plates (Marraffini et al., 2017). Habitat and species surveys (HELCOM, 2013b; HELCOM/OSPAR, 2013; Otero et al., 2013).	
	Vessel hull surveys (Several times per year?)	Inspections and scrape sampling (Gewing & Shenkar, 2017; Peters et al., 2019).	
Noise levels (2-4)	Hydrophones (During periods of OWF construction and operations)	Hydrophone use as per Bailey et al. (2010) and BSH guidelines (2011) and EU monitoring guidance for underwater noise (Dekeling et al. 2014).	
Number and/or area of oil spills (2-4)	Aerial surveys (Several times per year or at periods of peak risk i.e., peak vessel traffic)	Monitoring of oil spills as per Ferraro et al. (2009) in European seas	Could adapt existing HELCOM (2018c) oil spill indicator. Satellite-based remote sensing (sensu Li et al., 2017) when spills large enough

6.5 Research Needed to Improve Monitoring of Fish and Seabed Communities

The impacts of OWE and grid infrastructure, especially submarine power cables, on fish and seabed faunal and floral communities is not as well understood as it is for marine birds and marine mammals. Many of the questions being asked 20 years ago about the impacts of OWE on benthic communities (Gill & Taylor, 2001) are still relevant today.

Key research topics include:

- Use surveys and monitoring programmes around OWE to help fill shortfalls in invertebrate knowledge.
- Continue to explore the impacts of electromagnetic fields and noise on fish and benthic invertebrates, and gain a better understanding of the impacts of submarine power cables.
- Test the use of more recent monitoring techniques in the context of OWE, especially eDNA and ecoacoustics (for all taxa), BRUVs (for fish and crustaceans), and light traps (benthic invertebrates).
- Work to improve DNA reference databases for marine species to facilitate more widespread use of eDNA methods for monitoring.

7. Using Existing Data Sources for Biodiversity Monitoring

While every OWE operator will need to monitor biodiversity around the site, experience from conservation projects (e.g., Stephenson et al., 2015) demonstrates that in situ data can often be complemented by data from other sources. This section explores the existing databases with relevant marine biodiversity data, how they are used for monitoring or assessments, and how their use could be enhanced. Since there is no clear typology distinguishing data sets, databases, data portals and other forms of data, the term data source is used (sensu Stephenson & Stengel, 2020).

7.1 National Data Sources of Potential Use

As described in the sections above, HELCOM and OSPSAR nations are already monitoring some biodiversity indicators. These data are usually stored in national databases, which may be managed by governments, universities or NGOs. At the moment, these data sources are diverse and often unconnected. Some countries will have multiple data sources for certain taxa depending on who collects the data and how, and where they decide to store it. For example, BirdLife International identified 183 data sources for birds in 12 Baltic and North Sea countries (Piggott et al., 2021). These data sources covered anything from a single species to all seabirds, with data that had a temporal range of one year to over 40 years. Other national databases used for regional assessments include MUMM (Management Unit of the Mathematical Model of the North Sea) by the Royal Belgian Institute of Natural Science, the JNCC Offshore Wind Strategic Monitoring and Research Forum data in the UK, and data used in applying the Symphony marine spatial planning tool in Sweden. In the UK, the Crown Estate (2021) has also established a Marine Data Exchange website to provide access to survey data and reports collected on offshore renewables. Many national data sources have information on species distribution and relative abundance (especially for marine mammals and marine birds) that is of potential use to OWE sites, especially during the pre- and post-consent survey and development phases.

7.2 Regional Data Sources of Potential Use

Several data sources collate biodiversity information from within specific sea basins (e.g., HELCOM and OSPAR data management systems) or from across Europe (e.g., EurOBIS, EMODnet). A selection of such regional data sources is presented in **Table 7A**. As with national data sources, many of these regional data sources have information on species distribution and relative abundance (especially for marine mammals and marine birds) that is of potential use to OWE sites, especially during the pre- and post-consent development phases. Several of these regional data sources are linked directly to, and share data with, global data sources. For example, data from EurOBIS (European Ocean Biodiversity Information System) feeds into OBIS (Ocean Biodiversity Information System) which is itself linked to GBIF (Global Biodiversity Information Facility). However, there are no defined mechanisms for ensuring data collected during OWE surveys or monitoring are integrated into these data sources.

Table 7A. A selection of regional data sources of potential use in monitoring marine biodiversity around OWE sites. URLs provided for each data source.

Data source	Lead agency	Description
EurOBIS - European Ocean Biodiversity Information System	Flanders Marine Institute (VLIZ)	Distribution data on marine species, collected within European marine waters or collected by European researchers outside European marine waters. Over 1,000 data sets. Linked to OBIS and GBIF.
EMODnet Biology Data Portal	JNCC ICES Data Centre	Ship and aerial at-sea survey data from national parties covering seabird and marine mammal distribution in offshore areas. Over 3 million records of seabirds, cetaceans, pinnipeds, and other marine megafauna from NW European and North Atlantic waters. Largest database of at-sea seabird distributions, with data collected and contributed by the 10 European countries comprising the ESAS partnership.
HELCOM's Map and Data Service	HELCOM	Contains all geospatial data relevant for HELCOM work from status assessments to shipping density maps. Contains various functionalities for viewing datasets.
ICES Data Portal	International Council for the Exploration of the Sea (ICES)	Datasets are organised around specific thematic data portals. The biodiversity database hosts seabird and seal abundance and distribution records and is linked to ICES working groups on seabirds and marine mammals.
SEATrack database	SEAPOP: SEAbird POPulations project	Global location sensor data on the non-breeding distribution of 10 seabird species breeding in colonies encircling the Labrador, Greenland, Barents, Norwegian, North and Irish Seas, which includes colonies in Canada, Greenland, Russia, Norway (incl. Svalbard and Jan Mayen), Iceland, the Faroe Islands, Ireland, and the United Kingdom.

Data source	Lead agency	Description
Marine Ecosystems Research Programme – Top Predator Project	Bangor University	Cetacean and seabird data were collated from aerial and vessel-based surveys in the northeast Atlantic from 2.19 million km of cetacean transects and 1.36 million km of seabird transects. Species densities mapped for the 12 most common seabirds and the 12 most common cetacean species, at 10 km and monthly resolutions over 32 years.
OSPAR's Data & Information Management System	OSPAR	A platform for accessing OSPAR's geospatial maps, data and metadata. Includes datasets on habitats, marine ecosystems and several pressures, though nothing on species populations.

7.3 Global Data Sources of Potential Use

There are over 140 global data sources of potential use in monitoring biodiversity (Stephenson & Stengel, 2020), of which about 16 are of potential use for assessing or monitoring OWE sites (**Table 7B**). Many of these data sources collate information on the distribution and status of marine habitats and species, or the movement of species, and have at least some data of high enough spatial or temporal resolution to assess status or trends. However, most are still more useful for coastal and inshore areas, with offshore areas less well covered. In addition, the WREN Knowledge Base (Tethys, 2021) shares over 3,600 documents related to the environmental effects of land-based and offshore wind energy, many of them geotagged and viewable on a map viewer function. Many of the papers in the database include data that may be of use for monitoring.

Table 7B. A selection of global databases of potential use in monitoring marine biodiversity around OWE sites. Adapted from Stephenson & Stengel (2020).

Data source	Lead agency	Description
Aqua Maps	FishBase and SeaLifeBase	Generates model-based, large-scale predictions of natural occurrences of marine and aquatic species. Derived from GBIF, OBIS, FishBase, SeaLifeBase & AlgaeBase.
Birdlife Datazone	BirdLife International	Distribution and abundance of bird species worldwide, mostly presented as content of IUCN Red List. Population data only show general trend (as per Red List). Distribution maps need to be requested.
Ecologically or Biologically Significant Marine Areas	Secretariat of the Convention on Biological Diversity	As with KBAs and protected areas, the use of these area in monitoring is to identify sites of importance for conservation.
FishBase	FishBase consortium	A global biodiversity information system on finfishes: taxonomy, biology, trophic ecology, life history & uses, and historical data going back 250 years. Now has a BRUV data portal.

Data source	Lead agency	Description
Global Biodiversity Information Facility	GBIF	Houses over 1.6 billion species occurrence records from over 54,600 data sets (as of October 2020).
Global Marine Environment Datasets – GMED	GEOBON	Climatic, biological and geophysical environmental layers of both present day, past and future environmental conditions. For use with species distribution modelling software like Maximum entropy (MaxENT) and for any other marine environment visualisation exercise.
International Waterbird Census Database	Wetlands International	Current and historic estimates, trends and 1% thresholds for over 800 waterbird species and 2,300 biogeographic populations worldwide. More than half the effort for the annual census is concentrated in Europe and includes North Sea and Baltic Sea nearshore and inshore areas.
IUCN Red List of Threatened Species	The Red List Partnership – 10 organisations led by IUCN	Extinction risk of species with data on range, population trends, habitat use, life history traits, use and trade, threats, conservation actions currently in place and conservation actions needed.
Movebank	Max Planck Institute for Ornithology	Animal tracking data. Seabird tracking data can be searched and relevant data holders contacted to request access.
Ocean Biodiversity Information System – OBIS	Intergovernmental Oceanographic Commission of UNESCO	Huge global database on marine species linked to GBIF. Over 164 million records of over 137,000 species from more than 3,300 datasets (as of October 2020).
OBIS-SEAMAP	Duke University	Spatially referenced database aggregating marine mammal, seabird, sea turtle and ray & shark observation data.
Ocean Data Viewer	UNEP-WCMC	Includes data on global patterns and predictors of marine biodiversity across taxa and several species richness and cetacean distribution maps.
Ocean+ Library	UNEP-WCMC	An overview of global marine and coastal datasets of biodiversity importance.
Ocean Tracking Network Data Portal	Dalhousie University, Canada	Data from the tracking of aquatic animals

Data source	Lead agency	Description
Seabird Information Network	Seabirds.net	A list of databases on sea birds.
Seabird Tracking Database	BirdLife International Seabird Tracking Database	Serves as a central store for seabird tracking data from around the world and holds the largest collection of seabird tracking data (breeding, non-breeding, and foraging ranges; distribution data)

7.4 Summary of Challenges and Opportunities for Using and Sharing Biodiversity Data from Offshore Wind Energy

There are a number of national, regional and global data sources of potential use in assessing or monitoring biodiversity at OWE sites. Data are more abundant for the distribution and density of marine birds and marine mammals than for other taxa. Such data can help support not only site-based planning but also seascape-level marine spatial planning, as well as enhance the study of cumulative impacts. There are large differences in the way data are presented, the level of data access, and the indicators the data can measure. The spatial and temporal scale also varies, so that the level of resolution is often not adequate to make any informed decisions in relation to a given site. Even around the Baltic Sea and North Sea, countries do not have a consistent data collection format and the means of sharing data on all aspects of biodiversity related to regional plans. While some data sources are probably already consulted by agencies in the planning phase of OWE sites, there is no mechanism to ensure data generated by EIAs, SEAs and ongoing OWE monitoring is fed into national, regional or global data sources. In general, most data generated by the OWE sector seems to remain in reports and is difficult to find.

These findings reflect broader trends in biodiversity monitoring schemes and databases which often have taxonomic and geographic biases and data access limitations (Amano et al., 2016; McRae et al., 2017; Troudet et al., 2017; Stephenson & Stengel, 2020; Moussy et al., 2021). A recent review of European biodiversity data sets found only about one third of data providers offers unrestricted data access (Wetzel et al., 2018). Failure to follow data management best practices is also a common blockage to data sharing (Wilkinson et al., 2016; Stephenson & Stengel, 2020). Another prerequisite for data sharing and aggregation is the use of common scalable indicators (Stephenson, 2019; Stephenson & Carbone, 2021).

Nonetheless, opportunities exist that can be built on to enhance data sharing. Factors that provide a suitable enabling environment include the existing regional efforts to set common indicators and collate data through HELCOM and OSPAR. There are also efforts to standardise data collection formats for Europe through EurOBIS and EMODnet. If common data standards are applied more widely, data could then be aggregated or disaggregated at multiple levels, and also linked across databases in the way EurOBIS links to OBIS and GBIF. A similar level of effort to use common data collection protocols and share data needs to be applied to the OWE sector, as advocated by several authors (e.g., Fox et al., 2006; Bennun et al., 2021), but this will require some form of coordination and leadership to make it happen. Some examples exist of biodiversity data from OWE developments being shared in countries such as Australia, Belgium and Canada (see Bennun et al., 2021), and these efforts should be built on to create a culture within the OWE sector for data sharing. Furthermore, opportunities should be examined for increasing the scope and use of other existing information sharing platforms, such as the WREN Knowledge Base (Tethys, 2021) and the Marine Data Exchange (Crown Estate, 2021).

8. Summary of Key Findings and Conclusions

8.1 Pressures and Priority Species

The pressures placed by OWE and associated grid infrastructure on biodiversity are commonly agreed but differ between taxa. The level of understanding of the scale and severity of impact also varies. There is still inadequate understanding of many key pressures and impacts such as, for example, bat collision risks, the effects of EMF, and the cumulative impacts placed on species by multiple wind farms and multiple anthropogenic pressures. The impacts of submarine power cables are less well understood than the impacts of the turbines and towers.

Existing monitoring efforts focus primarily on marine mammals and marine birds, and to some extent on benthic fauna and flora, which is appropriate given the known impacts. Some taxa that do not seem significantly affected in a negative way in both the Baltic Sea and North Sea (e.g., marine turtles and whales, which are not common) may be less important for regular monitoring.

Monitoring needs to be adapted depending on the phase of OWE development to take account of the different impacts on different taxa. For example, surveys at the planning stage rely more on data on the presence of threatened or sensitive species and habitats; the construction phase has bigger impact on habitats, mammals and fish; operating wind farms have bigger impacts on birds; and the decommissioning phase is still relatively new and less well understood.

Conclusions include:

- Although national regulations will dictate precisely what taxa and pressures are monitored, overall, there should be a more concerted approach to focus on those species most impacted by OWE, namely marine birds, seals, small cetaceans and the benthic fauna and flora (infauna and epifauna). Bats may also need to be added to this list if more evidence emerges of negative impacts. Other taxa such as marine turtles and whales should probably be the focus of research, surveys or targeted monitoring only to meet an identified need.
- Therefore, monitoring across all stages of development should focus on the measuring regularly the abundance, distribution and behaviour of marine birds and marine mammals. The benthic and demersal habitats and species should be more of a focus in planning and then measured every few years. Pre-consent surveys will need to factor in relevant national legislation and expectations for EIAs, but should include an assessment of fish and benthic invertebrates, and the proximity to, and extent of, priority habitats and Natura 2000 sites.
- More detailed research and surveys are also often needed to address site-specific or species-specific questions.

8.2 Indicators and Monitoring Methods

Relevant regional indicators are in place for the Baltic Sea (through HELCOM) and the North Sea (through the OSPAR Commission), but they are different. Indicators at OWE sites are not always clearly defined and not always the same, hampering comparisons and data aggregation. Even for regional sea basin indicators, data collection takes place at the national level, with little regional co-ordination. As a result, regional assessments have many data gaps.

The main indicators relevant to all OWE sites are: species abundance and distribution, some key species behaviours (e.g., bird and bat flight height) and some key pressures (especially impulsive noise). There are numerous methods available to monitor marine biodiversity around OWE, mostly based on terrestrial, vessel-based and aerial surveys, direct sampling (with nets and grabs), and use of relevant technology, including digital video cameras, various types of passive acoustic monitoring devices, and cameras and sensors deployed through ROVs or AUVs.

