ICES Special Request Advice
Baltic Sea, Celtic Seas, and Greater North Sea ecoregions
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EU request on economic, social, and ecological impacts of offshore wind farms (OWFs) and floating offshore wind farms (FLOWs) on fisheries in the Baltic Sea, Celtic Seas, and Greater North Sea

Advice summary

This advice addresses aspects of the economic, social, ecological, and cumulative impacts of offshore wind farms (OWFs[1]) and floating offshore wind farms (FLOWs). It focuses on the scope of the existing evidence base, data, and methods to assess impacts, and it considers marine spatial planning[2] (MSP) and technical measures as approaches for mitigating unwanted impacts.

Systematic review of available studies identified OWF and FLOW impacts on income, fishing grounds, catch opportunities and operating costs in EU Member States. For all types of impacts, there were more studies reporting on negative impacts on fisheries than studies reporting on positive impacts. Observed impacts were dependent on context factors such as the type of wind farm, development phase of the wind farm (pre-construction, construction, operation, or decommissioning), and adaptive capacity of fishers. ICES did not identify any studies of trade-offs between the economic impacts of fisheries and wind farms.

ICES identifies five classes of data that are required for assessments of the economic and social impacts of wind farms on fisheries: vessel positional data, fisheries catch and effort data, fisheries economic data, fisheries social data and OWF and FLOW data. Existing available data are mostly not collected or collated at sufficiently high resolution, and cannot yet be linked in ways that enable full evaluation of direct or indirect economic and social impacts of wind farms.

Some pressures associated with the phases of OWF and FLOW development have known or predicted local impacts on commercially fished species. A trait-based analysis was applied to estimate the local vulnerability of commercially fished species to the operational phase of OWF development in the Baltic Sea, Celtic Seas, and Greater North Sea ecoregions. Sediment resuspension was the most impactful pressure. ICES, however, did not identify any population-level (stock-level) assessments of impacts on commercially fished species. Requirements for population-level assessments that account for wind farm impacts across the distributional range of populations are described.

ICES did not locate sufficient evidence to directly assess the effects of existing wind farms on the western Baltic herring. There was no direct evidence of wind farm effects on the critically endangered[3] Baltic Proper harbour porpoise. However, information on the responses of other harbour porpoise populations to pressures associated with OWFs or FLOWs, especially noise, is sufficient to conclude that wind farm developments in the Baltic Proper harbour porpoise core distribution area would lead to pressures that pose a risk of further population decline.

Wind turbines create atmospheric wakes, and their underwater structures modify currents and stratification. Atmospheric wakes reduce mixing of the water column on large scales, and underwater structures increase mixing on smaller scales. Especially in seasonally stratified areas, wakes reduce primary production, while underwater structures increase it. Underwater structures also support communities of filter feeders that consume additional primary production.

OWFs and FLOWs introduce artificial hard substrates and modify distributions of indigenous and non-indigenous species, especially in areas dominated by soft sediments and away from rocky coasts and seabeds. The magnitude of their impact in relation to other artificial hard substrates is not known. Based on the observed colonization of other floating structures, the transport of FLOW turbines between ports and wind farms may facilitate the spread of non-indigenous species.

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[1] For the definitions of all acronyms and initialisms used throughout this advice, see Annex 5.

[2] Marine spatial planning (MSP) and maritime spatial planning are treated as synonymous. MSP is defined as “a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process“ (a UNESCO-IOC definition from Ehler, C and Douvere, F [2009]. Marine Spatial Planning: a step-by-step approach toward ecosystem-based management. IOC Manual and Guides 53, ICAM Dossier no. 6. Paris: UNESCO. http://dx.doi.org/10.25607/OBP-43).

[3] IUCN Red List classification

Dynamic cables associated with FLOW may affect pelagic species because of direct energy emissions, physical effects, and/or indirect ecological effects. However, ICES identified no studies of the effects of dynamic cables. Effects were inferred from studies of other subsea power cables, which all reported local rather than population-level effects.

ICES evaluated existing methods and models with potential to assess the cumulative impacts of OWFs and FLOWs. Some were deemed either suitable (subject to evidence and data for parameterization), or to have potential through further development, to quantify cumulative impacts, and to test how these impacts could be modified by mitigation options. Cumulative assessments would be facilitated by higher resolution economic, social, and ecological data, including information on the locations and developmental phases of wind farms at ecoregion scales.

Mitigation is intended to reduce or compensate for adverse economic, social, and ecological impacts of OWFs and FLOWs. MSP and subordinate planning processes, instruments, and supporting procedures contribute to the identification and implementation of mitigation options. Multiuse and co-use approaches provide mitigation by enabling coexistence between users and activities. Technical mitigation options, such as the positioning of cables and noise abatement, modify aspects of wind farm design to improve options for the operability of fishing vessels within and around wind farms and to reduce adverse ecological impacts. These mitigation options facilitate MSP solutions but are usually enabled by sectoral policies. Mitigation through compensation provides substitute resources or environments. Stakeholder involvement, engagement and co-design help to enable development of mitigation options that are technically, economically, politically, socially, and ecologically feasible and that are supported, or at least accepted, by stakeholders.

Request

a) Assess data and resources available for the analysis of the economic[4] and social[5] impacts of ORE[6] developments on the fisheries sector.

On that basis:

b) Summarise the known and projected economic and social impacts of existing and planned offshore renewable developments (on fisheries, at metier and fleet levels). Trade-offs between negative economic impacts on fisheries and positive economic impacts of the ORE sector should be considered.
c) Describe sources of information available, methods that may be applied, and further data and information required, to address the economic and social impacts of ORE on fishers.
d) Summarise the known ecological impacts of ORE developments and their intensity (severe, medium, limited, unknown) on main commercial fish species[7] for the areas listed above and at population levels (positive and negative impacts) looking at the different phases of ORE development (survey, construction, operation, decommissioning). A specific case study on the effects on recruitment of western Baltic herring and of the effects on [Baltic] *harbour porpoises should be developed.*
e) Provide recommendations for next steps to define methodologies to model cumulative impacts of offshore wind on commercial fisheries (temporary, permanent) and the possibility to adopt mitigation measures.
f) Provide a review, based on the most recent literature, to describe how changes on hydrodynamic conditions produced by ORE may change the food availability to filter-feeders and influence phytoplankton primary production.
g) Provide a review, based on the most recent literature, of the ways artificial structures could influence the colonization of new areas by species, both indigenous and non-indigenous species. Based on data available for other structures (e.g. oil and gas), also from other locations (e.g. US), extrapolate how this colonization will affect ORE developments. Provide a review, based on the most recent literature, of the ways in which pelagic species (especially commercial fish species) may react to dynamic cables suspended in the water column (floating wind).

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[4] Focusing on economic impacts on fishers.
[5] Identifying priority impacts but focusing the assessment on employment of fishers.
[6] Almost all available information for the Baltic Sea, Celtic Seas, and Greater North Sea is for bottom-fixed offshore wind farms (OWFs), so this is the practical focus of this advice. References are made to floating offshore wind farms (FLOWs) when relevant.
[7] Species included in ICES advice on list of Descriptor 3 species to support reporting by EU Member States under Marine Strategy Framework Directive (MSFD) Article 17 (https://doi.org/10.17895/ices.advice.21332967).

h) *List options for mitigation measures, good practices, and spatial planning for ORE developments and assess their strengths, weaknesses, implications and uncertainties. List priorities for research and monitoring related to these options.*

Elaboration on the advice

Economic and social impacts (request items "a"–"c")

ICES summarized data, resources, and methods, available and required, for analysis of the economic and social (including cultural) impacts of OWFs and FLOWs. This contributed to the identification of data gaps that limit capacity to assess these impacts. A systematic review of published studies was used to describe known impacts. ICES is not aware of studies exploring trade-offs between any negative economic impacts on fisheries and positive economic benefits of wind farms.

The assessment of available data focused on regular data collection spanning large areas where data were collected by EU Member States for their own purposes and/or as a contribution to internationally coordinated and/or funded data collection programmes. The assessment aimed to provide good coverage of these data but did not focus on smaller-scale and project-based data collection activities. The assessment identified five classes of data required for the analysis of economic and social impacts of OWFs and FLOWs on fisheries: vessel positional data, fisheries catch and effort data, fisheries economic data, fisheries social data (including cultural elements), and OWF and FLOW data.

Existing data are often not suitable for assessing economic and social impacts of wind farms because they (i) are collected or collated at time and space scales that are too large for effective impact assessment, (ii) provide incomplete coverage or very little detail of parts of the fishing industry (e.g. smaller vessels), (iii) cannot be linked in ways that facilitate analyses of impact (e.g. linking economic and vessel position data), and (iv) are usually aggregated internationally on larger time and space scales than data collected nationally. Unlike fisheries data, the collection and collation of OWF and FLOW data is not coordinated internationally by management authorities. Consequently, they are largely inaccessible for scientific purposes and are not routinely collated on scales appropriate for fishery or ecoregion-scale assessments of economic and social impacts.

Further data and information are required to provide more informative and rigorous assessments of the economic and social impacts of OWFs and FLOWs on commercial fisheries. The priorities in this regard are i) greatly increased frequencies of position reporting with vessel monitoring systems (VMS), ii) full coverage of all types of fishing vessels with VMS, iii) analysis and compilation of steaming and harbour use data from VMS, iv) more effective linking of vessel positions with economic and social data, and v) fishery- and ecoregion-wide compilations of data on OWFs and FLOWs (developmental phases[8], physical and operating characteristics, and restrictions affecting fisheries). In all cases, mechanisms for compiling these data internationally and without substantially reducing resolution would be needed to maximize their analytical value. Existing projects and initiatives are addressing elements of these priorities.

Both *ex ante* and *ex post* methods are used to assess the economic and social effects of OWFs and FLOWs. These methods address topics including spatial and temporal descriptions of fishing grounds, economic dependency on fishing grounds, cultural importance of fishing grounds, and displacement and adaptation. The methods are often applied in a transdisciplinary approach involving the fishing sector.

Ex ante methods are used during the pre-construction phase of wind farm development. Two main types of *ex ante* analysis are used independently and in combination. Descriptive analyses consider past and current patterns in fisheries, while model simulations are used to investigate possible futures. Descriptive analyses provide insight into spatial use of the marine environment by different fisheries, their economic or social dependency on specific fishing grounds, and alternative fishing grounds. These analyses rely on vessel positional data coupled to catch, effort, economic, and social data. The quantitative analyses are ideally complemented with stakeholder experiential knowledge to capture the social (including cultural) importance of specific fishing grounds (e.g. safe fishing grounds in case of bad weather may be used infrequently and not identified as important in quantitative analysis). Model simulations are used to predict possible adaptations of fisheries. Model parameterization, validation, and scenario choices require effective collaboration with the fishing sector, and participatory modelling helps enable this. Results of modelling exercises can be combined with other sources of

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[8] Refer to Annex 1 for descriptions of the phases of offshore wind farm (OWF) and floating offshore wind farm (FLOW) development used in this advice and Annex 2 for examples of OWF and FLOW turbines.

information and used to trade off the economic, social, and ecological aspects of the system and to inform the decision-makers about the potential short- and long-term consequences of different options.

Ex post methods are used once an OWF or FLOW is operational. These require that the social and economic impacts on fisheries are monitored at appropriate time and space scales (e.g. on the scale of communities identified as potentially affected in an *ex ante* analysis) for *ex post* assessments. *Ex post* methods cover economic and social impacts. Examples are social impact assessment (SIA), the social well-being approach, the community capital framework (CCF), and cultural impact assessment (CIA). SIAs provide information on social and cultural factors to be considered in decision making. The social well-being approach provides a framework for evaluating the social and economic benefits that communities receive from fishing. Analyses of changes before and after wind farm establishment provide an integrated measure of social and economic impact. The community capital framework is used to assess social and economic impacts of interventions (in this case wind farm development) on community well-being, resilience, and development. CIA is used to evaluate the impact of interventions on the quality of life from a cultural perspective. Data to apply these ex-post methods are not routinely collected, or collected on large-scales, and the very few existing applications are on a project-by-project basis.

Economic and social impacts of OWFs and FLOWs on fisheries are a consequence of direct and indirect effects of both types of wind farm on fishing vessels and target species. Direct effects are understood from a small number of studies, predominantly focused on shellfish fisheries and the pre-construction phase of OWF development. Indirect effects, including those mediated through the ecosystem and resource species, and the downstream effects of changes in fisheries on coastal communities and value chains, have not been quantified at fishery or ecoregion scales.

A systematic review of available studies provided evidence for five types of direct impacts of wind farms. These are (i) changes in income from fishing activities, (ii) changes to fishing grounds, (iii) changes to catch opportunities, (iv) changes to fishing operating costs, and (v) changes in investment into technical or gear adaptation measures. Direct impact types i–iv were all recorded in studies of EU Member State fisheries and, for each type of impact, the review identified more than twice as many studies reporting deterioration, from a fisheries perspective, than improvements. Results are only indicative given the context specificity, the dominance of short-term studies and that the rationale for, and focus of, studies may be driven by expectations about impacts.

Studies of the direct social and economic impacts of OWFs and FLOWs on fisheries show context is critical in determining effects and impacts. Context factors include the type of wind farm, the development phase of the wind farm (pre-construction, construction, operation, or decommissioning), rules and regulations applying to fisheries inside and outside the wind farm areas, and the types of fisheries and their adaptive capacities (Figure 1).

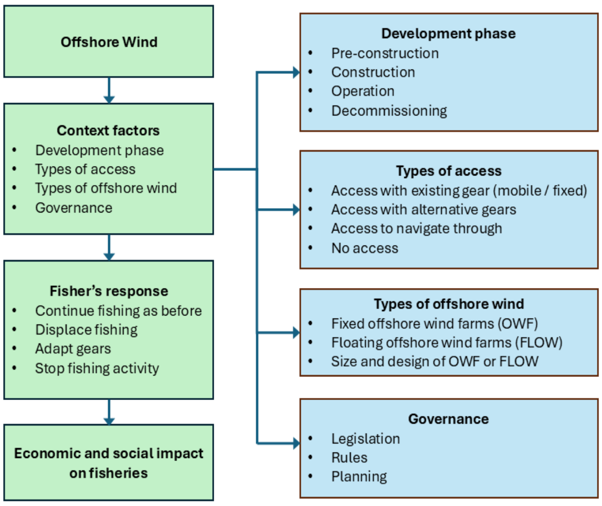

Figure 1 Examples of context factors that determine fisher responses to offshore wind developments and thus the social and economic impacts. Fisher responses may also be "in combination".

Impacts on commercially fished species (request item "d")

ICES did not identify any population-level (stock-level) assessments of the impact of any phase of OWF or FLOW development on commercial fish species. Such assessments require that the collective effects of OWFs and FLOWs on the growth and survival of different life stages across the distributional range of the population are incorporated into models of fish population dynamics. For these reasons, impacts on commercially fished species could not be classified as severe, medium, or limited at the population-level.

Prerequisites for assessment of population-level impacts are estimates of pressures[9] from OWF and FLOW developments on the species' life stages and their effects, information on the distribution of the population at each life stage, the frequency and duration of encounters of life stages with pressures, and a model of population dynamics that allows effects on life stages to propagate.

Given the expected complexity of population-level assessments of the impact of OWFs and FLOWs, risk assessment would provide a means of identifying those populations at greatest risk and requiring more detailed quantitative study. A risk assessment approach may combine estimates of the extent of spatial and temporal overlap of populations (or species when population-level information is not available) with wind farms. Risk would be assessed based on the extent of overlap and the effects of the pressures, in an approach comparable to existing methods of semi-quantitative risk analysis.

In the absence of sufficient evidence to develop population-level assessments of impacts, ICES applied a trait-based framework to assess local vulnerabilities of commercially fished species to different phases of OWF development. Vulnerabilities provide approximations of the severity of local (site-based) impacts but not population-level impacts.

The framework was applied for 34 commercially fished species in the Baltic Sea, Celtic Seas, and Greater North Sea to assess their vulnerability to the operation phase of OWFs. Trophic interactions and recruit survival were estimated to be most impacted by OWF developments, with sediment resuspension the most impactful pressure. Herring (*Clupea harengus*), great Atlantic scallop (*Pecten maximus*), and monkfish (*Lophius piscatorius*) were the species showing highest local vulnerability across the three ecoregions. However, high local vulnerabilities do not indicate consequences for populations and associated fisheries, as these also depend on the frequency and duration of encounters of life stages with OWFs and FLOWs, the effects of these encounters, and the proportions of the numbers of each life stage in the population having such encounters.

Impacts on western Baltic herring (request item "d")

ICES did not locate sufficient evidence to directly assess the effects of OWFs or FLOWs on the western Baltic herring stock. The western Baltic herring stock has reduced reproductive capacity (spawning-stock biomass [SSB] below B_{lim}) and recruitment in recent years has been at, or close to, historic lows. ICES advises zero catch for the stock. Spawning grounds of some components of the stock are degraded by eutrophication, and recruitment success is reduced by climate change effects. Even small additional pressures would prevent stock recovery, and reported recovery is currently very slow despite low and falling fishing mortality.

In the event of further wind farm developments that coincide with the distribution of the herring in space and time, impulsive noise (pre-construction, construction, and decommissioning phases) has potential to affect migration and habitat connectivity (pathways from feeding or overwintering grounds to spawning grounds). Alteration of spawning habitat by OWFs or FLOWs is unlikely for the spring-spawning component of the western Baltic herring stock. This is because the spring spawners are estuary and lagoon spawners, and it is unlikely that wind farms will be installed in these areas. Offshore spawning grounds of the autumn-spawning component (shelf spawners) would be adversely affected if wind farms were established there.

To better assess the future impacts of wind farms on western Baltic herring, more recent and complete descriptions of the migrations and spawning areas of the different stock components are required, so these can be used to assess overlap with plans for wind farm developments. This especially applies to the autumn-spawning components.

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[9] Refer to Annex 3 for a list of pressures attributed to offshore wind farms (OWFs) and floating offshore wind farms (FLOWs)

Impacts on Baltic Proper harbour porpoise (request item "d")

The Baltic Proper harbour porpoise population is categorized as "Critically Endangered" on the IUCN Red List, and an analysis by the North Atlantic Marine Mammal Commission (NAMMCO) and the Norwegian Institute of Marine Research (IMR)[10] indicated that anthropogenic mortality should not exceed 0.7 individuals per year to enable population increase. HELCOM[11] subsequently set an anthropogenic mortality limit of zero. With a population size estimated to be 71–1 105 individuals (95% confidence limit [CI]) there are significant challenges in monitoring the population and the effects of anthropogenic pressures. Although evidence of OWF and FLOW effects on Baltic Proper harbour porpoises is very limited, information on the responses of other harbour porpoise populations to noise is sufficient to conclude that wind farm development in the core distribution area leads to pressures that pose a risk of further population decline.

If any phase of OWF or FLOW development coincides in space and time with the use of the core distribution area, porpoises would be directly affected, especially by the introduction of underwater noise. Wind farm developments also have indirect effects on harbour porpoise, for example by changing bycatch risk if fisheries are restricted around these developments but displaced to other locations. Any benefits of reduced bycatch risk in the vicinity of wind farms would need to be offset against the risk of harm through displacement and noise during all phases of wind farm development. Given the very low population size and other risks to Baltic Proper harbour porpoises (the greatest of which is bycatch risk in fixed bottom set net fisheries), even moderate effects of wind farm developments will need to be avoided or mitigated to prevent further population decline.

Cumulative impacts (request item "e")

Wind farm installations impact commercial fisheries directly by affecting the normal operations of vessels and indirectly through the effects of a wide range of pressures on the resource species and ecosystem. Cumulative impacts are a result of these combined effects. Given the nature of the EU request, ICES focused on identifying methods with potential to support operational management advice on mitigation measures. Methods appropriate for modelling cumulative impacts[12] of OWFs and FLOWs, and for supporting advice on mitigation measures, need to link pressures (resulting from OWFs and FLOWs; Annex 3) to effects and to impacts. This ensures that the relationship between a mitigation measure and the changes in effects and impacts can be determined.

To identify the next steps for defining methods, ICES evaluated a non-exhaustive range of existing methods and models with potential to model cumulative impacts. Those selected were deemed capable, or had the potential through further development, to quantify cumulative impacts and to test how these impacts may be modified by mitigation measures.

No single model or assessment tool has the potential to account for all pressures linked to OWF and FLOW installations or to provide a comprehensive assessment of the economic, social, and ecological impacts of wind farms on commercial fisheries. Recommended next steps are to develop, further parameterize, calibrate, test, validate and apply models identified in the section on background to this advice, and related models, to assess cumulative impacts. These steps are highly resource intensive in some instances. Prioritization of resources may be guided by the economic, social, or ecological impacts of greatest concern to managers and stakeholders. These may be defined through policy or stakeholder processes, and qualitative or semi-quantitative risk assessments, based on existing information. Some social (including cultural) impacts of wind farms are described with qualitative methods; qualitative risk assessment and methods will be important for guiding discussions on priorities and mitigation measures in these cases.

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[10] North Atlantic Marine Mammal Commission and the Norwegian Institute of Marine Research (2019). Report of Joint IMR/NAMMCO International Workshop on the Status of Harbour Porpoises in the North Atlantic. North Atlantic Marine Mammal Commission and the Norwegian Institute of Marine Research, Tromsø, Norway.

[11] HELCOM (2023). Number of drowned mammals and waterbirds in fishing gear. HELCOM core indicator report. https://indicators.helcom.fi/indicator/bycatch/

[12] In this advice, cumulative impacts are defined as the combined effects (additive, synergistic, or antagonistic) of wind farms, in a defined sea area, on a specified aspect of commercial fisheries (e.g. social, economic, or ecological).

