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REPORT

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Environmental Impacts of Offshore Wind Power Production in the North Sea

A Literature Overview

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WWF is one of the world's largest and most experienced
independent conservation organizations, with over
5 million supporters and a global Network active in
more than 100 countries.
WWF's mission is to stop the degradation of the planet's
natural environment and to build a future in which humans live
in harmony with nature, by conserving the world's biological
diversity, ensuring that the use of renewable natural resources
is sustainable, and promoting

FOREWORD

Human kind faces a massive challenge: We need to contain global warming to hinder catastrophic consequences for people and nature. Luckily we already know what needs to be done: The global energy production needs to be shifted from fossil to renewable energy. How we make this shift, will have everything to say for its success.


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Nina Jensen,
CEO WWF-Norway

For renewable energy production to be environmentally sound, it has to replace and reduce the production of fossil energy as well as take the total environmental impacts of the new projects into consideration. The key to ensure minimal consequences for nature is thorough knowledge and a comprehensive planning process.

In this report, WWF has gathered research results and knowledge about offshore wind power projects and their influence on the marine environment. Offshore wind farms, with both floating and seabed-mounted turbines, hold vast potential as a sustainable energy source and as a contributor to the shift from fossil to renewable.

All energy projects affect nature to some degree, and we must make sure that the solution to tackle climate change is also a solution that minimizes the impacts on our natural environment. Crafting good solutions for producing more new renewable energy side by side with conserving ecosystems and biodiversity is crucial. Concerns have been raised about the potential risk of offshore wind farms on the environment. What happens, for instance, to whales and seals' sense of hearing when the turbine foundations are being driven into the ground? Can lighting a turbine tower with blue light rather than red be the difference between life and death for some bird species? This report seeks to answer questions like that, among many others.

For no other area are the plans of developing offshore wind farms greater than in the areas surrounding the North Sea countries.

Such great opportunities and large-scale plans have to be based on thorough scientific knowledge in order to be sustainable for the future. The main conclusion is that with proper planning and mitigation measures it is possible to construct offshore wind farms without significantly damaging the environment in the North Sea. To achieve this, cross-border coordination and a mutual agreement of project criteria between the countries surrounding the North Sea is essential. In the recommendation chapter you will find suggestions to how this can be done.

The most important find in this report is that we still know very little about how species are affected by offshore development. More research is needed, and the criteria for best practice offshore development must be continuously updated as new knowledge is gained.

Nina Jensen,
CEO WWF-Norway

Report

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SAMMENDRAG

Dersom en god, helhetlig planleggingsprosess og tilstrekkelig avbøtende tiltak ligger til grunn, er det mulig å etablere og drive havvindparker uten å vesentlig skade miljøet.

