WORKSHOP TO SCOPE FOR HARMONIZED REGIONAL MONITORING SCHEMES TO ASSESS THE IMPACT OF OFFSHORE WIND FARMS ON FISH, PELAGIC AND BENTHIC COMMUNITIES AND ECOSYSTEM FUNCTIONS (WKOMO)

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i Executive summary

Understanding the ecological impacts of offshore wind farms (OWFs) is hindered by a lack of harmonised monitoring data, despite the growing demand for coordinated assessments across countries. The Workshop to scope for Harmonized Regional Monitoring Schemes to Assess the Impact of Offshore Wind Farms on Fish, Pelagic and Benthic Communities and Ecosystem Functions (WKOMO) reviewed national monitoring efforts, collected meta data information on national monitoring activities and recommended steps toward a unified regional framework focused on OWF impacts on marine ecosystems, especially during the operational phase. Results showed that OWF monitoring varies widely across countries in context, focus, and data quality, with most efforts centred on individual wind farms and primarily targeting fish and invertebrates, while key infrastructure and ecosystem functions remain underrepresented. Spatial and taxonomic biases, along with inconsistent documentation and data centralization, hinder comprehensive assessments, although some high-confidence data exist in well-monitored regions like the North Sea. Case studies from multiple countries highlight both ecological benefits (e.g., habitat creation, biodiversity increase) and challenges (e.g., non-native species spread, hydrodynamic changes), underscoring the need for long-term, harmonized, and multidisciplinary monitoring to fully understand OWF impacts.

ii Expert group information

Expert group name	Workshop to scope for Harmonized Regional Monitoring Schemes to Assess the Impact of Offshore Wind Farms on Fish, Pelagic and Benthic Communities and Ecosystem Functions (WKOMO)
Expert group cycle	Workshop
Year cycle started	2025
Chairs	Steven Degraer; Belgium
	Vanessa Stelzenmüller; Germany
Meeting venue and dates	26-28 May 2025, ICES HQ, Copenhagen, Denmark (25 participants)

1 Background

Understanding the impacts of offshore wind development on ecosystem functions and processes is crucial to provide advice for the management and mitigation of human activities and to maintain and safeguard biodiversity and ecosystem health. During the development of the ICES roadmap for offshore renewable energy (ORE), and as part of the WKCOMPORE (Workshop to Compile Evidence on the Impacts of Offshore Renewable Energy on Fisheries and Marine Ecosystems) process, which compiled evidence on the impacts of offshore renewable energy on fisheries and marine ecosystems in response to a special request for advice from the European Commission (EU, DGMARE), experts highlighted a lack of data from harmonised monitoring efforts as a key knowledge gap.

Currently, there is a strong demand for internationally coherent advice and knowledge sharing about best practices for the monitoring and management of marine offshore renewables, given the ambitious development plans in many countries. However, a lack of data to understand ecological impacts and effects is also evident in several areas where offshore wind farms (OWF) have been in place for more than a decade. While not all dimensions of potential OWF impacts require regional-scale monitoring by their definition, the need for harmonised methodological approaches applies at all spatial scales in order to provide coherent assessments.

Currently, research on the effects of OWF is being developed and coordinated in several ICES working groups such as the Working Group on Offshore Renewable Energy (WGORE), the Working Group on Offshore Wind Development and Fisheries (WGOWDF) and the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED). However, there is no WG focusing on the monitoring aspects. This report is the outcome of WKOMO, which aimed to review national monitoring efforts with regard to offshore wind development and to scope for essential steps towards a harmonized regional monitoring to enable the assessment of regional impacts of OWF on fish, pelagic and benthic communities, and related ecosystem functions. The workshop coordinated and discussed existing information from OWF monitoring and research, and synthesised the results into recommendations for the next steps forward.

The results from the workshop focus on the monitoring aspect of environmental impacts from OWF, which encompasses a wide variety of aspects, such as local and regional monitoring and the monitoring of effects of specific infrastructure (e.g. to study effects of foundations and export cables). While the emphasis is on the operational phase, the data compilation and synthesis also include information provided by the workshop participants from surveys associated with siting decisions and licensing processes. As a delineation to other OWF related work strands, in-combination impacts, the accounting for multiple human activities and pressures and risks of their combined adverse effects on selected ecosystem components, are not considered.

The report does not provide a blueprint or give specific guidance but includes recommendations to ICES and the wider ICES community about how harmonised OWF monitoring could be developed to enable coherent assessment of OWF impacts on fisheries species and their resources across projects and countries. It aims to outline what an internationally harmonised OWF monitoring framework could look like, and to introduce aspects that need to be considered and developed further to improve collaboration within and across ecoregions.

2 The need to harmonise OWF impact monitoring and research

Long-term development of OWF will occupy large parts of the marine environment, from the seafloor, through the water column across the ICES region. It is, therefore, in the interest of ICES member states to ensure the scientific evidence and advice on the impact of offshore wind development is harmonised between countries. Harmonisation of environmental monitoring at the level of ICES countries is a way to: 1) increase scientific knowledge around OWF impacts on marine ecosystems, and 2) provide grounds for the implementation of common policies from regulation to mitigation measures based on the acquired knowledge within pre-existing governance frameworks.

Marine spatial planning (MSP), as a cross sectoral governance process that manages the use of space in order to achieve economic and environmental objectives (Stelzenmüller *et al.* 2013, Zuercher *et al.* 2023) entails also the development of offshore renewables. However, the cumulative pressures from multiple human activities or the combined effects of sectoral plans, like the development of OWF, are not yet adequately addressed ((Isaksson *et al.* 2025)). The EU Marine Spatial Planning Directive (EUMSPD) requires member states to implement legally binding spatial plans which help to achieve or maintain a good environmental status (GES) as required by the EU Marine Strategy Framework Directive (MSFD). Thus, marine spatial plans should build on a sound understanding of cumulative impacts, which are assessed through cumulative effects or impact assessments (CEA). EU policies also require member states to conduct strategic environmental assessments (SEA) which provide an overview of the ecological and socio-economic impacts of sectoral plans and conservation measures entailed in the marine spatial planning process. As yet, the monitoring and evaluation of MSP is not sufficiently addressed by members states (Stelzenmüller *et al.* 2021), which is also reflected in often generic SEAs.

In contrast, the national OWF licensing process entails a site-specific environmental impact assessment (EIA) which address the short- and long-term impact of the respective project on the marine environment. Thus, this means that local environmental impact assessments for offshore renewable energy projects or licensing sites need to be integrated with environmental assessments for maritime spatial plans or sectoral development plans such as SEA as well as regional sea assessments that determine good environmental status, as required by the MSFD. Thus, together EIA and SEA provide a complementary governance framework that should allow monitoring the combined effects of the regional development of offshore renewables.

3 National reports: scoping for needs and possibilities for harmonisation

During WKOMO, the detailed description of OWF monitoring activities of twelve countries were collected (Annex 4). Figure 3.1 outlines the type of information that has been collected. Below the state of OWF development, the national monitoring obligations and responsibilities, monitoring approaches and current knowledgebase of OWF impact are summarised.

Figure 3.1. Overview of WKOMO collected information regarding OWF monitoring activities by country.

3.1 Summary of current state of national offshore wind development

Offshore wind energy development is progressing at different rates across countries, shaped by national energy goals, available maritime space, and environmental governance frameworks. While some countries have well-established offshore wind sectors and national monitoring programs, others are only beginning to plan and allocate space for future development.

Several European countries have already developed significant portions of their Exclusive Economic Zones (EEZs) for offshore wind farms (OWFs). Belgium, for example, currently uses 6.8% of its EEZ and plans to increase this to 15%, equating to 5.4–5.8 GW of capacity by 2030. Belgium has a national monitoring program, WinMon.BE, coordinated by the Royal Belgian Institute for Natural Sciences. Similarly, Germany has developed 2.75% of its EEZ and targets 70 GW of capacity by 2045. Its monitoring is centrally coordinated by the Federal Maritime and Hydrographic Agency (BSH).

The Netherlands has installed 4.1 GW of offshore wind, covering 1.2% of its EEZ, and aims to reach 53 GW by 2040. Its approach includes structured environmental monitoring via the Offshore Wind Ecological Programme (Wozep), with several government agencies involved in permitting and data collection. Norway has a small portion of its EEZ designated for offshore wind, but with a target of 30 GW by 2040, supported by a national environmental monitoring system.

In contrast, France, despite having the largest EEZ globally, has only developed a negligible portion for offshore wind (0.0006%). However, its targets are ambitious—18 GW by 2030 and 45 GW by 2050. France requires project-level monitoring, but the state provides extensive baseline data and protocols for operators to follow, aiming for nationwide consistency. Ireland has minimal operational capacity but plans for 20 GW by 2040. It currently lacks a dedicated national OWF monitoring program, however, is committed to the development of an ecosystem-based approach to monitoring of OWF (Maritime Area Planning Act 2021) whilst also adhering to EU-wide marine directives.

The UK is more advanced, with 14.7 GW operational and plans for up to 50 GW by 2030 and 140 GW by 2050. Around 0.54% of the UK EEZ is developed for OWFs. Monitoring is project-specific and overseen by devolved national authorities such as the Marine Management Organisation in England and Marine Scotland. Sweden, although not setting specific targets for offshore wind, has a potential capacity of up to 14 GW currently permitted, with ongoing applications totaling around 40 GW. However, it relies on broader national environmental monitoring rather than OWF-specific systems.

In the United States, offshore wind remains in early phases, with less than 1% of its vast EEZ leased for development. National targets and strategies exist, and several projects are under construction. Monitoring is mandated at the project level by the Bureau of Ocean Energy Management (BOEM), though there is no standardized national program. Federal agencies like NOAA Fisheries conduct broader marine ecosystem monitoring that overlaps with OWF development areas.

Elsewhere, Portugal and Spain have set ambitious targets—10 GW and up to 3 GW by 2030, respectively—but have limited operational capacity. Monitoring frameworks are still developing, often relying on EU directives or project-level assessments. Poland has defined targets of 11 GW by 2040 but has yet to begin development. Monitoring in Poland is not yet specific to OWFs.

Overall, offshore wind development is expanding rapidly, but environmental monitoring approaches vary significantly, ranging from centralized national systems to project-specific, operator-led efforts.

3.2 National obligations, allocation of responsibilities and funding sources

Monitoring of offshore wind farms (OWFs) is an essential component of environmental governance in all countries engaged in wind energy development. Across the board, national obligations typically require environmental assessments before, during, and after project implementation. These obligations are mostly embedded within Environmental Impact Assessments (EIA), often linked with Strategic Environmental Assessments (SEA) and Marine Spatial Planning (MSP) to manage conflicts between OWFs and other sea uses.

In many countries such as Poland, Germany, Sweden, and Spain, monitoring is investor-driven. Developers are responsible for carrying out and funding both the EIA and post-approval monitoring. Data collection usually begins at the permitting stage and continues through construction and operation. National authorities such as environmental protection agencies review these studies, although data accessibility varies. For example, in Poland and Sweden, monitoring data are generally not publicly available, even though summaries appear in official reports.

In the UK and France, the government plays a strong role in spatial planning and early-stage data acquisition. Authorities define suitable development areas and conduct initial strategic

assessments. Once developers are selected, they are tasked with project-level EIAs and long-term monitoring. Government institutions maintain oversight, and while developers fund the monitoring, public funds may support early data collection or strategic research. France mandates developer-led monitoring through legally binding regional orders (Arrêtés Préfectoraux), ensuring that environmental concerns are addressed throughout the project lifecycle.

The U.S. employs a system where the Bureau of Ocean Energy Management (BOEM) requires developers to conduct monitoring at the project level to assess impacts on marine species and ecosystems. NOAA Fisheries is currently working with BOEM to establish standard methods for project-level monitoring and regional data integration. Funding mechanisms include requirements under development agreements, power purchase contracts, and anticipated additional funding streams that are still being defined.

Countries like Norway and the Netherlands emphasize nationally coordinated monitoring programs. In Norway, national institutes carry out baseline studies years before development begins, funded by ministries, national research councils, and EU programs. The Netherlands has shifted from government-led to developer-funded monitoring over time, guided by the national Offshore Wind Ecological Programme (Wozep), which helps close knowledge gaps and informs planning decisions.

Portugal and Spain are still developing more mature systems. Portugal requires EIAs and monitoring plans through maritime space use titles (TUPEM), with oversight by several regulatory bodies. Monitoring obligations fall on developers, and there is increasing alignment with broader environmental regulations. Spain's system is currently permit-driven and linked to the EIA process, but new regulations are expected to expand monitoring frameworks.

Belgium offers a unique approach through the WinMon.BE fund, which finances long-term, hypothesis-driven monitoring activities coordinated by the Royal Belgian Institute of Natural Sciences. This publicly managed fund supports collaboration with universities and research institutions and ensures data transparency through the Belgian Marine Data Centre.

Overall, while legal obligations and institutional structures vary, a general pattern is clear: developers are primarily responsible for funding and implementing OWF monitoring, while governments provide regulatory frameworks, strategic oversight, and, in some cases, initial funding. The evolution of national systems reflects a growing emphasis on cumulative impact assessments, strategic planning, and the integration of monitoring into marine spatial governance.

With regards to national data collection frameworks or data based the countries reports revealed that several countries have functioning open-access databases for offshore wind farm monitoring data. These include Belgium (Marine Data Centre, BISAR), Germany (MARLIN), Netherlands (Marine Information House, AquaDesk), Portugal (WEAREATLANTIC, SOMOSATLÂNTICO), Sweden (national databases hosted by SLU and SMHI), and France (DATAEMR). The UK also has central data frameworks such as MEDIN, although not always OWF-specific. Norway and Spain have monitoring frameworks with partial or decentralised data access. Other countries, such as Poland and the US, lack harmonised national databases or frameworks.

3.3 Overview of national monitoring activities

Several countries have established national initiatives for coordinated OWF monitoring. Belgium operates WinMon.BE, a coordinated national programme led by Royal Belgian Institute of Natural Sciences with multiple partners. The Netherlands runs Wozep, a national monitoring programme within a broader ecological framework. Sweden has ongoing projects (Wind4CoCO, Swedish Institute for the Marine Environment) aiming to develop nationally coordinated OWF

monitoring. The UK has multiple initiatives including UKMMAS, MEDIN, MDE, OWEER, and ScotMER to facilitate data sharing and research coordination. France is developing harmonised protocols via Ifremer and OFB and launched France Energies Marines to foster collaborative research. Norway's NVE coordinates monitoring across institutes and industry. In the U.S., NOAA is developing a national monitoring strategy and science plan. Other countries (Germany, Ireland, Portugal, Spain, Poland) currently lack national coordinated monitoring initiatives.

During WKOMO, standardised meta data were collected for the twelve countries detailing the monitoring context, purpose, spatial and temporal resolutions, ecosystem components, habitats, indicators, methods, ecosystem processes and functions being monitored, OWF status, confidence and data availability statements (Annex 5). Overall, 613 data entries on monitoring activities were gathered by workshop participants. Therefore, the collated dataset reflects monitoring activities as compiled and reported by national representatives and workshop participants. As such, it serves as a synthesis rather than a comprehensive inventory. Several limitations need to be considered. First, the entries represent aggregated summaries of multiple monitoring efforts and may not capture the full extent or spatial resolution of available data. Second, underrepresentation is likely in cases where data are proprietary (e.g., EIA by developers), unpublished, or not shared due to confidentiality or accessibility constraints. Overrepresentation may occur where the same monitoring activity is reported under multiple categories or duplicated across reports. Additionally, monitoring frameworks such as Scotland's PrePARED network and other national or regional initiatives may not be fully reflected if they were not explicitly cited or recognized by participants. Despite these limitations, this dataset provides a baseline overview to identify spatial and methodological gaps across European offshore wind monitoring.