Impacts of changes in hydrodynamic conditions (request item "f")

Throughout the operation phase, OWF and FLOW turbines create atmospheric wakes, and their underwater structures modify currents and stratification. The former reduce mixing of the water column on large scales, and the latter increase mixing on smaller scales. In general, and in areas where there is otherwise seasonal or permanent stratification of the water column, reduced mixing decreases nutrient availability in the euphotic zone and reduces phytoplankton production, while increased mixing increases phytoplankton production. Thus, negative effects of atmospheric wakes on mixing and primary production at larger scales are countered by positive effects of mixing at smaller scales. In unstratified shallow areas with strong tides, effects on primary production are predicted to be smaller, but may be influenced by changes in the light field when changes in mixing affect suspended sediment loads. Benthic filter feeders form dense colonies on underwater structures associated with wind farms and consumption of phytoplankton and zooplankton will result. Only the directional effects of changes in hydrodynamic conditions on primary production and filter feeders are understood at larger scales, as there are few observations or models of effects, and results are installation- or site-specific. The balance between increases in primary production linked to mixing and increased uptake of primary production by filter feeders is not known.

Colonization of structures by indigenous and non-indigenous species (request item "g")

Artificial hard substrates created by OWFs and FLOWs modify distributions of indigenous and non-indigenous species by allowing them to survive and to colonize otherwise unsuitable environments. The relative effect of wind farm substrates on both groups of species, and in relation to many other artificial hard substrates present in the marine environment, is not known. Evidence from colonization of other types of floating structures suggests FLOW can harbour non-indigenous species and will facilitate their spread through turbine transport between ports and wind farms.

While available evidence is sparse, it is sufficient to conclude that the impact of construction, operation, and decommissioning of OWFs has the greatest effect on distribution of colonizing species in the following areas:

- Those dominated by soft sediments because the addition of artificial hard substrates will greatly increase the habitat available to biofouling organisms;
- Those that are far from natural hard substrates, such as rocky coasts and rocky seabeds because these also host species that would colonize OWFs;
- Those where other artificial hard substrates are scarce because these also host species that would colonize OWFs;
- Those close to shipping lanes and other vessel routes because colonizing species may be introduced via hull biofouling.

Impressed current cathodic protection (ICCP) systems, which prevent corrosion of exposed parts of steel turbine foundations, enhance the growth of calcifying organisms, but direct tests of effects on turbine foundations have not been conducted. Galvanic anode cathodic protection (GACP) systems, which also protect steel turbine foundations from corrosion, leak metals into the marine environment. The impacts of GACP on colonizing organisms are not known.

Elevated temperatures on cooling water pipes and dynamic cables may influence community composition and growth rates although available evidence is inconclusive. Sound from OWFs and FLOWs affects the behaviour of biofouling organisms; relationships and differences among species, however, are poorly understood, and the ecological significance is uncertain.

Responses of pelagic species to dynamic cables (request item "h")

Dynamic power cables are physically present in the water column during the construction, operation, and decommissioning of OWF and FLOW installations. Pelagic species[13] and species with pelagic life stages may encounter the cables. Confidence in the assessment of the effects of dynamic power cables on these species is low. This is because there are few commercial-scale FLOW installations worldwide and no known studies of effects of dynamic cables on these species at the installations. Therefore, effects are inferred from studies of OWFs and subsea power cables. Dynamic cables share many

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[13] ICES classifies commercially exploited pelagic species based on the adult stage. For classifications, see ICES Stock Information Database. 2025. ICES, Copenhagen, Denmark. https://sid.ices.dk

attributes with subsea power cables, including the generation of electromagnetic fields (EMF), sound from electrical resonance, and heat. Both types of cable also create habitats that may be used by some species and life stages and artificial surfaces that are colonized by biofouling species. Such evidence is field- and/or laboratory-based and mostly related to the species' adult life stages.

The main emissions from cables are EMF, sound and vibrations, and heat. Timing of exposure to emissions is determined by the operational characteristics of cables and the period of encounter. Species may interact physically with cables through habitat association and potentially collision and entanglement. Indirect ecological effects may be linked to colonization of cables by prey species, hydrodynamic effects, and seabed abrasion close to the junction of dynamic cables and export cables.

An approach to assess interactions of commercial fish with dynamic cables would require (i) information on the location and spatial extent of FLOW installations and associated dynamic power cabling within an ecoregion, (ii) the range of depths and areas of occurrence of dynamic cables, (iii) species occurrence at different life stages and depths in relation to the location of cables, and (iv) results from studies of the responses of pelagic life stages of commercial fish species to the cables. Additional information on the frequency and duration of encounters with FLOW and the proportions of the population having such encounters would be required to express effects at the population-level.

Spatial planning, good practices, and mitigation measures (request item "i")

Mitigation is intended to reduce or compensate for adverse economic, social, and ecological impacts of OWFs and FLOWs. Mitigation options include avoiding, reducing, eliminating or rectifying the adverse impact or compensating for the impact by replacing or providing substitute resources or environments.

This advice focuses on mitigation options from an MSP perspective and is therefore focused on (i) area designations and zoning of marine areas and (ii) multiuse and co-use. There are also technical mitigation options that may facilitate MSP solutions. These are usually enabled by sectoral policies. Technical options to mitigate direct impacts of wind farms on fisheries include burying cables, creating shared cable corridors to minimize complexity and footprint of cabling, approaches to cable reinforcement that reduce the risks of snagging fishing gear (or anchors), and maintaining updated cables information on navigational charts. Technical options to mitigate ecological impacts include cable route selection to avoid sensitive habitats, shared cable corridors, and reducing sediment displacement. Other mitigation measures include spacing turbines to enable fishing vessels to transit wind farms, timing pre-construction and construction phases to account for seasonal dynamics of species and fisheries, and noise abatement, especially during pre-construction, construction and decommissioning phases. During these phases, and during operation, vessel noise can also be abated by reducing vessel speeds, route selection that accounts for ecological risks, and use of vessels with silent class notation. In addition to noise abatement, acoustic deterrent devices are used to deter marine mammals from approaching areas where pile driving is occurring and may lead to temporary threshold shift (TTS).

From an MSP perspective, any interaction between OWFs or FLOWs and fisheries is one of spatial allocation and spatial competition. Instruments in MSP for dealing with the spatial demands of sectors, and conflicts between sectors, include area designations and zoning of marine areas for co-use. The most common area designation is for an area that focuses on a single sector or activity. Area designations can be supplemented by regulations to ensure that a priority use is not impeded by any other use and that the priority use adheres to specific rules. A benefit of area designation is that it provides security for investors and users of marine resources because their use is administratively (and often legally) supported and approval for projects can be simplified. Multiuse and co-use approaches seek to enable coexistence between users and activities. They may involve varying levels of both spatial and temporal overlap and of compatibility and mutual dependency between users and activities.

Stakeholder involvement, engagement, and co-design are shown to enable development of mitigation options that are technically, economically, politically, socially, and ecologically feasible and supported or at least accepted by all relevant stakeholders. To inform the choices among mitigation options, scientific advice will ideally characterize their economic, social, and ecological consequences and will inform scenario analyses, such as to predict the impacts of different reallocation and multiuse options for stakeholders.

Specific research and monitoring priorities related to MSP, mitigation, and best practice, and that build on some national and project-based initiatives, are as follows:

- Develop and make more widely available readily accessible information to inform co-design, including maps of fishing grounds and habitats, spawning and nursery areas, and commercial species' distributions (accounting for within-year and among-year variation);
- Develop operational methods of cumulative impact assessment that enable managers to understand and respond to the cumulative impacts of different sectors;
- Develop and conduct scenario analyses to predict the impacts of alternate reallocation options and their economic, social, and ecological impacts in order to address trade-offs more systematically and inform decision-making;
- Design and conduct trials and monitoring to establish an evidence base to better support the adaptation of fisheries, considering direct and indirect effects of wind farms, the performance of alternate approaches to co-use, and the performance of technical mitigation measures.

Background to the advice

Economic and social impacts (request items "a–c")

ICES assessed the data, information, and resources available, methods that may be applied, and further data and information required for the analysis of the economic and social impacts of OWFs and FLOWs on the fisheries sector. The assessment focused on regular data collection spanning large areas where data were collected by EU Member States for their own purposes and/or as a contribution to internationally coordinated and/or funded data collection programmes. The focus was thus on data for economic and social assessments that would apply to many OWF or FLOW installations; data requirements, however, will also depend on the precise questions asked, the spatial and temporal resolutions of interest, and the methods applied.

Relevant data for the analysis of economic and social impacts of OWFs and FLOWs on fisheries can be allocated to five classes (ICES, 2025):

I. Vessel positional data
II. Fisheries catch and effort data
III. Fisheries economic data
IV. Fisheries social data (including cultural elements)
V. OWF and FLOW data

Fisheries-dependent data collection is legally requested and coordinated by the European Data Collection Framework (DCF). The DCF provides legal data provision requirements and coordinates and standardizes the data required from the defined fleets. It covers vessel positional data, catch and effort, economic and more recently social data for EU fleets.

Vessel positional data

The primary sources of positional data are VMS data (provision currently mandatory for vessels >12 m) and automatic identification system (AIS) data. The frequency of AIS position records is much higher than for VMS, enabling higher-resolution analyses. Both data sources provide geographical coverage of the Baltic Sea, Celtic Seas, and Greater North Sea but have gaps in their coverage for some groups of vessels. Fishing vessels < 12 m are generally not monitored with VMS (although there are some national and project-related exceptions). Most smaller fishing vessels do not carry an AIS, and, on those vessels that do, the strength of the signal can be modulated leading to some data not being recorded. A further limitation of AIS data is that it is primarily transmitted for navigational and collision avoidance purposes and not for fisheries monitoring, control, and surveillance (MCS). Consequently, vessel positions are not routinely or straightforwardly linked to vessel logbook data.

National authorities have access to VMS data for individual vessels, but international VMS collations at ecoregion scales have required that data for individual vessels and small groups of vessels be anonymized. ICES collates VMS data from its

Member Countries annually, with a data call via DCF national correspondents and ICES Advisory Committee (ACOM) members. The data call requests VMS and coupled logbook data that are anonymized and aggregated by month in 0.05° latitude × 0.05° longitude c-squares. Processed VMS data are considered "sensitive" if activities of individual vessels can be inferred from the data. To preserve vessel anonymity in the aggregated VMS data, any data for 0.05° latitude × 0.05° longitude c-squares with records for two vessels or fewer is only presented in the form of ranges.

Vessel speeds are used to differentiate whether the vessel is fishing or not fishing. Because the data are currently collated to describe fishing activity, information on steaming positions is not included. These positions, however, may be very relevant to the assessment of the impacts of OWFs and FLOWs, as wind farms could be located on steaming routes to fishing grounds.

ICES adopts c-squares of 0.05° latitude × 0.05° longitude for VMS analyses because they represent a suitable scale at which to grid VMS position records, predominantly but not exclusively reported at two-hour intervals. C-squares nest directly within the larger ICES rectangles (0.5° latitude × 1° longitude) used for the reporting and collation of vessel, landings, and other fisheries data in the logbooks that are linked to the VMS records. Given the scale of OWF and FLOW developments, the relatively large area of c-squares (from approximately 17 km^2 in northern EU waters to 25 km^2 in the south) limits high-resolution analyses of the relationship between fishing activity or landings value and OWFs or FLOWs. This is being addressed in some national and international projects, with institutes and countries agreeing to exchanges of higher-resolution data. These exchanges, however, are not occurring on a routine or recurrent basis.

Fisheries catch and effort data

Catch and effort logbook data are collected nationally. They are held in national labs at the individual vessel, ICES statistical rectangle, trip and day level; in the DCF Fisheries Dependent Information (FDI) data at fleet, ICES statistical rectangle, métier and quarter level; and in ICES Regional DataBase and Estimation System (RDBES) data at fleet, ICES statistical rectangle, métier, and month level. Coverage spans the Baltic Sea, Celtic Seas and Greater North Sea.

The primary use of RDBES is to host the commercial fisheries landings and sample data to support the stock assessments that underpin fishing opportunities advice. ICES collates the data for RDBES via an annual data call to DCF national correspondents and ACOM members.

Landings weights are allocated to more precise (VMS-derived) fishing positions by ICES Member Countries responding to the data call. In the workflow for answering the call, countries distribute vessel landings weights among the VMS location records where fishing activity is assumed – for example, based on the time interval between location records or to split equally among location records and by day, ICES rectangle, or trip. The approaches used may vary among countries.

Fisheries economic data

Economic data are collected nationally for the DCF. These include fleet capacity (number and technical characteristics of vessels), costs (energy, labour, capital, repair and maintenance, and other operating costs), investment and capital value, earnings (from fishing and others), subsidies, employment, energy consumption, and transversal variables to assess the level of fishing (landings and effort). These data are collected at the DCF fleet segment–level, and the coverage and resolutions vary depending on the variables, fleets, and countries. The coverage ranges from all vessels to only a sample of the fleet and the resolution from trip to annual level. The data are then aggregated at DCF fleet–level and annual level for the Annual Economic Report (AER) of the EU Scientific, Technical and Economic Committee for Fisheries (STECF), which covers all EU fishing fleets. Landings values are also allocated to more precise positions by countries responding to ICES VMS data call. Landings values may be derived from sales notes from individual fishing trips or calculated at lower resolution from the product of prices and weight.

Landings values do not account for the costs of fishing, so attempts were made to link other indicators, such as gross value added (GVA), to positional data at the c-square scale (ICES, 2024a). However, work to date shows that disaggregated GVA at the c-square scale may be larger than the value of landings reported in VMS data. This inconsistency is explained by the disaggregation of the high-level GVA calculation to the finer-scale landings value from the VMS data call (ICES, 2024a).

Fisheries social data

The collection of standardized social data for the DCF began in 2017 and is required every three years. The data collected nationally (similarly to AER data) include employment by gender, nationality, age, education level, and employment status. The data are reported nationally for all EU Member States; additional aggregation levels are provided but inconsistent between Member States, as the data is not (yet) required at the DCF fleet level. At this stage, only employment data have been requested, but STECF (2024) identified a set of operational variables to serve as social indicators. In addition, the same group has advanced the definition of fishing communities and proposed a roadmap to extend the coverage of fishing community profiles. The definition was that "fishing communities pertain to settlements around fishing harbours where the fisheries generate social and economic benefits (e.g. employment), and which enables new generations of fishers, due to shared norms and inter-generational links. Such norms are reflected in, for instance, resource stewardship, notions of shared materialities, cultural heritage, and interests, ways of life, and a sense of belonging. Fisheries communities are place-based but can pertain to wider geographical areas which gravitate towards the harbours and are likely to include fisheries-based organizations and ancillary industries in aquatic food value chains."

No social data are collated internationally by ICES. The "landing harbour" variable that has been used to link fishing activity to landings harbours is already contained in RDBES; harbours may be treated as proxies for fishing communities. Links between fishing activity data in ICES statistical rectangles and harbours are presented in ICES ecosystem overviews.

Linking social data to vessel positional data cannot currently be done with international datasets because of differences in the aggregation level of the available variables.

OWF and FLOW data

In contrast to the fisheries data sources, the collection of OWF and FLOW data to be used in the assessment of economic and social impacts is not coordinated internationally by regulators. To assess the pressures resulting from wind farms, data requirements include turbine location, phase of development (pre-construction, construction, operation, or decommissioning; Annex 1), design, and operational characteristics, and also the locations and timing of restrictions on fishing activity (disaggregated by type of activity). While many of these data are understood to exist, and some have been collated within projects, they are largely inaccessible and are not systematically collated on scales appropriate for fishery- and ecoregion-scale assessments of impact. There are commercially available compilations of the locations of turbines (e.g. as compiled by 4C Offshore).

Data gaps

The assessment of the economic and social impacts of OWFs and FLOWs requires highly resolved positional data on both fishing and steaming activity that can be linked at the finest possible resolution to economic and social data. For large-scale analyses of impacts in EU waters, these data must be compiled internationally. Positional data need to be linked to information on weight and value of landings and ideally other economic data to estimate GVA. Positional, landings, and economic data need to be linked to information on use of harbours. And information on turbine locations, OWFs, and FLOWs needs to include the phase of development and the locations and timing of restrictions on fishing activity (disaggregated by type of activity).

At present, publicly available and internationally collated data is often aggregated to ensure the confidentiality of individual fishers and companies. National datasets of catch and effort and economic data often contain data at a more appropriate resolution for the analysis of the effects of OWFs and FLOWs; access, however, is usually restricted, preventing international assessments. In addition, reducing the scale of compiled positional information to units smaller than 0.05° latitude × 0.05° longitude c-squares may not be meaningful when VMS positions are predominantly transmitted at two-hour intervals. Higher-frequency position records would enable higher-resolution analyses and improved capacity to separate "fishing" and "not fishing" activity; studies have described the benefits of transmissions at time intervals as short as 30 seconds for monitoring vessel behavior and assessing fishing activity in small-scale fisheries (ICES, 2022a, 2023).

The coverage of smaller vessels and small-scale fisheries is often highly incomplete, even at national scales, and data may be reported on coarser scales than for larger vessels – for example, logbook records at trip or monthly level instead of days, and VMS has not been required for vessels < 12 m.

For social data, the availability of a means to link fisheries activities at sea to fishing communities remains a requirement for meaningful analyses of OWF and FLOW impacts. The RDBES database offers an opportunity to link fishing activities to any landing harbours reported and to fishing community profiles developed by STECF and in *ad hoc* projects. However, access to RDBES is restricted, and catch and effort data per landing harbour cannot readily be linked to spatial and economic data.

Access to sufficiently detailed information about OWF and FLOW developments is still lacking. For social and economic analysis, it is necessary to know the precise locations of wind farms, development phases and timings of these phases, and temporal and spatial restrictions on fisheries that apply at each of the development phases. Further, for analyses at fishery and ecoregion scales, it is necessary to compile these data internationally.

Methods for assessing economic and social impacts

Several methods are used to assess the impacts and potential impacts of OWFs and FLOWs on fisheries. Depending on the phase of wind farm development, *ex ante* or *ex post* analysis can be used (Table 1). These analyses are complementary.

Table 1 Types of analyses for assessing the social and economic impacts of offshore wind farms (OWFs) and floating offshore wind farms (FLOWs) on fisheries.

Types of analyses			Examples	Development phase (Annex 1)
Ex ante	Descriptive	Identification of dependency/importance of fisheries for given fishing grounds	Spatial fisheries data analysis; communities at sea analyses	Pre-construction
	Model-based	Estimation of social and economic impacts	Bioeconomic modelling	Pre-construction
Ex post	Descriptive	Identification of impacts of a given measure on the fisheries (and beyond)	Social impact assessment; economic impact assessment; cultural impact assessment; social well-being approach	Operation

Ex ante analyses evaluate potential impact before a change occurs (here development of OWFs or FLOWs). There are two main types of *ex ante* quantitative analysis: descriptive analyses, which typically assess the relative economic or social importance of an area for fisheries, and model-based analyses, which project the effects of wind farms on the components modelled (e.g. fleets). *Ex post* analyses evaluate impacts after the change occurs. These can be done quantitatively or qualitatively or both, and they can be interdisciplinary.

Descriptive *ex ante* analyses can be used for mapping landings weights and values for different vessels, métiers, or fleets, and assessing the economic dependency of these units on different areas. They can also be used for more advanced analyses that consider other attributes of fishing grounds such as historical and cultural use, their role as safe fishing grounds during inclement weather, fishing locations with customary rules, and links between the grounds and fishing communities and value chains. There are few examples of the more advanced analyses, in part owing to data limitations (ICES, 2025). One example is the communities at sea approach, which takes account of a wide range of community-level processes and practices in mapping the value of fishing grounds, including labour inputs, community dependence, and historical and cultural values. The approach brings these community-level processes and practices into the maps and metrics that inform science and policy (St. Martin *et al*. 2017). The *ex ante* model-based analyses use models for projection, such as participatory scenario building or spatially explicit bioeconomic models (Thébaud *et al*, 2023), to examine the impacts of alternate planning and design scenarios. These may include behavioural responses of the fishers and feedback loops between the ecological system and fishing operations.

Qualitative methods include SIA, CIA, the social well-being approach, and the CCF. These can be *ex ante* or *ex post* methods, or both. Each of them can make use of different (and often a combination of) methods to do the analysis, for example interviews, focus groups, participant observation, surveys, and literature reviews. SIA and CIA focus more on social aspects to understand impact, while the social well-being approach and CCF assess social and economic aspects.

SIA provides information to managers and communities about social and cultural factors to be considered in any decision. Factors include (i) demographic characteristics, (ii) cultural aspects (attitudes, beliefs, and values), (iii) effects of proposed actions on social support and services, and health and safety issues, (iv) impacts on non-consumptive and recreational uses of living marine resources and their habitats like recreational fishing and diving, and (v) historical reliance on fisheries and participation in the industry (Clay and Colburn, 2020).

CIA is used to evaluate the impact of interventions on the quality of life from a cultural perspective. A range of CIA methods exist (Partal and Dunphy 2016), based on consultation with potentially impacted communities, and may include assessments of traditional use, cultural values and well-being. CIA is especially relevant for assessing social impacts of OWF and FLOW developments when they may impact, for example, long-established coastal communities, sites of cultural or spiritual significance, and culturally valued seascapes.