Guidance on each method, and details of protocols for applying each one to the OWE context, is inconsistent and not always very easy to find (many of the more useful protocols lie buried in EIAs, project reports and consultancy reports). Each method has a suite of pros and cons, and most are biased towards certain taxa, but there is little clear guidance on how to prioritise their use or which ones to favour for a given monitoring need. Indeed, some national protocols tacitly or explicitly encourage the use of a wide range of diverse methods. Different methods applied differently will make data hard to compare or aggregate across sites and across regions.

The level of detail available for each methodology varies, but tends to lay out options by taxon, focusing on mammals and bird separately, fish and benthos separately. In turn, the monitoring programmes are implemented by taxonomic focus and the data aggregated by taxon. As one expert put it: “Mitigation and monitoring is by receptor; it is not joined up” (Dr Paul Thompson, personal communication). This can add to confusion and inefficiencies, as well as some logistical problems (multiple surveys at one OWE site, competition for aircraft or vessel rental, etc).

Most of the more detailed sector-specific monitoring protocols pre-date recent advances in technology meaning they do not include much or any guidance on using tools such as digital aerial surveys, radar, infrared, and multi-sensor arrays. Many existing monitoring protocols have been developed using consultative processes (e.g., Thaxter & Burton 2009) but international, regional-level consultation and method harmonisation remain weak.

Threat monitoring regionally and at OWE sites focuses almost entirely on the impulsive noise generated by pile driving during construction, and bird collisions with turbines during operations. Pollution such as oil spills, and vessel, turbine and submarine power cable noise (and in some cases heat) are largely neglected.

The German StUK standard (BSH, 2013) is probably the most comprehensive guidance available on monitoring the phases of an OWE development, but it may not be applicable in all contexts, especially where consenting systems differ (such as in the UK). Many people have advocated that the use of the same methods for marine monitoring, especially in the context of OWE, is not ideal. Methods need to be flexible to take account of local needs and target species, and rapidly evolving technological tools. However, the methods themselves are not standardised, with different protocols used in different countries. For example, birds on one side of the North Sea may be counted differently to those on another side.

There have been calls to establish marine monitoring systems with consistent and standardised methods that facilitate data aggregation and data sharing across regions (e.g., EU, 2008), but systems are not yet in place regionally or in the OWE sector.

Conclusions include:

- A small set of common core state and pressure indicators should be adopted that are measured in all OWE sites to allow comparisons and aggregation. These should focus on species distribution and abundance and key pressures.
- The current approach – addressing the needs to taxa separately using a wide variety of unharmonised and unstandardised methods – needs to be changed. A more focused, harmonised and

integrated approach needs to be taken to monitor multiple priority taxa in a holistic way using a small set of the most effective methods and protocols.

- Wider scale collaboration is needed across borders to develop harmonised approaches.
- Monitoring methods that are potentially of most use to standardise across the sector include digital aerial surveys, static passive acoustic monitoring (C-PODs and devices fitted to rotor jackets, perhaps as part of multi-sensor arrays), different forms of underwater video (drop-down/ROV/AUV/BRUV), grabs and fyke-net fishing, complemented by targeted project-specific or species-specific vessel-based surveys, scuba diver surveys, towed PAM, and telemetry.
- Threat monitoring needs to be more consistent and longer term, especially noise and pollution levels.
- Common principles should be adopted in the design and implementation of biodiversity monitoring schemes for OWE; draft ideas are presented in section 9.

8.3 Data Sharing

While several national, regional and global data sources are of use in some OWE site assessments or monitoring schemes, data sharing is not systematic for marine biodiversity in general and for the OWE sector in particular. Many data collected around OWE sites are kept in reports, many of which are not shared or are difficult to find or access. While systems exist for standardising data collection so as to facilitate data sharing, these are not yet used widely. Lack of data sharing inhibits the information that can be accessed by EIAs or monitoring teams in the same or similar areas, and also reduces more in-depth research into cumulative impacts.

Conclusions include:

- Reports from EIAs and SEAs that assess OWE sites, and reports generated by ongoing biodiversity monitoring systems around planned and operational sites, should be published and posted online to disseminate lessons and trends; a common report-sharing platform should be agreed by key stakeholders. This should learn from and build on existing knowledge-sharing platforms such as the Tethys WREN Knowledge Base and the Crown Estate's Marine Data Exchange.
- Data standards need to be adopted to facilitate the sharing of data with national, regional and global data sources, and through platforms such as EurOBIS and EMODnet. This will allow wider contributions to EIAs in other sites as well as cumulative impact studies. Links to global databases such as OBIS and GBIF will further add value and usefulness to the data collected.

9. Recommendations: Towards an Integrated Approach to Biodiversity Monitoring Around Offshore Wind Energy Installations and Grids

A more integrated approach to biodiversity monitoring needs to be developed for the OWE sector, using multiple, harmonised systems and tools to monitor multiple species and pressures concurrently. While precise survey and monitoring needs at a site, and the methods used, will depend on environmental conditions and legal frameworks, the use of a more standardised approach across the sector, with at least some common indicators and common monitoring methods used at each site, will greatly help to compare sites, aggregate data, and study cumulative impacts, as well facilitating results-based decision-making.

The findings and conclusions of the review led to the identification of five key recommendations for biodiversity monitoring in the OWE sector:

1) Adopt common core indicators.
2) Use harmonised monitoring methods and standardised protocols in integrated systems.
3) Adopt a set of key monitoring principles and approaches, focused on:
    - best practice for indicator development;
    - choosing methods based on indicators and monitoring questions;
    - defining the appropriate scope and spatial and temporal scale;
    - engaging key actors;
    - designing fit-for-purpose monitoring programmes;
    - and collating data in standard formats to facilitate data sharing.
4) Conduct research to improve monitoring focus and effectiveness.
5) Enhance regional and sectoral collaboration on standardising monitoring protocols and data collection formats to facilitate data sharing and results-based decision-making.

9.1 Adopt Common Core Indicators

It is standard best practice in biodiversity monitoring to use common core indicators across sites to facilitate comparisons and data aggregation (Sparks et al., 2011; Secretariat of the Convention on Biological Diversity, 2014; Stephenson, 2019; Stephenson & Carbone, 2021). Key state indicators for OWE revolve around species and habitat area of occurrence (i.e., distribution), species diversity, abundance or relative abundance, and proximity to, and use of, the OWE area. Key pressure indicators focus on noise, pollution and invasive alien species. Response indicators (sensu Stephenson & Carbone, 2021) will also be needed to answer questions such as what tools have been applied to mitigate impacts. Common indicators need to be agreed and standardised so that, whatever the methods used to collect the data, the same unit of measurement is used in each site. Some of these indicators have already been aggregated and compared between sites, such as the study of abundance trends in fish (Methratta & Dardick, 2018).

9.2 Use Harmonised Monitoring Methods and Standardised Protocols in Integrated Systems

One of the main challenges in assessing marine biodiversity is the lack of standardised approaches for monitoring (Duffy et al., 2013; Teixeira et al., 2016; Przeslawski et al., 2019). “There is a large variation in approaches to data collection and assessment methodologies between sites” (MMO, 2014). However, no single method can answer all monitoring questions for all taxa for all phases of OWE development (Verfuss et al., 2018: Piggott et al., 2021) and “the optimal survey approach will vary based on location, species, and study goals” (Williams et al., 2015). Some stakeholders also feel that having fixed monitoring guidelines may make survey designs less flexible, especially with the fast pace of current technological developments (Piggott et al., 2021). Przeslawski et al. (2019) noted that “a top-down, one-size-fits-all approach to monitoring is unlikely to be effective in systems with large environmental variability”. However, the same authors note that standardisation of sampling designs is necessary because, “if variability between sampling techniques is sufficiently high, real changes that would trigger appropriate management responses may not be detected, incorrect advice might be provided to decision-makers and the influence and opportunities for marine science, especially monitoring is reduced” (Przeslawski et al., 2019).

Therefore, rather than prescribe specific methods for marine biodiversity monitoring, it is better to explore options for agreeing protocols and developing best practices (sensu Hörstmann et al., 2020) for marine monitoring in the OWE context. In this way, different schemes in different countries may measure the same common core indicators with different methods, but when they use the same method they will use it the same way, and whichever methods they use they will use the same unit of measurement. Furthermore, if at least a small selection of methods can be used more regularly for measuring common indicators across sites, this set of "minimum requirements" will help facilitate protocol harmonisation and data aggregation.

Based on the finding of this review, the following represent the minimum requirements for biodiversity monitoring and the main methods to use (to be complemented by additional monitoring where necessary depending on the phase and type of operation, and site-specific or species-specific needs and legal requirements).

› Monitoring marine birds and bats

At a minimum, all OWE developments and associated grid infrastructure should measure the presence, diversity and abundance of birds and bats, as well as habitat use, during all four operational stages (planning, construction, operation decommissioning). Threats such as collisions with turbines also need to be monitored. Favoured methods are digital aerial surveys, static PAM and targeted telemetry, complemented by vessel-based surveys (especially for behaviour data or where other options are not feasible).

› Monitoring marine mammals

At a minimum, all OWE developments and associated grid infrastructure should measure the presence, diversity and abundance of seals and toothed cetaceans at all four operational stages, as well as habitat use and anthropogenic noise levels. Favoured methods are digital aerial surveys, static PAM and targeted telemetry, complemented when necessary by vessel-based surveys.

› Monitoring fish and seabed communities

At a minimum, all OWE developments and associated grid infrastructure should measure the presence, diversity and relative abundance of fish species and benthic invertebrates and plants, the extent and quality of natural habitats, and key threats such as noise, pollution and invasive alien species. Favoured monitoring methods are grab sampling and video (drop-down/ROV/AUV) for habitats and benthic species and fyke-net sampling for fish, complemented when necessary by scuba diving for all species telemetry and BRUVs for fish, and acoustic mapping of the seabed habitats

The methods most likely to be used across sites therefore include digital aerial surveys, passive acoustic monitoring, underwater video surveys and grab sampling. Digital camera footage from aerial or underwater surveys and acoustic recordings has the advantage of providing a permanent and verifiable record of detections, which is especially useful given the long timeframe of OWE site monitoring (Thompson et al., 2014; Williamson et al., 2016). Whilst these methods are recommended based on this review, and a number of options for protocols are presented, the final choice of methods and protocols to standardise and roll out across the sector will need to be discussed and agreed by key stakeholders.

While there are some methodological differences for monitoring different taxa, many rely on similar vehicles or sensors. If deployed at the same time, it would maximise cost efficiencies (e.g., in boat or aircraft hire; observer salaries). Therefore, more effort needs to be made to explore options to integrate surveys to monitor multiple taxa concurrently. It is already happening for marine mammals and birds which can be monitored with the same digital aerial survey and the same vessel transect by different observers, as has happened with European Seabirds at Sea surveys (Macleod et al., 2011). However, if different methods are used on the same platform, "it is important that surveys for birds and marine mammals are conducted by specific staff trained for that purpose and that the two surveys are conducted simultaneously but separately with no interference between them (Macleod et al., 2011).

Therefore, an integrated approach should be adopted to biodiversity monitoring around OWE sites, using harmonised methods to address the key indicators across multiple taxa. This is in line with other recommendations that encourage the complementary use of multiple methods and tools in an integrated approach (e.g., Kunz et al., 2007; Walls et al., 2009; BSH, 2013; Molis et al., 2019). Detection performance has also been shown to improve with multiple concurrent methods (e.g., Smith et al., 2020).

9.3 Adopt a Set of Key Monitoring Principles and Approaches

Many existing protocols underline the importance of following best practices to ensure suitable monitoring programme design and implementation. Based on the material reviewed, five principles seem to be key to ensuring successful monitoring.

9.3.1 Follow best practice for indicator development

The development of indicators needs to follow best practices (Stephenson & Carbone, 2021) to ensure they are:

- scientifically credible (e.g., using methods that have been peer-reviewed in the scientific literature);
- feasible and cost-effective to apply (i.e., data can be collected either directly or through others using identified methods);
- measurable (in quantitative or qualitative terms);
- precise (defined the same way by everyone who uses them);
- consistent (always measuring the same thing);
- understandable (everyone who is concerned by the results can interpret what they mean);
- relevant to a specific owe impact on a specific species group or habitat type;
- sensitive to changes in the pressure, state, response or benefit being measured.

Pressures need to be monitored as well as biodiversity state and the mitigation responses.

9.3.2 Choose methods based on indicators and questions asked

Methods should be chosen primarily due to their relevance to the indicator being measured and the monitoring questions being answered. In some cases, of course, they will also be influenced by company policies or legal requirements imposed by national governments.

Stephenson & Carbone (2021) note that monitoring methods should be:

- accurate (with minimal error);
- reliable (consistently repeatable with minimal variation in results);
- cost-effective;
- feasible to use;
- appropriate (in this case, ensuring they answer specific questions and are statistically meaningful);
- precise enough to measure the change monitored and to signal any relevant thresholds identified.

Wherever possible, methods used should follow established, standardised protocols, to ensure harmonised approaches and to follow best practices for ensuring robust sampling design, statistical power (see below) and consistent replication of methods. Some flexibility is needed and in choosing the most appropriate method and protocol for a given case, a range of factors have to be taken into account including the relevant taxa impacted and the remoteness of the site.

9.3.3 Define appropriate scope and scale of monitoring

Monitoring needs to be planned at the appropriate temporal and spatial scales. These scales will vary depending on local needs but most protocols suggest monitoring biodiversity through all the phases of OWE development: planning (scoping, pre- and post- consent), construction, operation and decommissioning. The spatial scope tends to be the OWE site and a suitable buffer (Box 9.1), though guidance needs to be developed for a more standard interpretation of buffer zone. Principles used in International Finance Corporation Performance Standard 6 (IFC, 2012) should be considered as, for the marine environment, they include Project Area of Influence, seascape, Ecologically Appropriate Area of Analysis, and processes and functions for wide-ranging species (Cousins & Pittman, 2021), all of which are pertinent for OWE. Note, too, that Habitats Regulation Assessments and European Protected Species Licensing processes also require data beyond the development site boundaries, meaning that any data from the site-specific surveys must be supplemented with additional information (Thompson et al., 2014).

The proposed frequency of data collection varies but is regular (often monthly) until at least 3 years after operations begin, then phased down and restarted prior to decommissioning. This review of existing protocols suggests that, ideally, monitoring should involve monthly surveys continuous across contiguous seasons for at least 2 years before consent and up to 5 years after. However, it may not always be practical or cost-effective to conduct surveys on a monthly basis, especially for more remote offshore sites. It many sites it will likely prove more effective to conduct surveys at key periods with maximum power so as to detect longer-term trends and address key questions.

› Box 9.1: Example of spatial scope of monitoring

The BSH (2013) StUK4 standard provides guidance for the spatial scope of faunal monitoring around OWE as follows:

- Aerial surveys of birds and mammals: The area must cover at least 2,000 km^2. The wind farm shall be at the centre of the assessment area. The distance between the sides of the wind farm and the margins of the assessment area shall principally be at least 20 km.
- Ship based surveys of birds and mammals: The assessment area must cover at least 200 km^2. The distance between the sides of the wind farm and the margins of the assessment area shall principally be at least 4 km.
- Benthos/fish: The size of the assessment area corresponds to the current size and location of the wind farm.

Since the location of many species changes throughout the year (birds, for example, may have different breeding, passage and wintering areas), monitoring must consider temporal change (RSPB, 2012). Hemery (2020) noted that some authors recommend that monitoring studies last more than 3 years to enable accurate measurement of extreme and subtle changes (Wilding et al., 2017), if not six to 8 years to cover the recovery timeframe of some cable sites (Kraus & Carter, 2018; Sheehan et al., 2018; Taormina et al., 2018).

Cumulative impacts also need to be assessed to find out how multiple OWF can impact broader species populations and how OWFs adds to other anthropogenic pressures. Although such assessments remain challenging (e.g., Lindeboom et al., 2015; Scheidat & Porter, 2019), cumulative impact assessment frameworks (e.g., van Oostveen et al., 2018) need to be developed further. They will be better facilitated if data are shared between OWE developers and between the broader European marine community (see below).