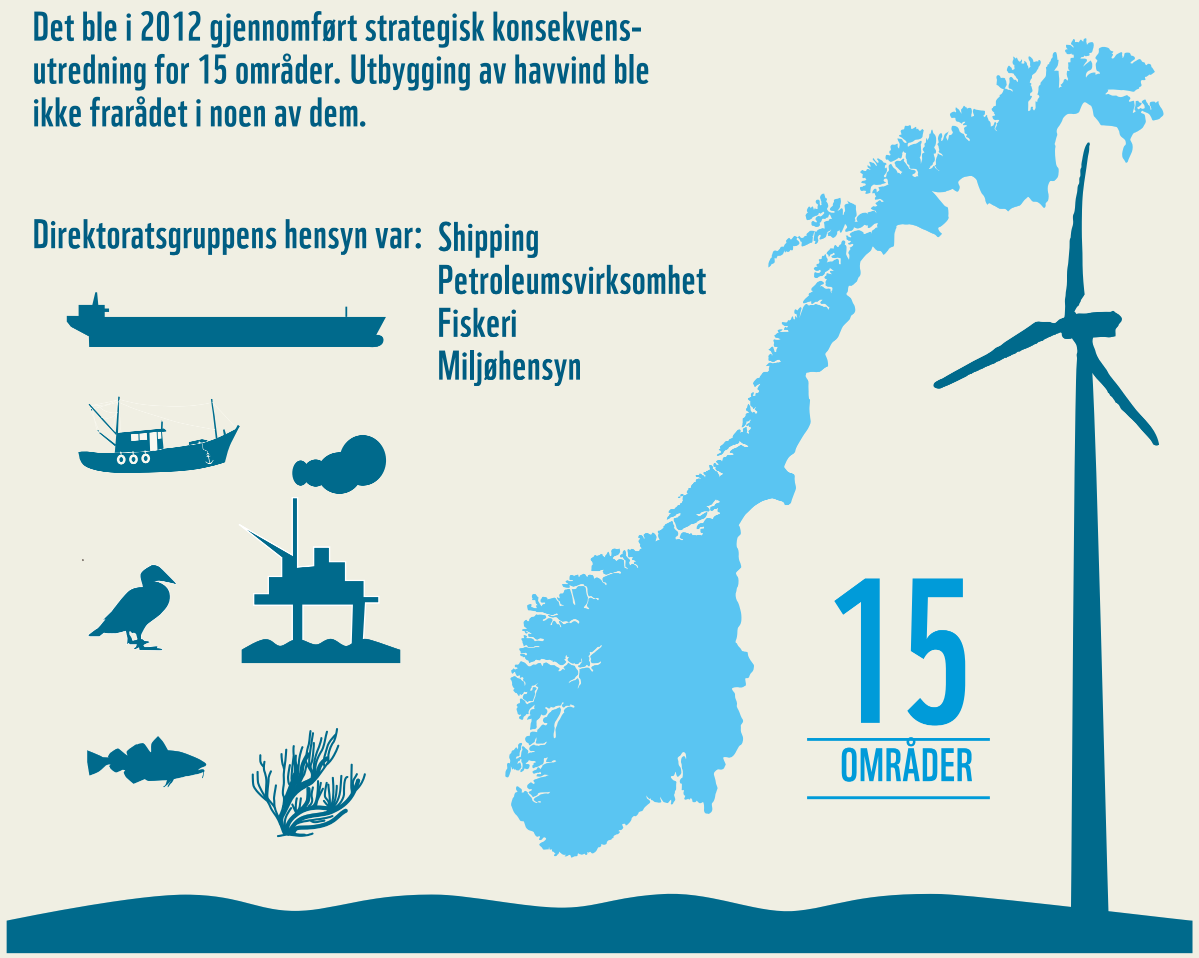
Rapporten gir en oversikt over den nyeste forskningen innen naturkonsekvenser av offshore vindkraft i Nordsjøen, men kan også være nyttig for aktører i andre regioner. Den er ment som et informasjonsverktøy for å gjøre beslutningstagere, forvaltningen og private utviklere av havvindkraftprosjekter i stand til å velge de beste prosjektene og dermed begrense de negative naturkonsekvensene.

Offshore vindkraft har mange potensielle negative konsekvenser for naturen. Både bunnfauna, fisk, fugl og marine pattedyr er funnet å bli påvirket av byggefasen og/eller driftsfasen, men kunnskapen om direkte og indirekte konsekvenser av havvind er begrenset. Særlig sårbare sesonger (for eksempel under reproduksjon), samt arters habitatbruk og migrasjonsmønstre er viktige faktorer for å redusere risikoen for fortrengning eller fatale forstyrrelser. Det må forskes mer på hvordan havvind påvirker arter og økosystemer, og forebyggende og avbøtende tiltak må videreutvikles i takt med at ny kunnskap kommer frem. Godt og effektivt samarbeid på tvers av landegrenser om for eksempel planlegging og utbygging av vindparker og nett samt utvikling av marine verneområder, er svært viktig for å minimere naturkonsekvensene av utbygging av havvind. Havvind kan vise seg å være grunnlag for nyttige synergieffekter; det er for eksempel blitt pekt på muligheten til å kombinere havvindparker med akvakultur. Slike prosjekter bør utforskes og eventuelt utvikles.