The social well-being approach provides a framework for evaluating the social and economic benefits that communities receive from fishing. Voyer *et al*. (2017), for example, used the approach to identify contributions the fishing sector to coastal communities in relation to (i) economic resilience, (ii) community health and safety, (iii) education and knowledge generation, (iv) health of the environment, (v) integration, cultural diversity and vibrancy, (vi) cultural heritage and community identity, and (vii) leisure and recreation.

CCF is used to assess the social and economic impacts of interventions on community well-being, resilience and development (Flora *et al*., 2023). The framework addresses seven types of capital that contribute to community properties: (i) natural capital – environmental resources like land, water, air, and biodiversity, (ii) cultural capital – traditions, values, heritage, and shared identity, (iii) human capital – skills, education, health, and knowledge of individuals, (iv) social capital – relationships, networks, and trust within the community, (v) political capital – influence, power, and access to decision-making, (v) financial capital – monetary resources, investments, and wealth and (vi) built capital – infrastructure, buildings, roads, and technology. CCF was developed assessing the consequences of interventions for rural communities on land but could be readily modified to address effects on fishing communities.

Types of economic and social impact

The economic and social impacts of OWFs and FLOWs on fisheries are a consequence of the following direct and indirect effects of both types of wind farm on fishing vessels and target species:

I. Direct effects on areas where fishing operations occur, as determined, for example, by the spatial scale of OWFs and FLOWs, their phase of development, and the regulations that apply to fishing around the wind farms;
II. Indirect effects on the distribution, abundance, and types of fishable species, resulting from the direct and indirect effects of OWFs and FLOWs on species biology, distribution, and life histories;
III. Indirect effects on the distribution, abundance, and types of fishable species, resulting from changes in the ecosystem attributed to the effects of both types of wind farm;
IV. Indirect effects on the fishing communities and value chains, resulting from changes in fishing activities.

The current focus on social and economic consequences considers the direct effects of OWFs and FLOWs. The indirect effects are currently too complex and insufficiently understood in direction and magnitude to address at fishery scales (ICES, 2025).

Context determines the social and economic impacts of OWFs and FLOWs on fisheries, and impacts cannot be generalized without context. Context factors include the type of wind farm, the development phase of the wind farm, rules and regulations applying to fisheries inside and outside wind farms, and the types of fisheries and their adaptive capacities (Figure 1).

Examples of other context factors that determine economic and social impacts are:

I. Changes in access permissions to OWF and FLOW sites from pre-construction, through construction, operation, and decommissioning;
II. Differences in access and gear restrictions among EU Member States during any given phase of development, including rights to navigate in and around OWFs and FLOWs;
III. Differences in design choices for OWFs (e.g. pilings, distance between turbines, arrangements for cabling) and FLOWs (e.g. moorings, distance between turbines, inclusion of corridors, arrangements for cabling, and dynamic cabling);
IV. Fishers circumstances (licence conditions, generational renewal, succession plans, financial resources, type of vessel, vessel size, and knowledge) and influences linked to policies and markets (policy changes, market prices, other closures, management measures, and requirements for insurance affecting the fishery);
V. Extent of engagement of fisheries in spatial planning and OWF or FLOW design.
VI. Other constraints on the gear and location choices of fishers linked to other human activities and nature conservation.

The responses of fishers and fishing fleets to OWFs and FLOWs include continuing as before (coexistence/co-location), continuing fishing but being displaced (displacement with or without capacity to navigate through OWFs), continuing fishing but adapting gear (gear adaptation), and by stopping part or all their fishing activities.

The economic and social impacts of commercial fishing were summarized based on a systematic literature review (ICES, 2025). This identified 47 publications that focused on the interactions of OWFs and fisheries from an economic or social perspective. Of these, 27 publications addressed interactions in EU Member States. Around half the studies focused on the effects on shellfish fisheries. In relation to phases of OWF development, most studies addressed the pre-construction phase, and there were no papers with a direct focus on the effects of decommissioning.

Evidence from the systematic review showed that five broad types of direct impacts were described in the available studies. These are (i) changes in income from fishing activities, (ii) changes to fishing grounds, (iii) changes to catch opportunities, (iv) changes to fishing operating costs, and (v) changes in investment into technical or gear adaptation measures. ICES assessed whether impacts were reported by study authors as leading to improvements or deteriorations (or no net impacts and therefore neutral) from a fisheries perspective.

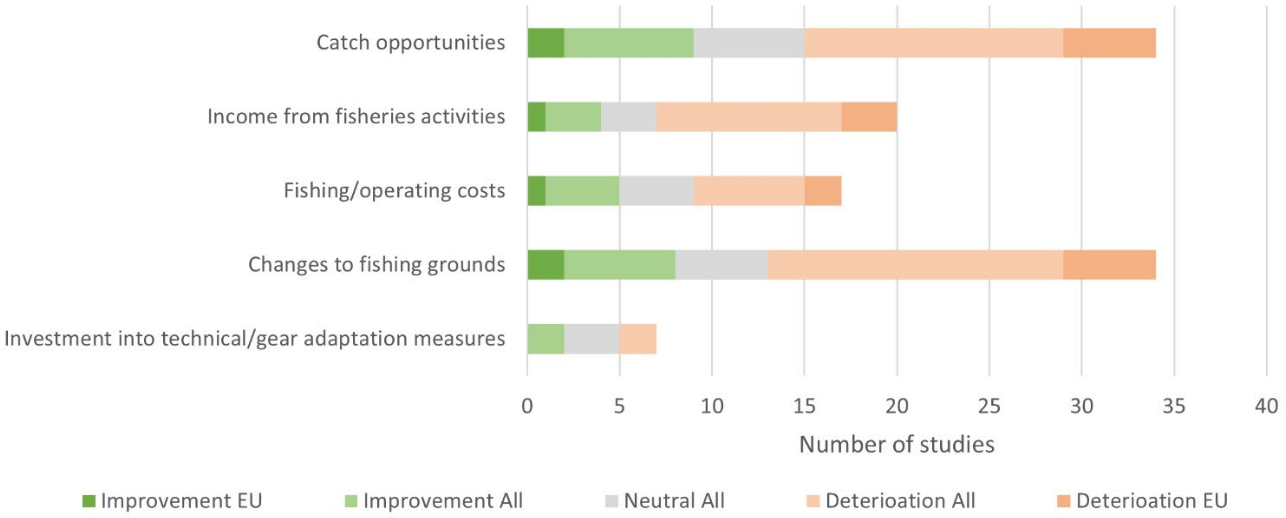

Figure 2 Studies of five types of direct impact of offshore wind farms (OWFs) and floating offshore wind farms (FLOWs) on fisheries. Bars indicate the number of studies interpreted to be showing improvements, no directional impact, or deteriorations from a fisheries perspective. Darker shades represent studies in EU Member States as a subset of studies in all countries. No studies in Member States showed no impact. Data from ICES (2025).

For studies in EU Member States and for impact types i–iv, the review identified more than twice as many studies reporting on deteriorations as improvements from a fisheries perspective. As emphasised in the elaboration of the advice, results are only indicative given the context specificity, the dominance of relatively short-term studies, and that the rationale for, and focus of, studies may be driven by expectations about positive or negative impacts. Social and economic impacts on fisheries will have related impacts on seafood processing and related value chains; these are not addressed.

ICES located almost no information on social (including cultural) impacts, including those on fishing communities associated with the affected fisheries. This is primarily a result of limited data. Potential indirect impacts include knock-on effects on coastal communities, affecting social cohesion, well-being and identity, with severity depending on the reliance of communities and wider industries on fisheries. ICES did not locate studies of trade-offs between the negative economic impacts on fisheries and the positive economic benefits from OWFs and FLOWs; ICES (2025) did, however, propose an approach to such an assessment.

Impacts on commercially fished species (request item “d”)

Current research on the effects of OWFs on fish focuses on local pressures, effects, and impacts of installations (Kulkarni and Edwards, 2022; Gill *et al*., 2024) rather than population-level effects. The current knowledge base is largely limited to adult fish life stages rather than pressures on egg, larval, and juvenile stages resulting from EMF, underwater noise, and chemical pollution (Öhman *et al*., 2007; Svendsen *et al*., 2022).

Current studies of OWF effects are summarized in ICES (2025) and Table 2. There are three main pathways causing direct and indirect effects on fish: i) changes to habitats and associated colonizing fauna through the OWF artificial hard substrate (Degraer *et al*., 2020; Glarou *et al*., 2020), ii) changes to local and regional hydrodynamic regimes, and iii) noise and EMF (van Berkel *et al*., 2020). Introduced hard substrates will also have direct and indirect impacts on fish abundance and diversity and may influence the exposure of fish to pressures associated with OWF installations (Gill *et al*., 2024).

Changes to local and regional hydrodynamics, including turbulence, mixing, and vertical stratification, may lead to temporary changes in fish behaviour and movement. The effects of noise and EMF on fish behaviour and physiology are complex and specific to species and their life stages.

In the absence of sufficient evidence to develop population-level assessments of impacts, ICES (2025) applied a trait-based framework to assess local vulnerabilities of different life stages of commercially fished species to pressures resulting from the operation phase of OWFs. The approach was applied to 34 commercially fished species (or higher taxa where species are not discriminated in landings value data) in the Baltic Sea, Celtic Seas, and Greater North Sea. Species were selected in each ecoregion from regional lists of commercially relevant taxa in ICES (2022b). Selection was made by identifying the shortest list of species that accounted for 90% of the total landings value in each ecoregion.

The trait-based assessment framework is based on a "lookup" table that describes the linkages between combinations of state change (Table A4.1), "population" characteristics (Table A4.2), and response traits (Table A4.3). For the purposes of this assessment, state change is defined as the change that occurs in response to a pressure exerted by the different activities and operations throughout the development phases of OWFs. Population characteristics are defined as ecological and behavioral properties or attributes of an adult, juvenile, or larval stage of a species that have the potential to be affected by state changes. Hence, these characteristics address all life stages of fish. Response traits are defined as traits that determine the response to environmental gradients, in this case the state changes. Each response trait is associated with a series of trait modes. The trait modes reflect the range of ecological and evolutionary characteristics associated with the response trait.

From the lookup table, any causal pathway resulting from the pressures associated with OWFs may be selected by choosing relevant state changes, population characteristics, and traits. The analysis of the vulnerability of the 34 species to OWFs focused on four response traits that reflect responses to state changes associated with the operational phase of OWFs, resulting in 17 causal pathways. To calculate local vulnerability of the taxa, a coding system was used to determine the relative impacts resulting from each of the causal pathways. Application of the trait-based assessment framework involves multiple steps where published evidence and expert judgement are combined and where confidence in the final assessment of local vulnerability results is moderate (ICES, 2025). Overall local vulnerabilities to OWF developments are summarized in figures 3, 4, and 5.

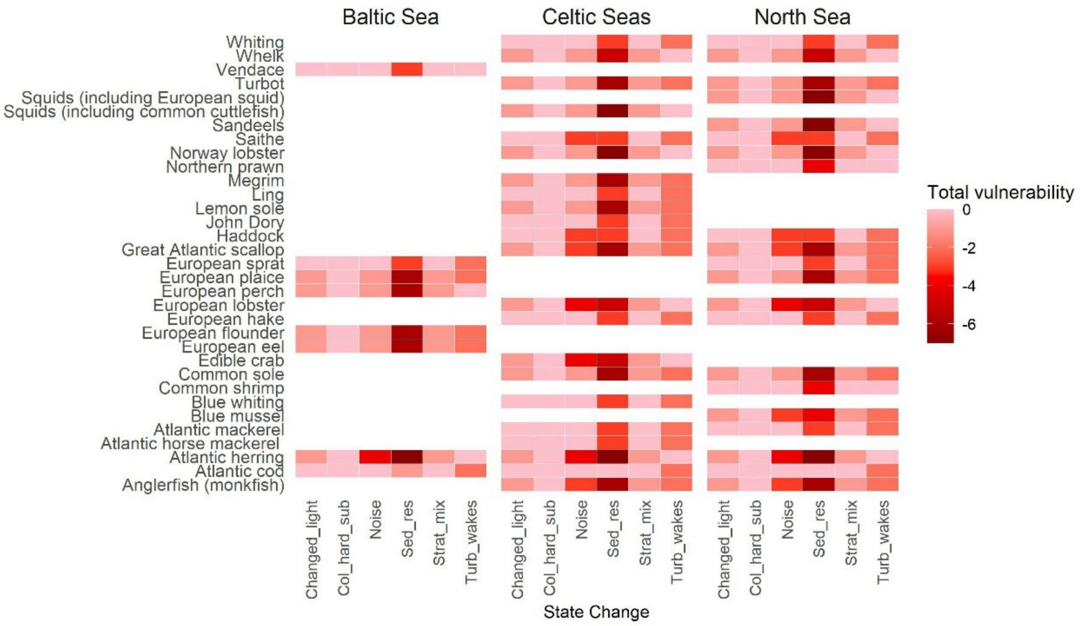

Figure 3 Heatmap depicting the overall vulnerability to state changes associated with the operation phase of an offshore wind farm (OWF) for each species and region. The values, ranging from 0 to −7, are derived by summing all impact scores, where more negative values (coloured in darker shades of red) indicate a higher vulnerability to the state change. White cells indicate species not assessed in the ecoregion. State change codes: changed_light = changed light cues, col_hard_sub = colonization of hard substrate, noise = changed energy emissions/environment noise, sed_res = sediment resuspension, strat_mix = changed seabed-water column, turb_wakes = turbulent wakes; for further details and taxonomic names see Tables A4.1 and A4.4.

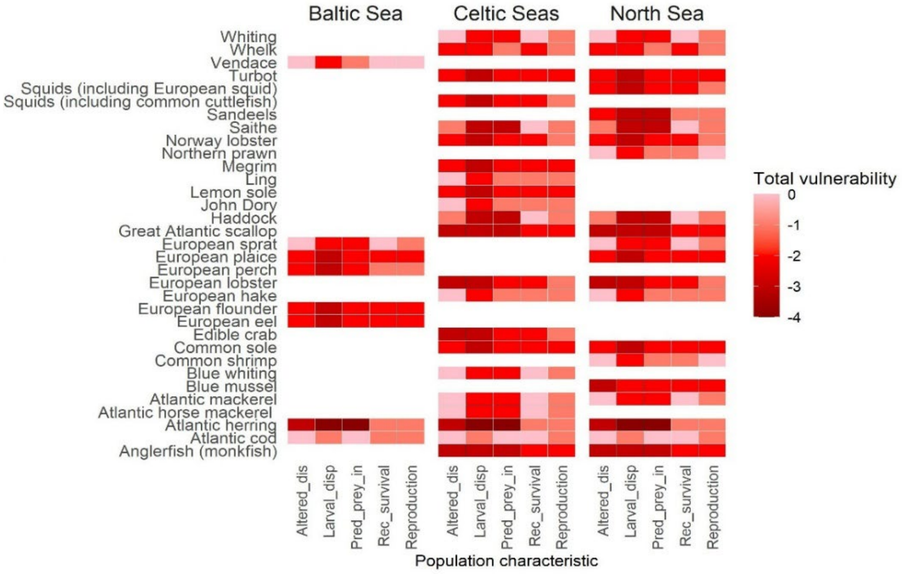

Figure 4 Heatmap depicting the overall vulnerability across selected population characteristics for each species and region. The values, ranging from 0 to −4, are derived by summing all impact scores, where more negative values indicate a higher vulnerability. White cells indicate species not assessed in the ecoregion. Population characteristic codes: altered_dis = altered distribution, larval_disp = larval dispersal – passive or active, pred_prey_in = predator–prey interactions, rec_survival = recruitment- survival of juveniles, reproduction = reproduction. For further details and taxonomic names see Tables A4.2 and A4.4.

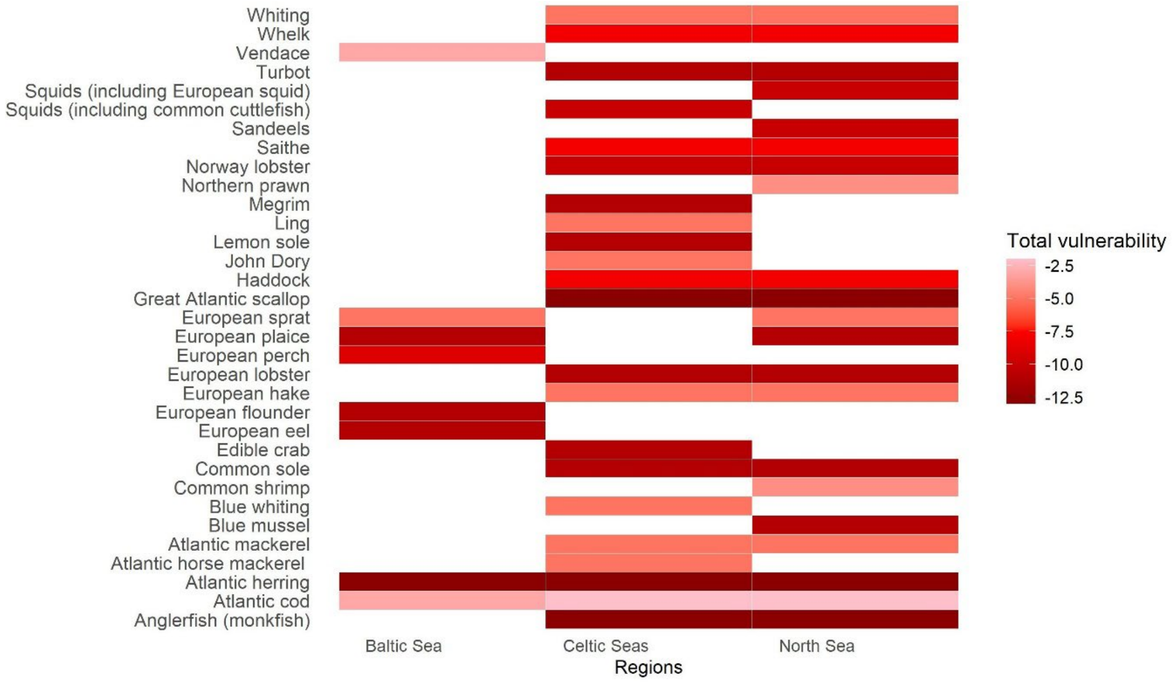

Figure 5 Heatmap depicting the overall vulnerability by species and region. The values range from −2 to −13, where more negative values indicate a higher vulnerability in relation to the here selected causal pathways and traits. White cells indicate species not assessed in the given ecoregions. For taxonomic names see Table A4.4.

Based on the selected traits, sediment resuspension had the potential to cause the most negative local responses. Across all regions approximately half the commercial species encountering sediment resuspension are predicted to be negatively affected by such encounters. This trait-based assessment focuses on local vulnerabilities of different life stages of commercially fished species to pressures resulting from the different phases of OWF development. High local vulnerability does not necessarily provide any insight into effects on a population. Such effects depend on the frequency and duration of encounters with OWFs throughout the population’s range, the proportion of the population encountering OWFs, and the abundance, productivity, and other biological characteristics of the population.

Risk assessment would provide a means of identifying populations for more detailed quantitative study. A risk assessment approach may combine estimates of the extent of spatial and temporal overlap of populations (or species when population information is not available) with OWF developments, and risk would be assessed from the extent of overlap and the effects of the various pressures.

ICES did not locate any population-level (stock-level) assessment of the impact of any phase of OWF development. Such an assessment would require incorporating the collective effects of OWF developments on the growth and survival of different life stages in the area used by the population into fish population dynamics models. Prerequisites for an assessment of this type are estimates of pressures from OWF developments on different life stages and their effects, information on the area used by the population at different life stages, the proportion of the numbers or each life stage encountering OWFs, the frequency and duration of encounters with pressures resulting from the phases of OWFs, and a population dynamics model that propagates these effects through the population.

Table 2 Examples of observed direct effects of offshore wind farms (OWFs) on adult, juvenile, and larval fish.