3.4 Stocktaking of current monitoring in European and U.S. waters to assess the impact of offshore wind development

The metadata revealed that the distribution of monitoring efforts across countries differs in the sources of data and the context of monitoring. Monitoring is primarily conducted under three main contexts: national regulatory requirements, environmental impact assessments led by developers, and research-driven activities. Countries like Germany rely largely on National led programs, while others show more contributions from academic research (Norway and Sweden) or industry-funded environmental impact assessments (Poland and France). These differences highlight potential gaps in standardized monitoring data integration.

Approx. two third (77%) of the total 660 reported monitoring entries were related to single wind farm projects. While, ~ 19% were focused on clusters, indicating that the monitoring was conducted in multiple wind farms simultaneously for across site comparison. Only 3% of the monitoring focused on infrastructure other than the installed turbines, their scour protection or surrounding habitats. This indicates a considerable gap of monitoring of other related infrastructure, such as underwater cables, barges, anchorage points and relay stations.

The relative comparison of monitoring efforts shows that OWF monitoring is predominantly focused on invertebrates and fish, with a strong emphasis on soft sediment and water column habitats (Figure 3.2). This bias towards fish and invertebrates might be due to their relevance to assess direct OWF impact and cross comparison to other reference sites and existing long-term data. In contrast plankton, shellfish or other trophic levels are significantly less represented in the summarised monitoring activities. Further, Figure 3.2 shows that biogenic habitats, scour protections and demersal habitat are comparatively less surveyed despite expected long-term impacts from OWF on these habitats and their relevance for ecosystem functions such as habitat provision and productivity related to the artificial reef effect.

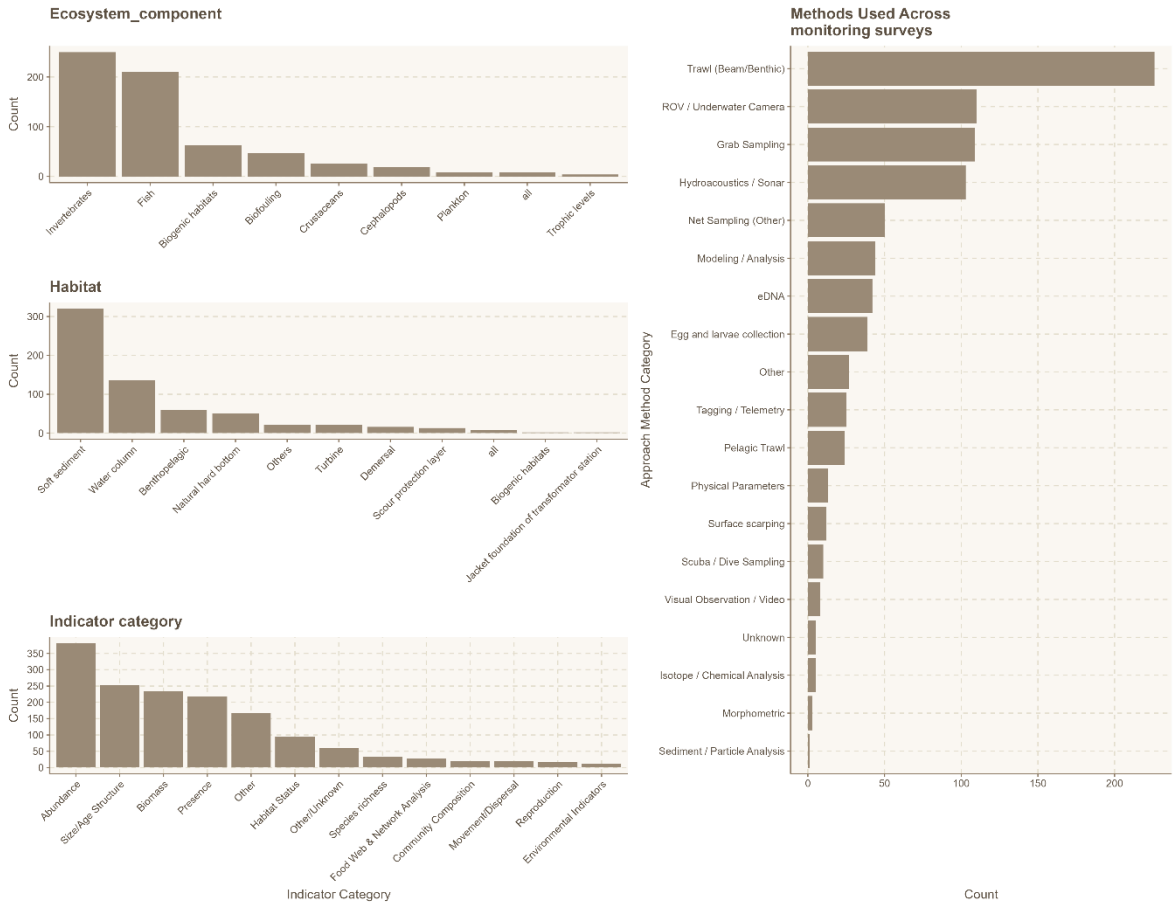

Figure 3.2. Barcharts showing the total number of monitoring activities by ecosystem component, habitat type, indicator category and methods used currently on OWF monitoring across all twelve countries.

While a broad number of indicators are reported, most monitoring programs concentrate on state descriptors or structural indicators, particularly those assessing abundance, biomass, and size structure (Figure 3.2). In contrast, functional indicators related to ecosystem processes (e.g., nutrient cycling, predator-prey dynamics) and ecosystem functions (e.g., carbon cycling, habitat provision) are far less frequently reported or considered during monitoring efforts or impact assessments (Figure 3.3). Secondary production and habitat provision are largely evaluated as they rely on state descriptors such as species counts, abundance and distribution of key species.

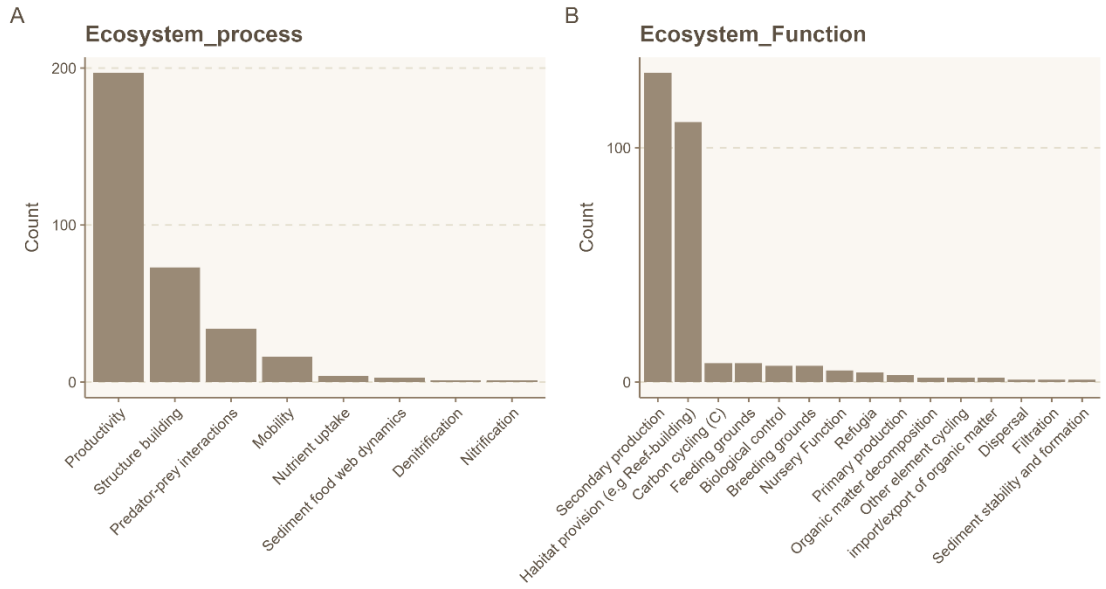

Figure 3.3. Barplots showing the total number of monitoring activities linked to (A) ecosystem processes and (B) ecosystem functions.

Monitoring efforts are yet sparsely distributed across regions (Figure 3.4). The North Sea and parts of the Baltic Sea exhibit higher concentrations of monitoring activity, which is aligned with OWF development. By contrast, areas in the Western Mediterranean and parts of the Atlantic have fewer or more isolated monitoring efforts, indicating spatial disparities in data availability.

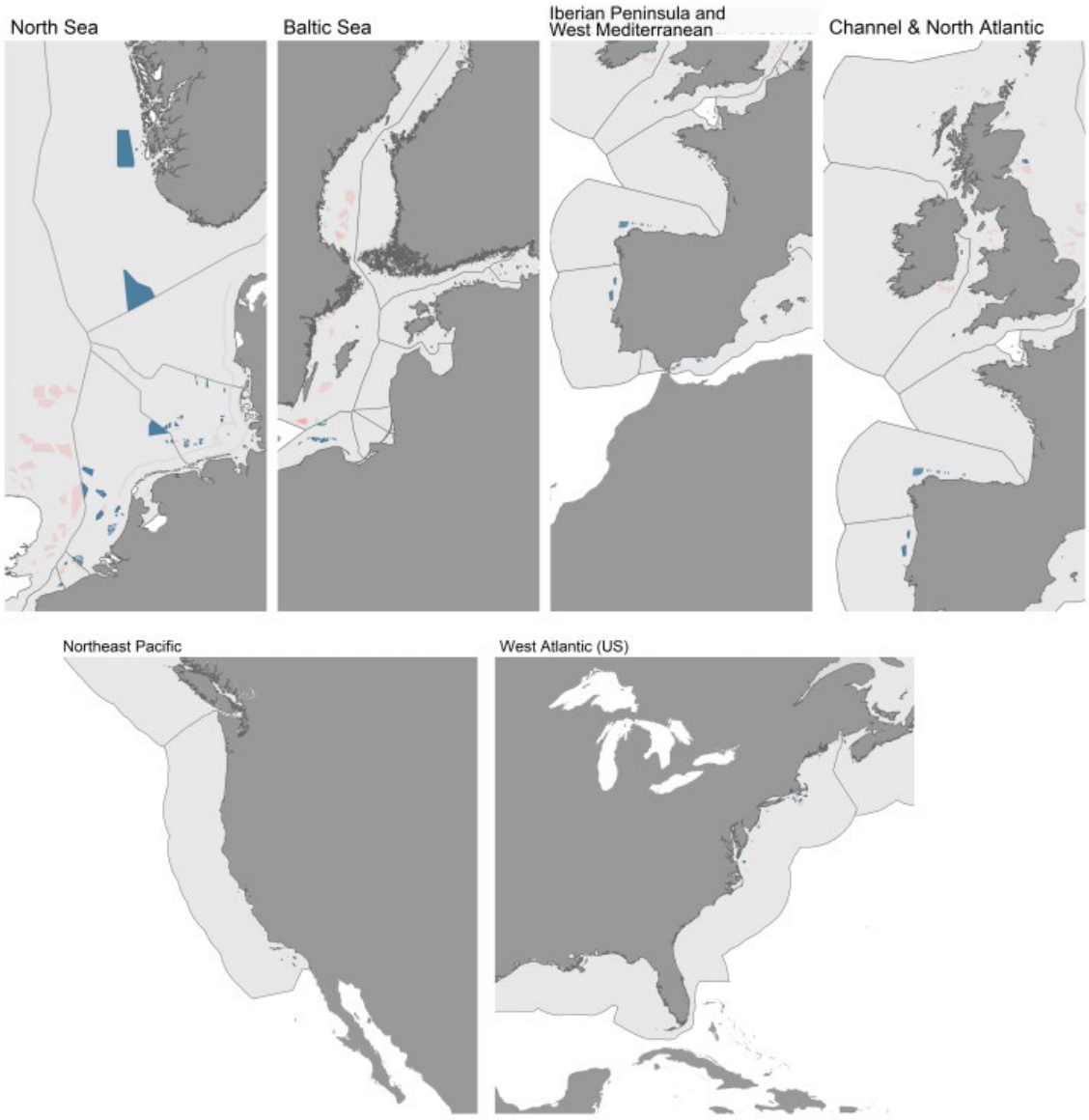

Figure 3.4. *S*patial location of OWF licence areas where monitoring takes place (blue polygons), as indicated by workshop participants together with all operational, licensed or under construction OWF polygons (light red) source: 4C offshore. EEZ boundaries are included as reference.

Workshop participants scored the confidence level to which the monitoring has been clearly documented and data is available to assess the spatial, temporal and focus of the efforts. Results show that 58% of monitoring entries are reported with a high level of confidence, indicating the participants had access to detail documentation covering the scope of the monitoring activities and the reported information (Figure 3.5). Nearly 33% of the entries were scored as medium confidence, showing partial documentation of the monitoring leading to some uncertainty. A total of 45 entries out of 660 were reported as low confidence, due to limited information. The uncertainty noted by the participants reflects limitations in the reporting rather than quality of the underlying data, which lies beyond the scope of this report. These results suggest strong perceived documentation but also highlights gaps in data centralisation that hinder evaluation of monitoring efforts.

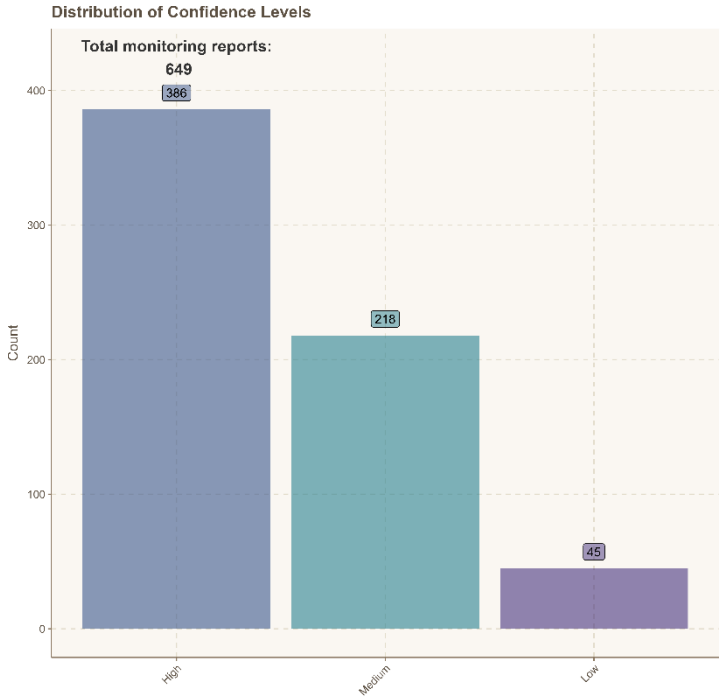

Figure 3.5. Workshop participants confidence across reported monitoring entries. Total number of monitoring reports (649 out of 660) that provided self-assessed confidence scores: High, Medium, and Low.

3.5 Current knowledgebase on OWF impacts

The above-described OWF monitoring activities across different countries reveals a complex picture of ecological impacts, emphasizing the need for sustained and comprehensive studies to understand these effects fully. However, while some effects refer to general processes, other observed impacts are the results of local conditions of OWF sites.