9.3.4 Engage key stakeholders in the development and implementation of monitoring plans

Involving key stakeholders is a key factor in the development, implementation and monitoring of biodiversity strategies across sectors (IFC, 2012; Stephenson & Carbone, 2021). The stakeholders involved in the development of a given OWE site (government departments, companies, contractors, NGOs, scientists) should work together from the outset on designing and implementing a biodiversity monitoring plan. Such collaboration is widely encouraged in the OWE sector (e.g., Thaxter & Burton, 2009; Macleod et al., 2010), and does often happen. For example, in the UK, expert input on site-specific survey and monitoring design is typically carried out during an early consultation process between industry and government bodies (Statutory Nature Conservation Bodies and regulatory bodies) to sign off on the survey methods and study design to be used (Piggott et al., 2021).

Consultation needs to be more extensive from the beginning of the planning phase and include all key stakeholders, including the universities and consultants who will carry out the work. Advantages of early collaboration include having scientists work with the design and development team from the outset to plan for the mounting of monitoring sensors on wind turbine jackets, so they can be factored into weight loading calculations and construction plans. There is also a need to co-ordinate activities of different stakeholders active in the OWE site, especially to ensure monitoring vessels or C-PODs do not obstruct construction vessels and vice versa, and to adapt programmes based on unexpected delays. It might also be worthwhile exploring opportunities for collaborating on biodiversity monitoring with other users of the seas around offshore wind farms, such as fisheries and shipping companies.

9.3.5 Design monitoring programmes that are fit for purpose

If a monitoring programme is to work, it needs to be designed to ensure the data can be used to measure change. Several factors need to be taken into account.

Proper sampling methods need to be used. For example, analyses of transect surveys need to use distance sampling (Buckland et al., 2001) and DISTANCE software (Thomas et al., 2010). Power analyses should be used to determine how much data is sufficient to answer the monitoring question (see Scheidat & Porter, 2019). This helps avoid being data rich but information poor. Several protocols highlight the minimum number of observations needed to detect change. For example, Buckland et al. (2001) recommend that at least 60-80 sightings are required for distance sampling analysis. All surveys should correct for observer bias and availability bias by verifying detection probability using standard methods (Macleod et al., 2011; Sheidat & Porter, 2019). Furthermore, survey design needs to ensure that all portions of the study area have an equal probability of being surveyed; for mammals, this might mean placing at least 10-20 replicate transect lines in a systematic but randomised manner “to provide a basis for an adequate variance of the encounter rate and a reasonable number of degrees of freedom for constructing confidence intervals” (Sheidat & Porter, 2019). Other aspects of the monitoring protocols will need to be adapted as necessary for local conditions. For example, during digital aerial bird surveys, flight height (usually about 450 m) can be lowered if no disturbance is caused to species and increased resolution is required for species identification (Thaxter & Burton, 2009).

Wherever possible, all biodiversity-related surveys should be conducted using a before-after control-impact (BACI) design or a Before-After-Gradient (BAG design) to demonstrate or infer cause and effect (Box 9.2). While both methods can be effective, BAG is preferred over BACI in the design of OWE biodiversity monitoring (as per Methratta, 2020).

In order to demonstrate or infer cause and effect from survey results, monitoring schemes are often conducted using a before-after control-impact (BACI) design or a Before-After-Gradient (BAG design) (Box 9.2).

Box 9.2: BACI and BAG

The before-after-control impact (BACI) approach (sensu Smith et al., 1993; Wauchope at al., 2021) ensures data collection during a time period before (B) and after (A) the impact in a control (C) and the impact area (I). Some challenges exist with using the BACI approach in the OWE context (Trendall et al., 2011; Webb & Nehls, 2019). For example, finding multiple control sites that are similar (in depth, seabed condition, tidal flow pattern, prey density, distance to a colony, etc.) to the impact area is often very difficult. Surveys of both control and impact sites during the same day or time is also challenging.

For certain indicators, such as fish or bird distribution and abundance and impact variables such as noise from pile driving, a before-after gradient or BAG design may be more effective at detecting meaningful change (Vanermen & Stienen, 2019 Scheidat & Porter, 2019; Methratta, 2020). In a BAG analysis, the offshore wind farm is placed in the centre of a large survey area and its effects are assumed to be a function of distance from the OWF. A significant before-after change that declines with distance from the OWF provides evidence that the wind farm is the cause of the change. The same approach can be used for submarine power cables. This has advantages over the BACI approach in that it does not have the challenges of finding suitable, independent control sites and the results are easier to interpret. A gradient design will be more sensitive to change when a contaminant or sound disperses with distance from a point source, and can also be used to assess the spatial scale of any impacts, thus informing future spatial planning decisions (Bailey et al., 2014).

9.3.6 Collate data in standard formats to facilitate data sharing

This review underlines the need for improved co-ordination and collaboration at national, regional and global levels on not only implementing more harmonised biodiversity monitoring programmes but also improving data sharing. If data on common indicators can be collated in standard formats, using standard typologies and definitions, it will be easier to aggregate and share, thereby enhancing our ability to conduct meta-analyses, to contribute to new EIAs, and to improve our understanding of cumulative effects. Furthermore, “increased reporting of survey and monitoring results in the peer-review literature and other accessible venues would greatly advance the scientific community’s understanding of wind farm effects” (Methratta & Darcik, 2018).

9.4 Conduct Research to Improve Monitoring Effectiveness

Further research and development is required to improve our knowledge of key pressures and impacts that may need to be monitored and to integrate new technologies into more holistic monitoring systems. Priority research topics include:

- the levels of collision experienced by bats, and the adverse effects of OWE on marine turtles;
- the impacts on marine biodiversity of electromagnetic fields (especially from submarine power cables) and pollution such as oil spills from vessels involved in construction, maintenance and decommissioning;
- the most nature-positive way of decommissioning OWE infrastructure, and if, and how best, to restore sites;
- the potential for new techniques to be integrated into OWE monitoring systems, especially environmental DNA techniques for assessing species diversity and relative abundance, baited remote underwater video for fish and possibly crustaceans, light traps for benthic invertebrates, acoustic soundscapes for fish and crustaceans, and the systematic monitoring of ship hulls for invasive alien species.

9.5 Enhance Regional and Sectoral Collaboration on Standardising Monitoring Protocols and Data Collection Formats to Facilitate Data Sharing and Results-Based Decision-Making

The effort to develop a more integrated biodiversity monitoring approach for OWE recommended in this report will require a greater level of sectoral and regional collaboration, cooperation and open data sharing than currently exists. All key stakeholder groups (see above) will need to work together more closely across projects and countries.

Existing initiatives, such as the Offshore Coalition for Energy and Nature, would be a good starting point, building on collaborative reviews of monitoring already conducted for birds (Piggott et al., 2021) to consider how to enhance and harmonise monitoring of other taxa and of habitats. Other collaborative initiatives in the Baltic Sea and North Sea should also be engaged and opportunities sought for their input into OWE monitoring. Examples include the Joint OSPAR/HELCOM/ICES Working Group on Seabirds (JWGBIRD; https://www.ices.dk/community/groups/Pages/ jwgbird.aspx), whose applied science work includes the development of common bird indicators under the EU's Marine Strategy Framework Directive. Similarly, the ICES Working Group on Marine Mammal Ecology (WGMME; https://www.ices.dk/ community/groups/Pages/WGMME.aspx) reviews information on, for example, population sizes, distribution, and management frameworks for marine mammals in the North Atlantic and impacts on marine mammals from marine industries. These bodies could be engaged in helping agree and apply common OWE indicators. Efforts to enhance co-ordination in the OWE sector should also learn lessons from other Europe-wide monitoring schemes, such as those in place for monitoring contaminants, radioactivity and sea temperature (Bean et al., 2017). Lessons should also be learned from outside Europe. Canada and the USA have active national marine monitoring schemes and an expanding OWE sector. Australia is a world leader in marine science and is at the forefront of many of the newer monitoring methods that should be tested, like BRUVs and multi-beamer echosounder sonar (Przeslawski et al., 2019).

9.6 Take Appropriate Next Steps to Improve Biodiversity Monitoring

As a first step towards sectoral and regional collaboration, the finding of this review should be widely disseminated and discussed with key stakeholders, including OWE companies, TSOs, governments, NGOs and the science community.

An abundance of effort and resources is already invested in researching and monitoring marine biodiversity around OWE and, to a lesser extent, the submarine power cables that make up the offshore grid. If stakeholders could just enhance the level of collaboration and coordination across borders and sites to identify common indicators and standardise methods and data collection formats, then the availability and use of data for decision-making in the OWE sector in the Baltic Sea and North Sea would be greatly enhanced, and cumulative impacts better understood. Such collaboration and adoption of more standardised approaches would improve results-based management and decision-making and ultimately reduce the impacts of OWE and associated power grids on biodiversity, enhancing the sustainability of energy production.

10. References Cited

1) Afzali, S., F., Bourdages, H., Laporte, M., Mérot, C., Normandeau, E., Audet, C., & Bernatchez, L. (2020). Comparing environmental metabarcoding and trawling survey of demersal fish communities in the Gulf of St. Lawrence, Canada. Environmental DNA, 3(1): 22-42
2) Ahlén, I., Baagøe, H.J. & Bach, L. (2009). Behavior of Scandinavian Bats during Migration and Foraging at Sea. Journal of Mammalogy, 90(6): 1318–1323
3) Amano, T., Lamming, J.D. & Sutherland, W.J. (2016). Spatial gaps in global biodiversity information and the role of citizen science. Bioscience, 66(5): 393-400.
4) ASCOBANS (2021). ASCOBANS. Website https://www.ascobans.org/ accessed 10 May 2021.
5) Bailey, H., K. L. Brookes and P. M. Thompson (2014). Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystems, 10(1): 8.
6) Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. & Thompson, P.M. (2010). Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine Pollution Bulletin, 60(6): 888-897.
7) Band, B. (2012). Using a Collision Risk Model to Assess Bird Collision Risks for Offshore Wind Farms. Report by British Trust for Ornithology (BTO). Report for The Crown Estate.
8) Batty, A (2008). Seabird & Marine Mammal Survey VOS Rambler 14-27 September 2008. Cork Ecology. Cork, Ireland.
9) Bean, T.P., Greenwood, N., Beckett, R., Biermann, L., Bignell, J.P., Brant, J.L., Copp, G.H., Devlin, M.J., Dye, S., Feist, S.W. & Fernand, L. (2017). A review of the tools used for marine monitoring in the UK: combining historic and contemporary methods with modeling and socioeconomics to fulfill legislative needs and scientific ambitions. Frontiers in Marine Science, 4: 263.
10) Benjamins, S., Harnois, V., Smith, H.C.M., Johanning, L., Greenhill, L., Carter, C. & Wilson, B. (2014). Understanding the potential for marine megafauna entanglement risk from renewable marine energy developments. Scottish Natural Heritage Commissioned Report No. 791. Scottish Natural Heritage, Edinburgh, Scotland.
11) Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. IUCN, Gland, Switzerland and The Biodiversity Consultancy, Cambridge, UK.
12) Berger, C. S., Bougas, B., Turgeon, S., Ferchiou, S., Ménard, N., & Bernatchez, L. (2020). Groundtruthing of pelagic forage fish detected by hydroacoustics in a whale feeding area using environmental DNA. Environmental DNA, 2(4): 477-492.
13) Bergstrom, L., Sundqvist, F. & Bergstrom, U. (2013). Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community. Marine Ecology Progress Series, 485: 199–210.
14) BFN (2021). Batmove. Website https://www.natur-und-erneuerbare.de/en/project-database/batmove/ accessed 15 April 2021.
15) Boehlert, G.W. & Gill, A.B. (2010). Environmental and ecological effects of ocean renewable energy development: a current synthesis. Oceanography, 23(2): 68-81.
16) Booth, C., Harwood, J., Plunkett, R., Mendes, S., & Walker, R. (2017). Using The Interim PCoD Framework To Assess The Potential Effects Of Planned Offshore Wind Developments In Eastern English Waters On Harbour Porpoises In The North Sea–Final Report. SMRUC-NEN-2017-007, Provided to Natural England and the Joint Nature Conservation Committee.
17) Booth, C. G., Sinclair, R. R., & Harwood, J. (2020). Methods for monitoring for the population consequences of disturbance in marine mammals: a review. Frontiers in Marine Science, 7: 115.
18) Borchers, D.L., Buckland, S.T., Goedhart, P.W., Clarke, E.D. & Hedley, S.L. (1998). Horvitz-Thompson estimators for double-platform line transect surveys. Biometrics, 54: 1221-1237.

19) Borja, A., Franco, J. & Pérez, V. (2000). A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin, 40(12): 1100-1114.
20) Borja, A., Miles, A., Occhipinti-Ambrogi, A. & Berg, T., 2009. Current status of macroinvertebrate methods used for assessing the quality of European marine waters: implementing the Water Framework Directive. Hydrobiologia, 633(1): 181-196.
21) Bouchet, P., Huang, Z., Phillips, C., Meeuwig, J., Foster, S. & Przeslawski, R. (2018). Comparative Assessment of Pelagic Sampling Platforms. University of Western Australia, Perth, WA, Australia.
22) Boyd, I.L, Bowen, W.D & Iverson, S.J. (eds.) (2010). Marine Mammal Ecology and Conservation: A Handbook of Techniques. Oxford University Press, Oxford, UK.
23) Bridge, T.C.L., Done, T.J., Friedman, A., Beaman, R.J., Williams, S.B., Pizarro, O. & Webster, J.M. (2011). Variability in mesophotic coral reef communities along the Great Barrier Reef, Australia. Marine Ecology Progress Series, 428: 63-75.
24) BSH (2013). Standard: Investigation of the impacts of offshore wind turbines on the marine environment (StUK 4). BSH, Hamburg & Rostock, Germany.
25) Buckland, S.T, Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L. (2001). Introduction to Distance Sampling. Oxford University Press, Oxford, UK.
26) Buckland, S. T., Burt, M.L., Rexstad, E. A., Mellor, M., Williams. A. E. & Woodward, R. (2012). Aerial surveys of seabirds: the advent of digital methods. Journal of Applied Ecology, 49: 960–967.
27) Buschbaum, C., Lackschewitz, D. & Reise, K. (2012). Nonnative macrobenthos in the Wadden Sea ecosystem. Ocean & Coastal Management, 68: 89-101.
28) Camphuysen, C.J., Fox, A.D., Leopold, M.F. & Petersen, I.K. (2004). Towards Standardised Seabirds at Sea Census Techniques in Connection with Environmental Impact Assessments for Offshore Wind Farms in the UK: a comparison of ship and aerial sampling methods for marine birds and their applicability to offshore wind farm assessments. Royal Netherlands Institute for Sea Research
29) Camphuysen C.J. & Garthe, S. (2004). Recording foraging seabirds at sea: standardised recording and coding of foraging behaviour and multi-species foraging associations. Atlantic Seabirds, 5: 1-23.
30) Cardoso, P., Erwin, T. L., Borges, P. A., & New, T. R. (2011). The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation, 144(11): 2647-2655.
31) Clough, S.C., McGovern, S., Campbell, D. & Rehfisch, M.M. (2012). Aerial survey techniques for assessing offshore wind farms. In International Council for the Exploration of the Sea, Conference and Meeting (CM) Documents.
32) Cole, S., Martinot, P., Rapoport, S., Papaefthymiou, G. & Gori, V. (2014). Study of the Benefits of a Meshed Offshore Grid in Northern Seas Region. Final Report to the European Commission. Available at https://ec.europa.eu/energy/sites/ener/files/documents/2014_nsog_report.pdf
33) Cook, A.S.C.P & Masden, E.A. (2019). Modelling collision risk and predicting population-level consequences. Pp 135-166 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.
34) Cook, A.S.C.P., Ward, R.M., Hansen, W.S. & Larsen, L. (2018). Estimating seabird flight height using LiDAR. Scottish Marine and Freshwater Science, 9: 14-66.
35) Copping, A., Hanna, L. & Whiting, J., (2017). Sharing information on environmental effects of wind energy development: WREN hub. Pp 277-289 in J. Koppel (ed.), Wind Energy and Wildlife Interactions. Springer, Cham, Switzerland.
36) Copping, A.E. & Hemery, L.G. (eds.). (2020). OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). doi:10.2172/1632878

37) Copping, A.E., Hemery, L.G., Overhus, D.M., Garavelli, L., Freeman, M.C., Whiting, J.M., Gorton, A.M., Farr, H.K., Rose, D.J. & Tugade, L.G. (2020). Potential Environmental Effects of Marine Renewable Energy Development—The State of the Science. Journal of Marine Science and Engineering, 8(11): 879.