Life stage	Effect type	OWF development phase	Observed direct effects of OWFs	References
Adult	Habitat change	Operation	Delays in migration and reaching destinations can negatively affect spawning activities.	Westerberg and Lagenfelt, 2008; Hawkins, 2020
	Habitat change	Operation	Increased abundance and (temporary and seasonal) aggregation of soft-bottom and complex-bottom species near OWFs; such as Atlantic cod (*Gadus morhua*), European plaice (*Pleuronectes platessa*), dab (*Limanda limanda*), haddock (*Melanogrammus aeglefinus*), or pouting (*Trisopterus luscus*) increased species diversity and changes in community composition.	Bergström *et al*., 2013; Stenberg *et al*, 2015; Methratta and Dardick, 2019; Gimpel *et al*., 2023; Bicknell *et al*., 2025
			Several observational studies indicate that demersal species associated with complex seabed habitats are attracted by the turbines and scour protection of OWFs.	Andersson and Öhman, 2010; Krone *et al*., 2013; Reubens *et al*., ; Reubens *et al*., ; Stenberg *et al*., 2015; van Hal *et al*., 2017; Wilber *et al*., 2022
			The effects of OWFs on soft-bottom–associated taxa are inconsistent. Some studies show no effects from OWFs on soft-bottom species, while other studies indicate negative effects.	Lindeboom *et al*., 2011; van Deurs *et al*., 2012; Krone *et al*., 2013; Buyse *et a*l., 2022
	Habitat change	Operation	Changes in diet and feeding behaviour, such as increased consumption of mussels and associated epifauna colonizing the turbines. However, reports of substantial changes in overall dietary habits are not consistent.	Mavraki *et al*., 2021; Wilber *et al*., 2022; Buyse *et al*., 2023; Gimpel *et al*., 2023
			Some observational studies particularly indicate a strong aggregation of piscivorous fish around OWF structures.	Methratta and Dardick, 2019
	Noise	Operation and construction	Noise can adversely affect fish such as Atlantic cod that rely on sound for spawning behaviours.	van Hoeck *et al*., 2023; Gimpel *et al*., 2023
	Noise and electromagnetic field (EMF)	Operation and construction	Noise and electromagnetic fields can influence the behaviour, development, and physiology of fish, including taxa such as Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), Atlantic cod, haddock, crabs, and lobsters. Some studies suggest minor effects on fish orientation and movement, but evidence is limited and not conclusive. *In situ* data are available but too limited to make any clear predictions on how electromagnetic changes affect sensitive species such as those of rays and sharks.	Hutchison *et al*., 2018; Popper and Hawkins, 2019 ; Hawkins, 2020
			Fish rely on sound for communication, prey detection, predator avoidance, and orientation. Noise from OWFs, particularly during pile driving, can mask critical biological sounds, alter behavior, and potentially cause injury or death.	Simpson *et al*., 2016 ; Jong *et al*., 2020 ; Hermans *et al*., 2023
Juvenile	Noise	Construction	*In situ* pile driving experiments showed no immediate or delayed mortality of juvenile European sea bass (*Dicentrarchus labrax*) but led to stress responses such as reductions in oxygen consumption rate and low whole-body lactate concentrations.	Debusschere *et al*., 2014; Debusschere *et al*., 2016
	Noise	Operation	Juvenile black rockfish (*Sebastes schlegelii*) exposed to wind farm noise showed temporary hearing threshold shifts	Wang *et al*., 2023

Life stage	Effect type	OWF development phase	Observed direct effects of OWFs	References
	Noise	Operation	Juvenile black rockfish exposed to wind farm noise showed altered swimming and feeding behaviors, indicating potential fitness consequence.	Wang *et al*., 2023
	EMF	Operation	Swimming speed of juvenile Atlantic lumpfish (*Cyclopterus lumpus*) was reduced by 16% as a result of EMF exposure.	Durif *et al*., 2023
Eggs and larvae	Turbidity	Operation and construction	Turbulences and mixing can influence survival rates and availability of patches of larvae food.	Schilling, 2020
	Noise	Operation and construction	Noise can affect European sea bass larvae, which can influence their survival and development. Continuous noise can affect Atlantic cod larval development.	Debusschere *et al*., 2016
	Noise	Operation	Low-frequency noise affects swimming orientation of Atlantic cod larvae.	Cresci *et al*., 2023
	EMF	Operation	Larval swimming speed was reduced by 60% as a result of EMF exposure (lab experiments) haddock larvae.	Cresci *et al*., 2022
	EMF	Operation	Accelerated rate of embryogenesis of northern pike (*Esox lucius*) as a result of EMF.	Fey *et al*., 2019

Effects on western Baltic herring (request item "d")

ICES did not locate sufficient evidence to assess the effects of OWF or FLOW development phases (pre-construction, construction, operation, and decommissioning) on the western Baltic herring. The current ICES advice for this stock is for zero catch (ICES, 2024b). Management measures have reduced fishing mortality to very low levels. Spawning-stock biomass (SSB) is recovering slowly although it remains well below the limit reference point below at which reproduction is impaired (B_{lim}; ICES, 2024b). The slow recovery is partly attributed to recruitment remaining at or close to recorded lows. Recruitment success in western Baltic herring is known to be linked to temperature (Cardinale *et al*., 2009), and Polte *et al*. (2021) demonstrated that the later onset and shorter duration of cold periods (water temperatures below 4°C on spawning sites) because of climate changes resulted in reduced reproductive success. Eutrophication and other stressors have also led to reductions in the quality and extent of spawning habitat and survival of early life stages (Moyano *et al*., 2022; ICES, 2024c).

The western Baltic herring stock assessed by ICES includes several genetically distinct components predominantly spawning in spring but with some spawning in autumn and winter. The relative contribution of the different components to the stock is not known but likely variable in time and is considered to add resilience to the stock. Although understanding of the biology of spawning components is very limited, there are some differences in migrations and spawning locations, which imply components will be differentially affected by human and environmental pressures. There is also some evidence of interannual variability in patterns of migrations (ICES, 2024b).

The herring undertake migrations from the western Baltic Sea into the more saline waters of ICES Division 3.a and to the eastern parts of Division 4.a during summer. Overwintering of spring-spawning components is predominantly in the Öresund (Nielsen *et al*., 2001), but more recent acoustic surveys indicate changes in distribution. In late winter and early spring, herring schools aggregate in front of the inlets to inshore spawning grounds along the west and south coasts of the Baltic Sea prior to spawning. In spring, they enter the inshore estuaries, bays, and lagoons to spawn, especially around Rügen (Polte *et al*., 2021).

ICES is not aware of any evidence of the effects of existing OWF sites on western Baltic herring and their migration routes and spawning grounds. However, generic evidence for the pressures resulting from OWF developments indicate that impulsive noise from all development phases may affect migration and habitat connectivity (pathways from feeding or overwintering grounds to inshore spawning grounds). Alteration of spawning habitat by OWF developments is considered unlikely for the spring-spawning components of western Baltic herring (which are estuary or lagoon spawners) given the assumed low likelihood of OWF or FLOW siting in these areas. Offshore spawning grounds of the autumn-spawning component (shelf spawners) would be affected if OWFs or FLOWs were located on spawning grounds. There is a possibility that alteration of electromagnetic fields may affect larval herring orientation and migration, if larvae encounter these fields.

To better assess the future impacts of OWFs on western Baltic herring, more recent and complete descriptions of the migrations and spawning areas of the different stock components will be required so that these can be used to assess overlap with plans for OWF developments. This especially applies to the autumn-spawning components. Additional and stock-specific understanding of the effects of pressures associated with OWFs on the different life stages of western Baltic herring is also required (e.g. effects of noise and effects on feeding conditions). Given the current state of the stock, and the effects of existing pressures such as climate change and eutrophication, even low levels of negative impact may prevent stock recovery.

Impacts on Baltic Harbour porpoise (request item "d")

In the Baltic Sea, two harbour porpoise populations are found to the east of the Belt Sea: the Baltic Proper population and the Belt Sea population (Amundin *et al*., 2022; Celemín *et al*., 2023).

The Baltic Proper harbour porpoise population is categorized as "Critically Endangered" on the IUCN Red List, is estimated to comprise 71–1105 individuals (95% CI, point estimate 491; Amundin *et al*., 2022), and is declining (Carlström *et al*., 2023; Koschinski *et al*., 2024). Analysis by NAMMCO and IMR (2019) indicated that anthropogenic mortality should not exceed 0.7 individuals per year to enable population increase. HELCOM (2023) subsequently set an anthropogenic mortality limit of zero. The low population density of this porpoise poses significant challenges for monitoring the effects of anthropogenic pressures on the population.

The Belt Sea harbour porpoise population has a much higher abundance than the Baltic Proper population, estimated at over 14 000 individuals (Gilles et al., 2023). The two populations overlap in the western Baltic Sea primarily during the winter, but there is spatial separation between the populations in summer (Benke *et al*., 2014; Carlén *et al*., 2018; Celemín *et al*., 2023; Koschinski *et al*., 2024; Figure 6). This advice focuses on the Baltic Proper population rather than the much larger Belt Sea population.

The pressures attributed to OWF (Annex 3; ICES, 2025) and their potential effects on Baltic Proper harbour porpoise can be inferred from studies of other locations and populations (ICES, 2025). Many pressures affect harbour porpoise, but noise is the most significant (ICES, 2025). Impulsive underwater noise, especially during pre-construction and decommissioning phases, has the potential to displace individuals in a wide area and to cause hearing damage and missed foraging events (Southall *et al*., 2007, 2019; Tougaard *et al*., 2009). During the construction phase, noise from pile driving displaces porpoises by up to approximately 20 km (Tougaard *et al*., 2009; Brandt *et al*., 2011). Since construction of an OWF typically requires repeated pile driving events over a period of two to four months, this will result in temporary loss of porpoise habitat (Brandt *et al*., 2016; Rumes and Degraer, 2020). Single events with very high sound levels may lead to TTS in porpoise hearing (Lucke *et al*., 2009; Schaffeld *et al*., 2019) as may repeated sound events with lower sound levels (Kastelein *et al*., 2016, 2017).

Vessel noise during all phases of OWF development induces a range of behavioural responses in porpoises ranging from vigorous fluking, bottom diving and interrupted foraging to cessation of echolocation (Dyndo *et al*., 2015, Wisniewska *et al*., 2018). During the construction phase, Benhemma-Le Gall *et al*. (2021) demonstrated behavioural reactions and displacement that extended up to 4 km from construction vessels. And one study of ship-based preparatory work immediately before pile driving led to a decrease in acoustic detections of harbour porpoises of up to 33 % in the 48 hours prior to the pile driving (Benhemma-Le Gall *et al*. 2023). To better assess risks from underwater noise to Baltic Proper harbour porpoise, there is a need for underwater noise measurements in the central region of the Baltic Sea. Existing pile driving sound propagation models were not developed for this region, which is influenced by stratification and low salinity.

OWF and FLOW developments may also have indirect effects, such as changes to bycatch risk if fisheries are restricted around these developments but displaced to other locations. Any benefits of reduced bycatch risk in the vicinity of OWFs and FLOWs would need to be offset against the risk of harm through displacement and maybe hearing loss during the phases of wind farm development. Although evidence of OWF and FLOW effects on Baltic Proper harbour porpoises is very limited, the critically low population size of harbour porpoise and other pressures on the population, especially bycatch in fixed bottom set net fisheries, implies that even moderate impacts of OWFs and FLOWs in the core distribution area will pose a risk to the population.

ICES (2024d) conducted a bycatch risk assessment for Baltic Proper harbour porpoises based on overlaps between habitat suitability for harbour porpoise (Carlén *et al*., 2018) and the distribution of fishing activity. Currently, OWF and FLOW planning in the porpoise distribution area (ICES, 2024d) is at an early stage, but habitat suitability models would contribute to risk assessment at candidate OWF and FLOW sites. ICES (2024d) habitat suitability approach did not distinguish between suitability for the Baltic Proper and Belt Sea populations, and there is known to be spatial overlap in the Arkona and Bornholm basins. This would currently influence the outcome of risk assessment in those areas. Further priorities are to gather evidence and data to enable application of process-based models of the impacts of OWF and FLOW on harbour porpoise.

Mitigation measures to reduce impacts of OWF developments on harbour porpoises have been proposed, trialled and applied, with varying effects (ICES, 2025). To avoid injuring porpoises, pile driving activities are often preceded by the use of acoustic deterrent devices, which intentionally generate evasive responses. But the devices also exclude harbour porpoises from their habitat (Elmegaard *et al*., 2023, Voß *et al*., 2023). The deterrence distances achieved by acoustic deterrent devices are not sufficient to prevent TTS from multiple exposures (Schaffeld *et al*., 2020). Other construction activities such as foundation and turbine installation also change acoustic habitats through increased vessel activity and have been shown to result in porpoise displacement (Benhemma-Le Gall *et al*., 2021). Mitigation also includes noise abatement during unexploded ordnance (UXO) removal and of vessel noise (e.g. by reducing vessel speed, optimizing routes, and using vessels with a silent class notation).

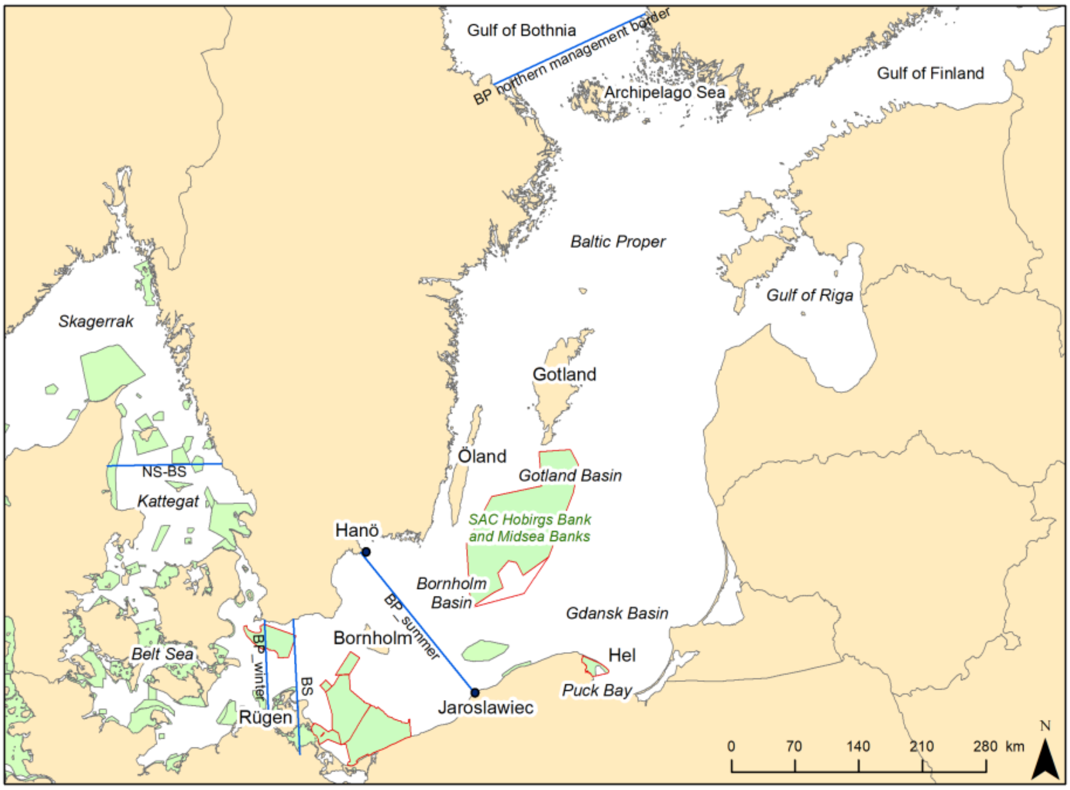

Figure 6 Map of distribution and management borders for the Belt Sea (BS) and the Baltic Proper (BP) harbour porpoise (*Phocoena phocoena*) populations. Natura 2000 sites where harbour porpoises are listed are shown in green. The extent of distribution of the North Sea population (NS) into the Baltic is also shown. Sites outlined in red are those to which seasonal or year-round closures for fisheries apply (Koschinski *et al*., 2024).

Cumulative impacts (request item "e")

To address this request, cumulative impacts are interpreted as the combined effects (additive, synergistic, or antagonistic) of wind farms in a defined sea area and on a specified aspect of commercial fisheries (e.g. social, economic, or ecological). And an "effect" is interpreted as the immediate consequence of a pressure, while "impact" is the endpoint of the effect (through direct or indirect pathways) for commercial fisheries. Combined effects are synergistic when the effect of multiple pressures is greater than the sum of the individual effects. Combined effects are antagonistic when the effect of multiple pressures is less than the sum of individual effects.

Given the request relates to adoption of mitigation measures, this advice focuses on methods with potential to support operational management advice on such measures. Methods should therefore have the potential to model pathways from pressures (resulting from OWF or FLOW installations) to effects and to impacts, such that the relationship between a mitigation measure (management action) that modifies a pressure and an impact can be determined.

Four potential pathways through which OWF and FLOW installations impact commercial fisheries are defined and listed below. All these effect pathways ultimately lead to social and economic impacts on the fishing industry.

I. Direct effects on areas where fishing operations occur, as determined, for example, by the spatial scale of OWFs and FLOWs, the phase of development of the wind farm, and the regulations that apply to fishing in and around the OWFs and FLOWs;
II. Indirect effects on the distribution, abundance, and types of fishable species, resulting from the direct and indirect effects of OWFs and FLOWs on species biology, distribution, and life histories;
III. Indirect effects on the distribution, abundance, and types of fishable species, resulting from changes in the ecosystem attributed to the effects of OWFs and FLOWs;
IV. Indirect effects on the fishing communities and value chains, resulting from changes in fishing activities.

Combined effects of OWFs and FLOWs are a consequence of (i) all pressures that result from the four phases of development (pre-construction, construction, operation, and decommissioning; Annex 1), (ii) all pressures that result from the number of wind farms and their combined spatial extent and phases of development in an ecoregion, and (iii) the pressures in (i) and (ii) in combination with all other pressures that are linked to other human activities. Cumulative impacts are a result of these combined effects. This advice addresses cases (i) and (ii).

To inform the process of identifying the next steps to define methods to model cumulative impacts, ICES (2025) evaluated a non-exhaustive set of existing methods and models. The methods and models selected for further consideration were those deemed capable, and with potential through further development, to quantify cumulative impacts and to test how impacts are modified because of mitigation measures. Evaluated models were considered based on the knowledge of participants in ICES Workshop to compile evidence on the impacts of offshore renewable energy on fisheries and marine ecosystems (WKCOMPORE; ICES, 2025) alongside web and literature searches and so may not represent a comprehensive set of those available. However, the set of models examined is considered sufficient to inform guidance on the next steps towards cumulative impact assessment.

Different models addressed social, economic, and ecological impacts. ICES did not identify any single model or assessment tool that had potential to provide a comprehensive assessment of social, economic, and ecological impacts of offshore wind installations on commercial fisheries, even if all the required data for parameterization and calibration, testing, validation, and application had been available.

Based on the review of a proportion of available models by ICES (2025), examples of suitable methods and models to address the direct impacts on the fishery by visualizing or predicting relocation and displacement include DISPLACE (Bastardie *et al*., 2014), VMStools (Hintzen *et al*., 2012) as already applied in EU waters, and FishSET (Haynie *et al*., 2024) in US waters. Examples of suitable models for addressing indirect effects on the fishery through changes in ecosystems include Ecopath with Ecosism (EwE; including Ecospace) (Christensen and Walters, 2024) and OSMOSE (OSMOSE, 2025).

The value of outputs from methods and models that visualize and predict fisheries relocation and displacement will depend on the spatial resolution of data and information on the economics of the fishery. In relation to the next steps, the strengths and limitations of existing data and the further data and information required to address the economic and social impacts of OWFs and FLOWs are described in the "Economic and social impacts" section of this advice. Provision of data to address the cumulative impacts at ecoregion scales requires additional integration of national datasets, especially in cases where national data are at higher resolution than the data currently collated internationally (e.g. VMS and landings data). For methods and models addressing the direct impacts on the fishery, valuable next steps would be to explore time-series fisheries and environmental data (> 10 years) to better describe and understand the spatial and temporal dynamics of core fishing areas and climate effects in response to OWFs and FLOWs. Options for increasing interoperability between economic, social, and ecological models also need to be identified and tested.

The effective development and application of process-based models is predicated on understanding of pressures and their effects on fisheries and on ecosystem components and attributes. For some models, considerable resources will be needed to further develop them to a level where they can be used to support operational management advice. Priorities for the next steps in development would depend, in part, on the economic, social or ecological issues of greatest concern to managers. These may be defined through policy or stakeholder processes and qualitative or semi-quantitative risk assessment based on existing information. ICES notes that data on social (including cultural) responses wind farms is often qualitative, and qualitative models and qualitative risk assessment will be important for guiding discussions on mitigation measures in these cases.

Impacts of changes in hydrodynamic conditions (request item “f”)

Physical effects of offshore wind installations

Understanding of the direct and indirect effects of OWFs or FLOWs on oceanographic processes underpins understanding of the potential effects on food availability to filter feeding organisms and on primary production. Direct effects occur because the underwater structures act as an obstacle, directly modifying the surrounding environment. Indirect effects occur because changes in atmospheric conditions caused by the turbines modify currents, the structure of the water column (stratification), turbulence, temperature, and salinity. Understanding of oceanographic effects is far more advanced than understanding of ecological consequences.

Direct effects

Direct effects of underwater structures result from friction and blocking (Sumer and Fredsoe, 2006; Lekkala *et al.*, 2022), as shown through observations and numerical models. The turbulent wakes behind the structures influence the mixing and the flow field (Lass *et al.*, 2008; Carpenter *et al.*, 2016). When water flows around a blunt object, a turbulent vortex street forms, with its extent determined by the object’s size, shape, flow speed, and water stratification and density (Lekkala *et al.*, 2022). This process increases turbulence and reduces flow velocity in the downstream area.

Research, especially on monopile structures commonly used in OWFs in the Baltic Sea and North Sea, shows that mixing resulting from increased turbulence is localized. Mixing increases by about 10% up to 400 m behind a structure (Lass *et al.*, 2008; Cazenave *et al.*, 2016; Schultze *et al.*, 2020), but strong tidal currents can extend the impact beyond 1 km (Cazenave *et al.*, 2016). Increased turbulence reduces water stratification, particularly thermal layering, in summer.

In coastal regions where constructive scour protection is not used around fixed installations, turbulent wakes are often characterized by an increased concentration of suspended particulate matter (SPM; Forster, 2018). This makes the wakes visually distinct from the surrounding water and easy to identify on satellite images (Vanhellemont and Ruddick, 2014). In a detailed study of wakes by Forster (2018), there was an increased concentration of re-suspended sediment in the surface water and a lower concentration of re-suspended sediment in the near-bottom water layer. The increased turbulence therefore leads to a vertical redistribution of SPM.