For instance, research in Belgium over 12 years demonstrated that biological communities colonizing turbine structures continue to evolve well after installation. Changes in sediment composition, benthic macrofauna, and demersal fish communities became evident after 5 to 7 years. Notably, the scour protection around turbines provides essential habitat and food for species such as plaice, enhancing their secondary production. Additionally, fouling organisms on turbine structures redirect organic material from the water column to the seabed, significantly affecting local food webs.

In Germany, monitoring efforts have generally not detected significant ecological effects directly linked to OWFs, with observed variations mostly attributed to natural fluctuations. However, these assessments are often limited to yearly snapshots or single-site analyses, indicating a need for more long-term, cumulative studies focused closer to turbine installations.

The Netherlands' ongoing Wozep program highlights how OWFs modify local hydrodynamics, influencing plankton distribution and productivity. The introduction of hard structures in soft-bottom environments fosters colonization by benthic organisms like mussels and barnacles, which can increase local biodiversity but also raise concerns about the spread of non-native species. OWFs also act as artificial reefs, potentially increasing fish abundance and diversity, although the broader ecological implications, such as altered predator-prey dynamics, remain unclear.

Norwegian studies reveal that floating turbines generate less noise than bottom-mounted ones and that electromagnetic fields can impact fish behaviour, including orientation and swimming patterns. In sandy habitats, sediment resuspension caused by OWF construction is a concern for species like sand eel. These structures may attract pelagic fish and larger predators while influencing local species composition through changes in food availability and colonization by alien species.

Portugal is conducting baseline studies funded by the EU to characterize physical, chemical, and biological conditions around planned OWF sites. Modelling shows that wind farms reduce wind intensity downstream, especially in summer, which could affect coastal processes. The studies also map fishing activity to assess potential interactions between fisheries and wind farms.

In the U.S. particularly the Northeast region, early research predicted several OWF stressors, including noise, electromagnetic fields, habitat conversion, and artificial reef effects. Post-construction monitoring has confirmed increased abundance of reef-associated fish species near turbine foundations. Ongoing research combines acoustic monitoring and habitat assessments to evaluate how OWFs influence marine ecosystems, though many results are still pending.

France reports that OWFs significantly alter marine habitats through sediment disturbance, increased turbidity, temperature changes near underwater cables, and emissions of noise, light, and chemicals. These impacts affect a wide range of species, from benthic invertebrates to marine mammals and seabirds, raising concerns about displacement, behavioural changes, collisions, and entanglement. OWFs also facilitate the introduction and spread of non-native species.

In Sweden, monitoring at the Lillgrund OWF revealed fish aggregations near turbines shortly after construction but no significant changes in overall fish abundance at the wind farm scale. Long-term studies suggest that OWF impacts on fish communities are less pronounced than those from fishing pressure or climate change. New survey methods, such as baited remote underwater video, help improve understanding of habitat effects.

The UK follows project-specific monitoring focused on benthic species, marine mammals, and birds rather than a unified national program. Fish populations tend to be mobile and show temporary avoidance of construction zones with no clear long-term impacts. Emerging interests in biodiversity net gain and nature-inclusive design reflect efforts to better integrate conservation with offshore wind development.

Poland, preparing its first OWF for operation by 2026, has developed environmental monitoring guidelines based on international experience. Studies indicate that benthic communities on artificial structures differ significantly from natural habitats and that non-native species tend to be more abundant on man-made substrates.

Taken together, these international experiences demonstrate that OWFs create new habitats and can enhance local biodiversity but also pose ecological challenges, including physical disturbance, altered environmental conditions, and changes in species interactions. Long-term, multidisciplinary, and standardized monitoring is essential to balance the expansion of offshore wind energy with the protection of marine ecosystems.

4 Considerations towards a harmonised impact assessment approach

Marine spatial planning frames the goals and objectives towards a harmonised and coherent impact assessment approach using pre-existing frameworks. However, the harmonisation of monitoring activities fit to address the effects of offshore renewables at local and regional scales will require a number of steps than entail the setting of priorities to define causal pathways from pressures generated by the construction, operation and decommissioning of offshore wind installations. The second step requires a careful selection of SMART (specific, measurable, achievable, realistic and time bounded) indicators (Cormier and Elliott 2017) at allows to measure responses of ecosystem components to those pressures. The following step addresses the need to design effective and efficient monitoring programmes to implement the indicators. Finally, the storage of data requires national harmonisation and standardisation ideally followed at regional levels. In the following sections for each step essential elements that need to be addressed are described in more detail.

4.1 Step 1 - How to prioritise the monitoring of possible environmental impacts?

When considering harmonisation in impact assessment it is important to set out clearly what we are looking to achieve through a harmonised approach. It may be that harmonisation is not necessarily required, such as when the impact is on a locally or nationally designated benthic feature. If, however, the aim is to understand how offshore wind development across an ecoregion affects a particular receptor, for example a fisheries species distributed across the Southern North Sea, where there are several country boundaries then harmonisation would be appropriate (Gill *et al.* 2020). Through a regionally harmonised approach, impact identification, prioritisation and data collection at agreed relevant scales using methods across the boundaries in the region would be beneficial. This will allow for early engagement with the nations that will be affected to identify impacts that will likely occur at large spatial scales. Harmonisation would also ensure monitoring is defined over appropriate temporal scales that provides the necessary scientific outputs to determine whether impacts are ecologically meaningful or not.

For effective and appropriate assessment of environmental impacts at a regional scale, there should be a clear scoping of the possible impacts that will affect receptors, or components of the ecosystem, or ecological structure and function. The target of the impact will be determined by the initial questions that were asked about the effects of offshore wind development. There are many direct and indirect interactions that occur between offshore wind developments and the environment (Dannheim *et al.* 2019); therefore, some sort of prioritisation is likely required. The decision on the prioritisation is required to have several elements, which are set out below.

The state of the environment is not a static entity; it varies through both natural and anthropogenic influences. Therefore, understanding the baseline status and the trajectory of the change in this status, whether the environmental feature we are interested in is improving or declining is critical to the impact assessment prioritisation. In some locations we may have a system that is already under high pressure from natural (e.g. climate change effects) and/or anthropogenic influences (e.g. eutrophication), and the system may be near the limits of resilience. Whilst in other locations the status may be very good and therefore the resilience of the system may be high. However, this consideration needs to be set within the context of how much change is deemed

acceptable (for negative impacts) or desirable (for impacts that are regarded as positive) against the existing pressure load that has been assessed using harmonised methods.

The marine environment will be affected during all parts of the life cycle of an OWF development (pre-construction, construction, operation and decommissioning) by a variety of pressures, each of them affecting multiple ecological structural and/or functional components of the environment. At the same time, a single structural/functional aspect can be affected by multiple pressures related to a part of an OWF life cycle monitoring of these effects requires (1) a clear definition and identification of these pressures and (2) an understanding of the cause-effect relationships through which the pressures cascade in the environment (Dannheim *et al.* 2019).

Examples of pressure lists related to OWF are provided in the scientific literature (Bergström *et al.* 2014, Galparsoro *et al.* 2022), web-based tools (ORIES) https://pml.ac.uk/science/offshore-renewable-impacts-on-ecosystem-services/ or earlier ICES work (ICES 2012, ICES 2021, ICES 2025b). Recent ICES work (ICES 2025a) reviewed and harmonised these lists, and related pressures to OWF life cycles. Pressures were relevant for both fixed and floating offshore wind farms (Table 4) and mapped to the most recent list of MSFD themes and pressures.

Table 4. List of pressures associated with different stages of offshore wind development (OWF: fixed offshore wind; FLOW: floating offshore wind) (taken from ICES 2025).

Pressure	Pre-construction	Construction	Operation	Decommissioning
Loss of soft sediment, covered by scour protection			presence of scour protection, cable mattresses, foundation footprint	
Introduction of artificial hard substrate			presence of scour protection, cable mattresses, foundation footprint	
Change in sediment composition			fining and organic enrichment of sediment due to presence of fouling fauna on turbines	cable & SPL removal activities
Sediment resuspension, transport and smothering		Piles (fixed OWF) or anchoring (FLOW) installation, cable trenching activity	Yes, scouring after installation of turbines and SPL (presence)	cable & SPL removal activities

Abrasion of sediment by seabed disturbance		cable trenching, seabed levelling activities; floating cables & moorings presence	FLOATING OWF: presence of dynamic cables and mooring installations	
Change in water current			presence of installations	
Change in stratification			presence of installations	
Introduction of Underwater noise: impulsive	seismic survey activity	UXO clearing and piling activities		possible drilling, explosions, seismic surveys
Introduction of underwater noise: continuous		noise generated by DP vessel activity	presence of devices, maintenance vessel activity	vessel traffic DP vessel activity
Electromagnetic fields	EMF survey activity		EMF from presence of cables	
introduction of synthetic and non-synthetic contaminants			presence of corrosion protection systems, anti-fouling paints, leaking of lubricants and hydraulic fluids, particles released during abrasion of turbine bladed	
Introduction of litter			breaking of turbine blades, fires in turbines	
Collision risk		maintenance vessel activity	maintenance vessel activity	

Entanglement risk in cables	seismic survey equipment		FLOATING OWF: presence of dynamic cables	
Visual disturbance		maintenance vessel activity (and moving ORE parts)	maintenance vessel activity: moving ORE parts	presence of vessels
Introduction non-indigenous species via relocation of floating turbines		presence of floating ORE relocated from other locations to farm site	relocation activity of floating ORE between farm and ports for repairs	Relocation of floating ORE from farms to decommissioning yard

While this pressure list is generic, the magnitude of the effects will depend on the local circumstances (proximity to other human activities, state of the environment, sensitivity of receptors to pressures. To avoid Data-Rich-Information-Poor monitoring programmes (Wilding *et al.* 2017), monitoring efforts can be guided by mapping the expected pressures to locally important aspects of the marine environment. This can be at the level of species groups, locally important ecosystem functions, or ecosystem services. As these receptors can be affected by multiple pressures, it is recommended to develop or use linkage frameworks that identify relevant receptors. There are a number of linkage frameworks that describe the cause-effect pathways from human activities to pressures and the expected direct link to receptors or ecosystem components, hence resulting in adverse effects.

Examples of such linkage frameworks have been developed by EU projects such as ODEMM or AquaCross, HELCOM or OSPAR. SCIARM is a framework that has been further developed and applied in the ICES working group on cumulative effects assessments for management (WGCEAM) (ICES 2025b). Other frameworks, that are specific to OWFs have been described in Baulaz *et al.* (2023) or Galpasoro *et al.* (2022). Also, the ICES working group marine benthal and renewable developments (WGMBRED) is in the process to develop a detailed linkage framework.

Only recently those linkage frameworks have been made operational through web-based tools. These tools provide a visual aid and/or semiquantitative assessment of pressure-impact relationships (see Figure 4.1 for an example) and guide decisions on which aspects of the marine environment need to be monitored. The Activity-Pressure-Ecosystem Linkage Viewer is a recently launched web-based tool under the GES4SEAS project (https://jc-cubillos.shinyapps.io/GES4SEAS_Linkage_Framework_15/) that allows not only for prioritisation of impact chain but also enables a gap analysis regarding the data required to analyse those linkages.

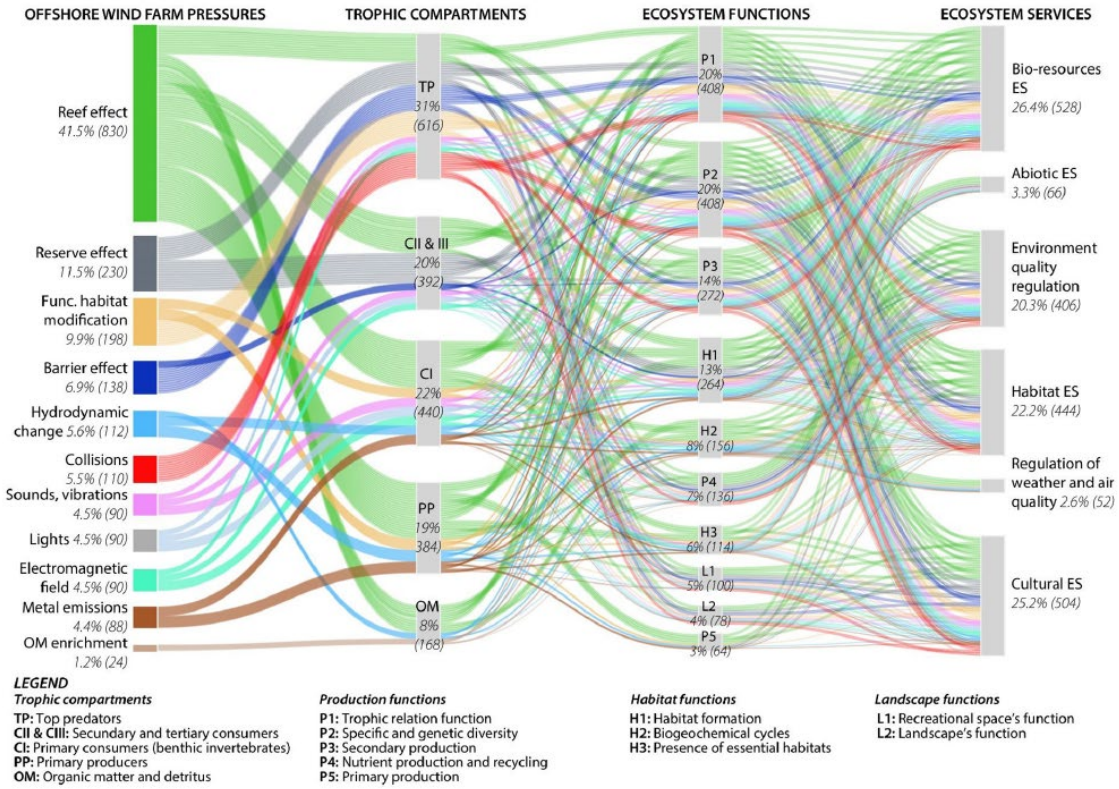

Figure 4.1. Example linkage framework detailing the links between pressures of offshore wind farms and ecosystem services (taken from (Baulaz *et al.* 2023)).

Thus, data collection resolution will matter to infer on impacts at different temporal and spatial scales. Quantifying impacts at the scale of a windfarm rely on BACI and BAG analytical framework, which require sufficient data collection at fine scale to understand local processes affecting biological communities (Methratta 2020; 2021). Regional effects on ecosystems can be approached through ecosystem modelling. Ecosystem models help the scientific community comprehend how ecosystem functioning pathways such as nutrient cycling, average trophic level or system omnivory are affected by the various pressures at play in the marine environment (Nogues *et al.* 2022). To provide reliable results, these models need quality assessed data on all compartments of the marine ecosystems. The foreseen development of OWF is an opportunity for the scientific community to gather coherent datasets at both fine scale and large scale, creating an integrated observatory for regional seas and supporting OWF impact assessment.

4.2 Step 2 - How to select informative indicators?

Selected indicators must align with current guidelines (SMART, Biological Diversity principles for selecting indicators) to be more effective in characterizing environmental impacts of OWF. They should either: 1) Focus on the **state** of the ecosystem, providing information on its parameters, or 2) Be **pressure-related**, reflecting the level of impact that a given pressure may exert on the ecosystem and its components. Each indicator must be **explainable**, meaning the relationship between the pressure and the indicator must be clearly defined and scientifically justified. Indicators should be **receptor-specific**, capturing changes in the environment that may result from the development and operation of an OWF. The indicator's response should be sensitive and proportional to the intensity of the pressure, clearly signalling specific ecological changes. To

support this, a **methodology must be established** to assess the direction and importance of observed changes, *i.e.* whether a change is ecologically meaningful (Wilding *et al.* 2017). This could involve: 1) threshold-based or "state space" approaches or 2) statistical analyses or effect size metrics. Such methods in combination with critical limits that should not be exceeded will help to communicate observed change. Furthermore, indicators should be both **time-bounded**—aligned with the different life stages of the OWF—and **spatially explicit**, allowing for mapping and clearer communication of the spatial extent of OWF impacts on ecosystem components. With respect to fisheries resources a comprehensive overview of indicators is shown in (Methratta and Degraer 2025).