38) Cousins , N., & Pittman, S.J. (2021). Guidance for Defining Ecologically Appropriate Scales of Analysis for Marine Biodiversity in Relation to IFC Performance Standard 6. Bluedot Associates, Bristol, UK.

39) CPMR North Sea Commission, 2016. North Sea Region 2020: North Sea Commission Strategy – Contributing to Europe 2020. CPMR North Sea Commission, Gothenburg, Sweden.

40) Crown Estate (2021). Marine Data Exchange. Website https://www.marinedataexchange.co.uk/ accessed 1 July 2021.

41) Dahlgren, T.G., Hammar, L. & Langhamer, O. (2019). Monitoring invertebrate and fish. Pp. 1-28 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 3. Offshore: Potential effects. Pelagic Publishing, Exeter, UK.

42) Danovaro, R., Fanelli, E., Aguzzi, J., Billett, D., Carugati, L., Corinaldesi, C., Dell'Anno, A., Gjerde, K., Jamieson, A.J., Kark, S. & McClain, C. (2020). Ecological variables for developing a global deep-ocean monitoring and conservation strategy. Nature Ecology & Evolution, 4(2): 181-192.

43) Dauer, D.M. (1993). Biological criteria, environmental health and estuarine macrobenthic community structure. Marine Pollution Bulletin, 26: 249–257.

44) Dauvin, J.C. (2018). Twenty years of application of Polychaete/Amphipod ratios to assess diverse human pressures in estuarine and coastal marine environments: a review. Ecological Indicators, 95: 427-435.

45) de Lucas, M., Janss, G.F.E., Whitfield, D.P. & Ferrer, M. (2008). Collision fatality of raptors in wind farms does not depend on raptor abundance. Journal of Applied Ecology, 45:1695–1703.

46) Dekeling, R., Tasker, M., Van Der Graaf, S., Ainslie, M., Andersson, M., André, M., Borsani, J., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D. & Young, J. (2014). Monitoring Guidance for Underwater Noise in European Seas. Part II: Monitoring Guidance Specifications. Publications Office of the European Union, Luxembourg.

47) Department of Communications, Climate Action and Environment (2018a). Guidance on Marine Baseline Ecological Assessments & Monitoring Activities for Offshore Renewable Energy Projects Part 1 April 2018. Government of Ireland, Dublin, Ireland.

48) Department of Communications, Climate Action and Environment (2018b). Guidance on Marine Baseline Ecological Assessments & Monitoring Activities for Offshore Renewable Energy Projects Part 2 April 2018. Government of Ireland, Dublin, Ireland.

49) Desholm, M., Fox, A.D. & Beasley, P.D. (2004). Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore wind farm. A report produced for COWRIE.

50) DHI (2019). BSH Cumulative Impact Study 2019. Comparative study of DEPONS and iPCoD. DHI, Hørsholm, Denmark.

51) Diederichs, A., Nehls, G., Dähne, M., Adler, S., Koschinski, S. & Verfuß, U. (2008). Methodologies for measuring and assessing potential changes in marine mammal behaviour, abundance or distribution arising from the construction, operation and decommissioning of offshore windfarms. BioConsult SH report to COWRIE Ltd.

52) Dolman, S. & Simmonds, M. (2010). Towards best environmental practice for cetacean conservation in developing Scotland's marine renewable energy. Marine Policy, 34(5): 1021-1027.

53) Duffy, J.E., Amaral-Zettler, L.A., Fautin, D.G., Paulay, G., Rynearson, T.A., Sosik, H.M. & Stachowicz, J.J. (2013). Envisioning a marine biodiversity observation network. BioScience, 63: 350–361.

54) EC (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora [1992] OJ 1992 L206/7 (Habitats Directive).

55) EC (2009). Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds [2010] OJ L20/7 (Birds Directive).

56) EC (2020a) Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. EU Biodiversity Strategy for 2030: Bringing nature back into our lives. COM/2020/380 final

57) EC (2020b) Communication From The Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. COM/2020/741 final

58) EC (2021). EASIN - European Alien Species Information Network. Website https://easin.jrc.ec.europa.eu/spexplorer/ accessed 24 June 2021.

59) Edgar, G.J. & Stuart-Smith, R.D. (2014). Systematic global assessment of reef fish communities by the Reef Life Survey program. Scientific Data, 1(1): 1-8.

60) EU (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) [2008] OJ L164/136 (MSFD).

61) EU (2014) Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for marine spatial planning [2014] OJ L257/135.

62) Eleftheriou, A. & McIntyre, A. (2005) Methods for the Study of Marine Benthos. Blackwell Science Ltd., Oxford, UK.

63) Evans, P.G.H. & Hammond, P.S. (2004). Monitoring cetaceans in European waters. Mammal Review, 34(1): 131-156.

64) Ferraro, G., Meyer-Roux, S., Muellenhoff, O., Pavliha, M., Svetak, J., Tarchi, D. & Topouzelis, K. (2009). Long term monitoring of oil spills in European seas. International Journal of Remote Sensing, 30(3): 627-645.

65) Foote, A.D., Thomsen, P.F., Sveegaard, S., Wahlberg, M., Kielgast, J., Kyhn, L.A., Salling, A.B., Galatius, A., Orlando, L. & Gilbert, M.T.P. (2012). Investigating the potential use of environmental DNA (eDNA) for genetic monitoring of marine mammals. PloS One, 7(8): e41781.

66) Fox, A.D., Desholm, M., Kahlert, J., Christensen, T.K. & Krag Petersen, I.B., 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis, 148: 129-144.

67) Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.F.J., McDonald, L.L., & Robertson, D.G. (1999). Marine Mammal Survey and Assessment Methods. CRC Press/Balkema, Rotterdam, The Netherlands.

68) Garthe, S., Hüppop, O. & Weichler, T. (2002). Anleitung zur Erfassung von Seevögeln auf See von Schiffen. Seevögel, 23(2): 47–55. [Instructions for the detection of seabirds at sea of ships]

69) Gewing, M.T. & Shenkar, N. (2017). Monitoring the magnitude of marine vessel infestation by non-indigenous ascidians in the Mediterranean. Marine Pollution Bulletin, 121(1-2): 52-59.

70) Gilbert, G., Gibbons, D. W. & Evans, J. (1998). Bird Monitoring Methods. RSPB, Sandy, UK.

71) Gill, A.B. (2005). Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology, 42(4): 605-615.

72) Gill, A.B. & Desender, M. (2020). Risk to Animals from Electromagnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices. In A.E. Copping and L.G. Hemery (Eds.), OES Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 86-103). doi:10.2172/1633088

73) Gill, A.B., & Taylor, H. (2001) The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes. Countryside Council for Wales, Bangor (UK). Vol 33, Issue 10. Report No. CCW-CSR—488.

74) Gittenberger, A., Rensing, M., Stegenga, H. & Hoeksema, B.W. (2010). Native and non-native species of hard substrata in the Dutch Wadden Sea. Nederlandse Faunistische Mededelingen, 33: 21-75.

75) Goetze, J.S., Bond, T., McLean, D.L., Saunders, B.J., Langlois, T.J., Lindfield, S., Fullwood, L.A., Driessen, D., Shedrawi, G. & Harvey, E.S. (2019). A field and video analysis guide for diver operated stereo-video. Methods in Ecology and Evolution, 10(7): 1083-1090.

76) Goodwin, K. D., Thompson, L. R., Duarte, B., Kahlke, T., Thompson, A. R., Marques, J. C., & Caçador, I. (2017). DNA sequencing as a tool to monitor marine ecological status. Frontiers in Marine Science, 4: 107.

77) Green, R. E., Langston, R. H., McCluskie, A., Sutherland, R., & Wilson, J. D. (2016). Lack of sound science in assessing wind farm impacts on seabirds. Journal of Applied Ecology, 53(6): 1635-1641.

78) Griffin, L., Rees, E. & Hughes, B. (2011). Migration Routes of Whooper Swans and Geese in Relation to Wind Farm Footprints: Final Report. WWT Report to the Department of Energy and Climate Change, Wildfowl & Wetlands Trust, Slimbridge, Gloucester.

79) Griffin, R. A., Robinson, G. J., West, A., Gloyne-Phillips, I. T., & Unsworth, R. K. (2016). Assessing fish and motile fauna around offshore windfarms using stereo baited video. PLoS One, 11(3): e0149701.

80) Groom, G., Stjernholm, M., Nielsen, R. D., Fleetwood, A. & Petersen, I. K. (2013). Remote sensing image data and automated analysis to describe marine bird distributions and abundances. Ecological Informatics, 14: 2–8.

81) Haelters, J. (2009). Monitoring of marine mammals in the framework of the construction and exploitation of offshore wind farms in Belgian marine waters. Offshore Wind Farms in the Belgian Part of the North Sea: State of the Art After Two Years of Environmental Monitoring. Royal Belgian Institute of Natural Sciences, Department MUMM, Brussels, Belgium, pp.237-266.

82) Halliday, W. D., Insley, S. J., Hilliard, R. C., de Jong, T., & Pine, M. K. (2017). Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. Marine Pollution Bulletin, 123(1-2), 73-82.

83) Hammar, L., Perry, D. & Gullström, M. (2016). Offshore wind power for marine conservation. Open Journal of Marine Science, 6(1): 66–78.

84) Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. & Øien, N. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39(2): 361-376.

85) Hammond, P.S., Lacey, C., Gilles, A., Viquerat, S., Börjesson, P., Herr, H., Macleod, K., Ridoux,V.,Santos, M.B., Scheidat, M., Teilmann, J., Vingada, J. & Øien, N. (2017). Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys.

86) Hammond, P.S., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G.P., Gilles, A., Gillespie, D., Gordon, J. et al. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation, 164: 107-122.

87) Haver, S.M., Gedamke, J., Hatch, L.T., Dziak, R.P., Van Parijs, S., McKenna, M.F., Barlow, J., Berchok, C., DiDonato, E., Hanson, B. & Haxel, J. (2018). Monitoring long-term soundscape trends in US Waters: the NOAA/NPS Ocean noise reference station network. Marine Policy, 90: 6-13.

88) HELCOM (2007). HELCOM Baltic Sea Action Plan. Baltic Marine Environment Protection Commission (Helsinki Commission - HELCOM), Helsinki, Finland.

89) HELCOM (2009). Biodiversity in the Baltic Sea – An integrated thematic assessment on biodiversity and nature conservation in the Baltic Sea. Baltic Sea Environment Proceedings No. 116B. HELCOM, Helsinki, Finland.

90) HELCOM (2012). Indicator based assessment of coastal fish community status in the Baltic Sea 2005-2009. Baltic Sea Environment Proceedings No. 131. HELCOM, Helsinki, Finland.

91) HELCOM (2013a). HELCOM Monitoring and Assessment Strategy. HELCOM, Helsinki, Finland.

92) HELCOM (2013b). HELCOM ALIENS 2- Non-native species port survey protocols, target species selection and risk assessment tools for the Baltic Sea. HELCOM, Helsinki, Finland.

93) HELCOM (2015a). Recommendations and Guidelines for Benthic Habitat Monitoring with Method Descriptions for Two Methods for Monitoring of Biotope and Habitat Extent. Baltic Sea Pilot Project (BALSAM). HELCOM, Helsinki, Finland.

94) HELCOM (2015b). Guidelines for COASTAL FISH monitoring sampling methods of HELCOM. HELCOM, Helsinki, Finland.

95) HELCOM (2018a). Abundance of waterbirds in the breeding season. HELCOM Core Indicator report. HELCOM, Helsinki, Finland.

96) HELCOM (2018b). Thematic assessment of biodiversity 2011–2016. Available from http://stateofthebalticsea.helcom.fi/biodiversity-and-its-status/marine-mammals/

97) HELCOM (2018c). Operational oil spills from ships. HELCOM core indicator report. Online https://www.helcom.fi/wp-content/uploads/2019/08/Operational-oil-spills-from-ships-HELCOM-core-indicator-2018.pdf accessed 2 May 2021. ISSN 2343-2543

98) HELCOM (2021a). HELCOM Monitoring Manual. Website https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-manual/ accessed 1 May 2021.

99) HELCOM (2021b). Red List of Species. Website https://helcom.fi/baltic-sea-trends/biodiversity/red-list-of-baltic-species/ accessed 9 April 2021

100) HELCOM/OSPAR (2013). Joint HELCOM/OSPAR Guidelines for the Contracting Parties of OSPAR and HELCOM on the Granting of Exemptions under International Convention for the Control and Management of Ships' Ballast Water and Sediments, Regulation A-4 (OSPAR Agreement 2013-09). Available at https://helcom.fi/media/documents/Joint-HELCOM_OSPAR-Guidelines.pdf

101) Hemery, L.G. (2020). 2020 State of the Science Report-Chapter 6: Changes in Benthic and Pelagic Habitats Caused by Marine Renewable Energy Devices (No. PNNL-29976CHPT6). Pacific Northwest National Lab, Richland, WA, USA.

102) Hernandez, O.M., Shadman, M., Amiri, M.M., Silva, C., Estefen, S.F. & La Rovere, E. (2021). Environmental impacts of offshore wind installation, operation and maintenance, and decommissioning activities: A case study of Brazil. Renewable and Sustainable Energy Reviews, 144: 110994.

103) Holt, R. & Sanderson, B. (2001). Procedural Guideline No. 3-5. Identifying biotopes using video recordings. In Marine Monitoring Handbook. (eds. J.M. Davies, J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull & M. Vincent). UK Marine SACs Project.

104) Hörstmann, C.; Buttigieg, P.L.; Simpson, P.; Pearlman, J. ; Karstensen, J. & Waite, A.M. (2020). Towards a Best Practice for Developing Best Practices in Ocean Observation (BP4BP): Supporting Methodological Evolution through Actionable Documentation. Intergovernmental Oceanographic Commission Manuals and Guides No. 84. UNESCO, Paris, France.

105) Hüppop, O., Michalik, B., Bach, L., Hill, R. & Pelletier, S. (2019). Migratory birds and bats. In: M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions, Volume 3 Offshore: Potential Effects. Pelagic Publishing, Exeter, UK.

106) Hussey, N.E., Kessel, S.T., Aarestrup, K., Cooke, S.J., Cowley, P.D., Fisk, A.T., Harcourt, R.G., Holland, K.N., Iverson, S.J., Kocik, J.F. & Flemming, J.E.M. (2015). Aquatic animal telemetry: a panoramic window into the underwater world. Science, 348(6240): 1255642.