While the effect of direct mixing attributed to a single installation is rather localized, the effect is increased with many fixed structures over a relatively large area. Dorrell *et al*. (2022) hypothesized that effects of additional mixing around an OWF would be on the same scale as topographically induced mixing, e.g. in flows over sandbanks. This would result in a broader, more permeable thermocline with possible consequences for vertical transport, surface water heat storage capacity, and carbon dioxide exchange with the atmosphere. The hypothesis of Dorrell *et al*. (2022) is based on a review of the processes and a scale estimate, and the relevant spatial scale for mixing at a pile is in the order of hundreds to thousands of meters. Initial modelling studies (Cazenave *et al.*, 2016; Christiansen *et al.*, 2023) and observations in existing wind farms (Floeter *et al.*, 2017) indicate local effects that are largely limited to mixing within the wind farms. However, the mixed water masses are transported beyond the wind farms (Christiansen *et al.*, 2023). Carpenter *et al*. (2016) attempted to quantify the potential for structure-induced mixing using a theoretical modelling approach. Despite relatively large uncertainties in the estimates, they concluded that the additional mixing is not as relevant for smaller OWFs (length scales ≈8k m). For larger OWFs (≈100 km), the effect can be up to 10 times stronger.

Indirect effects

Indirect effects of atmospheric wake vortices on the ocean are mainly caused by energy extraction from the atmosphere. Compared to the direct effects, these indirect effects impact currents on larger scales, as the wake vortices in the lee of wind farms can extend up to 65 km and even further under stable atmospheric conditions. Within these wake vortices, the wind speed is reduced by up to 43 % (Platis *et al.*, 2020). These changes in the wind field reduce current velocity and mixing in the affected areas. This in turn increases the stratification of the water. While the direct effect of offshore structures increases mixing, the indirect effect of reduced wind speeds counteracts mixing. Both processes lead to a reduction in flow velocity.

The combination of individual wake vortices from all wind turbines within a wind farm leaves a large-scale wind deficit behind the OWF. Modeling studies show that this effect grows with increasing OWF size (Akhtar *et al.*, 2022). These local modifications in water transport result in convergences and divergences in the current field. When the wind farm size approaches the internal Rossby radius (the scale at which rotational effects of the earth are comparable to other forces driving movement of water masses – around 10 km in the North Sea), vertical upwelling and downwelling circulations form, creating a dipole structure (adjacent regions of opposing circulation). These circulations cause vertical velocities of several meters per day and affect mixing, stratification, temperature, and salinity (Broström, 2008; Ludewig, 2015) (Floeter *et al.*, 2022). Although some basic processes are understood from observations and idealized modelling approaches, the reality is complex and the response depends not only on the wind field and its variability but also on the regional hydrodynamic structure (van Berkel *et al.*, 2020) including depths, tides, residual currents, stratification, and fluxes.

Christiansen *et al*. (2022a) described interactions between the effects of atmospheric wake vortices and tidal currents. On average, tides had a mitigating effect on the atmospheric wind resulting from OWF. However, tides cause significant mixing in the North Sea, and there is no seasonal stratification in the shallower regions. While tidal currents determine the hydrodynamic response to reductions in wind speed, stratification conditions determine the effects of vertical transport and mixing. Periodic tidal currents mitigated the effects of wind speed reduction on current velocities, resulting in hydrodynamic changes that are half as strong as in a system without tides. Changes in stratification are only relevant in regions that already stratify, such as much of the Baltic Sea, rather than in regions where the water column is strongly mixed, such as the southern North Sea.

Models show that the high density of wind farms in the German Bight is already altering its hydrodynamic structure (Christiansen *et al.*, 2022b). Simulations focused on the summer months (June–August), when stable atmospheric conditions favor wake vortex formation, show that closely spaced wind farms create cumulative effects, including a large-scale dipole-shaped anomaly in surface deflection, changes in stratification thickness, and altered temperature and salinity distributions. Reduced mixing resulting from atmospheric wakes further increases stratification, particularly as summer stratification declines and maintains lower nutrient availability near the sea surface.

Simulations by Daewel *et al*. (2022), using a hypothetical 120 GW wind farm scenario, confirm that closely spaced wind farms amplify cumulative effects. These include regional reductions in current velocity, stratification depth and strength changes, and dipole structures in vertical circulation. Reduced current velocities also decrease bottom shear stress, particularly in less tidally influenced parts of the southern North Sea, potentially redistributing sedimented biogenic material.

While the direct and indirect effects are of about the same order of magnitude in relation to the change in mixing, they act on different spatial scales. Both the size of the turbines (Akhtar *et al.*, 2024) and the installation density of the turbines play a role. It is assumed that the effects on mixing in the near field of the wind farms are rather dominated by the direct effects, while in the far field the indirect effects play a greater role.

Ecosystem effects

While the main physical effects of OWF installations are understood and can be modelled, the study of their consequences for primary production and filter feeders is not well advanced and is challenging in a highly variable chemical and biological environment.

Primary production

Direct mixing weakens stratification and, in the case of an otherwise stratified water column, introduces additional nutrients into the mostly (during summer stratification) nutrient-limited intermediate and surface water. This leads to an increase in phytoplankton production because nutrients are usually limiting during summer stratification. Floeter *et al*., (2017) assessed the effects of non-operational OWFs on the pelagic ecosystem under stratified conditions based on observations at and around two OWFs in the German Bight and found increased mixing within the OWF. This was expected to affect nutrient availability in the euphotic zone, but the measurements did not show a clear response of nutrients and chlorophyll *a* (an indicator of primary production). This result neither verified or falsified the existence of the process described because (i) primary production quickly enters the foodweb (Slavik *et al*., 2019), (ii) local changes are readily obscured by strong tidal and residual currents in dynamic systems, and iii) variable hydrodynamic conditions make it difficult to distinguish natural and induced changes.

In contrast with the direct effects of mixing, reduced wind-driven mixing and increased stratification is expected to reduce annual primary production, as the summer surface layer is more strongly separated from the deeper water (Zhao *et al*. 2019).

Most of the southern North Sea does not stratify, and available model results do not show an overall increase or decrease in total primary production (Daewel *et al*., 2022), although there is some spatial restructuring of primary production. This is manifested as reduced production within the wind farm clusters and increased production in the shallow coastal regions and in the Oyster Ground area. OWFs in relatively shallow, well-mixed areas of the North Sea (Dogger Bank), led to changes in water mixing that increased resuspension of sediment material and affected the benthic ecosystem and the light climate in the water column (van der Molen *et al*., 2014). Increased sediment concentrations reduce light penetration and hence primary production when light is limiting.

In contrast to the North Sea, the Baltic Sea is characterized by a permanent halocline. This is caused by a strong inflow of fresh water from the continent and Scandinavia and the limited exchange of water with the North Sea. The expected reduction in wind-driven mixing associated with OWFs may influence the depth of the summer surface layer and possibly the depth of the halocline. Since much of the expansion of OWFs will take place along the Swedish coast, the reduction in the wind field may also reduce the upwelling of deep water along the Swedish coast, thereby reducing primary production. In the Baltic Sea, it is assumed that indirect effects from the wind vortices dominate the effects on primary production because there are no significant tides and mixing at the structure is lower than in most of the North Sea (Arneborg *et al*., 2024). The Celtic Seas are largely influenced by the oceanographic conditions of the North Atlantic (Simpson, 1981; Ruiz-Castillo *et al.*, 2019). Shallow and coastal regions, like the Irish Sea, are mixed throughout the year and are separated by fronts from deeper, seasonally stratified regions. At the shelf edge and slope, observations and models indicate strong internal mixing over the 200 m isobath caused by a breaking internal tide during the stratified season (New and Pingree, 1990; Kossack *et al.*, 2023). ICES is not aware of studies of OWFs on primary production in the Celtic Seas. Based on models and observations in the North Sea, the impacts would differ between areas that are mixed throughout the year and those that seasonally stratify, with mixing induced by the action of tidal currents mitigating some of the indirect impacts from the atmospheric wakes.

In all regions, and on larger spatial scales, indirect effects linked to the atmospheric wakes are expected to have the dominant influence on primary production, while close to OWFs the direct mixing effects will dominate.

Filter feeders

Installations are rapidly colonized by biofouling communities, which mainly consist of mussels, macroalgae, barnacles, suspension feeding arthropods, and anemones (Degraer *et al*., 2020). Studies conducted in Belgian OWFs show that benthic biomass around the foundation structures can be up to 4 000 times higher than before construction, with 89% of the biomass concentrated on the scour protection (structures of rocks, concrete, and other hard materials to prevent sediment erosion at the base of a wind turbine). At the scale of an entire OWF, biomass can increase up to 14-fold (Rumes *et al.*, 2013).

More than 95% of the biomass on artificial reefs typically consists of suspension feeding organisms that extract particles, including phytoplankton. Voet *et al.* (2022) estimated the amount of water cleared by suspension feeders on a single turbine is approximately 19 000 m^3 per day. This reduces particle density, decreases water turbidity, and likely leads to a reduction in the standing stock of primary producers. A modeling study suggests that large-scale expansion of OWFs could reduce local primary production at the scale of OWFs by up to 10%

Colonization of structures by indigenous and non-indigenous species (request item "g")

Biofouling describes the community of organisms, indigenous or non-indigenous, settling on the submerged parts of turbine foundations and surrounding scour protection rocks, including directly associated species living on and between the attached biofouling organisms. Indigenous species are species living within their natural range (past or present) including the area which they can reach and occupy using natural dispersal systems. Non-indigenous species are species introduced outside of their natural range (past or present) and their natural dispersal potential. The presence of non-indigenous species in a given region is due to intentional or unintentional introduction resulting from human activities.

Biofouling studies have mostly been performed on OWF turbine foundations. The construction of OWFs, including turbine foundations which are often surrounded by a rocky erosion (scour) protection layer, introduces artificial hard substrate in the marine environment. OWFs are often constructed on soft sediment using foundations that extend from the seabed to the water surface (Coolen *et al.*, 2020a), creating a habitat suitable for settlement of indigenous as well as non-indigenous species (De Mesel *et al.*, 2015; Coolen *et al.*, 2020b; Boutin *et al.*, 2023). Many of the biofouling species found on these installations are rare on soft sediments (Coolen *et al.*, 2020d), thus the introduction of hard substrate leads to a local increase in species diversity and abundance (Degraer *et al.*, 2020; Coolen *et al.*, 2022). However, biodiversity and functional diversity on artificial structures can be lower than on natural hard substrata (Brzana and Janas, 2024).

Ecological effects of biofouling communities (Raoux *et al.*, 2017; Pezy *et al.*, 2020) introduced in areas with soft sediment are linked to shifts from deposit-feeding to suspension-feeding taxa (Coolen *et al.*, 2020d). Suspension feeders colonizing the turbine foundations consume plankton from the water column (Mavraki *et al.*, 2022), increasing fluxes of nutrients (Coolen *et al.*, 2024) and increasing organic material deposition (particles and biofouling drop-off; Degraer *et al*., 2020). The colonizing species also release eggs and larvae providing a food source (Reubens *et al.*, 2011). Biofouling communities may compete for prey with pelagic consumers such as juvenile fish and copepods. Empirical data on resource overlap and potential interspecific competition is scarce and evidence is indirect (Nunn *et al.,* 2012; Bruschetti *et al.,* 2016; Mavraki *et al.,* 2022). Existing OWF-specific studies have primarily focused on filter feeding by dominant biofouling species (Mavraki *et al.,* 2022; Voet *et al.,* 2022), whereas the dynamics within mixed fouling communities, where intraspecific competition for food resources may also occur, have received less attention (Mavraki *et al*., 2020).

Understanding of the impact of OWFs on the spread of biofouling organisms and their impact on the environment is limited. Only a small number of studies have been conducted, either short term or restricted to single observations (Zupan *et al*., 2023; Dauvin, 2024). Further, since most OWFs are currently located in the North Sea, and most biofouling studies carried out provide data on the southern North Sea (Degraer *et al.*, 2020; Coolen *et al.*, 2022), our understanding of the effects on the spread of species outside this region is highly limited.

Multiple pressures (Annex 3) may influence the spread of colonizing biofouling species via OWF (Wilding *et al.*, 2017; Dannheim *et al.*, 2020):

a) The introduction of artificial hard substrates may increase habitat availability from the intertidal zone to the deep circalittoral zone. This facilitates colonization by indigenous and non-indigenous species. The establishment of the biofouling community may further be affected by

    I. The use of impressed ICCP on turbine foundations. This likely increases growth rates of calcifying organisms in the biofouling community.
    II. Chemicals leaking from GACP. These chemicals may influence the biofouling community in diverse ways.
    III. Increased temperatures on cables and cooling water outlets. These may change survival and growth rates of species in the biofouling community.

b) The transport of floating wind turbines between ports and wind farms may lead to exchange of non-indigenous biofouling species between regions.

c) Continuous underwater noise from turbines affects settlement rates and behaviour of biofouling species.

d) Prior introduction and distribution of biofouling species affects patterns of settlement (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection [GESAMP], 2024)

Vessel traffic during pre-construction surveys, construction, maintenance and repair during operational life, and decommissioning of OWFs will influence the introduction and distribution of biofouling species. Biofouling from vessel activity is not addressed in this advice, but effects and mitigation are considered in ICES (2019).

Effects of introducing hard substrates

The placement of artificial hard substrates such as steel, concrete, and other materials in the marine environment increases habitat availability for biofouling species (Dannheim *et al.*, 2020). Especially when introduced in soft-sediment environments, such substrates increase local habitat complexity and biodiversity (Coolen *et al.*, 2020d; Dannheim *et al.*, 2020; Degraer *et al.*, 2020, Boutin *et al.*, 2023). The presence of turbine foundations during construction and operation phases of an OWF increases the extent of hard substrates. The extent of decrease in hard substrate following the decommissioning phase will depend on the amount of hard substrate (foundations and erosion protection layer) removed (Knights *et al*., 2023; Spielmann *et al*., 2023) although no measurements have been made.

The availability of artificial hard substrates in OWFs should be considered in the context of other forms of "fixed-location" artificial hard substrates present in the marine environment. Examples of these are oil and gas platforms (Picken, 1985; Guerin, 2009), shipwrecks (Leewis and Waardenburg, 1991; Zintzen *et al.*, 2006; Hickman *et al.*, 2023), navigational buoys (Macleod *et al.*, 2016; Coolen *et al.*, 2020a), artificial reefs (Vivier *et al.*, 2021; Taormina *et al.*, 2022), and coastal artificial hard substrates including jetties, pontoons, dikes, bridges (Fletcher, 1981; Ashton *et al.*, 2006). All of these add to the total extent of artificial hard structures (GESAMP, 2024). Mobile artificial hard substrates also form a network of pathways through which biofouling species are introduced and facilitate colonization of the fixed-location hard substrates. Mobile artificial hard substrates include jack-up rigs (Reichart *et al.*, 2017), semi-submersible offshore installations (Wanless *et al.*, 2010), large and small ships, recreational vessels, and ocean-observing infrastructure such as buoys and gliders (ICES, 2019; GESAMP, 2024).

Colonization of hard substrates is influenced by the suitability of the surrounding environment for successful recruitment of biofouling organisms (Tempesti *et al.*, 2022). OWFs may act as stepping stones for colonization in areas that would be otherwise unsuitable for survival of biofouling organisms because of a lack of hard substrates (Adams *et al.*, 2014; Coolen *et al.*, 2020a). The stepping -stone effect is most likely to facilitate colonization by species with relatively long pelagic larval stages, as distances between OWFs in areas where there would otherwise be ecological barriers may still be large (Coolen *et al.*, 2020a). As increasing numbers of OWFs are installed, distances between them will fall, facilitating colonization by species with increasingly short pelagic larval stages. OWFs also modify the currents and turbulence around the foundations which can influence the settlement rates of biofouling species (Ajmi *et al.*, 2022). Natural vectors, such as floating wood and algae, may affect patterns of colonization (Thiel and Gutow, 2005; Want *et al.*, 2023), alongside mobile artificial substrates.

Since the biofouling community may include non-indigenous species, the OWFs also facilitate the colonization of non-indigenous species (De Mesel *et al.*, 2015; Coolen *et al.*, 2020b). In studies comparing natural and artificial substrates, most non-indigenous species were more abundant on artificial substrate, especially on the parts closer to the water surface (Brzana and Janas, 2024). Generally, there are few available data on the colonization of OWF structures (Dauvin, 2024). Reports on fixed OWF foundations in the North Sea mostly show low percentages of non-indigenous species among the biofouling communities, with no first observations of non-indigenous species in the OWFs reported to date. Dauvin (2024) concluded that less than 3% of the non-indigenous species reported in European waters have been observed in OWFs, and no non-indigenous species exclusive to OWFs in Europe are known. OWFs may also facilitate the spread of pelagic species with a sedentary life stage such as jellyfish species, which may include non-indigenous species.

Species considered to have conservation value, such as the European oyster (*Ostrea edulis*)*,* the Ross worm (*Sabellaria spinulosa*), and the white stony coral (*Desmophyllum pertusum*) may use OWF habitats to colonize new areas. To date, one single observation of *O. edulis* on OWF structures has been reported, although the identification of the species was subsequently challenged (Lengkeek *et al.*, 2013; Kerckhof *et al.*, 2018). There are also anecdotal observations from other artificial structures in offshore waters (Kerckhof *et al.*, 2018; Coolen *et al.*, 2020c), but evidence for any meaningful influence of OWF on the colonization of *O. edulis* is lacking. Several initiatives are working towards methods for large scale reintroduction of *O. edulis* in the southern North Sea (Kamermans *et al.*, 2018; ter Hofstede *et al.*, 2023, 2024), making use of unfished areas in OWFs to conduct introduction experiments. Unlike *O. edulis*, *S. spinulosa* has repeatedly been reported as present on the foundations or rocks in OWFs (Leonhard and Christensen, 2006; Coolen *et al.*, 2020b; Zupan *et al.*, 2023, Kingma *et al.,* 2024) and at offshore gas platforms and pipelines (Braithwaite *et al.*, 2006; Coolen *et al.*, 2020d, 2020b) as well as on the seabed within OWFs, a possible consequence of reduced fishing effort in the OWFs (Pearce *et al.*, 2014).

Effects on the distribution of *S. spinulosa* are not reported, but given overlaps between existing and future offshore wind areas and the species' distribution (Pearce *et al.*, 2014; Bos *et al.*, 2019), it is likely that colonization is facilitated by the presence of OWFs in the region. *D. pertusum* was reported in a single study on a deeper-water floating turbine foundation (Karlsson *et al.*, 2022). Given this species is commonly recorded on deep-water offshore platforms (Gass and Roberts, 2006), it is likely that it will colonize most deep-water wind structures within its distributional range.

Monitoring biofouling on OWFs

To date, biofouling monitoring programmes lack international standardization (ICES, 2021, Coolen *et al.,* 2022). Some countries (e.g. Belgium and Germany), have standard data formats on a national level (e.g. German Federal Maritime and Hydrographic Agency [BSH], 2013), while in other countries methods vary between OWFs. Understanding of biofouling and its role in colonization, as well as international data exchange (Murray *et al.,* 2018), would be enhanced by standard monitoring protocols.

No studies quantify and partition the effects of colonization of OWFs in relation to other mobile and fixed artificial hard substrates. However, available evidence is sufficient to conclude that the impact of the installation, operation, and decommissioning of OWFs has the greatest effect in the following areas:

(i) Those dominated by soft sediments because the addition of artificial hard substrates will greatly increase the habitat available to biofouling organisms;

(ii) Those far from natural hard substrates such as rocky coasts and rocky seabeds because these also host species that would colonize OWFs;

(iii) Those where other artificial hard substrates are scarce because these also host species that would colonize OWFs;

(iv) Those close to shipping lanes and other routes of vessels because colonizing species may be introduced via hull biofouling.

Regional differences in patterns of colonization are expected between the Baltic Sea, Celtic Seas, and Greater North Sea. Rates of introduction via natural pathways such as water currents are likely lower in the Baltic, especially in the eastern parts. Shipping, and the spread of non-indigenous species previously introduced to the North Sea, are important introduction pathways in the Baltic Sea. With low salinities in the Baltic and low temperatures in winter, specific communities not found in the other seas will also colonize OWFs.

Effects of impressed current cathodic protection

Impressed current cathodic protection (ICCP) is a technique to prevent corrosion of exposed parts of steel turbine foundations by applying an impressed current, inducing a negative polarization and making the steel immune to corrosion (Christodoulou *et al.*, 2010). Although this technique is not regularly applied on offshore wind turbine foundations (Price and Figueira, 2017), it is used in some OWFs in the North Sea (personal observations, Joop Coolen, Wageningen University and Research, The Netherlands). One of the known effects of electrification of steel structures is mineral accretion, as the flow of electrons from the impressed current facilitates calcium carbonate and magnesium hydroxide adherence to the steel (Hilbertz, 1979). The principle of electrification is also applied in coral restoration in tropical waters, where it has been suggested to increase growth of corals attached to steel surfaces (Zamani *et al.*, 2010); it has also, however, been reported to have negative impacts on coral survival (Knoester *et al.*, 2024). The effects of ICCP have been tested on oysters in temperate waters, where increased growth rates were observed (Shorr *et al.*, 2013). Currently, no literature on the impact of ICCP on biofouling organisms on OWF foundations is available. If there are any impacts associated with ICCP, it is likely that the calcifying organisms among the biofouling communities will be predominantly affected. However, since the voltage and amperage both influence the mineral accretion effect and growth of the organisms (Goreau, 2014), it is unclear whether an increased growth effect can be expected on OWF foundations with active ICCP systems.

Conductivity increases with salinity, so changes in salinity would likely influence the mineral accretion process linked to ICCP and therefore biofouling. Thus, the effect of ICCP on biofouling growth rates is likely to be smaller in the less saline Baltic waters than in the Celtic Seas and North Sea. Water temperatures influence the accretion process (Margheritini *et al.*, 2020) so regional differences in accretion may also result from differences in water temperature.