4.2.1 Structural indicators

Structural indicators are typically parameters that are relatively 'easy' to measure, such as the number of individuals, abundance, biomass per unit area, or the presence or absence of species (Figure 4.2). Offshore wind monitoring programmes have traditionally focused on these indicators due to their practicality (see e.g. (Dannheim *et al.* 2025)). Hence, they offer limited insight into the underlying cause–effect mechanisms driving pressure–impact pathways (Wilding *et al.* 2017, Dannheim, 2019 #2). Thus, structural indicators contribute to a foundational understanding of how OWF affect ecosystem functions. Quantifying how those changes effect ecosystem services and societal benefits, requires more complex concepts and indices or ecosystem models. In order to calculate functional indicators, it is highly recommended to include biomass measurements (per unit of surface) in the list of measured indicators during regular monitoring activities.

4.2.2 Functional indicators

The development of operational functional indicators remains a scientific challenge, especially in light of current demands such as those outlined in the Marine Strategy Framework Directive (Wrede *et al.* 2018). Unlike traditional structure-based indices, functional indicators aim to assess ecosystem processes and functions, which are increasingly seen as critical for understanding ecological change (Figure 4.2). However, only a few such indicators exist, often relying on structural proxies like Biological Traits Analysis (BTA), which can be used to calculate community level indicators such as Bioturbation and Irrigation Potential of the Community (BPc and IPc, respectively) to infer how benthic ecosystem functions are affected by OWFs. BTA is broadly applicable across biological components—benthic organisms, fish, bacteria—but depends heavily on expert judgement for defining traits, raising questions about ecological validity. Harmonized trait databases, such as those developed by ICES BEWG (soft sediment macrofauna) and ICES WGMBRED (hard substrate macrofauna), are urgently needed to ensure consistency.

Indicators based on trait composition have been used to detect human pressures by summarizing organisms' positions within multidimensional trait spaces (de Juan and Demestre 2012, Mouillot *et al.* 2013, Schmera *et al.* 2017). Yet, most lack pressure-specific thresholds, and none have been explicitly designed to assess OWF impacts. Furthermore, these indicators are sensitive to the number of traits included, and thus of structural information (Legras *et al.* 2020) limiting their operational use despite their potential for cross-regional monitoring. Functional indicators are often derived from studies on the structure of communities.

To improve the current understanding of ecosystem changes and monitoring output knowledge gaps e. g. changes in the functioning of the ecosystem connected with construction and operational phases of OWF need to be filled (Isaksson *et al.* 2025).

Target monitoring/complementary studies focused on some crucial organisms' activities and ecosystem processes can help. Some tools have been developed in soft-bottom research and can be used in artificial hard-bottom and in modelling of ecosystem processes, (i.e. respiration, carbon and nutrient cycling). There are already some examples from artificial hard substrate e.g. oxygen and nutrient fluxes measurements (Coolen *et al.* 2024), diet composition, behavioural changes and refuge effect of OWF (Buyse *et al.* 2022, Buyse *et al.* 2023a, Buyse *et al.* 2023b).

Some functions of ecosystems cannot be quantified directly, although approximations can be made using structural information. Often, the complexity of these functions depends on the scope of their underlying mechanisms. One example is the biological control exerted by ecosystems through predatory pressure. This function relies on the dynamics of predatory species within the ecosystem—parameters that can be estimated using food web models based on biomass levels, physiological needs, and known trophic relationships, often derived from stable isotope analyses. Tools such as ecosystem models (e.g., Ecopath with Ecosim and Ecospace, Linear Inverse Modelling) and ecological network analysis can provide functional indicators relevant to offshore wind farm (OWF) development (Nogues *et al.* 2022, De Borger *et al.* 2025).

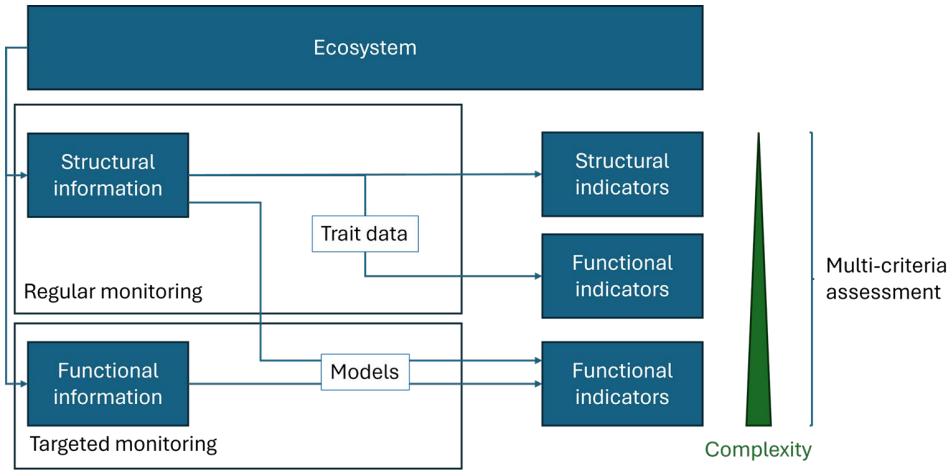

Figure 4.2. Schematic representation of the integration of structural and functional indicators.

4.3 Step 3 - How to design effective and efficient monitoring programmes?

4.3.1 Spatial coverage

Relevant spatial scales of the surveys vary with the geographical range of the studied receptor (i.e. ecosystem component or pressure) and with the focal aim of the study. Therefore, the spatial scale, including the spatial granularity, extent, and distribution of sampling, should be determined based on the question(s) to be addressed by the monitoring effort. The local scale is here defined as the study of effects of the individual OWF, and the regional scale as the effects of OWFs within the whole sea region (ICES Ecoregion). In practice, surveys could focus on subsections of the studied range and the findings extrapolated as far as applicable, for instance across OWFs with similar design located in similar environmental settings. Prior mapping and modelling are recommended as a basis for identifying relevant spatial scales for each survey. Within the OWF site, the study of small scale effects of the infrastructure requires a specific spatial strategy. For instance, a BAG (Before After Gradient) approach is suitable near the turbines to follow

the effects of biocolonisation of the turbines (further described below). The need for harmonised monitoring across OWF sites is highest for surveys targeting receptors with a wide spatial range, such as widely distributed fish species, to be able to detect potential changes in the receptor across its whole range, including both changes in abundance and spatial shifts. However, it is recommended to have as coherent monitoring as possible between studies at all spatial scales, to facilitate meta-analyses and the assessment of cumulative effects/in-combination effects.

Implementation of spatial sampling strategy requires not only the locations, but also the number and spatial distribution of samples taken to be considered. This should be proportional to the expected impact range of the offshore wind farm, including areas both within and outside this range. The location of the different stations should reflect the diversity of the site's habitats. Furthermore, the spatial strategy must consider the indicators that will be calculated. Depending on the component under consideration, the spatial strategy may differ.

As far as feasible, sampling locations used in the environmental impact assessment baseline should be kept in future data collection to limit biases in before-and-after comparisons. However, if justified, the sampling location density can be reduced compared to the environmental impact assessment baseline after power analysis.

The planned analyses determine the location of the monitored stations. For use of the BACI (Before-After-Control-Impact) approach, it is necessary to additionally define reference areas that are not impacted by the OWF project and that have the same environmental conditions as the stations inside the OWF (Methratta 2020). For the BAG (Before After Gradient) approach, stations should preferably be placed along a distance gradient from the middle of the OWF to a non-impacted zone (Methratta 2021). The location of sampling points should be designed to detect effect ranges when relevant, such as changes in fish abundance at different distances from a turbine.

4.3.2 Temporal coverage

The temporal scale, including the temporal granularity, duration, and intensity of sampling, should be determined based on the question(s) to be addressed by the monitoring effort. Collection of baseline data to establish existing patterns is necessary to be able to distinguish changes due to wind development from changes due to other sources of variability (Methratta 2025). The ecological changes resulting from OWFs may only become apparent several years after construction for certain ecosystem components e.g. (De Backer *et al.* 2020, Jammar *et al.* 2025) . Furthermore, succession dynamics evolve over time, influencing the progression of ecosystem responses (Zupan *et al.* 2023). This underlines the importance of ensuring that monitoring efforts are sufficiently long-term, tailored to effectively detect such changes. The duration and temporal resolution of monitoring should be aligned specifically with the ecosystem component under investigation and the associated monitoring question. Long-term studies suggest that a minimum monitoring period of 5–10 years is generally required to adequately detect ecological changes (*add relevant references*). Ideally, monitoring should occur regularly throughout the entire life cycle of an OWF (De Borger *et al.* 2025).

In addition to long-term temporal coverage, the timing of monitoring activities within each year is also critical. Seasonal patterns and natural variability in ecosystem components or indicators should inform the scheduling of monitoring surveys. Monitoring should ideally take place during periods when the target components are most stable, in order to reduce variability and increase comparability between years and regions. Finally, consideration should be given to the frequency of sampling, which will depend on the component under consideration.

Taking an integrated approach that aligns the timing, temporal frequency, and duration of sampling across sites for different ecosystem components will increase the effectiveness and interpretability of monitoring efforts across regions.

4.3.3 Methods for biological and oceanographic monitoring at OWF

The types of monitoring methods are inherently dependent on the scope and extent of the research questions and monitoring requirements at site, national and ecoregional levels (Annex 4). It is important not only to rely on existing methods but also to complement the monitoring with emerging, innovative techniques. Monitoring of OWFs has traditionally relied on various sampling techniques. The monitoring of marine fauna often faces increasing challenges due to the specific conditions within OWF and restrictions placed on access and activities in OWF enforced by operators. This has led to the development and application of alternative, often non-invasive, monitoring methods.

4.3.3.1 Hard Substrate Fauna Monitoring

Sampling of fauna on artificial hard substrates such as scour protection and monopiles has traditionally been conducted by divers or techniques like drop-cameras. While effective, this method involves high operational costs, safety risks, and limited accessibility due to weather and currents. As an alternative, sample acquisition using Remotely Operated Vehicles (ROVs), equipped with tools like the marine growth sampling tool (Coolen *et al.* 2025) has become more common. A further step is the deployment of Autonomous Underwater Vehicles (AUVs), which operate without continuous input from an operator, enhancing efficiency and safety.

4.3.3.2 Demersal Fish Monitoring

Demersal sampling methods are also evolving. Traditional bottom trawling presents significant limitations in OWFs, particularly due to restricted maneuverability and the potential for fish to avoid gear near turbines. Mitigation strategies for demersal fish monitoring are outlined e.g. in the NOAA Fisheries Survey Mitigation Plan (NOAA 2024) which includes methods such as baited trap video and hook-and-line methods to collect physical samples for biological measurements. Telemetry studies can additionally provide information on spatial behaviour of larger species (Bicknell *et al.* 2025). Stomach content analysis of demersal fish is another method that can indirectly provide information on the predator prey interactions or occurrence of other species (Gimpel *et al.* 2023). Depending on the accessibility of operational windfarms the use of hand fishing rods allows analysis of the abundance, stomach contents and fitness of fish thereby concluding on the suitability of OWF as feeding or spawning ground, hence reflecting habitat functions (Gimpel *et al.* 2023, Werner *et al.* 2024).

4.3.3.3 Pelagic Fish Monitoring

Monitoring of the water column has traditionally involved a combination of hydroacoustics, trawling, plankton nets, and water sampling. While hydroacoustic methods are suitable for water column monitoring (Jech *et al.* 2023) trawling can be impractical in OWFs. Animals aggregating near turbines may also avoid capture, leading to biased data. As a result, alternative methods must be developed and calibrated against traditional methods. Potential solutions include Baited Remote Underwater Video (BRUV) systems (Jackson-Bué *et al.* 2023), AUVs and ROVs outfitted with active acoustic instrumentation (Jech *et al.* 2023, Jech *et al.* 2024), and baited cages, provided they are appropriate for the species of interest.

4.3.3.4 Oceanographic Monitoring

Monitoring of oceanographic variables (e.g., temperature, salinity, elemental composition, current velocity and direction), oceanographic features (e.g., upwelling and downwelling dipoles),

phytoplankton, and zooplankton can be achieved with traditional oceanographic instrumentation (e.g., plankton nets, ACDP). Active acoustics have also been used to evaluate the distribution and abundance of zooplankton (Jech *et al.* 2024). Oceanographic instrumentation can be deployed from ships or via ROV or AUV.

4.3.3.5 Infauna and Soft Sediment Monitoring

Monitoring of benthic infauanal fisheries species (e.g., clams) and the biological and geological status of soft sediments can be achieved using sediment profile and plan view imaging (SPI/PV, Germano *et al.* 2011) together with traditional sediment grab or core sampling.

4.3.4 Examples of novel non-invasive methods

Emerging non-invasive methods, such as environmental DNA (eDNA) metabarcoding and passive acoustics, are gaining attention. eDNA involves analyzing water samples for DNA traces left by organisms, allowing detection of a broad range of taxa from fish to plankton (Cornelis *et al.* 2024, Dukan *et al.* 2024). However, this method faces challenges related to DNA degradation, gene region selection, analytical protocols, and reference database completeness. DNA metabarcoding can also be applied to bulk samples from traditional collection methods like trawling nets and grab samples.

Non-invasive imaging techniques are increasingly used to monitor benthic and epifaunal communities. High-resolution still images or videos, collected via ROVs or AUVs, enable extensive sampling without diver involvement. Advances in data storage and AI-assisted analysis allow for the efficient processing of large volumes of image data.

Imaging is also used for assessing pelagic community composition, including phytoplankton and zooplankton (Giering *et al.* 2022). In situ imaging systems, when combined with CTD (Conductivity, Temperature, Depth) measurements, can provide detailed insights into the influence of OWFs on plankton distribution, as demonstrated by (Floeter *et al.* 2017) in a German wind farm. A limitation of imaging methods is their generally lower taxonomic resolution compared to traditional microscopic analysis; species-level identification is often not achievable. Satellite-based remote sensing is extensively applied in oceanographic and climate research. This technology holds potential for assessing OWF impacts on water column stability and primary productivity. Passive acoustics can estimate biodiversity and ecosystem complexity (Dröge *et al.* 2024), and also provide information on the presence of specific species and fitness-related behaviours such as reproductive behaviour, making it a promising tool for behavioural monitoring. Active acoustics are also being applied to evaluate biomass and abundance of zooplankton and pelagic fish species (Jech *et al.* 2023, Jech *et al.* 2024).

4.4 Step 4 - How to design data storage and analysis?

4.4.1 Data storage

Currently no centralised portal for the compilation, standardisation of existing OWF monitoring data exists at a pan European scale, indicating the necessity of implementing a fair data policy (Findable, Accessible, Interoperable and Reusable, Wilkinson *et al.* 2016) to facilitate its creation. Such implementation would increase transparency and facilitate further understanding of ecosystem cumulative effects (Dannheim *et al.* 2025). It is understood and acknowledged that the transparency of data is subject to regional restrictions and therefore certain data sources will not

be accessible, it is therefore recommended that a two-phase ICES- wide data storage repository could be implemented, providing the basis for future research and analysis, this proposed framework could be:

i. Meta-database – outlining the availability of data, time frames, host institutions, data availability
ii. Centralised queryable database – site specific monitoring data, standardised format

It is important to note the recommended contents of such data bases is not exhaustive and consideration should be given to content prior to implementation.