107) Hvidt, C., Leonhard, S., Klaustrup, M., & Pedersen, J. (2006). Hydro-Acoustic Monitoring of Fish Communities at Offshore Wind Farms (Report No. 2624-03-003 Rev2). Report by BioConsult SH.
108) International Finance Corporation (IFC) (2012).Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources. IFC, Washington DC, USA.
109) International Hydrographic Organization - IHO (2008). IHO Standards for Hydrographic Surveys, 5th Edition, February 2008. Special Publication No. 44. IHO, Monaco.
110) IUCN (2021a). The IUCN Red List of Threatened Species. Version 2021-1. https://www.iucnredlist.org
111) IUCN (2021b). Global Invasive Species Database. Website http://www.iucngisd.org/gisd/ accessed 24 June 2021.
112) ISO (2007). ISO 19493. Edition: 2007-09-01. Water quality — Guidance on marine biological surveys of hard substrate communities. International Organization for Standardization, Geneva, Switzerland.
113) ISO (2014). ISO 16665. Edition: 2014-08-01. Water quality — Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna. International Organization for Standardization, Geneva, Switzerland.
114) Jackson, D. & Whitfield, P. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 4. Birds. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.
115) Johansen, K.L., Boertmann, D., Mosbech, A. & Hansen, T.B. (2012). Manual for Seabird and Marine Mammal Survey on Seismic Vessels in Greenland. 3rd revised edition. Scientific Report from DCE – Danish Centre for Environment and Energy No. 38. Aarhus University, DCE – Danish Centre for Environment and Energy, Aarhus, Denmark.
116) Johnston, A., Thaxter, C.B., Austin, G.E., Cook, A.S., Humphreys, E.M., Still, D.A., Mackay, A., Irvine, R., Webb, A. & Burton, N.H. (2015). Modelling the abundance and distribution of marine birds accounting for uncertain species identification. Journal of Applied Ecology, 52(1): 150-160.
117) Kemper, G., Weidauer, A. & Coppack, T. (2016). Monitoring seabirds and marine mammals by georeferenced aerial photography. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 8.
118) King, S. L., Schick, R. S., Donovan, C., Booth, C. G., Burgman, M., Thomas, L., & Harwood, J. (2015). An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution, 6(10): 1150-1158.
119) Kolmårdens Djurpark AB (2017). SAMBAH Project Report. http://www.sambah.org/SAMBAH-Final-Report-FINAL-for-website-April-2017.pdf
120) Komdeur, J. Bertelsen & Cracknell, G. (1992). Manual for aeroplane and ship surveys of waterfowl and seabirds. IWRB Special Publication No. 19. International Wildfowl Research Bureau, Slimbridge, UK.
121) Koschinski, S. & Lüdemann, K. (2020). Noise Mitigation for the Construction of Increasingly Large Offshore Wind Turbines: Technical options for complying with noise limits. Report commissioned by the Federal Agency for Nature Conservation, Isle of Vilm, Germany.
122) Kowarski, K.A., Gaudet, B.J., Cole, A.J., Maxner, E.E., Turner, S.P., Martin, S.B., Johnson, H.D. & Moloney, J.E. (2020). Near real-time marine mammal monitoring from gliders: Practical challenges, system development, and management implications. The Journal of the Acoustical Society of America, 148(3): 1215-1230.
123) Krägefsky, S. (2014). Effects of the alpha ventus offshore test site on pelagic fish. Pp 83-94 in A. Beiersdorf & K. Wollny-Goerke (eds.), Ecological Research at the Offshore Windfarm Alpha Ventus: Challenges, Results and Perspectives. Springer, Cham, Switzerland.

124) Kraus, C. & Carter, L. (2018). Seabed recovery following protective burial of subsea cables - Observations from the continental margin. Ocean Engineering, 157: 251-261.

125) Krijgsveld K.L., Fijn R.C., Japink M., van Horssen P.W., Heunks C., Collier M.P., Poot M.J.M, Beuker D. & Dirksen S. (2011). Effect studies Offshore Wind Farm Egmond aan Zee Final report on fluxes, flight altitudes and behaviour of flying birds. Bureau Waardenburg report nr 10-219, The Netherlands.

126) Kunz, T.H., Arnett, E.B., Cooper, B.M., Erickson, W.P., Larkin, R.P., Mabee, T., Morrison, M.L., Strickland, M.D. & Szewczak, J.M. (2007). Assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document. The Journal of Wildlife Management, 71(8): 2449-2486.

127) Laake, J.L. & D. L. Borchers. 2004. Methods for Incomplete Detection at Distance Zero. Pp. 108-189 in Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. B. & Thomas, L. (eds.), Advanced Distance Sampling. Oxford University Press, Oxford, UK.

128) Lacoursière-Roussel, A., Howland, K., Normandeau, Grey, E. K., Archambault, P., Deiner, K., Lodge, D. M., Hernandez, C., Leduc, N., & Bernatchez, L. (2018). eDNA metabarcoding as a new surveillance approach for coastal Arctic biodiversity. Ecology and Evolution, 8(16): 7763-7777

129) Lagerveld, S., Noort, C.A., Meesters, L., Bach, L., Bach, P. & Geelhoed, S. (2020). Assessing fatality risk of bats at offshore wind turbines (No. C025/20). Wageningen Marine Research, Wageningen, The Netherlands.

130) Lagerveld, S., Poerink, B. J., Haselager, R. & Verdaat, H. (2014). Bats in Dutch offshore wind farms in autumn 2012. Lutra, 57(2): 61-69.

131) Langlois, T. J., Harvey, E. S., Fitzpatrick, B., Meeuwig, J. J., Shedrawi, G., & Watson, D. L. (2010). Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. Aquatic Biology, 9(2), 155-168.

132) Largey, N., Cook, A. S. C. P., Thaxter, C. B., MCluskie, A., Stokke, B. G., Wilson, B., & Masden, E. A. (2021). Methods to quantify avian airspace use in relation to wind energy development. Ibis, 163(3): 747-764.

133) Leduc, N., Lacoursière-Roussel, A., Howland, K. L., Archambault, P., Sevellec, M., Normandeau, E., Dispas, A., Winkler, G., McKindsey, C. W., Simard, N., & Bernatchez, L. (2019). Comparing eDNA metabarcoding and species collection for documenting Arctic metazoan biodiversity. Environmental DNA, 1(4): 342-358

134) Lewis, M. & Dunn, T.E. (2020). Volunteer Seabirds At Sea Survey Methods JNCC Report No. 663. JNCC, Peterborough, UK

135) Li, Y., Cui, C., Liu, Z., Liu, B., Xu, J., Zhu, X., & Hou, Y. (2017). Detection and monitoring of oil spills using moderate/high-resolution remote sensing images. Archives of Environmental Contamination and Toxicology, 73(1): 154-169.

136) Lindeboom, H., Degraer, S., Dannheim, J., Gill, A.B. & Wilhelmsson, D. (2015). Offshore wind park monitoring programmes, lessons learned and recommendations for the future. Hydrobiologia, 756(1): 169-180.

137) Lobo, J., Shokralla, S., Costa, M.H., Hajibabaei, M., & Costa, F.O. (2017). DNA metabarcoding for high-throughput monitoring of estuarine macrobenthic communities. Scientific Reports, 7(1): 1-13.

138) Maclean, I.M.D, Wright, L.J., Showler, D.A. & Rehfisch, M.M. (2009) A Review of Assessment Methodologies for Offshore Windfarms. British Trust for Ornithology Report Commissioned by COWRIE Ltd.

139) Macleod, K., Lacey, C., Quick, N., Hastie, G. & Wilson J. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 2. Cetaceans and Basking Sharks. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.

140) Macreadie, P. I., Fowler, A. M., & Booth, D. J. (2011). Rigs-to-reefs: will the deep sea benefit from artificial habitat? Frontiers in Ecology and the Environment, 9(8): 455-461.

141) Mallet, D., & Pelletier, D. (2014). Underwater video techniques for observing coastal marine biodiversity: a review of sixty years of publications (1952–2012). Fisheries Research, 154: 44-62.

142) Marraffini, M.L., Ashton, G.V., Brown, C.W., Chang, A.L. & Ruiz, G.M. (2017). Settlement plates as monitoring devices for non-indigenous species in marine fouling communities. Management of Biological Invasions, 8(4): 559-566.

143) Martin, G., Kotta, J., Möller, T., & Herkül, K. (2013). Spatial distribution of marine benthic habitats in the Estonian coastal sea, northeastern Baltic Sea. Estonian Journal of Ecology, 62(3): 165-191.

144) Masse, J. (1996). The structure and spatial distribution of pelagic fish schools in multispecies clusters: An acoustic study. ICES Journal of Marine Science, 53: 155–160.

145) Mauvisseau, Q., Kalogianni, E., Zimmerman, B., Bulling, M., Brys, R., & Sweet, M. (2020). eDNA-based monitoring: Advancement in management and conservation of critically endangered killifish species. Environmental DNA, 2(4): 601-613

146) Maclean, I.M.D, Wright, L.J., Showler, D.A. & Rehfisch, M.M. (2009). A Review of Assessment Methodologies for Offshore Windfarms. British Trust for Ornithology Report Commissioned by COWRIE Ltd.

147) McLeod, L.E. & Costello, M.J. (2017). Light traps for sampling marine biodiversity. Helgoland Marine Research, 71(1): 1-8.

148) McRae, L., Deinet, S. & Freeman, R. (2017). The diversity-weighted Living Planet Index: Controlling for taxonomic bias in a global biodiversity indicator. PLoS One, 12: e0169156.

149) Mellor, M. & Maher, M. (2008). Full Scale Trial of High Definition Video Survey for Offshore Windfarm Sites (Report No. HIDEF-03-08). Report by HiDef Aerial Surveying Ltd commissioned by COWRIE Ltd.

150) Methratta, E. T. (2020). Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs. ICES Journal of Marine Science, 77(3): 890-900.

151) Methratta, E.T. & Dardick, W.R. (2019). Meta-analysis of finfish abundance at offshore wind farms. Reviews in Fisheries Science & Aquaculture, 27(2): 242-260.

152) MMO (2014). Review of post-consent offshore wind farm monitoring data associated with licence conditions. A report produced for the Marine Management Organisation, pp 194. MMO Project No: 1031.

153) Molis, M., Hill, R., Hüppop, O., Bach, L., Coppack, T., Pelletier, S., Dittmann, T. & Schulz, A. (2019). Measuring bird and bat collision and avoidance. Pp 167-206 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.

154) Monk, J., Barrett, N., Bridge, T., Carroll, A., Friedman, A., Ierodiaconou, D., Jordan, A., Kendrick, G. & Lucieer, V. (2018). Marine sampling field manual for autonomous underwater vehicles (AUVs). In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2. Przeslawski, R. & Foster, S. (Eds). National Environmental Science Program (NESP).

155) Moulton, V.D. & Mactavish, B.D. (2004). Recommended seabird and marine mammal observational protocols for Atlantic Canada. LGL Rep. SA775-1. Rep. from LGL Ltd., St. John's, NL, for Environmental Studies Research Funds, Calgary, AB, Canada.

156) Moussy, C., Burfield, I.J., Stephenson, P.J., Newton, A.F.E., Butchart, S.H.M., Sutherland, W.J., Gregory, R.D., McRae, L., Bubb, P., Roesler, I., Ursino, C., Wu, Y., Retief, E.F., Udin, J.S., Urazaliyev, R., Sanchez-Clavijo, L.M., Lartey, E. & Donald, P.F. (2021). A quantitative global review of species population monitoring. Conservation Biology. DOI: 10.1111/cobi.13721

157) Muniz, P., Venturini, N., Pires-Vanin, A. M., Tommasi, L. R., & Borja, Á. (2005). Testing the applicability of a Marine Biotic Index (AMBI) to assessing the ecological quality of soft-bottom benthic communities, in the South America Atlantic region. Marine Pollution Bulletin, 50(6): 624-637.
158) Nabe-Nielsen, J. & Harwood, J. (2016). Comparison of the iPCoD and DEPONS models for modelling population consequences of noise on harbour porpoises. Aarhus University, DCE – Danish Centre for Environment and Energy, 22 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 186.
159) Nabe-Nielsen, J., van Beest, F. M., Grimm, V., Sibly, R. M., Teilmann, J., & Thompson, P.M. (2018). Predicting the impacts of anthropogenic disturbances on marine populations. Conservation Letters, 11(5): e12563.
160) New, T.R. (1998). Invertebrate Surveys for Conservation. Oxford University Press, Oxford, UK.
161) Niemi, J. & Tanttu, J.T. (2019). Automatic bird identification for offshore wind farms. Pp 135-151 in (R. Bispo et al., eds.), Wind Energy and Wildlife Impacts. Springer, Cham, Switzerland.
162) NIRAS (2015). Subsea Cable Interactions with the Marine Environment. Expert review and Recommendations Report. Niras Consulting, Cambridge, UK.
163) Nogues, Q., Raoux, A., Araignous, E., Chaalali, A., Hattab, T., Leroy, B., Lasram, F.B.R., David, V., Le Loc'H, F., Dauvin, J.C. & Niquil, N. (2021). Cumulative effects of marine renewable energy and climate change on ecosystem properties: Sensitivity of ecological network analysis. Ecological Indicators, 121: 107128.
164) Noordzeeloket (2021). Maritime Information Provision Service Point. Website https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/maritime-information-provision-service-point/ accessed 24 May 2021.
165) OSPAR (2008a). OSPAR Commission report: Assessment of the environmental impact of offshore wind-farms https://www.ospar.org/documents?v=7114
166) OSPAR Commission (2008b). OSPAR List of Threatened and/or Declining Species and Habitats. Ref. 2008-6. OSPAR Commission, London, UK. https://www.ospar.org/work-areas/bdc/species-habitats
167) OSPAR Commission (2010a). The North-East Atlantic Environment Strategy. Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010-2020. OSPAR Commission, London, UK.
168) OSPAR Commission (2010b). Quality Status Report 2000. OSPAR Commission, London, UK.
169) OSPAR Commission (2016a). OSPAR Coordinated Environmental Monitoring Programme (CEMP). OSPAR Commission, London, UK.
170) OSPAR Commission (2016b) OSPAR CEMP Guidelines. Common Indicator: Marine Bird Abundance (B1). OSPAR Commission, London, UK.
171) OSPAR Commission (2018). OSPAR CEMP Guidelines Common indicator: Condition of benthic habitat communities (BH2) – common approach. OSPAR Commission, London, UK.
172) OSPAR Commission (2019) OSPAR CEMP Guidelines Common indicator: Abundance and distribution at the relevant spatio-temporal scale of cetacean species regularly present (M4) – version March 2019. OSPAR Commission, London, UK.
173) OSPAR Commission (2021). Intermediate Assessment 2017. Website https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/ accessed 16 April. 2021
174) Otero, M., Cebrian, E., Francour, P., Galil, B. & Savini, D. (2013). Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): A strategy and practical guide for managers. IUCN, Malaga, Spain.
175) Palomino-González, A., Kovacs, K.M., Lydersen, C., Ims, R.A., & Lowther, A.D. (2021). Drones and marine mammals in Svalbard, Norway. Marine Mammal Science, 2021: 1-18. DOI: 10.1111/mms.12802.

176) Paxton, C.G.M., Scott-Hayward, L., Mackenzie, M., Rexstad, E. & Thomas, L. (2016). Revised Phase III data analysis of Joint Cetacean Protocol Data resource. JNCC Report, 517. JNCC, Peterborough, UK.

177) Pearman, J.K., von Ammon, U., Laroche, O., Zaiko, A., Wood, S.A., Zubia, M., Planes, S. & Pochon, X. (2021). Metabarcoding as a tool to enhance marine surveillance of nonindigenous species in tropical harbors: A case study in Tahiti. Environmental DNA, 3(1): 173-189.

178) Perrow, M.R. (2019a). A synthesis of effects and impacts. In M.R. Perrow (eds.), Wildlife and Wind Farms, Conflicts and Solutions, Volume 3 Offshore: Potential Effects. Pelagic Publishing, Exeter, UK.

179) Perrow, M.R. (ed.) (2019b). Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.