Effects of galvanic anode cathodic protection

Galvanic anode cathodic protection (GACP) makes use of a sacrificial anode that is more electrochemically reactive than the material to be protected (here: the turbine foundation) and is commonly used to protect steel structures from corrosion in OWFs (Watson *et al*., 2024). Aluminium-based and to a lesser extent zinc-based galvanic anodes are routinely used, resulting in substantial amounts of material dissolving over the typical 25-year life of a structure (Kirchgeorg *et al*., 2018; Watson *et al*., 2024). These metals (and others such as indium, but in much lower quantities) are known to be toxic to marine life, but the evidence for direct effects is limited to specific species e.g. Pacific oysters (*Magallana giga*s; Levallois *et al*., 2022, Ebeling *et al*., 2023) and species that are not likely to be part of the biofouling community (Levallois *et al*., 2023). Salinity and temperature are likely to affect the dissolution rate and bioavailability of the metals, which would Influence effects on the biofouling community. However, no studies describing these interactions have been found. Currently, no literature on the impact of GACP on biofouling on OWFs is available, so effects on the whole biofouling community are not known.

Effects of cooling water and increased surface temperature of power cables

The disposal of cooling water and increased surface temperature of power cables in OWFs likely increases temperatures of the habitat available to biofouling communities or to small infauna living near the cables. This may influence growth, survival, and colonization rates.

Power generated in OFWs is converted to high-voltage direct current (HVDC) before transport to shore. This takes place in HVDC converter stations and generates heat which may be removed by cooling water, which is pumped from, and released into, the surrounding sea (Middleton and Barnhart, 2022). The use of cooling water increases local water temperatures and growth of fouling organisms (Jenner *et al.*, 1998). If cooling water is discharged via submerged pipelines, this may influence survival of organisms during low winter temperatures or high summer temperatures. Limited information on the use of cooling water in converter stations in existing wind farms is available. Many converter stations are also air-cooled (personal communication Annemiek Hermans, TenneT), and no direct evidence for the effect in OWFs is available.

Dynamic power cables in FLOWs are exposed to the surrounding water. During the transport of electric energy through the cables, some of the energy is lost as heat which increases their external surface temperature (OSPAR, 2012). This heat is conducted to the outer surface of the cable where it will dissipate into the surrounding water. Biofouling communities on the cable are exposed to these increased temperatures, of up to 10°C greater than surrounding water temperatures (Maksassi *et al.*, 2022). This increase in temperature may change biofouling colonization success by favouring species with a tolerance to higher water temperatures (Taormina *et al.*, 2018). In California, no difference was found in the biofouling communities between exposed power cables on the seabed and nearby pipelines, but differences in surface temperatures of the cable and pipeline were not measured (Love *et al.*, 2019). The *in situ* data acquired at the Jersey–Cotentin electric connection (30 MW), at the Ushant (Brittany; 500 KW) test site, and at the SEM–REV (Northeast Atlantic; 8 MW) test site showed (all cables on the seabed) no significant heating of the surface of the cables and therefore of their immediate environment (Taormina *et al.*, 2020). Considering that the temperature deviations measured on these three cables were always lower than the probes' sensitivity (0.06°C), it is likely that the ecological impact related to the temperature of cables laid on the seabed and in the water column during operation is negligible, but this hypothesis has not been tested. Moreover, the electrical power of the cables used in these studies was low compared with those of industrial-scale OWF export cables. A study around an exposed cable in Australia, which was encased in an iron shell, showed no differences in colonization with the surrounding reef, but surface temperature was not measured (Sherwood *et al.*, 2016). Anecdotally, in the Hollandse Kust Zuid offshore wind farm, during ROV inspections on the scour protection and power cables leading into the turbine foundations, high densities of the non-indigenous slipper limpet (*Crepidula fornicata*) were observed on the cables but not on the scour protection (personal observations Oscar Bos, Wageningen University and Research, The Netherlands). This indicates the biofouling community on the cables may differ from the other hard substrates although no observations were made that explained the differences.

Floating wind turbines

Currently, three FLOWs, which have a reduced scale compared to OWFs, are operational in the North Sea. In each case, the operational wind turbines were assembled at coastal locations and towed to the offshore locations (principlepower.com, 2022; Equinor, 2025a, 2025b), often over large distances such as from the southeastern to the northwestern North Sea (principlepower.com, 2022). During their operational life, FLOW turbines may be transported to coastal locations for maintenance and repairs and then redeployed (Equinor, 2025b) or relocated to a new site. No direct evidence from FLOWs exists, but the transport of other types of large floating structures, such as drilling platforms, between locations is a well-described vector for the dispersal and introduction of non-indigenous species (Foster and Willan, 1979; Mienis, 2004; Ferreira *et al.*, 2006; Gard AS, 2008; Wanless *et al.*, 2010; Yeo *et al.*, 2010). When transported across barriers to natural migration such as currents, different temperature and salinity regimes, and unsuitable habitats, this creates a significant risk for non-indigenous species introduction (Lewis *et al.*, 2005; GESAMP, 2024). In addition, traffic from supply and surveillance vessels and secondary transport within regions may promote the colonization of non-indigenous species. This has been shown for the transport of non-indigenous species between marinas, where small vessels travel relatively short distances but still provide pathways for further spread of non-indigenous species after initial introduction (Ashton *et al.*, 2006; Marchini *et al.*, 2015; Foster *et al.*, 2016).

No non-indigenous species were observed at the Hywind FLOW farm (east coast of Scotland) although the authors noted the ROV video survey method had limited ability to detect small species (Karlsson *et al.*, 2022). Studies of ROV footage obtained around oil and gas platforms also suggested low detectability of small species or species covered by others (van der Stap *et al.*, 2016; Schutter *et al.*, 2019; ter Hofstede *et al.*, 2022). Therefore, a lack of observations of non-indigenous species cannot be interpreted as proof that non-indigenous species are absent on FLOW foundations and cables, especially when non-indigenous species are present at several bottom-fixed OWFs (De Mesel *et al.*, 2015; Coolen *et al.*, 2020b; Dauvin, 2024), as well as on many other types of floating structures (Thiel and Gutow, 2005; Macleod, 2013; Ros *et al.*, 2013; references in GESAMP, 2024). Additionally, outside the sea areas addressed in this request, the non-indigenous species *Schizoporella errata* (Bryozoa) was found in the WindFloat 1 location in Portugal, the first evidence of this species in Portuguese mainland waters (unpublished data WavEC). No information was located on non-indigenous species on floating turbines before and after transport or on the success of non-indigenous species colonization at their destination.

The risk of colonization by non-indigenous species is likely to be higher when floating turbines are transported between similar environments but across species natural distribution barriers; for example, from a future wind farm in the Celtic Sea to a maintenance port in the North Sea, or vice versa. Transport within an ecoregion could facilitate the further distribution of the non-indigenous species inside the ecoregion. Following recommendations from the GESAMP expert group on non-indigenous species in biofouling (GESAMP, 2024), when transporting floating turbines between ecoregions, biofouling should be removed and disposed of in a safe manner before entering destination ports. Transport within ecoregions should be minimized to reduce further spread of non-indigenous species after introduction.

Effects of operational turbine noise on settlement of invertebrates

The continuous movement of turbine components causes sound to be transferred via the turbine foundation to the water column (Pangerc *et al.*, 2016). Noise influences settlement of many species of invertebrate larvae (Anderson *et al.*, 2021; Schmidlin *et al.*, 2024). Further, noise may influence behaviour of adult invertebrate species (Wang *et al.*, 2022; Ledoux *et al.*, 2023) although the size of the effect varies considerably among species (Solan *et al.*, 2016). Indifference to anthropogenic low-frequency noise and substrate-borne vibration has been suggested to facilitate the success of dominant fouling species on OWF turbine foundations (Burgess *et al.*, 2023; Wang *et al.*, 2024), giving them a competitive advantage over other potential colonizers. Understanding of the impact of anthropogenic noise on invertebrates is limited (Solé *et al.*, 2023) and specific studies of the effects of noise from OWF turbines on colonization were not found

Responses of pelagic species to dynamic cables (request item "h")

Dynamic power cables are used to transmit the power generated by FLOW installations from the sea surface, through the water column, between the array of turbines, and on to either offshore substations or fixed export cables under or on the seabed. For FLOW installations, cables are categorized as turbine array cables and export cables. There are very few commercial-scale FLOW installations worldwide, and no studies of effects of dynamic power cables are known to ICES. Potential environmental effects of cables in general were described by Farr *et al* (2021) and the International Renewable Energy Agency (IRENA, 2024) and a subset of these are relevant to dynamic cables (3). Therefore, this review draws on evidence from studies of (fixed) OWF and subsea power cables to infer the effects of dynamic power cables on pelagic species. Pelagic species[14] and species with pelagic life stages may encounter dynamic cables.

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[14] ICES classifies commercially exploited pelagic species based on the adult stage. ICES Stock Information Database. 2025. ICES, Copenhagen, Denmark. https://sid.ices.dk

If buried cables from OWFs or mooring systems for other marine structures are treated as proxies for dynamic power cables their comparability should be assessed both from a physical perspective, (such as cable size and extent within the habitat), and in terms of the different energy emissions (such as electromagnetic fields, noise and vibration, and temperature) that will lead to interactions with different species and life history stages (Table 3). The placement and motion of dynamic cables in the water column is expected to lead to some effects unique to this technology, but these have not been assessed directly.

Table 3 Summary of key attributes of dynamic cables and their potential direct and indirect interactions with pelagic species. “P” indicates shared attributes; “O” indicates no shared attributes with seabed or buried cables.

Cable interactions	Key attributes	Dynamic cables – floating technologies	Seabed/buried cables – fixed technologies	Interconnectors
Direct				
Electromagnetic fields	Electric and magnetic fields are emitted by power transmission	P	P	P
Sound	Cables can electrically resonate and create sound (e.g. hum) during operation	P	P	P
Vibration	Cables can mechanically resonate (i.e. vibrate)	P	O	O
Temperature	Power transmission creates heat within the cable and at the cable surface	P	P	P
Physical				
Collision	Species may physically collide with the cable structure in the water column	P	O	O
Entanglement	Following collision, some species may become entangled in the cable(s)	P	O	O
Habitat association	Commercial species (one or more life stages) associate with the cable (e.g. refuge for early life stages)	P	P	P
Indirect				
Colonization by prey species	Species that colonize/associate with the cable physical structure attract predators that are commercial species	P	P	P
Hydrodynamic effects	Water movement affects thermal, saline or physical properties (e.g. turbidity) that influence species within the water column	P	O	O
Seabed sweep	Potential for physical abrasion of seabed introducing sediment into water column	P	O (buried) P (laid on seabed)	O (buried) P (laid on seabed)

FLOW installations have individual mooring systems and dynamic power cables. The cables usually hang freely in the water column between devices within an array and will therefore move. Cables can be rigged in various ways depending on the depth of water and the design of FLOW installations and moorings. For example, the mooring system can be tensioned or non-tensioned (catenary). Catenary moorings can also be adjusted in terms of their movement

Transmission of power to shore will be routed through one or more export cables, in some cases via an offshore substation. Each export cable will have a dynamic section and a fixed section (if the cable is on the seabed or buried). Several components reduce the physical movement of the export cable relative to the free-hanging inter-array cables[15] (Figure 7). Cables from individual turbines are smaller and transmit less power than export cables.

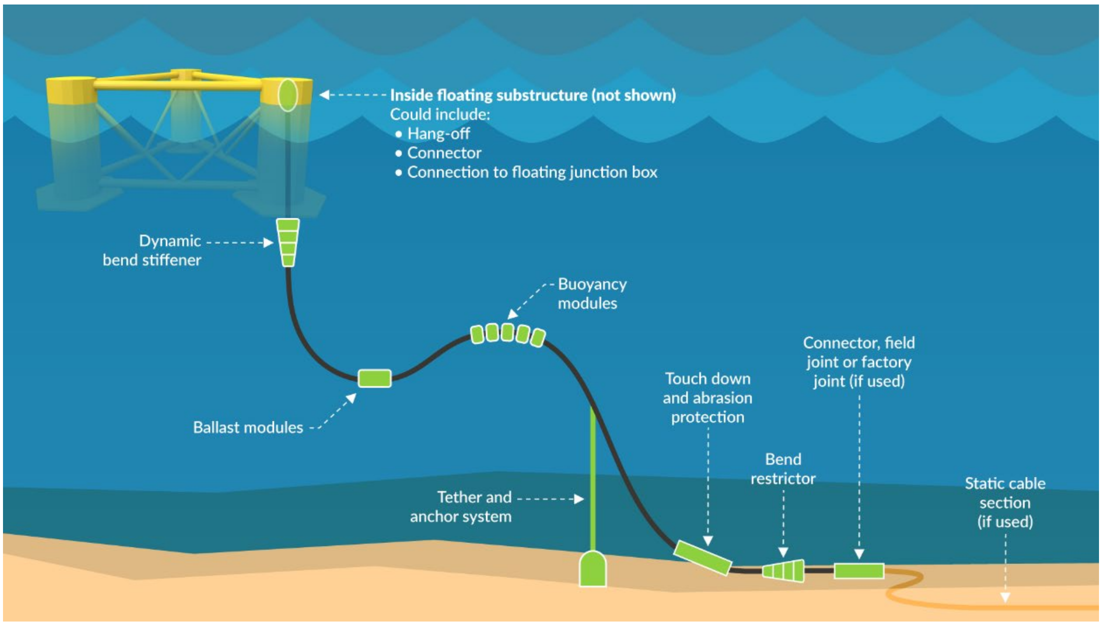

Figure 7 Typical dynamic cable system components for floating offshore wind (FLOW) turbines. An actual system may not include all these components. Image courtesy of BVG Associates. All rights reserved.

Inter-array and export cable(s) share other properties less dependent on their location and movement. These relate to energy emissions, in the form of EMF, sound and vibrations, and temperature (Table 4). The intensity and frequency of sound and vibration from cables will likely change with the level of tension and to some degree physical movement. External temperature changes are expected to be restricted to the surface of the cable and dissipated quickly by the surrounding water, based on knowledge from seabed associated cables (Taormina *et al.*, 2018). The magnetic component of the EMFs is not expected to be affected by physical movement but induced electric fields resulting from movement are possible. The magnetic field will propagate regardless of whether the cable is in the water column, running on the surface of the seabed, or buried although different groups of organisms will encounter the magnetic field in the different locations and at different intensities (Figure 8; Hutchison *et al.*, 2020). Induced electric fields from dynamic cables propagate further in the open water than those associated with buried cables, where the seabed properties reduce the propagation distance.

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[15] "Inter-array" is the industry term for free-hanging cables situated within an array.

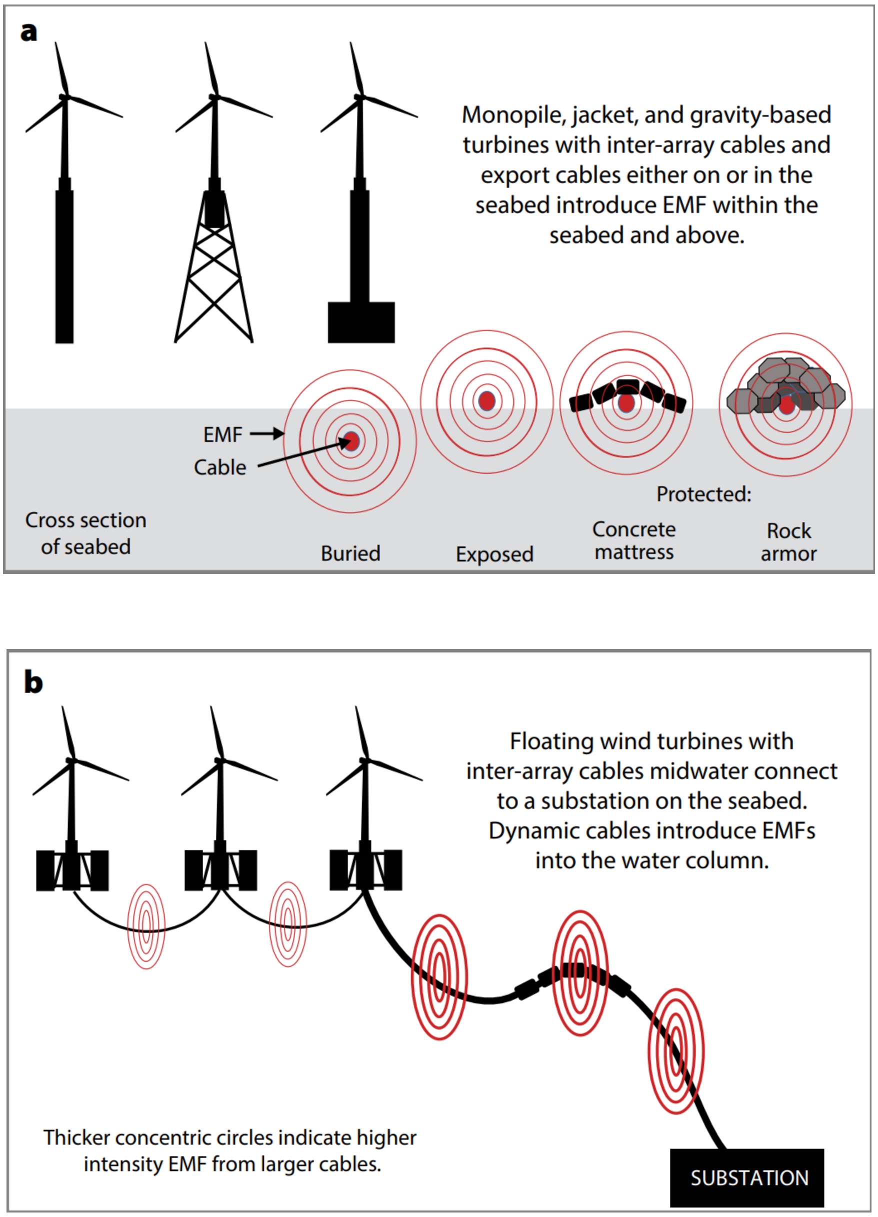

Figure 8 Introduction of electromagnetic fields (EMFs) into the marine environment by (a) fixed and (b) dynamic cables. Hutchison *et al*. (2020). Licensed under a Creative Commons Attribution 4.0 International License.

Dynamic power cables will be either high-voltage alternating current (HVAC) or direct current (HVDC). Alternating current (AC) reverses direction periodically while direct current (DC) flows in only one direction. Engineering and economic consideration determine the type of cable used. Current expectations are that HVAC is used for turbine inter-array cables and when cable to substation distances are relatively short. If the FLOW installation is located at some distance from shore, HVDC export cables are more likely to be used given better power transmission efficiencies and lower relative costs (van Eeckhout *et al*., 2010). The properties and materials of the cable and the transmission type (HVAC or HVDC) will determine the intensity, frequency, and duration of the EMFs emitted (Taormina *et al*., 2018). EMFs will be present along the length of the cable and propagate into the surrounding water column with an expected propagation distance of metres to tens of metres, which will be determined by the EMFs intensity and frequency (Taormina *et al*., 2018). HVDC cables directly emit magnetic fields but contain direct electric fields, whereas HVAC cables directly emit magnetic fields and induced electric fields (Gill and Desender, 2020). Thus, while there are some similar effects between the two types of cables, there are also defined differences, which may result in different effects on pelagic species that encounter them.

Reactions of commercial pelagic fisheries species to dynamic cables

There is an extremely limited evidence base on reactions to dynamic cables (Gill *et al*., 2020; Hutchison *et al*., 2020; Farr *et al*., 2021). Consequently, this review draws substantially on expert judgement, based on knowledge of the effects of other types of cables (Table 4, Figure 9).

Table 4 Summary of potential reactions of commercial fisheries species to subsea cables associated with floating renewable energy devices. Supporting evidence is provided by published studies or reviews of subsea power cables of fixed renewable energy devices and interconnectors, so reactions to dynamic cables are inferred unless otherwise stated.

Cable interactions	Potential reactions to dynamic cables	Reference
Direct		
Energy emissions		
Electromagnetic fields (EMFs)	Species may react to either electric or magnetic fields or both. The reactions, which can occur at one or more life stages, are behavioural, developmental or biochemical.	Gill and Desender 2020
Sound	Cables can electrically resonate and create sound (e.g. hum) during operation, which could be heard by some species.	Taormina *et al*., 2018
Vibration	Cables can mechanically resonate (i.e. vibrate), which can be detected by the mechanosensory apparatus of some species.	Taormina *et al*., 2018
Temperature	Power transmission creates heat within cables and at the cable surface, leading to raised temperature encounter of different life stages.	Taormina *et al*., 2018
Physical		
Collision	Species may physically collide with cables in the water column.	Copping *et al*., 2021
Entanglement	Following collision, some species may become entangled in the cable(s).	Copping *et al*., 2021
Habitat association	Commercial species (one or more life stages) associate with cables (e.g. refuge for early life stages).	Copping *et al*., 2021
Indirect		
Colonization by prey species	Species that colonize or associate with cable physical structures may attract predators that are commercial species.	Farr *et al*., 2021
Hydrodynamic effects	Water movements affecting thermal, saline, or physical properties (e.g. turbidity and wake changes) affect species occurrence and/or abundance.	Farr *et al*., 2021
Seabed abrasion	Physical abrasion of seabed may introduce sediment into the water column, which increases turbidity and the potential for seabed spawners and eggs to be disturbed.	Farr *et al*., 2021

Energy emissions

Electromagnetic fields, sound and vibrations, and temperature change are the main energy emissions from dynamic power cables. The range of intensities, frequencies, and duration of energy emissions that species experience depends on cable characteristics and materials, as these influence the emissions. Species may respond actively or passively to energy emissions. Species with sensory apparatus to detect emissions and the capacity to respond to them through changes in movement and behaviour are regarded as active responders. Passive responders do not sense or respond to energy emissions, but exposure to the emissions may affect their physiological, biochemical, or developmental or genetic processes.