4.4.2 Data Analysis

This report does not look to make definitive suggestions on the type or scope of analysis to be conducted with this being country, site, and research question specific. With this in mind, however, the use of models is needed both to design the monitoring scale, predict effect sizes and spatial extent of the impact. Monitoring data should be used to update (calibrate and verify) ecosystem models providing assessment of impacts on the ecosystem/population level.

4.5 Step 5 – How to determine whether the monitoring is achieving intended goals?

It is recommended that OWF monitoring continues for the entire lifecycle of OWF development which may span several decades. As standard methods are developed and applied, more knowledge will be gained about cause-effect relationships and the practical application of the methods used to study them. Periodically, monitoring programs should be evaluated for performance to determine whether monitoring is achieving its intended goals, i.e., whether it is able to answer the questions it is intended to answer. This can be achieved by: defining performance metrics, periodic review of the performance metrics, and adapting monitoring approaches as needed. Additional monitoring should also be considered during and after decommissioning of OWF infrastructure.

4.5.1 Define Performance Metrics

Performance indices can be identified to characterize the ability of the monitoring plan to detect a change in the responses measured. This can be evaluated with metrics specific to the monitoring goals as well as statistical indices such as confidence intervals. Performance metrics and acceptable levels of precision should be identified prior to the initiation of monitoring. Additional performance metrics could be added over time.

4.5.2 Review Performance Metrics and Adapt as Needed

The performance metrics selected should be evaluated on a periodic basis (e.g., every 2–3 years). If portions of the monitoring plan are found to be consistently performing poorly (i.e., unable to provide sufficiently precise estimates of effects), then relevant elements on the monitoring approach should be considered for adaptation.

5 Recommendations from the workshop

The following recommendations relate to the steps and actions that help to implement the ICES ORE Roadmap:

- ICES to develop practical guidance to implement regional monitoring of OWF to enable impact assessment.
- This ICES practical guidance needs to address also EU environmental policy requirements such as good environmental status.
- Review current terms of reference of ORE related working groups how the WKOMO suggested harmonisation framework can be supported.
- Carefully review the temporal, spatial and intensity of monitoring requirements to match the scale and level of expected impact realisation and keep the methods consistent overtime.
- Complementing the monitoring programs with new methods including non-invasive methods.
- Through harmonisation of monitoring efforts new opportunities emerge to study cross-boundary effects or at ecoregion scales.
- Implementation of meta data base to facilitate cross-border collaborations as a first step towards harmonisation.
- ICES to facilitate harmonisation process of environmental impact assessments across countries.
- More emphasis on targeted monitoring to enable the assessment of state and changes of ecosystem functions and processes.

Annex 1: List of participants

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Annex 2: WKOMO resolution

Workshop to scope for Harmonized Regional Monitoring Schemes to Assess the Impact of Offshore Wind Farms on Fish, Pelagic and Benthic Communities and Ecosystem Functions (WKOMO), chaired by Steven Degraer, Belgium; and Vanessa Stelzenmüller, Germany; will be established and will meet at ICES HQ, Copenhagen, Denmark, 26–28 May 2025 to:

Describe implemented and planned offshore wind monitoring and research programs at various scales (local, national, regional) across ICES regions (Science Plan codes: 3.2, 3.3,3.4,3.5, 4.4);

1. Review of national monitoring and research activities that address the impact of offshore wind farms on fish populations, communities and key ecosystem functions (e.g. production).
2. Brief description of allocation of responsibilities and funding sources.

Produce an overview of the assessed indicators (ecosystem functioning, single species, biodiversity, etc) (Science Plan codes: 2.7, 3.1, 3.2,3.3,3.4,6.27.4);

3. Categorise the indicators, monitoring and research approaches and collected data to identify synergies and gaps of prevailing activites identified under ToR a;
4. Document any known national or local impact thresholds or reference levels being used to assess ecological effects.

Summarise research and monitoring activities in and around offshore wind areas by habitat type and regional sea;

5. Mapping of activities and categories and overlay analysis with different habitat types (as idenitifed by the group).

Identify and recommend steps towards harmonised monitoring and research activities to inform the ICES Strategy to assess the impacts of OREs and the effectiveness of mitigation measures (Science Plan codes : 2.7, 3.2, 3.4,3.6,4.5, 5.1, 7.3).

Scoping for follow-up workshop with national authorities to explore the potential for coordinated regional monitoring activities.

WKOMO will report by 15 July 2025 for the attention of ACOM and SCICOM.

Supporting information

Priority	ORE Roadmap published in January 2024 identifies goals, objectives, and priority actions for the development of ORE science in ICES. This workshop addresses multiple goals and objectives in the roadmap with a particular focus on Priority Action 4 for 2024/ 2025: the assessment of OMRE developments on fishery and ecosystem observation surveys, fisheries management advice, and recurrent ICES advice. This workshop was identified as a recommendation to ICES from WGOWDF 2024 annual meeting.
Scientific justification	There is an urgent need to understand the impact of OWF on fish, pelagic and benthic communities and key ecosystem functions at national and regional scales to inform the respective management advice requirements. The lack of data and harmonised monitoring efforts are the main reasons why such effects can not be described even in areas where OWFs have been

	implemented for more than a decade. As highlighted in the ORE Roadmap, ICES needs to develop a strategy to address the impacts of OWF at various scales to allow for further actions to mitigate, for instance impacts of area closures on long-term scientific surveys and the resulting scientific advice to support fisheries and ecosystem management. Many ICES member countries are experiencing large-scale offshore renewable energy development and will require a better understanding of how monitoring activiteis could be effectively harmonised.
Resource requirements	None
Participants	• SCICOM Country representatives • Survey Working Groups representatives • HAPISG; ORE Working Groups, e.g. WGOWDF • EO Steering Group; relevant Working Groups • Members of planning groups with ORE/MPA/ spatial planning knowledge • Members of the WGMBRED and WGFBIT
Secretariat facilities	ICES HQ as venue and support
Financial	No financial implications.
Linkages to advisory committees	The loss of and changes to survey areas and the loss of extraction of animals will have considerable impact on the future of fisheries and ecoysystem advice.
Linkages to other committees or groups	This workshop straddles already different commitiees and groups, such as EOSG, HAPISG, as well as FRSG and HUDISG.
Linkages to other organizations	The work should be closely linked with the work of ORE and MPA managers and specialists.

Annex 3: Reference list

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Annex 4: Countries OWF monitoring activities

Country: Belgium

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
6.8%

b) National development targets by 2030/2040:
Move towards 15 % of surface area for OWF (total of 5.4 – 5.8 GW)

c) Authority responsible for monitoring of OWF impacts:
Royal Belgian Institute for Natural Sciences (RBINS)

d) Does a national monitoring of marine environmental impacts exist?
Yes: WinMon.BE

2. Brief description of national obligations, allocation of responsibilities and funding sources

According to their environmental permit, all OWF concession holders need to contribute to the WinMon.BE fund, that is managed by the Management Unit of the Mathematical Unit, a service within RBINS. The fund is used to finance monitoring activities (birds, bats, demersal fish and epibenthos, fouling fauna, soft-sediment macrobenthos, operational underwater sound and hydrodynamical effects). Monitoring is done along two axes: (1) documenting change as required for EIA and (2) targeted monitoring along cause-effect hypotheses. Activities and annual reporting is coordinated by RBINS, monitoring is executed by RBINS, UGent, ILVO and INBO, depending on expertise. Monitoring activities are focussed on 3 OWF (out of the existing 9 OWF), each of them representing a particular situation on the Belgian part of the North Sea. Data need to be delivered to the Belgian Marine Data Centre, who is responsible for making the data public. The WinMon.BE programme strongly interacts with 'research projects' funded through regional, national and international funding mechanisms, where WinMon.BE provides a backbone of long-term integrated data collection, and the scientific programmes add scientific understanding and method development to the WinMon.BE programme.

3. Summary of current knowledgebase on OWF impacts

The long-term monitoring effort showed that communities colonising turbines are still changing after 12 years. Effects on soft-sediment variables (grain size variables, organic matter content), macrofaunal communities and demersal fish communities were detected after 5-7 years, suggesting that monitoring effects should be planned over a sufficiently long period. Targeted monitoring revealed the importance of the scour protection layer for plaice, as it provides food and shelter, ultimately resulting in increased secondary production of this fish species. The interaction between WinMON.BE and several research projects showed the impact of fouling fauna on the water column, and increased deposition of organic matter within the OWF area. Food-web modelling – based in data collected in the field within OWFs – suggest an important role for fouling fauna, strongly redirecting organic material from the pelagic to the benthic domain.

4. Is there are national data base or central data collection framework?

Data need to be transferred to the Belgian Marine Data Centre, that has the responsibility to make the data publicly available. Efforts are currently happening to make the data more accessible. Benthos (soft sediment and fouling) data are available through the BISAR database as well (https://critterbase.awi.de/#projects-bisar)

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

WinMon.BE is the national monitoring programme responsible for coordinated monitoring and annual reporting. It operates as an independent scientific programme, coordinated by RBINS and executed by several partners (UGent, ILVO, INBO).

Key references/links: https://odnature.naturalsciences.be/mumm/en/windfarms/

Country: France

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:

In May 2025, there are 3 offshore wind farms in operation in the French EEZ, representing a total surface of less than 200 km². France has the largest EEZ in the world due to overseas territories, making the percentage of area occupied by OWF negligible. There are currently no OWFs projects in the overseas territories. The metropolitan EEZ is also large (large continental shelf and 3 maritime facades) so the percentage of the metropolitan seabed covered by OWF is very limited: 0.0006 %.

b) National development targets by 2030/2040:

France has set out ambitious targets for OWF development in its national strategic plan for energy provision (Programmation Pluriannuelle de l'Énergie). The target is set to reach 18GW in 2030 and 45GW in 2050 with 50 wind farms in activity, which requires an important effort in planning and deploying this emerging technology.

c) Authority responsible for monitoring of OWF impacts

OWF impacts monitoring is under the responsibility of each farm operator (funded by the farm operator but surveys are performed by private consultancies), with the exception of the baseline study of the EIA which is partially funded by the French state and performed by private consultancies. To ensure that monitoring is carried out in a coherent scheme at the scale of the country, France has implemented a legislative framework making the State responsible for providing future operators with the baseline information for the EIA in the form of (1) a literature review based on all available data, grey literature and scientific literature, (2) 2 years of baseline monitoring for all ecosystem components, and (3) standardised protocols to follow throughout the OWF construction, exploitation and decommissioning phases. The General Direction for Energy and Climate (Direction General de l'Energie et du Climat - DGEC) of the Ministry of the Environment is responsible for the production of this partial baseline information. Connection cables' construction and monitoring are the responsibility of RTE (Réseau de Transport de l'Electricité), the state owned company in charge of the electricity network throughout France. Monitoring of cables is carried out by private consultancies based on RTE requirements.

d) Does a national monitoring of marine environmental impacts exist?

No specific monitoring of marine environmental impacts of OWF exists in France. There are other national monitoring programs of marine ecosystems in place in the context of the MSFD and for stock assessment needs (DCF).

2. Brief description of national obligations, allocation of responsibilities and funding sources

National obligations for OWF follow the Code de l'Environnement (Environmental Law) and additional laws existing for industrial projects at sea (i.e. lease procedure). Areas suitable for OWF development are designated in Regional Strategic Documents (Documents stratégiques de Façade) through a process where economic, societal and environmental concerns are confronted to reach a consensus among the different stakeholders , and include a public consultation phase (Débat Public). The definitive spatial extent of each OWF is decided upon by the French Ministry of the Environment through an official publication in the Journal Officiel de la République Française (JORF), based on the conclusions of the process previously described.

The DGEC is in charge of organising the public consultation, where all information available on the potentially suitable areas are provided, of organising and financing the production of the partial baseline information (including 2 years of data collection and the definition of suitable protocols for monitoring), and to carry out the tender award procedure.

Once the operators of a specific OWF have been designated, they are in charge of completing the EIA through data acquisition, risk of impact evaluation (where pressures, effects and receptors' sentitivity are confronted to determine the extent of future monitoring) and mitigation strategies development. EIA reports are submitted to reference scientific institutes and agencies (i.e. Ifremer, OFB, SHOM…) for evaluation and advice to the State on their respective fields of expertise. In accordance with the authorities in charge of marine space (Direction Inter-Régionale de la Mer and the Préfecture Maritime) and of environmental matters (Direction Régionale de l'Environnement et de l'Aménagement et du Logement and the Préfecture) locally, monitoring programs are described in the Arrêtés Préfectoraux of each OWF making them legal obligations.

Throughout the life of the OWF, scientific institutes provide advice to the State and to the operators to ensure that monitoring programs will allow estimation of impacts of OWF on marine ecosystems and populations.

3. Summary of current knowledgebase on OWF impacts

OWFs can significantly alter marine habitats in multiple ways. The loss of benthic habitats, particularly affecting bottom-dwelling species, occurs during all phases—pre-installation, construction, operation, and decommission—leading to dynamic shifts in community composition. Similarly, changes in marine habitats due to OWFs influence all species, resulting in community-level changes, particularly during the operation phase.

The modification of hydrodynamic conditions during operation can disrupt planktonic species and their life cycles, leading to shifts in species distribution. Likewise, turbidity, or water cloudiness caused by sediment displacement, impacts benthic feeders by altering their foraging efficiency. This effect spans across all OWF phases.

Temperature changes, particularly near underwater cables, can affect benthic species living close to these structures, causing distributional changes. Meanwhile, sound emissions during OWF construction and operation disturb marine mammals and turtles, with potential effects ranging from altered foraging behaviour to species displacement.

Electromagnetic emissions from OWF infrastructure can interfere with species sensitive to such stimuli, including many top predators, affecting their ability to forage effectively. Light emissions, especially problematic for light-sensitive species such as seabirds, cephalopods, and fish, occur

during construction, operation, and decommission, disrupting both foraging behaviour and spatial distribution.

Chemical pollution, another consequence during most OWF phases, impacts all marine life by altering physiological development processes. Additionally, OWFs can facilitate the introduction of non-native species such as algae, mollusks, fish, and crustaceans, which can change existing community structures.

Physical hazards are also notable. Collisions primarily affect top predators like seabirds and cetaceans, altering both population numbers and spatial patterns. OWFs can also act as obstacles to movement, modifying the natural behaviour of these top predators. Finally, entanglement risks for large marine species, particularly marine mammals, can lead to population-level consequences.

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

Together with standardized protocols, the French state also pushed forward the need to have standardized datasets and databases for all biodiversity related data collected during OWF monitoring. This sets the basis of the project "DATAEMR", which has three main goals: to provide systematic formats and databases for OWF monitoring datasets, to ensure that this information is easily accessible for anyone who wants to use it, and to help both projects operators and other end users access information from these data through dedicated visualisation tools. DATAEMR is one of the projects that are funded directly by the State of France through the "National Observatory for Offshore Wind Farms", the ambitious initiative which runs from 2022 to 2025 and will allocate 50 million euros for research and development around the deployment of OWF.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

Until today, each French OWF had its own monitoring program. Despite scientific advice in their elaboration process, existing monitoring programs have shown inconsistencies in terms of objectives and in some cases failed to achieve the goal of impact evaluation. The need for harmonized protocols has been pointed out by scientists, which for the DGEC has commissioned Ifremer and the French Agency for Biodiversity (OFB - Office Français de la Biodiversité) to draw up these protocols. The ultimate goal is to be able to upscale the effects of single OWFs to the scale of ecosystems, and assess cumulative effects of anthropic activities. Ifremer is in charge of fish and fisheries resources and of benthic communities monitoring, while OFB takes charge of birds, bats and marine mammals.