Rapporten konkluderer med at dersom en god, helhetlig planleggingsprosess og tilstrekkelig avbøtende tiltak ligger til grunn, er det mulig å etablere og drive havvindparker uten å vesentlig skade miljøet. Resultatene fra miljøkonsekvensanalyser utført over mange år ved Horns Rev vindpark i Danmark støtter konklusjonen.

Med bakgrunn i rapporten anbefaler WWF:

- Det må etableres et internasjonalt direktiv med rammeverk for marine arealplanlegging og integrert kystforvaltning.
- Bruken av miljøkonsekvensanalyser forbedres.
- Mulighetene for økt produksjonen av offshore vindkraft i Nordsjøen må følges opp og bygges ut der det er miljømessig mulig.
- Den norske regjeringen må få på plass en nasjonal strategi for fornybar energi til havs, som gjenspeiler de ambisjoner og prosedyrer for beste praksis andre europeiske land har vedtatt.



Under arbeidet med klimameldingen i 2007 (St. meld. nr. 34(2006-*2007*)) bestemte Stortinget at det skulle etableres en nasjonal strategi for fornybar kraftproduksjon til havs. Som en del av denne nasjonale strategien ble arbeidet med en havenergilov påbegynt. Loven ble vedtatt og trådte i kraft i 2010. Havenergilovens §2-2 slår fast at utbygging av fornybar energi til havs kun skal finne sted etter at Regjeringen har åpnet aktuelle geografiske regioner for konsesjonstildeling. Før områder kan åpnes må det gjennomføres en strategisk konsekvensutredning.

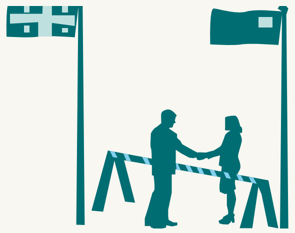
En direktoratsgruppe ledet av Norges Vassdrags- og Energidirektorat (NVE) utpekte i 2010 15 områder langs norskekysten som potensielle for utbygging av vindkraft. Ifølge direktoratsgruppen ble områdene identifisert med bakgrunn i hensyn til viktige interesser som shipping, petroleumsvirksomhet og fiskeri, samt miljøhensyn. Det ble i 2012 gjennomført strategisk konsekvensutredning for alle de 15 områdene. Utbygging av havvind ble ikke frarådet i noen av dem.

Før områder kan åpnes må det gjennomføres en strategisk konsekvensutredning.

SUMMARY & CONCLUSIONS

With proper planning and mitigation measures it is possible to construct offshore wind farms without significantly damaging the environment.

This report has provided an overview of potential environmental impacts of offshore wind power generation. The conclusion, that it is possible to construct offshore wind farms without significantly damaging the environment, is supported by the results from environmental impact assessments (EIA) conducted over several years at Horns Rev offshore wind farm in Denmark. However, these results are not necessarily transferable to other geographic areas, and the cumulative impacts of new offshore wind farms have not been thoroughly addressed for the North Sea. Effective cross-border co-ordination of plans and projects such as the development of offshore wind farms, the European integrated offshore grid and the efficient development of Marine Protected Area networks will be essential to develop more offshore wind while minimizing the environmental impact.



CO-ORDINATION ACROSS BORDERS IS ESSENTIAL

There are still large knowledge gaps in the field of environmental impacts of offshore wind. The considerable lack of baseline data is a significant impediment to the evaluation of impacts. Environmental impact assessments require solid baseline data on the state of the marine environment in order to serve as a basis for comparison over time following construction. This may include information on the distribution of important and vulnerable species and habitats, as well as migration routes of birds, fish and marine mammals. Baseline research is thus needed on species distribution and abundance over annual cycles, population structures and status, in addition to assessments of ecosystem dynamics and cumulative effects of multiple impacts.