Some commercial fisheries species have specific electro- and/or magneto-sensory apparatus (e.g. elasmobranchs use electroreception to find prey and seasonal migratory species navigate using magnetic cues in the environment; Gill *et al*. 2020; Gill and Desender, 2020) and can respond actively when encountering EMFs. Direct active responses could be attraction or avoidance of the cable or diversion from a migratory path or local orientation (Figure 9). Indirect effects could be predation on sedentary life stages or low-mobility prey species that associate with the cable because of the physical surface that the cables present and/or EMF attraction (Table 4).

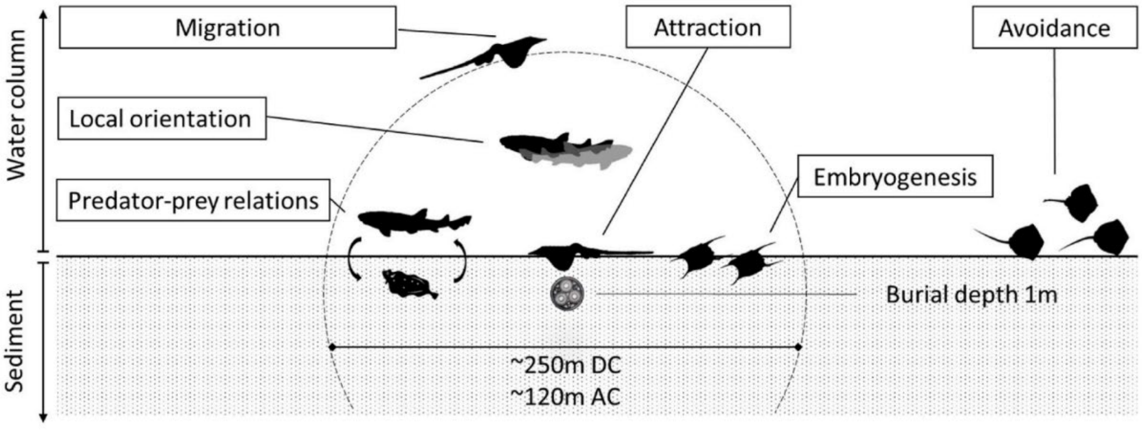

Figure 9 Summary of active and passive responses of elasmobranchs to electromagnetic fields (treating fixed, buried cables as a proxy for responses to electromagnetic fields in general). Potential spatial extent of responses for direct current (DC) and alternating current (AC) electromagnetic fields is based on the lowest known magnetic field perception level of 0.005 µT. Note: animals are not to scale (Hermans *et al*., 2024). Licensed under a Creative Commons Attribution 4.0 International License.

Sound

The primary source of sound that can be regarded as noise (where noise is defined as artificial sound adding to the ambient sound to the extent it is a pollutant) comes from the cables electrically resonating during power transmission. This sound appears as a hum and the characteristics, duration and propagation distance of the sound will be determined by its intensity and frequency, with high frequencies propagating tens to hundreds of metres, while low frequencies propagate furthest, reaching kilometres for the very lowest. The hum may cause an attraction or avoidance response by pelagic species, depending on their sensitivity and proximity to the sound. Whether there is an attraction or avoidance reaction or no response will be determined by the sensory ability of a species and life stage. The response or lack of response, in turn, determines the period of exposure to the sound (Popper and Hawkins, 2019).

Vibration

The source of vibration is mechanical resonance of the cable within the water column (Ringsberg *et al*., 2025). This resonance can either be transmitted from vibrations of the turbine tower to which the cable is connected or created directly by the cable. Propagation distance of the vibration is determined by the intensity and frequency, with low frequencies propagating over tens to hundreds of metres. Whether there is attraction, avoidance, or no response of a species will depend on the sensory sensitivity of the species and life stage. The response or lack of response, in turn, determines the period of exposure to the vibration.

Temperature

During electrical transmission, the cable components heat up. Engineers design cable operating temperatures to be lower than 90° C to reduce the energy transfer losses (Gulski *et al*., 2021). ICES did not locate any reports of *in situ* measurements of heating at the surface of a dynamic cable. However, with water moving past the cable surface the propagation of the heat into the surrounding environment is expected to be very limited. Therefore, the likelihood of pelagic species actively encountering higher temperatures is expected to be negligible. For species that have more sedentary or passive traits, there may be some interaction and therefore the raised temperature of the cable may influence behaviour directly or indirectly through the colonization or growth and development of organisms.

Physical interactions

Collision

Collision will only occur if pelagic fish species encounter the physical cable but do not or cannot avoid it. As pelagic fisheries species have sensory abilities allowing them to detect physical objects, collision is expected to be unlikely. However, ICES is not aware of any evidence of pelagic species movement responses to dynamic power cables. It is known from reviews of interactions between species and other marine energy devices (e.g. tidal turbines; Copping *et al*., 2021) that collision will only occur if the structure moves faster than the species can respond. Dynamic power cables will move to some degree; however, any movement is expected to be slow relative to the fisheries species.

Entanglement

As with collisions, entanglement is unlikely based on knowledge of species behaviours and cable configurations, but no direct evidence is known to ICES. Risk may be influenced by movement of the cables. For FLOWs with catenary moorings the potential for entanglement in both mooring lines and dynamic cables may increase but would still be low.

Habitat association

The direct association of commercial species with dynamic cables is possible, given the cables are attached to huge floating turbine structures and many species of pelagic fishes are known to aggregate around underwater structures. This effect is used in the context of fish aggregation devices that are deliberately deployed in a fisheries context. They may also provide refugia for early life stages. The whole FLOW structure (turbines, floating foundations, mooring systems and dynamic cables) is large and is expected to attract some pelagic species. The habitat association/attraction could be for several reasons and could occur for one or more life stages. Habitat association by any fisheries species could increase the risk of it interacting with other dynamic cable attributes such as energy emissions (noise, EMFs, and temperature).

Indirect effects

Colonization by prey species

Any structure in the water will be colonized by epibenthic species, particularly species with planktonic phases of life that settle out of the water column onto hard structures. A review of the colonization of structures in provided in response to request item “g”.

Such colonization may provide food for commercial species at different life stages. Therefore, this indirect trophic-based attraction of predators to the prey that are colonizing dynamic cables could increase the likelihood of these species encountering the cables.

Hydrodynamic effects

Both the main turbine structures, the mooring system, and the array of dynamic power cables may affect local hydrodynamics by increasing mixing, changing water velocity, and increasing turbidity. The hydrodynamic environment is particularly important for pelagic species, and changes in water clarity, water temperature or salinity may affect local occurrence and abundance. Further, early life stages within the water column may be affected in terms of dispersal or position with the water column by downstream effects associated with hydrodynamic changes. A review of hydrodynamic effects is provided in response to request item ‘f’.

Seabed abrasion

If dynamic cables come into contact with the seabed, then seabed sweep and potential abrasion will occur. This is most likely in areas where FLOWs are deployed in shallower waters and also in waters with high tidal ranges that may bring the cable nearer to the seabed. If catenary moorings are used, it is expected that dynamic cables will add to the sweep and abrasion of the mooring lines. The main considerations for pelagic fisheries species are local increases in suspended sediment in the water affecting visual predation. If there are benthic spawning grounds at the installation site, then eggs may be physically disturbed by the sweep and abrading action of the dynamic cable and/or the settling out of suspended sediment, which could smother the developing eggs.

Areas identified for FLOW

ICES did not identify any publicly available information on the specific locations identified as suitable for FLOW development in the Baltic Sea, Celtic Seas, and Greater North Sea. It is necessary to have this information to assess the potential interaction between commercial pelagic fisheries species and dynamic cables. Only very general information is available from Ørsted (2022) to indicate areas globally that have floating offshore wind potential, and this includes areas of the Baltic Sea, Celtic Seas and Greater North Sea.

Assessing the effects of FLOWs

The potential for commercial species to encounter dynamic cables depends on the distribution of FLOWs and of the species. Different life stages of a species usually have different distributions. Many species that are classified as demersal (bottom-dwelling) and benthic based on the adult stages will have pelagic life stages, especially, egg, larval, and early juvenile stages.

Confidence in this assessment of the effects of dynamic power cables on pelagic species is low. This is because there are few commercial scale FLOW installations worldwide, and no known studies of effects of dynamic power cables on pelagic species at the installations. Therefore, effects are inferred from studies of OWFs and subsea power cables.

An approach to reliably assess interactions of commercial pelagic fish with, and reactions to, dynamic cables requires

I. Information on the location and spatial extent of FLOW installations and associated dynamic power cabling within an ecoregion;
II. The range of depths and areas of occurrence of dynamic power cables;
III. Knowledge of species occurrence at different life stages and depths in relation to the location of cables;
IV. Results from studies of the responses of pelagic life stages of commercial fish species to dynamic power cables.

Additional information on the frequency and duration of encounters with FLOWs and the proportions of the population having such encounters would be required to express effects at the population level rather than local effects.

Spatial planning, good practices and mitigation measures (request item “i")

Mitigation is intended to reduce or compensate for adverse economic, social and ecological impacts of OWFs and FLOWs. The US Bureau of Ocean Energy Management (BOEM, 2025) adopted a definition of mitigation, in the context of wind farm development, which includes

I. Avoiding the adverse effect altogether by not taking a certain action or parts of an action;
II. Minimizing the adverse effect by limiting the degree or magnitude of the action and its implementation;
III. Rectifying the adverse effect by repairing, rehabilitating, or restoring the affected environment;
IV. Reducing or eliminating the adverse effect over time by preservation and maintenance operations during the life of the action;
V. Compensating for the adverse effect by replacing or providing substitute resources or environments.

This section of the advice focuses on mitigation options and good practices from an MSP perspective. A range of technical mitigation options were summarized in the section on elaboration of the advice.

MSP and subordinate planning processes, instruments, and supporting procedures (Table 5) contribute to the identification and implementation of management measures for OWFs and FLOWs, including mitigation options. Marine spatial plans need to be understood in conjunction with subordinate processes. For example, while marine spatial plans may designate priority areas for wind farms, the ways in which specific wind farms are constructed within priority areas, and any operating conditions required, are generally specified in more technical licensing or permit conditions within a project specific approval procedure. Mitigation options in approval procedures might additionally include technical measures and compensation schemes (e.g. OSPAR, 2012; Fishing Liaison with Offshore Wind and Wet Renewables Group [FFLOW], 2014; ICES, 2025). These fall outside the MSP process and are usually enabled by sectoral policies but play a significant role in enabling MSP solutions.

From the perspective of MSP, any interaction or conflict between a wind farm and fisheries is one of spatial allocation and spatial competition. Instruments in MSP for dealing with spatial demands and competition between different sectors are (i) area designations and zoning of marine areas and (ii) proposing multiuse patterns and designating areas for co-use of multiple human activities.

For all instruments and types of mitigation applied, local and regional context factors and specificities such as types of fishing (e.g. mobile or fixed gears), characteristics of the vessels, métiers and fleets (e.g. lengths, seaworthiness, and access to fishing grounds), and traditions (e.g. times and places of fishing) need to be considered. Any affected fishing community, and the people and industries supporting and supported by this community, have specific resilience and adaptive capacities (Stelzenmüller *et al*., 2024).

The following sections assess the strengths, weaknesses, implications, and uncertainties of instruments and supporting procedures contributing to MSP and mitigation. These instruments and supporting procedures are summarized in Table 5.

Area designations and zoning

Area designations usually make “positive” provisions in the sense of explicitly encouraging specific activities (Zaucha *et al.,* 2025). The most common designation is a priority area that focuses on single sector or activity. The meaning and legal consequences of designations differs among nations. Area designations can be supplemented by regulations that ensure that a priority use is not impeded by any other use and that the priority use adheres to specific rules. Using such additional provisions, area designations can also enable co-existence and multiuse. Only limited and fragmented cases of area designations applied specifically for fisheries exist (Zaucha *et al.,* 2025).

The main strength of area designation approaches (especially when they have legally binding status) is to provide security for investors and users of marine resources because their activity is administratively (and legally) supported and thus approval for specific projects is likely. Legally binding zoning also accelerates administrative approval procedures. This is particularly relevant for OWF operators, where financial investments are large and carry significant economic risks. mA weakness of zoning and area designations is that they are often contentious among fishers who have traditionally followed the resource and relied on the freedom to fish over large sea areas. In addition, fishers expect further challenges as resources redistribute spatially with climate change. To some extent, these challenges may be addressed with more dynamic and adaptive MSP, but there are limits to adaptive approaches when OWFs and FLOWs are typically built for lifetimes of at least 25 years. Further, spatial planning for wind farms is unlikely to be reversed because it is linked to commitments to, and investments in, European and national large-scale energy infrastructure on decadal timescales. Given the current political priorities for OWFs, the legislative requirements for protected areas, and predominantly national structures of spatial planning, it has proved difficult to designate specific areas for fisheries in marine areas of high use intensity such as those in Belgium and Germany.

Table 5 Overview of planning processes, policy instruments, and other supporting procedures relevant to marine spatial planning (MSP).

Option (characteristics)	Implication	Strengths	Weaknesses	Requirements
Area designations and zoning (policy instrument, spatial)	Defining priorities for use of specific areas	Transparency and security for investors and marine resource users Acceleration of administrative approval procedures (if designations have a legally binding status)	Under given political priorities the loss of areas for fisheries may be obvious and unavoidable Designations challenge freedom of fishers to fish over large and varying sea areas (often a cultural expectation) Reduction of spatial adaptation options for fisheries May not recognize or account for the mobility of fisheries resources and future effects of climate on distributions	Stakeholder involvement Good knowledge base on spatial distribution of human activities and spatial requirements of different sectors Understanding of interactions between human activities and economic, social and ecological risks.

Option (characteristics)	Implication	Strengths	Weaknesses	Requirements
Multiuse and co-use (policy instrument, partly spatial)	Enabling co-existence of different actors in the same place or in vicinity of OWFs and FLOWs	Increase of spatial efficiency Mitigation of spatial conflicts Option to transform (parts of) fisheries sector Potential business option for (probably) small groups of fishers Potential to share infrastructure and emergency systems	Risk of accidents More complex insurance requirements Fisheries as co-use in OWFs and FLOWs may create tensions with nature conservation Requires incentives for OWF and FLOW developers and fishers Economic viability may be uncertain May require financial support for (small-scale) fisheries to adapt to new (e.g. passive) types of fishing May require development of new value chains and market structures	Stakeholder involvement Extension to non-spatial policy fields Inclusion of local knowledge, social and economic risk assessment
Compensation schemes (policy instrument, non-spatial, not limited to MSP)	Identifying non-spatial trade-offs among actors in a spatial conflict	Supporting negatively affected actors and communities in transformation processes	Requires financial investments (directly as financial compensation or indirectly as investments into a community or in infrastructure) Compensation may have to come from other policy areas May experience resistance by affected user groups	Stakeholder involvement/co-design Inclusion of different policy fields, e.g. regional development and local knowledge Economic and social risk assessment
Technical measures (policy instrument, spatial and non-spatial, not limited to MSP)	Identify technical measures to mitigate impacts	Relatively simple to implement Usually less contentious than other mitigation options	May increase costs for development Limited to a few aspects of OWF or FLOW design	Communication among affected actors Spatial possibilities for alternatives to be identified (e.g. other cable routes than originally envisaged)
Stakeholder Involvement/Co-Design (procedural, supporting tool)	Ideally establishes solid and trustful communication among actors	Establishes commitment from actors or at least acceptance among affected actors Increases legitimacy of decision-making	Time and resource consuming Professional support often required in moderation and mediation May slow down planning and decision-making	Trust and good will among actors. Professional moderation or mediation may be required Formats designed and appropriate for specific actor groups

Option (characteristics)	Implication	Strengths	Weaknesses	Requirements
Scientific Advice (procedural, evidence base)	Provides independent science-based information and knowledge in quantitative and qualitative formats for decision-making	Providing a scientific and independent information base covering economic, social and ecological impacts	Risk of information bias (i.e. a focus on easily accessible or measurable data) Risk of ignoring local social knowledge Uncertainty and potential misinterpretation by stakeholders	Development of operational approaches for economic, social and ecological risk assessment, and cumulative impact assessment

Multiuse and co-use

Multiuse approaches seek to enable co-existence between users and activities. Multiuse is characterized by different levels of spatial and temporal overlap, and varying levels of compatibility and mutual dependency, between users and activities. Guyot-Téphany *et al*. (2024) define multiuse as the "co-location of complementary activities at sea, their clustering, or their combination", and understand multiuse as joint use of maritime resources by several users in geographical proximity, with the aim of increasing efficiency. The most intense form of multiuse is when uses take place in the same area, at the same time, with shared services, and with shared infrastructure.

Co-use[16] refers to uses or activities taking place in the same space at the same time, most often without shared infrastructure or functions (Schupp *et al*., 2019). Co-use may benefit fishers because they can potentially retain access to an area for fishing. Implementation is best achieved through co-design, or at least by having co-use options checked by the affected actors to ensure operability, for example concerning maintenance and safety operations for OWFs and practical operability and safety of fishing activities (ICES, 2025). Risk assessment can help to inform decisions about trade-offs.

OWFs can lead to biomass increases of some fishery resources in their vicinity. Depending on the extent of spill-over effects and access or conditions for access (e.g. gear restrictions) for fisheries, these resources can potentially be exploited around OWFs. Co-location of wind farms and fisheries has mostly been considered in relation to static gear targeting crustaceans such as pots but not in relation to static gears aimed at finfish, such as gillnets.

Co-location of fisheries and OWFs can be supported by design measures that actively stimulate the development of specific (hard substrate) habitats and increase settlement opportunities for reef-building species (e.g. mussels or oysters), which, in turn, attract other organisms. Erosion protection can be designed to provide a habitat in spaces between the scour protection, and further fish supporting structures could be installed directly on turbine towers or foundations, such as "fish hotels", which the grid operator TenneT has attached to a transformer platform. Additional artificial reefs can be created between the individual turbines, for example by laying out stones, concrete blocks, dead wood, mussel shells, or other objects (ICES, 2025).

From a fisheries perspective, co-location solutions have potential to mitigate some lost fishing opportunities. Such options may be explored in MSP processes and facilitated through MSP and regulation. However, observations and interviews in one German project show that using artificially constructed habitats for fisheries may create tensions with nature conservation perspectives, tending to argue that the habitats should serve habitat restoration and not resource extraction. Generally, according to Zaucha *et al*. (2025), Belgium, the Netherlands, Estonia, and Sweden are the only EU Member States to specify elements of co-use and coexistence in their spatial plans.

From an MSP perspective, the creation of additional artificially constructed habitats (beyond the structures needed from an engineering perspective) may require incentives in the regulatory process or in auctions for wind farm areas. The development of new fisheries also requires adaptive capacity in the fishing sector and associated value chains. In the case of North Sea co-use, Bonsu *et al*. (2024) identified economic viability of proposed passive fishing gear and uncertainties regarding implementation as barriers to the development of co-use solutions. Other barriers related to the legal basis of arrangements, the implementation of safety regulations, the definition of minimum requirements for fishing vessels to fish

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[16] "Co-existence" and "co-location" are used synonymously with "co-use".

in OWFs, and licencing procedures. Insurance issues in case of damage to fishers, OWFs, or FLOWs are another obstacle to fishing operations near to these installations.

There are innovative concepts such as mariparks, which are suggested to enable multiuse by de-risking investment and simplifying licence procedures for multiuse (Ramieri *et al*., 2024). Barriers to transforming fisheries specifically relate to financial aspects. For example, converting from bottom trawling to passive fishing will require new fishing gear and is likely to require new or refurbished vessels. Fishers may therefore need direct financial support to adapt.

Theoretically, co-location of pelagic fisheries in OWFs is possible. This would require solving questions of insurance and design, e.g. by providing larger distances between turbines (which could be dealt with in regulations in marine spatial plans, approval procedures, and auction design). But reducing the number of turbines within an OWF by increasing distances between turbines may result in lower levels of electricity production within the same area or require expansion of the OWF to achieve a given rate of electricity production.

Compensation schemes

Compensation, typically financial payments in exchange for lost fishing opportunities, may be adopted as a mitigation measure, for example if planning requires significant adaptations from the fisheries sector. Some challenges with designing compensation schemes are eligibility and the extent to which this is linked to direct or indirect effects, for example, direct loss of fishing grounds vs crowding of existing fishing grounds because of displacement (ICES, 2025). Compensation for disruption and displacement of fishing activities is ideally evidence-based, but this poses challenges if fisheries do not have evidence of track record, for example the inshore < 12 m sector (currently not included in routine VMS monitoring and very rarely using AIS). This may result in a reliance on qualitative data or voluntary vessel tracking, but this is often short-term. An example of a project whose output could be adapted for vessels operating in offshore wind areas of interest is the Irish iVMS project, which saw installation of bespoke VMS instruments on selected vessels < 12 m.

Compensation is not necessarily well received by some fishers. For example, the North Sea Dialogue in the Netherlands led to the North Sea Agreement (NSA). This was signed by all parties except the fisheries organizations. The fishers are compensated within the NSA through a Transition Fund for the loss of fishing grounds because of OWF and protected areas expansion; this supports a decommissioning scheme to adapt the size of the Dutch fleet to the remaining space for fisheries and to finance sustainability innovations for the vessels that do not opt for decommissioning. Fishers may also hold divergent views about appropriate types of compensation. For example, fishers on the Scottish west coast were not in favour of compensation for stimulating or investing in alternative livelihoods because these are not always available for fishers in rural areas. Fishers preferred that compensation should focus on the long-term well-being of the fishing communities, for instance by investing in local education opportunities (Alexander *et al*., 2013).