The first versions of these protocols should be finalised by the end of the year. Protocols will provide the guidelines for further approval of monitoring programs in the EIA process, considering spatio-temporal strategies, sampling methods, data treatment and data-management. For each OWF project, an additional consultation process involving scientists and operators will ensure compliance between the protocols and site-specific requirements in terms of ecological issues.

Another French initiative, to launch research activities on environmental monitoring is the creation of an Institute for Energy Transition named France Energies Marines (FEM). FEM was born from an Ifremer initiative to enable cross institute research programs to test and develop environmental monitoring programs to better assess OWF impacts. FEM is at the initiative of 50+ research programs aimed at better understanding OWF impacts on all environmental receptors.

6. Key references/links:

French official website on OWF development and associated activites: www.eoliennesenmer.fr

Public consultation process towards marine spatial planning: https://www.debatpublic.fr/la-mer-en-debat-mise-jour-des-documents-strategiques-de-facade-dsf-et-cartographie-de-leolien-en

France Energies Marines: https://www.france-energies-marines.org/

Country: Germany

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
2,75% (9,2 GW); 3,3% by the end of 2025

b) National development targets by 2030/2040:
30 GW by 2030, 40 GW by 2035, 70 GW by 2045 (WindSeeG 2022)

c) Authority responsible for monitoring of OWF impacts
Federal Maritime and Hydrographic Agency (BSH)

d) Does a national monitoring of marine environmental impacts exist?
Nationally coordinated OWF monitoring

2. Brief description of national obligations, allocation of responsibilities and funding sources

Germany has an OWF industry-financed monitoring according to the Standard Investigation concept (StUK) to monitor impacts of OWF on seabirds, migratory birds, marine mammals, fish & benthic communities. The StUK is currently in its forth iteration and will soon be updated. Wind farm operators are legally obliged to conduct and pay for monitoring according to StUK and have ownership over the data. Environmental consultancies carry out surveys and data analyses, submit data and technical reports back to approval authority (BSH).

The **SEA carried out as port of MSP processes informs the EIA** by pre-identifying suitable areas. The EIA operates at the **project level**.

3. Summary of current knowledgebase on OWF impacts

No significant effects were found via StUK monitoring by environmental consultants and if changes occur they are generally attributed to natural variability. Advice is often based on past research carried out in alpha ventus or international publications. Potential influencing factors are the limited scope of data analyses. Data are assessed per year (monitoring event) per OWF. No cumulative or compressive BACI analyses has yet been carried out. Also, the survey design or methodology may need to be adapted to facilitate more sampling close to the turbines and the operational phase of the monitoring may need to be extended.

4. Is there are national data base or central data collection framework?

Yes, the Marine Live Investigator (MARLIN) database is operational since 2020 and centrally stores and quality controls all OWF monitoring data. Before, data were held decentralised at the BSH. Not

all data is uploaded yet. Since 2022 environmental consultancies are responsible to upload the data directly into MARLIN.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes
   Not to my knowledge

6. Key references/links:

Monitoring concept:

https://www.bsh.de/DE/PUBLIKATIONEN/_Anlagen/Downloads/Offshore/Standards/Standard-Investigation-impacts-offshore-wind-turbines-marine-environment_en.html

MARLIN database: https://linmarlin60.bsh.de/MARLINDMZ/publicSites/MainAppPublic.jsf

Country: Republic of Ireland

1. State of offshore wind development:

a. % surface area of EEZ covered by OWF development:
   There are no current large commercial scale OWF in operation In Ireland EEZ. A single 25.2MW site is currently in operation but will soon be entering the decommissioning phase.
b. National development targets by 2030/2040:
   A total of 0.39% of Irelands EEZ in designated for OWF development by 2030. Targets:

- 25.2MW – 2025
- 5GW – 2030
- 20GW – 2040

c. Authority responsible for monitoring of OWF impacts
   MARA - Maritime Area Regulatory Authority. Responsible for Compliance and enforcement of MACs, licences and offshore development consents. https://www.maritimeregulator.ie/

d. Does a national monitoring of marine environmental impacts exist?
   Ireland is governed by the Common Fisheries Policy and the marine strategy framework directive (MSFD) to monitor marine environmental impacts.
   In relation specifically to OWF no national monitoring programme is currently in place.

2. Brief description of national obligations, allocation of responsibilities and funding sources

Current national legislation outlined under the Designated Marine Area Plan (DMAP) through the Maritime Area Planning Act 2021 dictates an ecosystem-based management approach in monitoring the impacts of ORE in Ireland.

The degree and extent of this monitoring is however yet to be established.

3. Summary of current knowledgebase on OWF impacts

In Irish waters no dedicated research has been undertaken into the effect of OWF to date. This is principally due to the current lack of large scale OWF project in construction/operation to date.

An early pilot project – Arklow Bank was installed in 2002. Limited information is available on the environmental monitoring for this site, with this site now entering its decommissioning phase.

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

- No OWF national data base in currently in operation.
- Extensive national data bases relating to Irelands obligations under the EU data collection framework (DCF) are in operation and maintained actively by the Marine Institute in relation to environment, fisheries and ecosystem.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

Key references/links:

Maritime Area Planning Act 2021- https://www.irishstatutebook.ie/eli/2021/act/50/enacted/en/html

Country: The Netherlands

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
2024 installed OWFs: app. 4.1 GW - 1,2% of EEZ

b) National development targets by 2030/2040:
Roadmap 2032: 21 GW : est. 3.9% of EEZ* - 2.7% from 2025 – 2032
Estimate for 2040: 53 GW: est. 8.6% of EEZ* - 4,7% from 2032 – 2040.

c) Authority responsible for monitoring of OWF impacts
Responsible: Ministry of Climate Policy and Green Growth (KGG)
Rijkswaterstaat (RWS, executive body of Ministry of Infrastructure and Water Management, IenW) executes permitting and monitoring.
RVO (Netherlands Enterprise Agency) executes T0 surveys for tender preparation.

d) Does a national monitoring of marine environmental impacts exist?
Yes, the Offshore Wind Ecological Programme (Wozep).

2. Brief description of national obligations, allocation of responsibilities and funding sources

Mitigation responsibilities of OWF are part of Environment and Planning Act (Omgevingswet) which carries out the EU obligations as part of legislation such as Habitats Directive and Birds Directive. National research and monitoring resulting from this is coordinated by the Offshore wind ecological monitoring programme (Wozep). The goals of Wozep are reducing (scientific) uncertainties regarding knowledge gaps and assumptions within the OWF decision-making cycle, particularly those identified in the Framework for Ecology and Cumulative Effects (KEC), the

Environmental Impact Assessment (MER), and the Appropriate Assessment (PB), all of which inform and precede the plot decision process.

Funding sources for monitoring differ between projects and can be government funded (national or EU) or funded by the wind farm operator. Especially for the early OWF monitoring was mainly government subsidised with responsibilities for funding monitoring shifting more to OWF operators for later developments. Monitoring in some newer OWF has been made responsibility of operators as part of the tender process.

3. Summary of current knowledgebase on OWF impacts

The Wozep 2024–2030 programme (https://www.noordzeeloket.nl/publish/pages/198061/mariene_strategie_deel_1_actualisatie_2018_v2.pdf) outlines the current understanding and research priorities regarding the ecological effects of offshore wind energy on various marine components, including benthos, biofouling, zooplankton, phytoplankton, and fish.

Zooplankton and Phytoplankton

Changes in hydrodynamic conditions around OWFs can influence the distribution and productivity of planktonic communities. For example, the presence of OWFs may modify local current patterns, affecting nutrient availability and, consequently, phytoplankton growth. Additionally, increased filtration by biofouling organisms could reduce phytoplankton concentrations, impacting zooplankton populations that rely on them for food.

Benthos

Offshore wind farms (OWFs) introduce hard substrates into predominantly soft-bottom marine environments, leading to the colonisation by benthic organisms such as mussels and barnacles. These artificial structures can alter local biodiversity and community composition. However, the extent to which these changes affect broader benthic ecosystems remains insufficiently understood. Key knowledge gaps include the long-term (>10 years) development of benthic communities on OWF structures and their interactions with surrounding soft-bottom habitats.

Biofouling

The accumulation of organisms on OWF structures, known as biofouling, can have significant ecological implications. For instance, the proliferation of filter feeders like mussels can enhance local filtration rates, potentially impacting nutrient dynamics and primary productivity. While some studies suggest that biofouling communities may increase local biodiversity, concerns persist regarding the spread of non-indigenous species and the alteration of native habitats.

Fish

OWFs can serve as artificial reefs, providing new habitats for various fish species. This habitat enhancement may lead to increased local fish abundance and diversity. However, the broader ecological consequences, such as changes in predator-prey relationships and potential displacement of species, are not fully understood. Moreover, the exclusion of fishing activities within OWF areas could have both positive and negative effects on fish populations.

In summary, while OWFs present opportunities for habitat creation and biodiversity enhancement, they also pose challenges to marine ecosystems. The Wozep 2024–2030 programme seeks to advance our understanding of these effects through targeted research, thereby supporting the sustainable development of offshore wind energy in harmony with marine conservation objectives.

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

Data from national monitoring and a selection of research projects can be accessed through the Marine Information House (https://viewer.openearth.nl/ihm-viewer) where they can be searched and downloaded openly.

Data pertaining to Wozep is available at the Wozep data portal (https://wozep.nl/en/)

For data on biota there is a central data collection framework called AquaDesk (https://live.aquadesk.nl/).

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

There is a national monitoring programme: the Offshore Wind Ecological Programme (Wozep). Wozep is part of the Monitoring-Research-Nature Enhancement-Species Protection (MONS) program which aims to answer the central question of whether and how the changing use of the North Sea fits within the ecological carrying capacity of the North Sea. Additionally, some monitoring is carried out in different collaborations between NGOs, institutes and industry, via the Rich North Sea programme (https://toolbox.therichnorthsea.com/inspirational-projects/)

Key references/links:

Offshore Wind Ecological Programme Wozep and reports: https://www.noordzeeloket.nl/en/functions-use/offshore-wind-energy/ecology/offshore-wind-ecological-programme-wozep/
MONS programme and reports: https://www.noordzeeloket.nl/omgeving/noordzeeoverleg/mons-onderzoeks-monitoringprogramma/
Marine information house: https://viewer.openearth.nl/ihm-viewer
Rich North Sea programme: https://toolbox.therichnorthsea.com/inspirational-projects/
Wozep data portal: https://wozep.nl/en/)

Country: Norway

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
<0.1%

b) National development targets by 2030/2040:
30GW by 2040, 2.3 million km2 EE – 54 000 km2 identified for development = 0.2 %

c) Authority responsible for monitoring of OWF impacts:
The ministry of energy (ED) is the authority responsible for monitoring of OWF impacts, NVE Norwegian water resources & energy directorate is coordinating activities

d) Does a national monitoring of marine environmental impacts exist?
Yes

2. Brief description of national obligations, allocation of responsibilities and funding sources

National monitoring: 3 years of baseline monitoring before development, benthic habitat / physical description – MAREANO www.mareano.no, benthopelagic / pelagic marine ecosystem/oceanographic data – IMR, seabirds NINA

Strategic environmental assessments SEA exist for the sector and requirements for EIA follow from this.

NVE coordinates EIA, ED funds research, partly open calls, partly directs funds to IMR & NINA & MAREANO

Other sources of funding: Norwegian Research Council, JPI Oceans, EU

3. Summary of current knowledgebase on OWF impacts

Noise levels, floating more silent than bottom mounted, Hywind Tampen more silent than Hywind Scotland.

Electromagnetic fields can affect swimming behaviour and orientation in cod & haddock

Wake effects, Ekman transport, will be different in deep water

Sediment erosion, resuspension is a concern in the Southern North Sea, because sand eel is extremely dependent on grain size sediment.

Trawl marks disappearance is expected

Attraction pelagic fish, but also larger predators is expected

Ongrowth, food availability, alien species is expected to change

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

NVE is coordinating monitoring by institutes and industry. Data from the institutes is (should be) accessible via www.nmdc.no and www.mareano.no. It is yet unclear where the data from the industry will be shared, currently reports are shared on industry websites, for example: Impact assessments for Hywind Tampen - Equinor

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

NVE is coordinating monitoring by institutes and industry.

6. Key references/links:

www.nmdc.no

www.mareano.no

Impact assessments for Hywind Tampen - Equinor

Country: Portugal

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
0.83%

b) National development targets by 2030/2040:

10 GW by 2030

40 GW by 2050

c) Authority responsible for monitoring of OWF impacts
General-Directorate of Natural Resources, Security and Maritime services (Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos, DGRM)

d) Does a national monitoring of marine environmental impacts exist?
Yes. There is no specific single document but a set of instruments and activities that aim to control the environmental impact of projects and activities in various areas, including water, climate and radioactivity.

2. Brief description of national obligations, allocation of responsibilities and funding sources

The National Maritime Spatial Planning (NMSP) instrument, governs maritime space use, requiring Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) for activities not initially covered.
Private use of maritime areas is granted through Titles for the Use of Maritime Space (TUPEM), generally issued as 50-year concessions for OWFs by DGRM. Applications must include detailed project descriptions, a monitoring, signalling and safety plan, and may require a water resource permit (TURH) from the Portuguese Environment Agency (APA) if coastal waters are involved. TUPEMs do not authorise resource exploitation, which requires a separate energy production licence. Projects under 10 MW must be approved by the General Director of *Energy and Geology* (DGEG), while larger projects need ministerial approval. Stakeholders such as APA, DGEG, the Institute for Nature and Forest Conservation (ICNF), regional coordination commissions, and maritime authorities must be consulted before granting a TUPEM. OWFs operate under either a general or guaranteed remuneration regime and require additional licences for onshore infrastructure. All OWF projects must undergo an EIA under DL 151-B/2013, which, though originally designed for onshore projects, applies due to a lack of specific offshore regulations. The EIA spans the entire project lifecycle—construction to decommissioning—with periodic monitoring, reporting, site inspections, and audits required by APA.

3. Summary of current knowledge base on OWF impacts

The Portuguese Institute for the Atmosphere and the Sea (IPMA) was tasked by the Portuguese government, funded by the EU Recovery and Resilience Plan (RRP, Component REPowereu (C21-i07) to conduct technical studies to support the development of projects in two of the areas approved for installation of OWF by the Allocation Plan for Ocean Renewable Energies (PAER), Leixões and Figueira da Foz (IPMA,2024). The project, running from 2024 to 2026, aims to carry out a baseline study including the chemical characterisation of the water column and sediment, patterns of circulation and larval dispersion, primary and secondary productivity, and assessments of benthic, demersal, and pelagic marine fauna communities, as well as birds, mammals, and reptiles. Additional areas of study include biodiversity, the trophic chain, ecological quality, and the conservation status of ecosystems, VMEs and fishing activity. Although the aim of the project is not to provide

information on possible impacts of offshore windfarms, studies using modelling and simulation provide that information as a natural by-product. This is the case of WP- Circulation patterns and upwelling, a simulation study using the WRF atmospheric model and ERA5 reanalysis, of wind fields between 2009 and 2013 including 1,114 wind turbines across seven areas, showed a reduction in wind intensity downstream of the farms as expected, mainly in summer months, the shadow extending to the coastal area. The analyses of fishing activity using logbook data provided maps of fishing effort, catches in weight and value in the period 2015 -2023 for the surface longline fishery, bottom trawl and multi-gear fleets. The frequency of occurrence of fishing events and the proportions of effort, catch weight and value inside the areas for the development of offshore windfarms were calculated.