180) Peterson, T., Pelletier, S. & Giovanni, M. (2016). Long-term Bat Monitoring on Islands, Offshore Structures, and Coastal Sites in the Gulf of Maine, mid-Atlantic, and Great Lakes—Final Report. Stantec, Topsham, ME, USA.

181) Pettorelli, N., Laurance, W.F., O'Brien, T.G., Wegmann, M., Nagendra, H. & Turner, W. (2014). Satellite remote sensing for applied ecologists: opportunities and challenges. Journal of Applied Ecology, 51: 839-848.

182) Phillips, R.A., Croxall, J.P., Silk, J.R.D. & Briggs, D.R. (2007). Foraging ecology of albatrosses and petrels from South Georgia: two decades of insights from tracking technologies. Aquatic Conservation: Marine and Freshwater Ecosystems, 17(S1): S6-S21.

183) Pieretti, N., Martire, M.L., Farina, A. & Danovaro, R. (2017). Marine soundscape as an additional biodiversity monitoring tool: a case study from the Adriatic Sea (Mediterranean Sea). Ecological Indicators, 83: 13-20.

184) Piggott, A., Vulcano, A. & Mitchell, D. (2021). Impact of offshore wind development on seabirds in the North Sea and Baltic Sea: Identification of data sources and at-risk species. Summary Report. BirdLife International, Brussels, Belgium.

185) Pohle, G., & Thomas, M. (2001). Marine biodiversity monitoring. Monitoring protocol for marine benthos: Intertidal and subtidal macrofauna. A Report by The Marine Biodiversity Monitoring Committee (Atlantic Maritime Ecological Science Cooperative, Huntsman Marine Science Centre) to the Ecological Monitoring and Assessment Network of Environment Canada.

186) Portt, C.B., Coker, G.A., Ming, D.L. & Randall, R.G. (2006). A review of fish sampling methods commonly used in Canadian freshwater habitats. Canadian Technical Report of Fisheries and Aquatic Sciences 2604.

187) Przeslawski, R. & Foster, S. (eds.) (2018). Field Manuals for Marine Sampling to Monitor Australian Waters, Version 1. 2018. National Environment Science Programme Marine Biodiversity Hub, Canberra, ACT, Australia.

188) Przeslawski, R., Foster, S., Monk, J., Barrett, N., Bouchet, P., Carroll, A., Langlois, T., Lucieer, V., Williams, J. & Bax, N. (2019). A suite of field manuals for marine sampling to monitor Australian waters. Frontiers in Marine Science, 6: 177.

189) Raoult, V., Colefax, A.P., Allan, B.M., Cagnazzi, D., Castelblanco-Martínez, N., Ierodiaconou, D., Johnston, D.W., Landeo-Yauri, S., Lyons, M., Pirotta, V. & Schofield, G. (2020). Operational protocols for the use of drones in marine animal research. Drones, 4(4): 64.

190) Reef Life Survey (2019). Standardised Survey Procedures for Monitoring Rocky & Coral Reef Ecological Communities. Reef Life Survey, Hobart, Australia.

191) Reggio, V.C., Jr. (1987). Rigs-to-Reefs: The use of obsolete petroleum structures as artificial reefs. US Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, USA.

192) Reubens, J.T., Degraer, S. & Vincx, M. (2014). The ecology of benthopelagic fishes at offshore wind farms: a synthesis of 4 years of research. Hydrobiologia, 727(1): 121-136.

193) RGI (2019). Marine Grid Declaration. Renewables Grid Initiative, Bonn, Germany.
194) Ritter, C. & Montagna, P.A. (1999). Seasonal hypoxia and model of benthic response in a Texas bay. Estuaries, 22: 7–20.
195) Rosenberg, R., Blomqvist, M., Nilsson, H.C., Cederwall, H. & Dimming, A. (2004). Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. Marine Pollution Bulletin, 49(9-10): 728-739.
196) RSPB (2012). RSPB Guidance on the Use of Bird Data in Marine Planning. RSPB, Sandy, UK.
197) Russell, D.J., Hastie, G.D., Thompson, D., Janik, V.M., Hammond, P.S., Scott-Hayward, L.A., Matthiopoulos, J., Jones, E.L. & McConnell, B.J. (2016). Avoidance of wind farms by harbour seals is limited to pile driving activities. Journal of Applied Ecology, 53: 1642-1652.
198) Santana-Garcon, J., Newman, S.J. & Harvey, E.S. (2014). Development and validation of a mid-water baited stereo-video technique for investigating pelagic fish assemblages. Journal of Experimental Marine Biology and Ecology, 452: 82-90.
199) Saunders, G., Bedford, G.S., Trendall, J.R. & Sotheran, I. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 5. Benthic Habitats. Unpublished draft report to Scottish Natural Heritage and Marine Scotland
200) Scheidat, M. & Porter, L. (2019). Monitoring marine mammals. Pp 29-59 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.
201) SEANSE (2019). The Common Environmental Assessment Framework - CEAF. SEANSE. Available at https://northseaportal.eu/downloads/
202) Secretariat of the Convention on Biological Diversity (2014). Global Biodiversity Outlook 4. Secretariat of the Convention on Biological Diversity, Montréal, Canada.
203) Sheehan, E.V., Cartwright, A.Y., Witt, M.J., Attrill, M.J., Vural, M. & Holmes, L.A. (2018). Development of epibenthic assemblages on artificial habitat associated with marine renewable infrastructure. ICES Journal of Marine Science, 77: 1178-1189.
204) Skov, H., Heinanen, S., Norman, T., Ward, R., Mendez-Roldan, S. & Ellis, I. (2018). ORJIP Bird Collision and Avoidance Study. Final report – April 2018. The Carbon Trust, UK.
205) Smith, E.P., Orvos, D.R. & Cairns, J., Jr (1993). Impact assessment using the before-after control-impact (BACI) model: Concerns and comments. Canadian Journal of Fisheries and Aquatic Sciences, 50: 627–637.
206) Smith, H.R., Zitterbart, D.P., Norris, T.F., Flau, M., Ferguson, E.L., Jones, C.G., Boebel, O. & Moulton, V.D.(2020). A field comparison of marine mammal detections via visual, acoustic, and infrared (IR) imaging methods offshore Atlantic Canada. Marine Pollution Bulletin, 154: 111026.
207) Soria-Rodríguez, C. (2020). The international regulation for the protection of the environment in the development of marine renewable energy in the EU. Review of European, Comparative & International Environmental Law.
208) Sparks, T.H., Butchart, S.H., Balmford, A., Bennun, L., Stanwell-Smith, D., Walpole, M., Bates, N.R., Bomhard, B., Buchanan, G.M., Chenery, A.M. & Collen, B. (2011). Linked indicator sets for addressing biodiversity loss. Oryx, 45(3): 411-419.
209) Sparling, C., Grellier, K., Philpott, E., Macleod, K. & Wilson, J. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 3. Seals. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.
210) Spencer, M. L., Stoner, A. W., Ryer, C. H., & Munk, J. E. (2005). A towed camera sled for estimating abundance of juvenile flatfishes and habitat characteristics: Comparison with beam trawls and divers. Estuarine, Coastal and Shelf Science, 64(2-3): 497-503.
211) Starmore, G., Iredale, R., Mulder, S. (2020). Assessment of relative impact of anthropogenic pressures on marine species in relation to offshore wind. Royal Haskoning DHV, Amersfoort, The Netherlands.

212) Stenberg, C., Støttrup, J.G., van Deurs, M., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T.M. & Leonhard, S.B. (2015). Long-term effects of an offshore wind farm in the North Sea on fish communities. Marine Ecology Progress Series, 528: 257-265.
213) Stephenson, P.J. (2019). The Holy Grail of biodiversity conservation management: monitoring impact in projects and project portfolios. Perspectives in Ecology and Conservation, 17(4): 182-192.
214) Stephenson, P.J. (2020). Technological advances in biodiversity monitoring: applicability, opportunities and challenges. Current Opinion in Environmental Sustainability, 45: 36-41.
215) Stephenson, P.J., Burgess, N.D., Jungmann, L., Loh, J., O'Connor, S., Oldfield, T., Reidhead, W. & Shapiro, A. (2015). Overcoming the challenges to conservation monitoring: integrating data from in situ reporting and global data sets to measure impact and performance. Biodiversity, 16 (2-3): 68-85.
216) Stephenson, P.J. & Carbone, G. (2021). Guidelines for Planning and Monitoring Corporate Biodiversity Performance. IUCN, Gland, Switzerland. DOI: 10.2305/IUCN.CH.2021.05.en
217) Stephenson, P.J., & Stengel, C. (2020). An inventory of biodiversity data sources for conservation monitoring. PLoS One, 15(12): e0242923.
218) Sugai, L. S. M., Silva, T. S. F., Ribeiro Jr, J. W. & Llusia, D. (2019). Terrestrial passive acoustic monitoring: review and perspectives. BioScience, 69(1): 15-25.
219) Taberlet, P.. Bonin, A., Zinger, L. & Coissac, E. (2018). Environmental DNA for Biodiversity Research and Monitoring. Oxford University Press, Oxford, UK.
220) Taormina, B., Bald, J., Want, A., Thouzeau, G., Lejart, M., Desroy, N. & Carlier, A. (2018). A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. Renewable and Sustainable Energy Reviews, 96: 380-391.
221) Tasker, M. L., Jones, P. H., Dixon, T. I. M., & Blake, B. F. (1984). Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. The Auk, 101(3): 567-577.
222) TCE (2010). Approaches to Marine Mammal Monitoring at Marine Renewable Energy Developments. Final Report prepared by SMRU Ltd for The Crown Estate. 110 pp.
223) Teixeira, H., Berg, T., Uusitalo, L., Fürhaupter, K., Heiskanen, A. -S., Mazik, K., et al. (2016). A catalogue of marine biodiversity indicators. Frontiers in Marine Science, 3: 207.
224) Tethys (2021). WREN Knowledge Database. Website https://tethys.pnnl.gov/about-wren accessed 1 May 2021.
225) Thaxter, C.B. & Burton, N.H.K. (2009). High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols. British Trust for Ornithology Report Commissioned by Cowrie Ltd.
226) Thaxter, C.B. & Perrow, M.R. (2019). Telemetry and tracking of birds. Pp 96-134 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.
227) Thaxter, C.B., Buchanan, G.M., Carr, J., Butchart, S.H.M., Newbold, T., Green, R.E., Tobias, J.A., Foden, W.B., O'Brien, S. & Pearce-Higgins, J.W. (2017). Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. Proceedings of the Royal Society B: Biological Sciences, 284(1862): 20170829.
228) Thomas, L.T., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A. & Burnham, K.P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology, 47: 5–14.
229) Thompson, P., Hammond, P., Borchers, D., Brookes, K. & Graham, I. (2014). Methods For Monitoring Marine Mammals At Marine Renewable Energy Developments. Project No. RERAD/001/11.

Report to Marine Scotland, Scottish Government. University of Aberdeen and University of St Andrews, Scotland.

230) Thoresson, G. (1996). Metoder för övervakning av kustfisk - bestånd (Methods for monitoring of coastal fish communities; in Swedish). Kustrapport, 1996: 3.

231) Thouzeau, G., Robert, G., & Ugarte, R. (1991). Faunal assemblages of benthic megainvertebrates inhabiting sea scallop grounds from eastern Georges Bank in relation to environmental factors. Marine Ecology Progress Series, 74: 61–82.

232) Tomé, R., Canário, F., Leitão, A.H., Pires, N. & Repas, M. (2017). Radar assisted shutdown on demand ensures zero soaring bird mortality at a wind farm located in a migratory flyway. Pp. 119-133 in Köppel, J. (ed.), Wind Energy and Wildlife Interactions. Springer, Cham, Switzerland.

233) Topham, E., & McMillan, D. (2017). Sustainable decommissioning of an offshore wind farm. Renewable energy, 102: 470-480.

234) Trendall, J.R., Fortune, F. & Bedford, G.S. (2011). Guidance on Survey and Monitoring in Relation to Marine Renewables Deployments in Scotland. Volume 1. Context and General Principals. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.

235) Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R. & Legendre, F. (2017). Taxonomic bias in biodiversity data and societal preferences. Scientific Reports, 7(1): 1-14.

236) UNEP EUROBATS (2021). Protected bat species. Website https://www.eurobats.org/about_eurobats/protected_bat_species accessed 12 May 2021.

237) Urian, K., Gorgone, A., Read, A., Balmer, B., Wells, R. S., Berggren, P., Durban, J., Eguchi, T., Rayment, W. & Hammond, P.S. (2015). Recommendations for photo-identification methods used in capture-recapture models with cetaceans. Marine Mammal Science, 31(1): 298-321.

238) van Bleijswijk, J. D. L., Engelmann, J. C., Klunder, L., Witte, H. J., Johannes IJ. Witte, J. IJ., & van der Veer, H. W. (2020). Analysis of a coastal North Sea fish community: Comparison of aquatic environmental DNA concentrations to fish catches. Environmental DNA, 2(4): 429-445

239) van Polanen Petel, T., Geelhoed, S. & Meesters, E. (2012). Harbour porpoise occurrence in relation to the Prinses Amaliawindpark. Report number C177/10. IMARES Wageningen University and Research Centre, Wageningen, The Netherlands.

240) Vanermen, N. & Stienen, E.W.M (2019). Seabirds: displacement. Pp 174-205 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 3. Offshore: Potential effects. Pelagic Publishing, Exeter, UK.

241) Verfuss, U. K., Gillespie, D., Gordon, J., Marques, T. A., Miller, B., Plunkett, R., Theriault, J.A., Tollit, D.J., Zitterbart, D.P., Hubert, P. & Thomas, L. (2018). Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. Marine Pollution Bulletin, 126: 1-18.

242) van Oostveen, M., Sierdsma, F., Kwakkel, J. & van Mastrigt, A. (2018). Inventory and assessment of models and methods used for describing, quantifying and assessing cumulative effects of offshore wind farms. Royal HaskoningDHV, Amersfoort, The Netherlands.

243) Walls, R.J., Pendlebury, C.J, Budgey, R., Brookes, K. & Thompson, P. (2009). Revised Best Practice Guidance for the Use of Remote Techniques for Ornithological Monitoring at Offshore Windfarms. Published by COWRIE Ltd.

244) Walsh, P. M., Halley, D. J., Harris, M.P. del Nevo, A., Sim, I.M.W. & Tasker, M.L. (1995). Seabird Monitoring Handbook for Britain and Ireland. JNCC/RSPB/ITE/Seabird Group, Peterborough, UK.

245) Wauchope, H.S., Amano, T., Geldmann, J., Johnston, A., Simmons, B.I., Sutherland, W.J. & Jones, J.P. (2021) Evaluating impact using time-series data. Trends in Ecology & Evolution, 36: 193-205.

246) Webb A. & Durinck J. (1992). Counting birds from ships. Pp 24-37 in J. Komdeur, J. Bertelsen & G. Cracknel (eds.), Manual for Aeroplane and Ship Surveys of Waterfowl and Seabirds, I. IWRB Special Publicaton No. 19. International Wildfowl Research Bureau, Slimbridge, UK.