Technical measures

Other measures to support co-use may be technical, for example to modify turbine array design and cabling (Green *et* al., 2022) that affect the operability of fishing vessels within an array and along cable routes outside the wind farm. Interactions between cables and fishing gear create risks to the vessel, crew, and cables. Impact minimization measures for cabling identified in a US study (Green *et* al., 2022) were (i) designing cable routes to maximize the potential for responsible cable burial, (ii) optimizing grid connection and inter-array cable layouts to account for existing fishing activity, including minimizing the amount of cable laid, (iii) laying power cables using a method that reduces damage to the seabed, (iv) laying high voltage direct current (HVDC) cables with opposing electrical currents alongside each other and with sufficient burial, (v) planning cable location and directionality with delineation of cable locations on charts, (vi) considering removal of cables in case of decommissioning, and (vii) bundling cables in corridors to reduce spatial disturbance. It is unknown which, if any, of these measures would help in terms of mitigation in the North Sea, given the extremely high density of OWFs planned.

Stakeholder involvement/co-design

Stakeholder involvement, engagement, and co-design supports development of mitigation options that are technically, economically, politically, socially, and ecologically feasible and supported or at least accepted by all relevant stakeholders. To develop suitable planning and mitigation options, OWF and FLOW planning ideally involves fisheries sectors in co-design from the beginning (Morf *et al*., 2019). Co-design, the active involvement of stakeholders in the design of planning solutions, is an important tool for policy-makers in many fields and is applied to engage with stakeholders and the wider public to find solutions to complex problems and to ensure that policies have the necessary support (Urquhart *et al*., 2023).

Many advantages of participatory and collaborative planning processes are recognized, including generating a broad knowledge and evidence base, improved understanding of the issues at hand, recognition of different interests and values, fair and equitable representation of all relevant sectors and stakeholders, and joint ownership of planning solutions; there are also intangible process benefits such as learning, mutual understanding, and trust-building (Ehler and Douvere, 2009). At the same time, co-design presents challenges – such as building trust between stakeholders and policymakers, overcoming traditional modes of evidence-based policymaking, accessing hard-to-reach groups, and getting discussions to move beyond the general to the specific – that are time-consuming and resource-intensive (Urquhart *et al*., 2023). And co-design may hinder fast and time efficient decision-making and can be manipulated by single groups to delay decisions.

In the context of OWF and FLOW planning, co-design approaches will benefit from fisher knowledge of preferred fishing areas, target species, and other sector-specific needs and expectations. Fishers may also identify the potential conflicts that may arise from displacement and reduced areas available for fishing and consider the impacts of climate change on fisheries and the implications this may have for fishing opportunities. In Finland, for example, dedicated workshops have taken place with small-scale fishers to identify expected climate change impacts and how this might affect fishing activities in the medium term (Arki *et al*., 2024). This knowledge can then be introduced to broader spatial planning processes, e.g. to anticipate future fishing patterns and inform appropriate location decisions for other marine activities, including OWFs.

Successful planning and stakeholder engagement are shown to require specialized human resources with relevant experience and local expertise. For an effective co-design process, it is also necessary to define in detail the timing and methods for stakeholder involvement as well as optimizing the cost-benefit ratio. Different forms of participation and stakeholder engagement can be used (Table 6), but only higher levels of involvement will allow development of truly co-designed mitigation measures. Consensus-building and negotiation-based methods are shown to increase the level of acceptance and reduce implementation-related opposition. Capacity-building initiatives may be used across all sectors to enable equitable participation, particularly for less organized groups like small-scale fisheries. Key sectors are ideally sufficiently well represented to prevent exclusion, while managing expectations realistically to uphold commitments. Additionally, participatory processes are shown to be more effective when guided by impartial, experienced moderation teams to ensure transparency and efficiency. They are also shown to more effective when a clear communication mechanism is established allowing stakeholders to provide feedback, raise concerns, and resolve disputes effectively.

Table 6 Methods for stakeholder participation and engagement (adapted from Bouamrame [2006]).

Participation method	Description	Level of stakeholder involvement	Common tools
Communication	Management team shares information without seeking feedback	No active involvement	Videos, brochures
Information	Information is provided for stakeholders to react or take a stance.	Passive reaction or stance-taking	Presentations, seminars, info sessions
Consultation	Gathering stakeholder opinions to ensure they are considered	Low	Meetings, workshops, interviews
Dialogue	Equal interaction among parties to understand perspectives and find solutions	Low/medium	Meetings, workshops
Consensus-Building	Developing a shared position among stakeholders for presentation to authorities.	Medium/high	Meetings, workshops
Negotiation	Equal decision-making power between stakeholders and management	High	Meetings, workshops
Dispute resolution mechanism (DRM)	Tool for resolving disagreements between stakeholders	High	DRM process, meetings

Scientific advice

The policy cycle covering MSP and subordinate planning processes, instruments, and supporting procedures is usefully informed by scientific advice, including risk assessment (Cormier *et al.*, 2017, Cormier and Kannen, 2019). Advice may be provided in quantitative and qualitative formats and address economic, social, and ecological impacts. Development of operational approaches for economic, social, and ecological risk assessment and cumulative impact assessment can be resource intensive. Given the relatively rapid development of wind farms, there are risks of information bias when advice developed at short notice may utilize easily accessible or measurable data that was not collected or collated for the primary purpose of providing wind farm–related advice.

To inform the choices among mitigation options science advice will ideally characterize the economic, social, and ecological consequences of different reallocation and multiuse options for fisheries and help other stakeholders to identify feasible options. A list of research and monitoring priorities developed by ICES (2025) was provided in the section on elaboration of the advice.

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Annex 1 Phases of offshore wind farm (OWF) and floating offshore wind farm (FLOW) development

The phases of OWF and FLOW development referred to in this advice are as follows:

1 **Pre-construction phase (survey phase).** This is the period during which the physical environment (bathymetry, seabed, underwater heritage, obstructions, hydrodynamic conditions, etc) at the potential site of a future OWF is investigated. Pre-construction ends when the survey is completed. Pre-construction pressures are only related to survey activities.

1. **Construction phase**. This is the phase during which the OWF is built. The construction phase starts with the first construction activity and ends when the OWF is fully constructed. Construction pressures are related to construction activities (seabed levelling, cable burial, turbine piling, and scour protection layer (SPL) installation).
2. **Operation phase**. This phase when the turbines are operating. It starts with the end of the construction phase and ends with the start of the decommissioning phase. Operation phase pressures are related to the presence of operational turbines, and maintenance activities.
3. **Decommissioning phase**. This phase starts with the first activities leading to removal of the OWF and ends when the OWF is fully removed. Decommissioning phase pressures are related to decommissioning activities only.

Annex 2 Designs of offshore wind farm (OWF) and floating offshore wind farm (FLOW) turbines

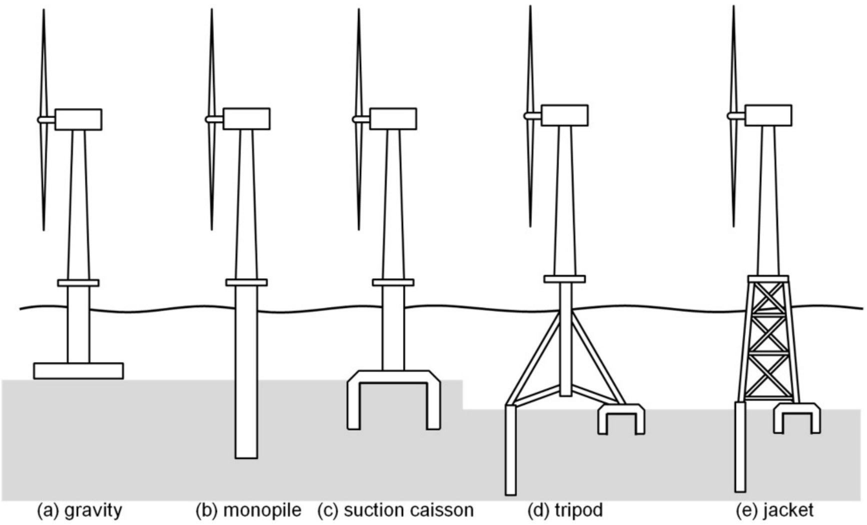

Figure A2.1 Foundations of fixed wind offshore wind farm turbines (Oh *et al.*, 2018).

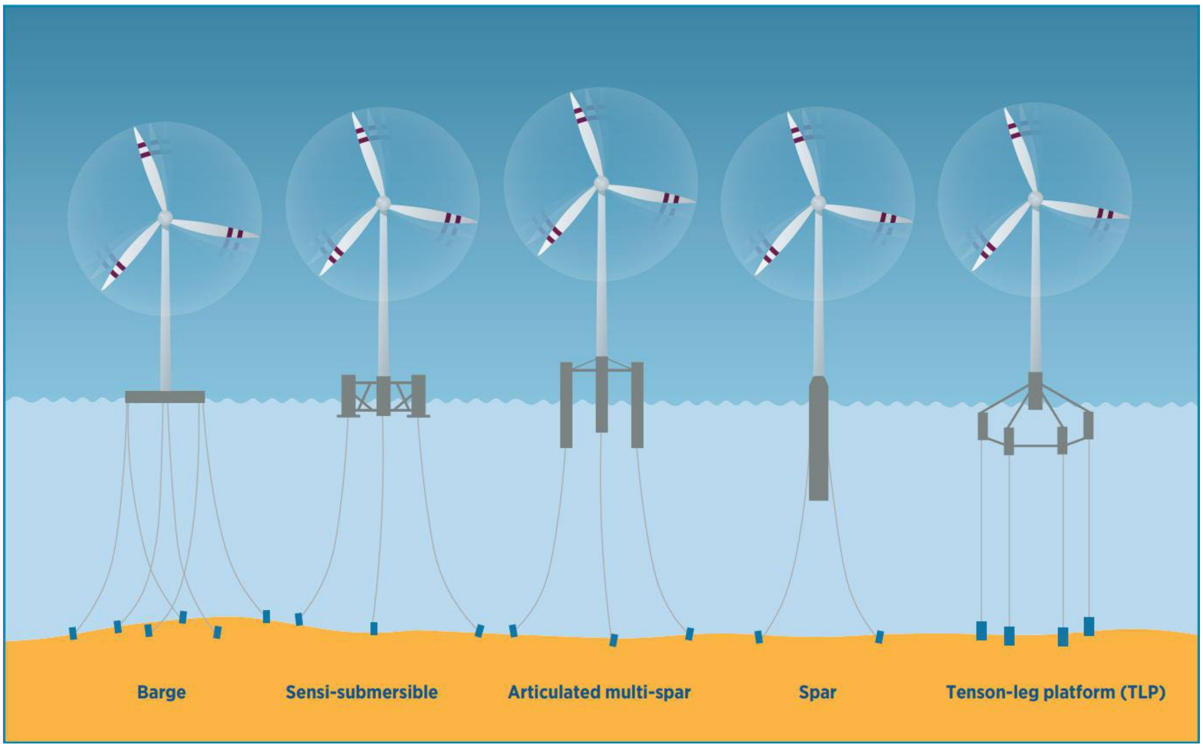

Figure A2.2 Types of floating offshore wind farm turbines (IRENA 2021) © IRENA 2021.

Annex 3 Pressures associated with offshore wind farm (OWF) and floating offshore wind farm (FLOW) development

Table A3.1 Classification of pressures associated with all phases of offshore wind farm (OWF) and floating offshore wind farm (FLOW) development.

Table 3	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 because of presence of fouling fauna on turbines	Cable and scour protection layer (SPL) removal activities
Sediment resuspension, transport and smothering		Piles (OWF) or anchoring (FLOW) installation, cable trenching activity	Yes, scouring after installation of turbines and SPL (presence)	Cable and SPL removal activities
Abrasion of sediment by seabed disturbance		Cable trenching, seabed levelling activities, presence of floating cables and moorings	FLOW: 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	Unexploded ordnance (UXO) clearing and piling activities		possible drilling, explosions, seismic surveys
Introduction of underwater noise: continuous		Noise generated by dynamic positions (DP) vessel activity	Presence of devices, maintenance vessel activity	Vessel traffic, DP vessel activity
Electromagnetic fields (EMF)	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		FLOW: Fpresence of dynamic cables	
Visual disturbance		Maintenance vessel activity and transport of materials and parts. and moving)	Maintenance vessel activity	Presence of vessels
Introduction non-indigenous species via relocation of floating turbines		Presence of FLOW turbines relocated from other locations to farm site	Relocation activity of FLOW turbines between farm and ports for repairs	Relocation of FLOW turbines from farms to decommissioning yard

The pressures associated with all phases of OWF and FLOW development can be mapped to the higher-level of pressure classification used in the Marine Strategy Framework Directive (MSFD). This directive provides a higher-level classification of pressures. All OWF- and FLOW-associated pressures can be mapped to MSFD (EC, 2017) pressures except introduction of artificial hard substrate.

Table A3.2 Relationships between pressures associated with all phases of offshore wind farm (OWF) and floating offshore wind farm (FLOW) development and pressures identified in the Marine Strategy Framework Directive (MSFD) list of pressures as last updated in 2017 (EC, 2017). Associated state changes from ICES (2025).

Pressure (OWF and FLOW)	Corresponding MSFD pressure	Associated state change
Loss of soft sediment, covered by scour protection	Physical – physical disturbance to seabed (temporary or reversible)	Sediment/nutrient/ contaminant fluxes
Introduction of artificial hard substrate	Not covered by MSFD	Colonization of hard substrate
Change in sediment composition	Physical – physical disturbance to seabed (temporary or reversible)	Sediment/nutrient/ contaminant fluxes
Sediment resuspension, transport and smothering	Physical – physical disturbance to seabed (temporary or reversible)	Sediment/nutrient/ contaminant fluxes
Abrasion of sediment by seabed disturbance	Physical – physical disturbance to seabed (temporary or reversible)	Sediment/nutrient/ contaminant fluxes
Change in water current	Physical – change to hydrological conditions	Turbulent wakes, wind wakes
Change in stratification	Physical – change to hydrological conditions	Changed thermal stratification
Underwater noise: impulsive	Substances, litter, and energy – input of anthropogenic sound (impulsive, continuous)	Noise
Underwater noise: continuous	Substances, litter, and energy – input of anthropogenic sound (impulsive, continuous)	Noise
Electromagnetic fields	Substances, litter, and energy – input of other forms of energy (including electromagnetic fields, light, and heat)	Noise
Introduction of synthetic and non-synthetic contaminants	Substances, litter, and energy – synthetic substances, nonsynthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events	Sediment/nutrient/ contaminant fluxes
Introduction of litter	Substances, litter, and energy – input of litter (solid waste matter, including micro-sized litter)	Sediment/nutrient/ contaminant fluxes
Collision risk	Biological – disturbance of species (e.g. where they breed, rest, and feed) due to human presence	Collision
Entanglement risk in cables	Biological – disturbance of species (e.g. where they breed, rest, and feed) due to human presence	Entanglement
Visual disturbance	Biological – disturbance of species (e.g. where they breed, rest, and feed) due to human presence	Changed light clues
Introduction of non-indigenous species via relocation of FLOW	Biological– input or spread of nonindigenous species	Colonization of hard substrate

Annex 4 Basis of the trait-based framework used to assess local vulnerabilities of different life stages of commercially fished species to pressures resulting from the operation phase of offshore wind farms (OWFs).

Table A4.1 List of state changes that are related to the pressures exerted by the different activities and operations throughout the development phases of offshore wind farms (OWFs; pre-construction, construction, operation, and decommissioning).

State change	Abbreviation	Explanation
Sediment resuspension	Sed_res	Process of particles being resuspended into the water column and *inter alia* causing turbidity
Sediment deposition	Sed_depo	Deposition of sediment from the water column on the floor
Colonization of hard substrate (at monopiles and scour protection)	Col_hard_sub	The colonization of monopiles by fouling communities, which in turn attract other species
Sediment/nutrient/contaminant fluxes	Sed_Nut_Con_flux	Fluxes and transport of sediment, nutrients, and contaminants across OWF boundaries
Changed seabed-water column (stratification, mixing)	Strat_mix	Variations in water mass stratification and mixing that modify the exchange of fluxes between the seabed and the water column
Turbulent wakes	Turb_wakes	Chaotic flow pattern behind monopiles.
Changed thermal stratification	Thermal_strat	Changes in thermal stratification of the water column.
Changed energy emissions/environment (noise)	Noise	Changes in electromagnetic and noise emissions.
Changed light cues	Changed_light	Changes in light pattern affecting the light sources that are used for migration, feeding, etc.
Wind wakes	Wind_wakes	Disturbed air flow behind the wind farms

Table A4.2 The nine population characteristics, abbreviations and life stages to which they are applied.

Characteristics	Abbreviation	Life stage
Altered aggregation	Altered_agg	Adult
Altered distribution	Altered_dist	Adult
Altered migration	Altered_mig	Adult
Changed colonisation	Changed_col	Adult
Changed feeding patterns	Changed_fee	Adult
Larval dispersal (passive or active)	Larval_disp	Eggs and larvae
Predator-prey interactions	Pred_pray_in	Adult
Recruitment (survival of the juveniles)	Rec_survival	Juveniles
Reproduction	Reproduction	Adult

Table A4.3 List of 14 response traits and trait modes that determine the response to state changes induced by the activities and operations (and hence pressures) associated to the development phases of offshore wind farms (OWFs).

Response traits	Trait modes
Behavioural plasticity (i.e., migration shifts and habitat switching)	High
	Low
Diet specialization	Generalists
	Specialists
Fecundity	High
	Moderate
	Low
Feeding behaviour	Group feeders
	Solitary
Feeding mode	Benthivores
	Detritivores
	Herbivores
	Piscivores
	Planktivores
Feeding time	Diurnal
	Nocturnal
Habitat dependence /resilience to habitat alteration	Generalists
	Specialists
Habitat selection/spawning location	Demersal spawners
	Egg guarders
	Egg hider
	Pelagic spawners
	Viviparous
Migration behaviour (or migrating pattern)	Life-stage migration
	No migration
	Seasonal migration
Oxygen tolerance	Hypoxia-sensitive
	Hypoxia-tolerant
Salinity tolerance	Large tolerance
	Small tolerance
Sensory adaptations	Electrosense and magnetosense*
	Mechanosense (lateral line)
	Smell and taste
	Hearing
	Vision
Thermal tolerance (biogeographic affinities)	Arctic
	Atlantic
	Boreal
	Lusitanian
Trophic level	Apex predator
	Primary consumer
	Secondary consumer

* Note that electric relates to feeding, and magnetic relates to migration and orientation.

Table A4.4 Common names and taxonomic names of taxa in figures 3–5. Common names for species follow those included in the ICES advice on the list of Descriptor 3 species to support reporting by EU Member States under Marine Strategy Framework Directive (MSFD) Article 17 (ICES, 2022b).

Common name	Taxon (scientific name)
Sandeels	*Ammodytes* spp
European eel	*Anguilla anguilla*
Whelk	*Buccinum undatum*
Edible crab	*Cancer pagurus*
Atlantic herring	*Clupea harengus*
Vendace	*Coregonus albula*
Common shrimp	*Crangon crangon*
Atlantic cod	*Gadus morhua*
European lobster	*Homarus gammarus*
Megrim	*Lepidorhombus whiffiagonis*
Squids (including European squid)	*Loligo* spp
Anglerfish (monkfish)	*Lophius piscatorius*
Haddock	*Melanogrammus aeglefinus*
Whiting	*Merlangius merlangus*
European hake	*Merluccius merluccius*
Blue whiting	*Micromesistius poutassou*
Lemon sole	*Microstomus kitt*
Ling	*Molva molva*
Blue mussel	*Mytilus edulis*
Norway lobster	*Nephrops norvegicus*
Northern prawn	*Pandalus borealis*
Great Atlantic scallop	*Pecten maximus*
European perch	*Perca fluviatilis*
European flounder	*Platichthys* spp
European plaice	*Pleuronectes platessa*
Saithe	*Pollachius virens*
Atlantic mackerel	*Scomber scombrus*
Turbot	*Scophthalmus maximus*
Squids (including common cuttlefish)	*Sepiidae, Sepiolidae*
Common sole	*Solea solea*
European sprat	*Sprattus sprattus*
Atlantic horse mackerel	*Trachurus trachurus*
John Dory	*Zeus faber*

Annex 5 Acronyms and initialisms

Table A5.1 A list of acronyms and initialisms used in this document.

Acronym/initialism	Full term
AC	alternating current
AIS	automatic identification system
CCF	community capital framework
CIA	cultural impact assessment
DC	direct current
DCF	Data Collection Framework
EMF	electromagnetic field
FLOW	floating offshore wind farm
GACP	galvanic anode cathodic protection
HELCOM	Baltic Marine Environment Protection Commission
HVAC	high-voltage alternating current
HVDC	high-voltage direct current
ICCP	impressed current cathodic protection
IMR	Norwegian Institute of Marine Research
IUCN	International Union for Conservation of Nature
MCS	monitoring, control, and surveillance
MSFD	Marine Strategy Framework Directive
MSP	marine spatial planning
NAMMCO	North Atlantic Marine Mammal Commission
OWF	offshore wind farm
RDBES	ICES Regional DataBase and Estimation System
SIA	social impact assessment
TTS	temporary threshold shift
UXO	unexploded ordnance
VMS	vessel monitoring system