4. Is there are national data base or central data collection framework?

Yes. The IPMA platform WEAREATLANTIC, is an infrastructure capable of acquiring, aggregating, geoprocessing, and providing access to marine environmental data. OWF project data are managed, stored, and visualised through the SOMOSATLÂNTICO platform and the IPMA's GIS system.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes
   To my knowledge there are none.

6. Key references/links:
   IPMA. (2024). *Technical studies for offshore energy potential (PRR REPowereu, C21-i07)* (p. 18). https://www.ipma.pt/pt/investigacao/prr/c21/

Country: Spain

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
   0%
b) National development targets by 2030/2040:
   1-3 GW

c) Authority responsible for monitoring of OWF impacts
   Developer, according to Spanish EIA law.

d) Does a national monitoring of marine environmental impacts exist?
   The EU-funded ESMARES programme aims to assess marine environmental impacts and propose measures to achieve BEA.

2. Brief description of national obligations, allocation of responsibilities and funding sources

The Marine Spatial Planning in Spain has summarised the monitoring activities required within marine wind energy developments. These requirements include the assessment of fishing activity and the characterisation of impacted habitats, among others. A new regulation is currently being developed and may expand the monitoring requirements outlined in the MSP.

In principle, monitoring will be permit-driven and fall within the EIA framework. However, Spain is still in the early stages, so additional monitoring may be undertaken further down the line.

According to Spanish EIA law, monitoring will be the responsibility of the developer, and funding is expected to come from private sources.

3. Summary of current knowledgebase on OWF impacts

There is not any OWF currently operating in Spain, therefore there is not any known impact yet.

4. Is there are national data base or central data collection framework?

The IEO (Instituto Español de Oceanografía) contributes to the Marine Strategies (under the EU MSFD) by designing and conducting monitoring programs that assess biodiversity, non-indigenous species, food webs, pollution, underwater noise, marine litter and pressures on ecosystem. The IEO also leads fisheries monitoring through the National Program for Basic Fisheries Data (under the EU Data Collection Framework) by collecting information on landings, fishing effort, and species size. Additionally, it conducts scientific surveys aboard oceanographic vessels to evaluate fish and invertebrate populations, covering both demersal and pelagic species and oceanographic data. There are also other scientific projects monitoring programs that are managed by different institutions and regional authorities.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

There is not any national monitoring initiative since there is not any operating wind farm in Spanish waters yet.

6. Key references/links:

IEO data catalogue: http://datos.ieo.es

Country: Sweden

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:

< 1% (0,16 GW)

b) National development targets by 2030/2040:

Sweden has no specific target for offshore wind. The development goal for onshore and offshore wind energy production taken together is 300TWh. For sea areas, the newly updated MSP makes room for an annual production of 120 TWh, which would cover <5 % of the SEZ. However, the Swedish MSP is not binding and there is no expectation that all of this will be filled. The outcome will depend on EIA processes, the market and developments of other energy sources. Current OWF permits in place enable around 14 TWh (Swedish agency for Marine and Water management), which may correspond to a capacity of around 3 GW by estimation from available data. Applications currently in process correspond to an estimated additional 40 GW, however it is not expected that all of these will be approved (Swedish Energy Agency). The current grid capacity for offshore wind is 14 GW (SOU 2024:89).

c) Authority responsible for monitoring of OWF impacts

The County Administrative Boards (regional authority) and Coast Guard are supervising authorities. The OWF company is responsible for the monitoring.

d) Does a national monitoring of marine environmental impacts exist?

A national environmental monitoring program is in place, which follows up on actions towards national environmental quality objectives and the MSFD objectives. No national monitoring program is specific for OWF.

2. Brief description of national obligations, allocation of responsibilities and funding sources

An SEA is carried out in connection to the MSP, which gives the recommended spatial outline of OWF developments in relation to potentially conflicting sea uses.

For the OWF permit, the OWF company carries out the environmental impact assessments in alignment with national and EU regulations. The preparation of the EIA includes the collection of various monitoring data that remain closed property of the companies, albeit described in the environmental impact assessments.

For approved OWF projects, the OWF company is required to conduct a monitoring program to follow up on the impacts of its operation. In addition, special surveys may be requested to focus on specific questions about for example bats, fish or marine mammals. These can be more extensive and longer term. The general conditions and focal topics are defined in the permit (which is given by the Government), while the details of the program are specified later on between the OWF company and relevant authorities. Regulatory and supervising authorities are the County Administrative Board (regional authority) and Coast Guard. The OWF company carries all costs.

OWF monitoring is not tied to the publicly financed national environmental monitoring program, although possibilities for coordination are being discussed.

3. Summary of current knowledgebase on OWF impacts

Benthic fish monitoring was conducted in the Lillgrund OWF in the Sound, in connection to its first years of operation (Davy 2009). The design was a BACI approach with 3 years before constructions and 3 years after, including two references areas. This was funded by the OWF company based on requirements in connection to the permit. Currently, these sites are revisited in a research project (Wind4CoCo) to study the long -term effects using the same approach. Results from years 15-17 of operation will be ready in 2027.

A clear aggregation of certain fish species was observed close to the turbines within the first 1-3 years of operation, while no effects on fish abundance or species composition were observed at the spatial scale of the whole OWF (Bergström *et al*, 2013a). Initial results from the long-term studies suggest that OWF effects in the fish assemblages are smaller than on the effects of other pressures, such as fishing, the introduction of NIS, climate changes and natural predation from cormorants and seals (SLU, in prep).

In addition to the fish surveys, which use fyke nets, BRUVs were used to study reef effects close to the turbines compared to further away in the OWF and two reference areas. These studies were carried out at after 15 years of operation. The results verified clear differences in which fish species are associated with the new structures and which appear to be indifferent to it (SLU, in prep.). They also show low level of habitat disturbance inside the OWF. Future evaluation will focus on how the BRUV can complement traditional, capturing, fish survey methods.

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

The existing fish monitoring data from Lillgrund (see point 3 above) is stored in the national database for coastal fish with an associated sampling protocol, hosted by SLU (Bergström *et al.* 2013b).

National data bases supporting open data are in place for all aspects relevant for OWF monitoring, and it is expected that any OWF data would also be stored in the existing national data bases, hosted by SLU or SMHI. The same data could potentially also be shared further with international databases. Examples for other types of data are in place, where different types of national data are shared through databases hosted by Helcom and Ices.

A minimum requirement for harmonised data collection would be the sharing of key metadata within ICES.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

- The Wind4CoCO project (project duration: 2024-2027) will deliver recommendations for the monitoring of local and cumulative effects of OWF on fish, based on developments within the project and coordination with other national and international efforts on OWF monitoring (see link).
- The Swedish Institute for the Marine Environment has initiated a project to support the development of nationally coordinated OWF monitoring (project duration: 2024-2025). The aim is to initiate a discussion with central authorities on how an environmental monitoring of new offshore wind farms in Sweden could be designed. The scope includes potential effects on key target components of the EU MSFD descriptors and focuses on the operational phase. The work is structured around identifying 1) potential effects of OWFs on the surrounding marine ecosystem, 2) to what extent these could be associated with risks to the environment and 3) evaluation of methods that could support the monitoring of these indicators. The work identifies which of the indicators could be monitored by methods used in the existing Swedish environmental monitoring programme for environmental quality objectives and the MSFD. To fill remaining identified gaps, potential novel approaches will be recommended for testing (SLU, in prep).

6. Key references/links:

Bergström L, Sundqvist F, Bergström U (2013a) Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community. Marine Ecology Progress Series 485: 199–210.

Bergström *et al.* 2022

Bergström L, Lagenfelt I, Sundqvist F, Andersson I, Andersson M H, Sigray P (2013b). Study of the Fish Communities at Lillgrund Wind Farm – Final Report from the Monitoring Programme for Fish and Fisheries 2002–2010. On behalf of Vattenfall Vindkraft AB. Swedish Agency for Marine and Water Management, Report number 2013:19, 134 pp, ISBN 978- 91-87025-43-3.

Davy T (2009) Environmental Monitoring - Lillgrund Offshore Wind Farm

SLU (in Prep.) Swedish University of Agricultural Sciences, Department of aquatic resources (SLU Aqua). See: https://www.slu.se/en/departments/aquatic-resources1/research/ecosystems/effects-offshore-energy/

Country: United Kingdom (England, Wales and Northern Ireland info combined, Scotland separate where shown)

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:

Scotland (EEZ 462,315 km2; 64%): Wind 766.37 km2, cable 140.93 km2
England/Wales/NI: Wind 2405.06 km2, cable 827.47 km2
% UK EEZ (4140/773,676 km2) = 0.54 %
% Scotland = 0.2 % ; % E/W/NI = 1.07%,

UK 2025: 14.7GW operational (45 OWFs); 15+ GW Committed OSW

b) National development targets by 2030/2040:

2030 up to 50GW (UK – policy target; incl. 5GW FLOW)

2050 up to 140GW (Net Zero)

c) Authority responsible for monitoring of OWF impacts: (Developers/consultants monitor project sites; authorities licence and national oversight of the developers' data)

England – Marine Management Organisation (MMO); Crown Est (leasing)
Wales – Natural Resources Wales (NRW); Crown Est (leasing)
Northern Ireland – Department of Agriculture, Environment and Rural Affairs (DAERA - Marine and Fisheries Division); Crown Est (leasing)
Scotland – Marine Directorate Licensing Operations (MD-LOT); Crown Est Scotland (leasing)

d) Does a national monitoring of marine environmental impacts exist?

Not specifically, project-based monitoring to national guidelines

2. Brief description of national obligations, allocation of responsibilities and funding sources

The UK Government determines the potential areas for offshore wind development and then invite bids for the areas. Around the country there are marine plan areas, which have policies in place to encourage sustainable development and balance the needs of the environment, economy, and society. The competent authority/regulators (for all UK countries) are responsible of the OSW development process to meet UK Government policy (e.g. offshore wind targets for Net Zero) and set the conditions of licences. The Planning Inspectorate and The Crown Estate lease the nearshore and land areas, and the seabed (respectively) - increasingly getting developers to submit monitoring data to central data hub. Industry are responsible for submitting planning applications (including baseline characterisation) including EIA (with CEA) to support the process. Project-based EIA is the primary monitoring data source based on available data, industry specific monitoring depending on the identified impacts, risk assessments and modelling. Impact is assigned category by the developer/consultant for review by competent authorities.

Legislation is under the UK Marine Strategy (devolved nations have country specific version), Habitats Regulations Assessment (including SPAs- Special Protection Area; HMPAs – Highly Protected Marine Areas, SACs – Special Areas of Conservation) - highlights the needs to conserve/protection, Birds Directive, Marine Conservation Zones Assessment, Marine Plans, Water Framework Directive Regulations. Funding for project monitoring – developers and operators (Industry). Funding for competent authority is Govt (devolved) – (Government). Research projects are Public money – National Research Councils + Industry (co- or full funding).

Strategic Environmental Assessment and Marine Spatial prioritisation determine the areas for promoting offshore wind development. There is no formal link with EIAs. The EIAs are project

specific and have cumulative assessments within them. Some moves towards plan-led approach and strategic areas for development.

3. Summary of current knowledgebase on OWF impacts

In the UK there is no specific national monitoring for OSW impacts. However, for each OSW development specific EIA monitoring is a requirement and specific monitoring may be a condition of the licence that the Developer is responsible for delivering. Monitoring follows (some) national guidance. In R&D projects there is some monitoring of fish/fisheries and or benthos as part of objectives (e.g. OWEC programme; ECOWIND; see The Crown Est Marine Data Exchange).

National fisheries monitoring follows standard approaches, but this is not specifically for ORE (and the data are at too coarse a scale). Also, there is a national programme to meet GES, which is Government funded but not specific to ORE.

Research and monitoring are focussed on baseline surveys of benthic and demersal species presence and absence, and in some cases abundance. Soft sediment grabs are used, whereas hard substrate has video-based methods. The focus is on conservation features / designated habitats or species of conservation interest. Some projects require monitoring to ensure no detrimental impact on fish and shellfish (receptor group) population post-construction if the site is utilised by commercially important fish species for spawning activity. However, there are no specific fisheries-independent surveys in or around ORE. There are some fisheries-dependent data, such as log books, vessel movement data (VMS). The consideration of potential nursery and spawning areas in the North Sea for a range of species are identified by Coull et 1998. Fish are regarded as highly mobile and likely to avoid the construction area temporarily without any long-term effects at the population level. Generally 2m beam trawls are used to sample epibenthos, however, this is inadequate at sampling adult populations of fish and not considered suitable for site characterisation. Currently there are poor suitable background data on UK fish/fisheries species populations with regards to their response to OWF impacts, the better use of long-term monitoring projects and landings data may help. For the new floating offshore wind (FLOW) there is a more coordinated approach to baseline data (lessons from Fixed OWFs). There are agreed site-specific methodologies for addressing local concerns, but this can give rise to differences in data collected making comparisons of fish/shellfish populations between OWFs difficult. Monitoring results rarely adequately show change over the duration of the development because of the broad scale approach taken. Changes observed during the monitoring of a wind farm over the duration of a project are invariably reported as being the result of high inter-annual variability of the species concerned.

Industry has started stakeholder mapping and consultation. Most monitoring is around nature conservation, Marine mammals and birds. New interest in the Biodiversity Net Gain (BNG) concept has changed some of the current needs/ actions and Nature Inclusive Design consideration is on the rise. There are challenges around CEA methodologies and climate change. There are new needs under European Bank for Reconstruction and Development (EBRD, 2024)- IFS 5/6 Livelihood and restoration (fisheries) and 6 (Biodiversity and living resources).

4. Is there a national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

Some national central data collection (not currently specific to Offshore wind are:

- National agreed standards for ecosystem proxy metrics (e.g. MEDIN)

- OneBenthic –

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

UK Marine Monitoring and Assessment Strategy (UKMMAS) aims to ensure that all marine data community are made openly available for long-term access and use. Developed in conjunction with the Marine Environmental Data and Information Network (MEDIN).

Marine Data Exchange (MDE), The Crown Estate – brings together all the data from leased sites and new leases require data to be submitted as a condition.

OWEER – a centralised register of environmental research relating to offshore wind with a focus on conservation receptors (OWEER launch | JNCC - Adviser to Government on Nature Conservation).

Scottish Marine Energy Research (ScotMER) Programme – The National Marine Plan commits Scotland to make decisions on the best available scientific evidence. Where evidence gaps and uncertainties exist, the ScotMER programme seeks to address these evidence gaps, where it is most needed. New information can then be fed back into planning, licensing and consenting processes as well as policy (https://www.gov.scot/policies/marine-renewable-energy/science-and-research/).

6. Key references/links:

Coull, K.A., Johnstone, R. and Rogers, S.I., 1998. Fisheries sensitivity maps in British waters. Published and distributed by UKOOA Ltd, 9.

Gill, A.B., Bremner, J., Vanstaen, K., Blake, S., Mynott, F. and Lincoln, S., 2025. Limited Evidence Base for Determining Impacts (Or Not) of Offshore Wind Energy Developments on Commercial Fisheries Species. *Fish and Fisheries*, *26*(1), pp.155-170.