247) Webb, A. & Nehls, G. (2019). Surveying seabirds. Pp 60-95 in M.R. Perrow (ed.), Wildlife and Wind Farms, Conflicts and Solutions. Volume 4. Offshore: Monitoring and Mitigation. Pelagic Publishing, Exeter, UK.
248) Webb, A., Irwin, C., Mackenzie, M., Scott-Hayward, L., Caneco, B. & Donovan, C. (2017). Lincs Wind Farm: Third Annual Post-Construction Aerial Ornithological Monitoring Report. Report by HiDef Aerial Surveying Ltd to Centrica Renewable Energy Ltd.
249) Weigand, H., Beermann, A.J., Čiampor, F., Costa, F.O., Csabai, Z., Duarte, S., Geiger, M.F., Grabowski, M., Rimet, F., Rulik, B. & Strand, M. (2019). DNA barcode reference libraries for the monitoring of aquatic biota in Europe: Gap-analysis and recommendations for future work. Science of the Total Environment, 678: 499-524.
250) Wetlands International (2010). Diversity and Abundance of Bird Species: Field Protocol for Waterbird Counting. Wetlands International, The Hague, Netherlands.
251) Wetzel, F.T., Bingham, H.C., Groom, Q., Haase, P., Kõljalg, U., Kuhlmann, M., Martin, C.S., Penev, L., Robertson, T., Saarenmaa, H. & Schmeller, D.S. (2018). Unlocking biodiversity data: Prioritization and filling the gaps in biodiversity observation data in Europe. Biological Conservation, 221: 78-85.
252) Wich, S.A. & Koh, L.P. (2018). Conservation Drones: Mapping and Monitoring Biodiversity. Oxford University Press, Oxford, UK.
253) Wilding, T.A., Gill, A.B., Boon, A., Sheehan, E., Dauvin, J.C., Pezy, J.P., O'beirn, F., Janas, U., Rostin, L. & De Mesel, I. (2017). Turning off the DRIP ('Data-rich, information-poor')–rationalising monitoring with a focus on marine renewable energy developments and the benthos. Renewable and Sustainable Energy Reviews, 74: 848-859.
254) Wilkinson, M., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.W., da Silva Santos, L.B., Bourne, P.E. & Bouwman, J. (2016). The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data, 3: 160018.
255) Williams, K.A., Stenhouse, I.J., Adams, E.M., Connelly, E.E., Gilbert, A.T. & Duron, M. (2015). Integrating novel and historical survey methods: a comparison of standardized boat-based and digital video aerial surveys for marine wildlife in the United States. Chapter 13 in Williams, K.A., Connelly, E.E., Johnson, S.M. & Stenhouse, I.J. (eds.), Wildlife Densities and Habitat Use Across Temporal and Spatial Scales on the Mid-Atlantic Outer Continental Shelf: Final Report to the Department of Energy EERE Wind & Water Power Technologies Office. Biodiversity Research Institute, Portland, Maine, USA.
256) Williamson, L.D., Brookes, K.L., Scott, B.E., Graham, I.M., Bradbury, G., Hammond, P.S. & Thompson, P.M. (2016). Echolocation detections and digital video surveys provide reliable estimates of the relative density of harbour porpoises. Methods in Ecology and Evolution, 7(7): 762-769.
257) Zhang, Y., Pavlovska, M., Stoica, E., Prekrasna, I., Yang, J., Slobodnik, J., Zhang, X., & Dykyi, E. (2020). Holistic pelagic biodiversity monitoring of the Black Sea via eDNA metabarcoding approach: From bacteria to marine mammals. Environment International, 135: 105307.
258) Žydelis, R., Dorsch, M., Heinänen, S., Nehls, G., & Weiss, F. (2019). Comparison of digital video surveys with visual aerial surveys for bird monitoring at sea. Journal of Ornithology, 160(2): 567-580.

Annexes

Annex 1: People Consulted and Acknowledgements

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Annex 2. Pros and Cons of the Main Methods Used for Monitoring Marine Birds Near OWE

Adapted from various sources, including Jackson & Whitfield (2011), Clough et al. (2012), Williams et al. (2015), Webb & Nehls (2019), Molis et al. (2019), Largey et al. (2021) and Piggott et al. (2021). Key strengths and weaknesses identified in the review are marked with an asterisk (*).

Method	Pros	Cons
Vessel-based line transect surveys	*Data allow for estimation of absolute or relative density & abundance using distance sampling; Can collect data on age, sex, behaviour (such as foraging sites) and flight height; Well established and robust methods for assumption violations, especially for large vessels; High detection and accuracy of species identification compared to visual aerial surveys (taxa identified to species more often from the boat than in the video aerial data); Additional environmental data can be collected (e.g., water temperature, salinity, depth); *Other taxa can be monitored at the same time, especially marine mammals; e.g., PAM with towed arrays can be used at the same time; Surveys can cover distant offshore waters; Data can be used in species distribution models and sensitivity mapping; Increased survey time gives higher chance of surveying pursuit-diving birds and reduces availability bias compared with faster aerial survey methods; *Large amount of historical data available.	Can be expensive (depending on spatial and temporal scale required); Restricted by weather conditions and to daylight hours; *Can cause responsive movement of animals (avoiding vessel or attracted to vessel); *Surveying speed does not allow coverage of large areas in single trip and causes temporal mismatch in different parts of survey area; Constraints on surveying nearshore in shallow water or near reefs/sandbanks; Lower detection of divers, grebes and seaducks compared to aerial surveys and poor detection of migrant species or other groups; Observers require training period and must have good species identification skills.

Method	Pros	Cons
Aerial line transects (using fixed wing aircraft, helicopters, microlights, and blimps)	Data allow for estimation of absolute or relative density & abundance using distance sampling; Data can be used in species distribution models and sensitivity mapping; *Can cover large areas quickly and the entire range of a population in a relatively short time; Can monitor species sensitive to vessels; Can take advantage more readily of good weather windows than slower boat surveys; Can also be used to collect mammal data.	*Identification of birds is considerably harder than land or ship surveys; some species groups can be identified up to the genus level only (auks, terns, divers, and gulls). Higher speeds than vessels reduce time for species detection and reduces scope for species identification (and less time to detect, identify, count, and record birds compared to vessel-based and digital aerial surveys); Not suitable for small, inconspicuous species such as grebes or auks. Difficult to determine age classes and sex for certain species. Responsive movement may be a problem for some aircraft types or some species; Larger flocks tend to get underestimated; Detection rates decrease rapidly with increasing distance from the plane, especially for smaller species; Can be expensive (depending on spatial and temporal scale required and type of vehicle used); *Specialised aircraft needed for optimal transects (high-winged with bubble windows); Restricted by weather conditions and sea conditions and to daylight hours; Logistical limitations including height limit around OWFs and time limits due to fuel capacity; Subject to observer bias; Field experts need additional training on species recognition, bird detection and estimation of flock size; Cannot collect simultaneous environmental data.

Method	Pros	Cons
Digital aerial surveys (manned and unmanned aerial vehicles)	Can estimate relative abundance of some species using distance sampling and flight height; Data can be used in species distribution models and sensitivity mapping; *Can cover large areas in a relatively short time; *No observers required (just pilots), reducing costs and some health and safety risks; *No observer bias; Still or moving imagery can be collected; *Sightings can be replayed and reviewed, minimising bias and providing long-term record of survey; *Can also be used for marine mammals; *Advances in technology have improved ability to identify birds to a species level; species identification can be as high as 95% and as good as human observers on vessel surveys; AI software can increasingly assist in species identification; *Surveys flown at higher altitudes reduce the risk of disturbance to birds and operate above wind farm rotor blade height; Camera equipment and resolution of footage continues to improve with advancing technology; Recommended by statutory nature conservation bodies in Germany and the UK.	Can be expensive (depending on spatial and temporal scale required and type of vehicle used); Requires specialist equipment and experts; Restricted by weather conditions and to daylight hours UAVs currently have operational limitations (range, weather sensitivity); *Large volumes of data make take time and money to store, process and analyse; Species identification not always possible; Some drones can disturb some species, especially in certain seasons; Diving birds are easily missed when foraging underwater; more comparison studies need to determine detectability of different species in different habitats; Difficult to determine age classes and sex for certain species; Cannot collect simultaneous environmental data; Accuracy for flight height estimation has been questioned.

Method	Pros	Cons
Vantage point surveys	Inexpensive (compared to vessel-based or aerial methods); High detection and accuracy of species identification; Observers not influencing behaviour of animals; Can provide spatial and temporal data on usage and distribution; *Can collect detailed information such as behaviour, age, and sex; Established analysis frameworks exist. Can be extended to assess long-term trends and impact monitoring; *Good method for small, inshore sites; Can measure flight height if using a laser rangefinder; Colour ringing can help; Can be automated with certain receivers (PIT, MODUS); Can collect data for marine mammals at the same time.	*Need to find a suitable elevated site close to the sea overlooking the survey area which is often difficult or impossible; *Only monitors coastal areas up to 1 km from shore; *Difficult to use distance sampling methods; Generally not possible to estimate abundance unless additional methods are employed; Experienced observers are required; Weather restricted; May need more than 1 vantage point per survey; Low detection rate of small birds at increasing distance.

Method	Pros	Cons
Telemetry	Large amount of high-resolution temporal and spatial data on animal location and movements can provide useful information on species-specific distribution and behaviour; *Data can be collected on habitat use, connectivity between breeding colonies and development sites, and interactions with installed devices to inform collision risk modelling; *Behaviour data (foraging, flying, flight altitude, resting, dive profiles) can be collected; Usage maps can be produced; *Some sensors allow collection of additional data (depth, sea temperature, noise, etc); Some sensors transmit data avoiding need to retrieve tag; Observers not influencing behaviour of animals; *Not weather or daytime restricted; Established analysis frameworks; Has been used in context of OWE since 2006; *Telemetry estimates of time spent by species underwater can also be used to correct vessel or air counts by factoring in the probability of detection and avoiding underestimates.	Expensive; *Only a small (potentially unrepresentative) proportion of population tagged (hard to adjust for individual behavioural differences); Foraging and migration patterns can vary between seasons and years, requiring longer-term surveys; Limited life of tags; *Catching of animals for tagging can be difficult and stressful for the animal; Permits required for catching and tagging; Very experienced team required; *Not possible to estimate abundance; *Tagged animals may not enter area of interest; *Location data resolution may not allow small-scale movement of animals in proximity to installations to be determined; Data analysis and interpretation highly specialised; Some often-unknown degree of impact on tagged animal behaviour, movement and survivorship; Most data are restricted to the breeding season and with short temporal cover.
Radar, LiDAR and other sensors such as infrared	Sensors can be attached to turbines and collect data remotely; Can be used to for automated detection, identification and tracking of birds as they enter the OWF; *Radar probably most useful technique for use in triggering turbine shut-downs to prevent collisions; *Technologies evolving rapidly and offer potential for real-time monitoring of bird and bat presence at a site.	*Still in development phase; May be expensive to attach devices to adequate number of turbines; Spatial resolution not adequate to detect of collisions occurred or not; *Few ready to use sensors are easily available yet.

Annex 3. Pros and Cons of the Main Methods Used for Monitoring Marine Mammals Near OWE

Adapted from various sources, including Sparling et al. (2011), Macleod et al. (2011), Thompson et al. (2014), and Scheidat & Porter (2019). Key strengths and weaknesses identified in the review are marked with an asterisk (*).

Method	Pros	Cons
Aerial surveys (seal haul-outs)	*Provides absolute population numbers for a breeding/moulting colony; Can collect data from a large area relatively quickly to provide large-scale spatial and temporal trends; Cost effective for large areas (compared to boat- or land-based methods); Observers not influencing behaviour of animals; Established analysis frameworks; If complemented by telemetry, can provide insights into connectivity.	*Restricted window of opportunity for surveys each year (usually moulting or weaning); Data on grey and harbour seal pupping collected in different seasons; Requires different approaches for different habitats or different species; Well trained and experienced surveyors and pilots required; Specialised imaging cameras may be required; Desk-based processing of images to extract data may be time consuming; Weather restricted; *Difficult to relate changes in local seal population to wind farm development

Method	Pros	Cons
Vessel-based line transect surveys	*Data allow for estimation of absolute or relative density & abundance using distance sampling; Still the only way besides aerial transects to estimate absolute abundance of cetaceans; Can cover entire range of a population; Can collect data on age, sex, behaviour (such as foraging sites) and flight height; Well established and robust methods for assumption violations, especially for large vessels; High detection and accuracy of species identification compared to visual aerial surveys (taxa identified to species more often from the boat than in the video aerial data); Additional environmental data can be collected (e.g., water temperature, salinity, depth); *Other taxa can be monitored at the same time, especially marine birds *PAM towed arrays can be used at the same time; Surveys can cover distant offshore waters; Data can be used in species distribution models and sensitivity mapping; *Large amount of historical data available.	*Currently very limited use for seals; Can be expensive (depending on spatial and temporal scale required); Restricted by weather conditions and to daylight hours; *Can cause responsive movement of animals (avoiding vessel or attracted to vessel); *Surveying speed does not allow coverage of large areas in single trip and causes temporal mismatch in different parts of survey area; Constraints on surveying nearshore in shallow water or near reefs/sandbanks; Observers require training period and must have good species identification skills.

Method	Pros	Cons
Aerial line transects (using fixed wing aircraft, helicopters, microlights, and blimps)	Data allow for estimation of absolute or relative density & abundance using distance sampling; *Can cover large areas and the entire range of a population; Fewer issues with responsive movement; Can take advantage more readily of good weather windows than slower boat surveys; May already be taking place to carry out bird surveys; *Still the only way besides digital aerial or vessel transects to estimate absolute abundance of cetaceans.	Can be expensive (depending on spatial and temporal scale required and type of vehicle used); *Requires highly skilled observers who can detect, identify and position cetaceans at high survey speeds (observers with these skills are rare within Europe); *Specialised aircraft needed for optimal transects (high-winged with bubble windows) Restricted by weather conditions (especially for small cetaceans) and to daylight hours; Logistical limitations including height limitations around wind farms (making it harder for low-level flights needed for small cetaceans) and time limitations due to fuel capacity; Higher speeds than vessels reduce time for species detection and reduce scope for species identification; Responsive movement may be a problem for some aircraft types or some species; Currently has limited use for seals.

Method	Pros	Cons
Digital aerial surveys (manned and unmanned aerial vehicles)	Can estimate relative abundance of some species (e.g., harbour porpoise) *Can cover large areas in a relatively short time; *No observers required (just pilots), reducing costs and some health and safety risks; *No observer bias; Still or moving imagery can be collected; *Sightings can be replayed and reviewed, minimising bias and providing long-term record of survey; *Can also be used for marine birds; *Advances in technology have improved ability to identify birds to a species level; species identification can be as high as 95% and as good as human observers on vessel surveys; AI software can increasingly assist in species identification; *Surveys flown at higher altitudes reduce the risk of disturbance to birds and operate above wind farm rotor blade height; Camera equipment and resolution of footage continues to improve with advancing technology; Recommended by statutory nature conservation bodies in Germany and the UK.	Can be expensive (depending on spatial and temporal scale required and type of vehicle used); Requires specialist equipment and experts; Restricted by weather conditions and to daylight hours UAVs currently have operational limitations (range, weather sensitivity); *Large volumes of data make take time and money to store, process and analyse; Species identification not always possible (but this is true of most methods); Some drones can disturb some species, especially in certain seasons; Cannot collect simultaneous environmental data.
Satellite imagery surveys	Has been used to count some large whales and some pinnipeds; *Large areas of remote habitat can be surveyed; Behaviour not affected.	*Image resolution not yet high enough to be of use for small cetaceans; Analytical protocols still under development; Not yet a very practical option.

Method	Pros	Cons
Vantage point surveys	Inexpensive (compared to vessel-based or aerial methods); High detection and accuracy of species identification; Observers not influencing behaviour of animals; Can provide spatial and temporal data on usage and distribution; *Can collect detailed information such as behaviour, age, and sex; Established analysis frameworks exist; Can be extended to assess long-term trends and impact monitoring; *Good method for small, inshore sites; Can collect data for marine birds at the same time.	*Need to find a suitable elevated site close to the sea overlooking the survey area which is often difficult or impossible; *Only monitors coastal areas up to 1 km from shore; *Difficult to use distance sampling methods; Generally not possible to estimate abundance unless additional methods are employed; Experienced observers are required; Weather restricted; May need more than 1 vantage point per survey; Low detection rate of small birds at increasing distance.
Passive acoustic monitoring - towed arrays	Can estimate relative abundance using distance sampling; Some species vocalisations (e.g., sperm whale) can allow estimates of absolute abundance; *Data are independent of daylight and most weather conditions; Can be implemented along with line transect observations; Can provide high resolution spatial information on abundance and distribution; Some behavioural information can also be inferred.	*Methods to estimate abundance are only developed for some cetaceans (e.g., harbour porpoises, sperm whales); for others it is only possible to estimate indices of abundance; Species identification is difficult for some species; Performance is dependent on the noise level of the vessel; High frequency vocalisations have a limited detection range (approximately 200 m); *Large volumes of data make take time and money to analyse.