Country: United States

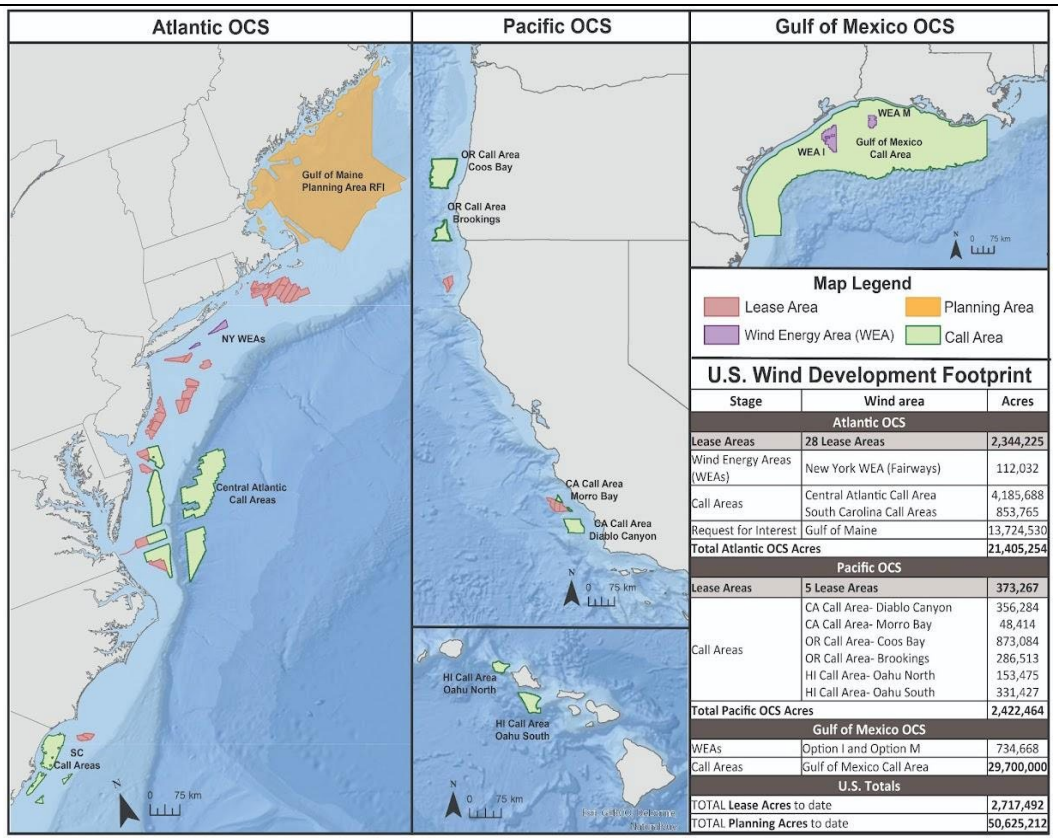
1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:

<1% of the surface area of the United States EEZ is covered by OWF development. Specifically, ~0.37% of the EEZ has been leased for OWF and ~0.70% of the EEZ has been designated for OWF planning.

OWF lease acres: 2,717,492 lease acres to date / ~7,264,640,000 acres in US EEZ * 100 = 0.37% of EEZ

OWF planning acres: 50,625,212 planning acres to date / ~7,264,640,000 acres in US EEZ * 100 = 0.70% of EEZ



U.S. Wind Development Footprint

Stage	Wind area	Acres
Atlantic OCS		
Lease Areas	28 Lease Areas	2,344,225
Wind Energy Areas (WEAs)	New York WEA (Fairways)	112,032
Call Areas	Central Atlantic Call Area	4,185,688
	South Carolina Call Areas	853,765
Request for Interest	Gulf of Maine	13,724,530
Total Atlantic OCS Acres		**21,405,254**
Pacific OCS		
Lease Areas	5 Lease Areas	373,267
Call Areas	CA Call Area- Diablo Canyon	356,284
	CA Call Area- Morro Bay	48,414
	OR Call Area- Coos Bay	873,084
	OR Call Area- Brookings	286,513
	HI Call Area- Oahu North	153,475
	HI Call Area- Oahu South	331,427
Total Pacific OCS Acres		**2,422,464**
Gulf of Mexico OCS		
WEAs	Option I and Option M	734,668
Call Areas	Gulf of Mexico Call Area	29,700,000
U.S. Totals		
TOTAL **Lease Acres** to date		**2,717,492**
TOTAL **Planning Acres** to date		**50,625,212**

b) National development targets by 2030/2040:

Offshore wind energy development is active and in different phases on all coasts of the United States. There are three operational wind projects in the northeast United States region (e.g., Block Island, Coastal Virginia Pilot, South Fork). Construction of utility scale offshore wind is underway in the Southern New England Wind Energy Area and the Coastal Virginia Offshore Wind commercial project. On January 20, 2025, a Presidential Memorandum was issued on offshore wind energy development in the United States. The Presidential Memorandum, entitled 'Temporary Withdrawal of All Areas on the Outer Continental Shelf from Offshore Wind Leasing and Review of the Federal Government's Leasing and Permitting Practices for Wind Projects."

c) Authority responsible for monitoring of OWF impacts

Offshore wind developers lead monitoring at individual wind farms. Specifically, project-level environmental monitoring is required by the Bureau of Ocean Energy Management (BOEM) to evaluate the effects "of proposed activities on physical, biological, and socioeconomic resources, as well as to evaluate the seafloor and sub-seafloor conditions that would be affected by the construction, installation, and operation of meteorological towers, buoys, cables, wind turbines, and supporting structures (BOEM 2023)." The monitoring plans from offshore wind developers are not harmonized, as there are major differences in research questions addressed, indicators measured, sampling methods and designs used, gear types used, duration of baseline data collection, duration of post-construction data collection, and information sharing (Methratta *et al.* 2023).

d) Does a national monitoring of marine environmental impacts exist?

There is no standardized national monitoring for marine environmental impacts associated with offshore wind energy development. However, NOAA Fisheries conducts scientific surveys to assess populations at ecosystem scales. While these long-term scientific surveys may be capable of detecting and quantifying impacts associated with offshore wind energy development, the

surveys themselves will also be impacted by development (e.g., preclusion, impacts to statistical survey design, habitat change, impacts to sampling) (Methratta *et al.* 2023). Strategies and plans to mitigate impacts of offshore wind energy development on scientific surveys are underway in the Northeast and Southeast regions of the United States (Hare *et al.* 2022, Hanisko *et al.* In prep).

2. Brief description of national obligations, allocation of responsibilities and funding sources

Project-level environmental monitoring is required by BOEM to evaluate the effects "of proposed activities on physical, biological, and socioeconomic resources, as well as to evaluate the seafloor and sub-seafloor conditions that could be affected by the construction, installation, and operation of meteorological towers, buoys, cables, wind turbines, and supporting structures" (BOEM 2023). To understand regional-scale effects of wind development on NOAA Trust Resources, BOEM and the NOAA Fisheries jointly identified the need for standard approaches for offshore wind project-level monitoring (Hare *et al.* 2022). Standard approaches conducted across individual wind projects within and across lease areas will enable the comparison of data across projects and facilitate the integration of data from multiple projects within the region into ecosystem and socio-economic analyses and modelling. Recommended regional monitoring standards are in development to evaluate the effects of fixed-foundation offshore wind development on protected species, fisheries species, oceanography, and socioeconomics. While some funding mechanisms for monitoring are established or required, for example through power purchase agreements with states, or through BOEM development requirements, some additional funding mechanisms for monitoring offshore wind development are not yet decided upon.

3. Summary of current knowledge base on OWF impacts

In the Northeast U.S. region and nationally, a synthesis of science effort (Hogan *et al.* 2023) was conducted prior to the construction of OWF that covered impacts on ecosystem, fishing operations, fisheries management and data collection. The report was mainly hypothetical as it was developed prior to construction, but outlined a number of new stressors due to OWF including include noise, electro-magnetic fields (EMFs), altered patterns of local and regional hydrodynamics, habitat conversion, artificial reef effects (i.e. effects of interactions that form and maintain a reef and its associated community), and fish attraction device (FAD) effects (i.e. attraction of fish to structure for forage, habitat, or refuge). Research since in the Northeast on the first constructed OWF, has found greater abundance of reef oriented species near turbine foundations after construction (i.e., black sea bass) (Wilber *et al.* 2022, Jech *et al.* 2022).

A number of research efforts, including both modelling and field studies, are currently underway to examine the potential impacts of offshore wind development on physical and biological oceanography that may cascade to higher trophic level predators. Current monitoring also includes using passive acoustics to monitor pile driving, and various fisheries and habitat studies. However, most of these studies are still underway, and therefore have yet to contribute to the knowledge base.

In the Southeast U.S. region, the knowledge base on OSW impacts is mainly hypothetical as no OWF construction is underway. In the Gulf of America, in particular, oil and gas infrastructure may be the most suitable proxies for understanding effects of future OWF development, yet there are differences in the two types of infrastructure, such as those related to structure density, spacing, and design. There are also lessons learned from artificial reefs that may help guide development of OWF monitoring.

Efforts nationally include developing region-specific research priorities to determine effects of OWF development on fish and fisheries (e.g., Sura *et al.* 2025; Klabjor *et al. In prep.*; Czaja *et al.*

2025; Hogan *et al.* 2023; Methratta *et al.* 2023). Additional efforts are underway to quantify effects of future OWF development using conceptual modelling, ecosystem modelling, and other synthesis techniques.

4. Is there are national data base or central data collection framework? If not what would be the minimum requirements to implement a harmonised data collection.

There is no national database in the United States for monitoring offshore wind energy development. Several regional science collaborative entities maintain lists of active offshore wind research and monitoring efforts; however, these efforts are not standardized nor centralized at a national level.

The minimum requirements to implement a harmonized data collection would be collaboration between federal agencies (NOAA, BOEM, BSEE, USFWS], state agencies, OWF developers, and regional coordination organizations (e.g. RWSC and ROSA).

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes
   - Methratta (2025) evaluated potential indicators for determining impacts of offshore wind development on fisheries resources. The examined indicators exhibited a high degree of temporal and spatial variability. This led to recommendations for future monitoring (e.g., 3-5 year minimum baseline data collection, monitor for project lifetime).
   - NOAA is developing a draft monitoring strategy that provides recommendations for project-level standardized monitoring in the Northeast U.S. region. The draft monitoring standards aim to provide offshore wind developers with a roadmap for assessing responses of specific organism groups to impact producing factors. Response groups include physical and oceanographic variables, phytoplankton and zooplankton, ichthyoplankton, protected mammals, protected sea turtles, protected fish, fisheries species, benthic habitat, and socioeconomics). Impact producing factors include noise, hydrodynamics, altered cumulative effects on movement and behaviour, vessel strike and entanglement, artificial reef effects, electromagnetic fields, presence of structure, traffic, port utilization).
   - NOAA is developing a national science plan for studying impacts of offshore wind development that calls for standardized monitoring, especially to facilitate cumulative impact assessments.
   - Several others mentioned earlier in document, too.

Key references/links:

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Country: Poland

1. State of offshore wind development:

a) % surface area of EEZ covered by OWF development:
0%

b) National development targets by 2030/2040:
2030 r. - 5,9 GW, 2040 r. – 11 GW

c) Authority responsible for monitoring of OWF impacts
Developer

d) Does a national monitoring of marine environmental impacts exist?

Yes/but not for OWF

2. Brief description of national obligations, allocation of responsibilities and funding sources

In Poland there is OWF industry-financed monitoring. Obligatory studies on the designated areas are carried out on the request of the investor. Result of this studies are included in EIA with plans for further monitoring (during construction and in operational phase). Reports have to be

submitted to the General Directorate for Environmental Protection and are publicly available when permissions are received, but data are not freely available.

The Chief Inspectorate of Environmental Protection (GIOŚ) is responsible for conducting environmental monitoring.

Maritime spatial plan for the internal marine waters, the territorial sea and the exclusive economic zone on a scale of 1: 200 000 was adopted by the Regulation of the Council of Ministers of April 14, 2021 (Journal of Laws of 2021, item 935). The regulation entered into force on May 22, 2021.

3. Summary of current knowledgebase on OWF impacts

There are no offshore wind farms in Poland yet. In total 23 sites have been chosen and approved for wind farms construction. First offshore wind farm (Baltic Power) should deliver power to the grid at the end of 2026. Several monitoring studies for EIA have been finished.

On the base of current knowledge on the OWF impacts from other countries document on the request of The Chief Inspectorate of Environmental Protection (GIOŚ) "Guidelines for environmental analysis and monitoring during the construction of offshore wind farms" (ed. M. Stryjski *et al.*) has been prepared in 2024.

Several studies have been done on artificial structures and its effect on soft bottom and hard bottom communities in the southern Baltic Sea. We found that:

- Benthic communities at artificial structures are not substitutes for communities at natural substrates;
- Artificial structures with dense benthic assemblages affect the adjacent soft bottom communities;
- Most alien species are more abundant on artificial substrate, especially at shallower depths (Brzana *et al.*, 2020, 2024, Brzana & Janas 2025).

This knowledge can be used in predicting the effect of OWF on benthic assemblages in the Baltic Sea.

4. Is there are national data base or central data collection framework?

Harmonised national data base for data collected for OWF projects doesn't exist.

A project is needed to create and initiate harmonised data collection.

5. Existing national initiatives to achieve collaborative/ coordinated monitoring programmes

No information about such initiative.

6. Key references/links:

MSP – SIPAM

Annex 5: Metadata sheet

	Columns	
1	**Country**	Select the country where the monitoring is taking place. *(Dropdown)*
2	**Spatial ID**	Unique identifier or code for the monitoring area/layer. *(Free text)*
3	**Monitoring context**	Purpose of monitoring (e.g., regulatory, research, impact). *(Dropdown)*
4	**Spatial coverage**	Geographic scale of the monitoring
		Example: Project would be one windfarm
		Cluster: several windfarms
		Specific infrastructure: Cables etc
5	**Spatial resolution**	The spatial resolution of the dataset (e.g., 100m, 1km). *(Free text)*
6	**Temporal coverage**	Time period covered by the dataset (e.g., 2020–2023). *(Free text)*
7	**Temporal resolution**	Temporal granularity (e.g., daily, monthly, seasonal). *(Free text)*
8	**Ecosystem component**	Select the main ecosystem component being monitored (e.g., fish, cephalopods). *(Dropdown)*
		Choose abiotic if components like temperature, noise are measured (please only add components relevant to fish and benthos)
9	**Habitat**	Specify the habitat type monitored. *(Dropdown)*
10	**Indicator/variable**	Name or description of the indicator or measurement used. *(Free text)*
11	**Approach/method**	Brief description of the monitoring method or sampling approach. *(Free text)*
12	**EVs (Essential Variable)**	Select the EBV category relevant to the data. *(Dropdown)*
13		**Variable** **Dependent on EV** — choose from the list of variables under the selected EV. *(Dropdown)*
14	**Ecosystem process**	Ecosystem process class. *(Dropdown)*
15	**Ecosystem Function**	Ecosystem Function linked to the monitoring activity. *(Dropdown)*
16	**Windfarm**	Select from the dropdwon menu, if possible, a winfarm name
17	**Status**	Is monitoring part of an operating OWF or prior/parallel monitoring eg: fisheries data, monitoring for area scoping
18	**Use**	Are the indicators used for reporting on monitoring, CIA/CEA, modeling?
19	**Confidence**	Personal confidence about the information provided
20	**Reference**	Dataser reference
21	**Dataset availability**	
22	**Notes**	