Method	Pros	Cons
Passive acoustic monitoring - static devices	*The most powerful and cost-effective method for monitoring cetacean density; devices such as the C-POD and Deep C-POD have proven effective, especially for small cetaceans, with software aiding data analysis; Data can be used to monitor relative abundance as well as habitat use and behavioural patterns; Estimation of population density is evolving rapidly Stationary click detectors provide high temporal resolution; *Data collection can be relatively inexpensive; Long-term data sets can be collected; Can have higher detection rate than visual surveys for some species (especially deep-diving toothed whales); *Less likely to disturb animals than using vessels *Some new systems such as Costal Acoustic Buoys can broadcast data, allowing almost real-time monitoring; *Can also be used to record construction noise (especially high-impulse piling sounds).	Devices require deployment and retrieval to obtain data, adding logistical challenges and effort; Anchoring the devices can be challenging; Can be at risk of damage from construction vessels and fishing boats; High frequency vocalisations have a limited detection range (approximately 200 m); No background noise compensation; Limited ability for most designs to provide detection range; *Limited spatial coverage compared with towed devices; May attract some inquisitive species; *Large volumes of data make take time and money to analyse; Some species more easily detected than others (e.g., harbour porpoises more easily detected than bottlenose dolphins).

Method	Pros	Cons
Telemetry	Large amount of high-resolution temporal and spatial data on animal location and movements can provide useful information on species-specific distribution and behaviour; *Data can be collected on habitat use, connectivity between breeding colonies and development sites, and interactions with installed devices to inform collision risk modelling; Dive profiles (and behaviour) data can be collected; Data can help correct haul out counts to account for proportion of animals at sea; Usage maps can be produced; *Some sensors allow collection of additional data (depth, sea temperature, noise, etc); Some sensors transmit data avoiding need to retrieve tag; Observers not influencing behaviour of animals; *Not weather or daytime restricted; Established analysis frameworks; *Telemetry estimates of time spent by species underwater can also be used to correct vessel or air counts by factoring in the probability of detection and avoiding underestimates.	Expensive; *Only a small (potentially unrepresentative) proportion of population tagged (hard to adjust for individual behavioural differences); Foraging and migration patterns can vary between seasons and years, requiring longer-term surveys; Limited life of tags; *Catching of animals for tagging can be difficult and stressful for the animal; Permits required for catching and tagging; Very experienced team required; *Not possible to estimate abundance; *Tagged animals may not enter area of interest; *Location data resolution may not allow small-scale movement of animals in proximity to installations to be determined; Data analysis and interpretation highly specialised; Some often-unknown degree of impact on tagged animal behaviour, movement and survivorship; Most data are restricted to the breeding season and with short temporal cover.

Annex 4: Mammal Case Study - Comparison of Cetacean Monitoring Methods and Protocols

A comparison of methods and protocols for monitoring cetacean distribution, abundance, behaviour and threats around wind farms. Sources: Germany (BSH, 2013), Ireland (Department of Communications, Climate Action & Environment, 2018a,b), Scotland (Macleod et al., 2011) OSPAR (OSPAR Commission, 2019).

Specifications	Guidance or protocols			
	Germany (BSH, 2013)	**Ireland (DCCAE, 2018a,b),**	**Scotland (Macleod et al., 2011)**	**Other sources**
Methods	Digital aerial surveys; Vessel-based surveys (as a complement to bird surveys); Static PAM (CPODs) Recording underwater noise (using BSH protocols)	Visual aerial surveys; Digital aerial surveys; Vessel-based surveys; Static PAM (CPODs) Active PAM (towed) Vantage point surveys Stranding schemes (for mortality and injury) Reporting of entanglements and collisions	Visual aerial surveys; Digital aerial surveys (to test) Vessel-based surveys; Static PAM (CPODs) Active PAM (towed) Vantage point surveys Telemetry Photo-ID Stranding schemes (for mortality and injury) Reporting of entanglements and collisions	OSPAR for regional surveys: Visual aerial surveys (using SCANs methods); Vessel-based surveys using SCANs Static PAM Mark-recapture Photo-ID using Urian et al. (2015) methods;

Specifications	Guidance or protocols			
	Germany (BSH, 2013)	Ireland (DCCAE, 2018a,b),	Scotland (Macleod et al., 2011)	Other sources
Timing/frequency	At least 2 years pre-construction data (consecutive complete seasonal cycles) Vessel-based surveys once per month; digital aerial surveys 8-10 times per year; year-round acoustic deployment after construction Continue all surveys for 3-5 years after commissioning. Noise levels needs to be measured throughout construction and for first year of operation	3 years pre-construction data preferred (2 at minimum) Vessel-based surveys quarterly in all seasons (ideally monthly) for pre-construction monitoring; lower levels post-construction; Ideally, surveys should be designed to be carried out in a single day or a maximum of two consecutive days if weather is suitable.	Monthly surveys recommended; the exact frequency of sampling depends on the location of the site, the amount of data collected at each sampling period, the metric being measured (in particular it's variability) and the survey method used.	OSPAR: regional surveys are supposed to be implemented every 6 years as per the EU Habitats Directive and the Marine Strategy Framework Directive, though in reality they are less frequent.

Specifications	Guidance or protocols			
	Germany (BSH, 2013)	Ireland (DCCAE, 2018a,b),	Scotland (Macleod et al., 2011)	Other sources
Spatial scale	Transects should cover at least 10 % of the assessment area; for aerial surveys, the area must cover at least 2,000 km², with the wind farm at the centre of the assessment area; the distance between the sides of the wind farm and the margins of the assessment area shall principally be at least 20 km; for vessel-based surveys, the assessment area must cover at least 200 km². The distance between the sides of the wind farm and the margins of the assessment area shall principally be at least 4 km.	Impact area and a buffer zone of a minimum of 10 km	The use of buffers beyond the boundaries of a development site is often incorporated in a Before After Gradient design for impact monitoring. Study design for should extend beyond the development site and the exact extent of this should be informed by the likely impact footprint and the sensitivity of the population.	
Impact assessment	BACI design proposed	BACI or BAG proposed	BAG favoured	

Specifications	Guidance or protocols			
	Germany (BSH, 2013)	Ireland (DCCAE, 2018a,b),	Scotland (Macleod et al., 2011)	Other sources
Monitoring design	Surveys need to focus on measuring abundance and distribution, habitat use and noise emission Detailed protocol for vessels surveys though they are bird focused (e.g., transect spacing is 3-4 km; transect width is 300 m to either side of the vessel, each side covered by 2 observers); Vessel cruising speed 7-16 knots, with 10 knots optimal Digital aerial surveys need to cover at least 10% of the assessment area Static PAM with 4-5 PODs during construction (installed in suitable distances to the wind turbines; 2 PODs 750 m and 1,500 m distance during pile driving) and at least 3 PODs during operation;	Visual surveys should be carried out in sea-state ≤2 inshore if harbour porpoise is present or ≤3 for offshore sites. For static PAM, restricted stratified random sampling in defined grids with enough units to ensure statistical robustness Data to be presented per unit effort (e.g., PAM records as % of detection positive minutes); Power analysis using pre-construction data can identify resolution at which change can be determined.	Visual surveys should be discontinued when sea state is above Beaufort 4 for ships and Beaufort 3 for aircraft As per Buckland et al. (2001), at least 60-80 sightings are required for distance sampling analysis; Vessel cruising speed of 10 knots is optimal Aerial surveys best at 183 m altitude (higher than the 80m for birds); Collect POD data periodically (e.g., every 3 months)	At least 10-20 replicate transect lines should be placed in a systematic, randomised manner to provide adequate variance in encounter rate and reasonable confidence limits; minimum sample size of 60-80 sightings (or 50-100 aerial race tracks) needed to estimate a reliable detection function (Scheidat & Porter, 2019: Vessel cruising speeds should be twice the swim speed of species being monitored (Ibid); Optimal height for aerial surveys 150-180 m (Hammond et al., 2017) C-PODs should extend tens of kilometres from wind far as harbour porpoise displacement can exceed 20 km (Scheidat & Porter, 2019)

Annex 5. Pros and Cons of the Main Methods Used for Monitoring Fish and Seabed Faunal and Floral Communities near OWE

Based on various sources, including Spencer et al. (2005), Portt et al. (2006), Saunders et al. (2011), and HELCOM (2015a). The effectiveness of most methods is taxa specific. Key strengths and weaknesses identified in the review are marked with an asterisk (*).

Method	Pros	Cons
Benthic grab sampling	*Grab sampling collects a snapshot of an entire infauna community which can be analysed in detail in a laboratory; provides a level of biological detail, and taxonomic resolution, beyond what can be achieved for other methods or for epibenthic habitats; A full account of infauna community composition is possible, with fully quantitative species abundance data that can subsequently be used to calculate diversity metrics; *Higher taxonomic resolution possible when compared with scuba divers or video; *Surveys combining drop-down video and grab from the same vessel have several advantages, one of the most obvious being cost- and time effectiveness. Whenever a sandy or soft sediment substrate without vegetation is encountered with drop-video, the grab can be used for sampling of infauna. Some grab samplers may also be used for sampling of vegetation when needed which may improve the quality of drop-video interpretations.	*Grabs are heavy and bulky pieces of equipment and require vessels equipped with adequate lifting gear and of a suitable size from which they can be safely deployed; Grab sampling requires a large vessel including a crew.; this cost item is by far the most expensive for the method; *Grabs are very difficult to deploy successfully in moderate current speeds or large swell and generally require relatively calm seas and slack tides as the optimal conditions for obtaining good samples; A considerable amount of effort is required to process each sample, rendering the task both time-consuming (weeks or months) and expensive (The retained organisms have to be painstakingly removed from the remaining benthic debris before being identified and enumerated by an expert taxonomist);

Method	Pros	Cons
Direct observationdivers	*Can provide high level of taxonomic detail; have consistently proved to be the best means of obtaining quantitative epifaunal data and good quality video or photographic documentation; Observations on species, habitat, biotope and substratum presence, abundance and distribution can be completed with a greater degree of confidence than with the use of remote systems, particularly where there is a high occurrence of cryptic biota which usually requires manual manipulation to reveal obscured individuals; similarly, some reef or bed-forming species are not immediately obvious and require a divers viewpoint, intuition and ability to physically handle the substrata and associated biota before confirmation of presence can be made; *Where the recovery of epifaunal specimens for taxonomic identification is required, diver collection is by far the most efficient method of doing so; Divers can obtain quantitative soft sediment samples by means of hand-deployed cores, which can be accurately replicated and provide a reliable basis for statistical analyses; Individual epibenthic species density counts using replicated quadrats can be achieved in situ, or, where time constraints are an issue, quadrats can be carefully recorded using video or photography and quantitatively analysed later; Does not harm fish, which can be especially important when working with endangered populations.	*Largely restricted to depths shallower than 30 m; Difficult in turbulent or fast flowing sea conditions; *Intrinsic logistical restrictions, with safety considerations and time limitations dictated by air supply and diver deployment time restrictions for physiological reasons *Only suitable for investigations of discrete locations or very small areas that can be adequately surveyed within a short time; High species identification skills required; Efficiency decreases if fish abundance is high and accurate counts may not be possible; Efficiency varies with visibility and cover, and with fish size, coloration and behaviour; The presence of divers affects some species behaviour.

Method	Pros	Cons
Direct observation – drop-down video	Drop-down video (or drop video) is a visual survey method for benthic vegetation and epifauna as well as benthic substrate. *Time- and cost efficient compared to methods such as diving since limited number of staff needed for operation, the drop-camera can be operated from a small vessel (without need for other crew than the drop-video staff), and only a few minutes are needed at each station; *Recent advances in digital video technology and reductions in costs make this a particularly cost-effective survey method for all substrate types; Supports planning and use of other methods such as grabs. *Can survey a wider area more quickly than grabs and divers; HELCOM (2015) estimates that drop-down video can survey 30 sites per day compared to 3-9 sites a day by divers; Surveys combining drop-down video and grab from the same vessel have several advantages, one of the most obvious being cost- and time effectiveness (see above).	Restricted by weather conditions and to daylight hours; The quality of visual data reduces substantially with increasing current speed and high swell; this may lead to under-reporting of habitats present in very exposed locations or in areas where there is little or no slack water May be challenges with steeply-sloping or vertical rock faces; Images can be too blurry to identify some species; *Lower taxonomic resolution than methods such as diving and grab sampling and it may be difficult or impossible to distinguish between some species (e.g., several species of filamentous algae); Performed in several different ways (e.g., there is no standard for this method in the Baltic Sea yet);

Method	Pros	Cons
Digital survey through remotely operated vehicles (connected to the vessel) and autonomous underwater vehicles (independent of vessel)	*Can survey habitats and some species seen and assess diversity or relative abundance; Useful where steep or vertical substrates need to be examined, or where periods of positional stability are required to identify the presence and possibly the broad abundance of particular species; When suitably equipped, ROVs can also perform some limited remotely-operated manipulative functions, such as collecting voucher specimens; *Surveys can be replayed and reviewed; No observers required (just pilots), reducing costs and some health and safety risks; Still or moving imagery can be collected.	*All ROVs are mechanically complex and require considerable maintenance, operational attention and adherence to set-up routines; Substantial time can be lost to technical failure, while the vehicles themselves are expensive to buy or hire. Turnaround times between deployment, recovery and relocation is longer than that of drop-down video systems, potentially resulting in a significant reduction in the number of survey stations achieved; Can be expensive (depending on spatial and temporal scale required and type of vehicle used); Restricted by weather conditions and to daylight hours; ROVs have operational limitations (range, weather sensitivity); Some AUVs can disturb some species.
Fishing – gill nets	*Effective and relatively simple to use; Can be used in most habitats where there is ample unobstructed depth to allow the mesh to be extended between the float and lead lines; Quantification of fishing effort usually considers the length of gear and the time set.	*Fish mortality varies among species and with habitat conditions, but is typically high; Cannot be used in strong currents; Highly selective in species caught; The nets are susceptible to damage, and modern nylon mesh must be replaced rather than mended; The lead and float lines are expensive; Normalising catches from different mesh sizes and soak times can be complex.
Fishing – fyke nets	*Allows live capture for mark-recapture or tagging studies; The sizes normally used for research purposes can be set and lifted by two people; Fyke nets tend to be easier and faster to set and to lift than trap nets; Well suited to targeted studies such as intercepting fish moving along known migration routes.	Difficult to use where currents are strong and/or carry a lot of debris; These nets are passive gear, and only catch fish that are moving; They are size and species selective and catches are often highly variable.

Method	Pros	Cons
Fishing – beam trawl	*Provides description of epifauna (macrobenthos, demersal fish); Samples can be collected relatively quickly; Recommended by some national governments (e.g., BSH, 2013).	It is less effective at detecting some benthic fish and crabs than divers or cameras; *Destructive technique: ground gear crushes and dislodges animals on the seabed, and non-target animals can be caught and killed in the trawl.
Acoustic mapping	*Useful to measure seabed topography and identify some habitat types; IHO standards exist for its use; Can help plan use of other methods.	*Only provides low resolution assessment of habitat and topography.

Renewables
Grid Initiative

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