In some countries EIA standards require up to two years of data on the state of the marine environment before construction can be approved. However, even these time frames may not be sufficient to fully understand the variability over different seasons and over several years at ecosystem level, or at species level. The quality of the EIA is largely influenced by the existing baseline data since "Before-After-Control-Impact" studies are often used as a standard approach. However, a growing number of offshore wind-related environmental studies are being conducted, suggesting that more of the reliable baseline data needed will soon become available[18].

The empirical results presented in this report largely stem from monitoring programs in the North Sea. Results from these sites should not be interpreted as necessarily being applicable to other regions in the world. The large variations in species and habitat types, as well as numerous other factors, limit the applicability of results from one region to another[19].

Appropriate mitigation measures should be further developed as more results from research on environmental impacts become available. The following section presents a selection of mitigation measures currently being applied or developed.

Potential synergies between offshore wind farms and other projects or stakeholders utilizing the same areas should be explored and developed. An example of integrating aquaculture with wind farms is discussed. Finally, three specific recommendations are presented.

Wind turbines funnel wind from the Columbia River Gorge, Washington-Oregon border, United States.

Potential for habitat enhancement

Hard substructures introduced into the marine environment, for example as a result of wind farm development, often end up functioning as artificial reefs[20]. The ecological progression following the submersion of such substructures can lead to an increase in species diversity[21]. One of the most important reasons for high fish abundance recorded in many offshore wind farms is the increased production and availability of benthic prey species in connection with the "reef" infrastructure. Additionally, the exclusion of trawling activities in and near wind farms is a major contributing factor to their high biological productivity[22].

The establishment of wind farms may thus in some cases be considered an enhancement of the marine environment, due to the increased biological productivity that ensues. While such habitat enhancement in general may have only a negligible effect on species populations, for some vulnerable species providing a protected and productive habitat may be significant[23].

This report highlights a few options for optimizing marine habitats for increased biological production through wind farm development.

To mitigate seabed erosion around the wind turbine foundations "scour protection" is commonly applied. It can be designed to cater to specific species' needs in terms of refuge or foraging, thus increasing the species viability.

Species attracted to reef-like habitats may not colonize or survive in wind farms if the distance to other similar reef-like habitats is too great. By placing additional reef patches in close proximity to the wind farm the connectivity between habitats is increased, which may lead to greater biological productivity over a larger area[24]. However, concern has been raised about introducing artificial reefs, as they might serve as stepping stones for invasive species infiltrating and dominating habitats of native species[25].

Thus, thorough impact assessments must always evaluate and clarify the risk of species dispersion in relation to the wind farm infrastructure, as well as to any additional reef patches in nearby areas, before any development is initiated.

SOFT-STARTING TECHNIQUES GIVE MARINE MAMMALS AND FISH AN OPPORTUNITY TO MOVE AWAY

Reducing impacts of construction noise

The construction of offshore wind farms generates noise that poses a potential threat to fish and marine mammals. Impacts from noise include forced movement out of foraging or reproductive areas, temporary hearing loss and disorientation for marine mammals and fish, as well as tissue damage and even death for fish[26]. A number of mitigation measures have been proposed to reduce such negative impacts.

To reduce the likelihood of displacement during important reproductive periods for various species, habitat use and migration patterns must be considered, and both construction and decommissioning activities should be avoided within the relevant periods.

In order to avoid injuries from intense sound pressures from pile driving activities, the use of the "soft start" technique has become standard practice. Pile driving starts at a low intensity while increasing to full strength over 15 – 20 minutes, thus giving marine mammals and fish an opportunity to move away.

"Pingers" have also been employed. A pinger is a device that transmits an acoustic signal underwater. The pingers' signal has been shown to scare away both fish and marine mammals before construction, thus reducing their exposure to the intense noise from pile driving.

NATIONAL GEOGRAPHIC STOCK / SARAH LEEN / WWF

A fourth mitigation measure that has been suggested involves covering the pile driving area with sound-protective materials, thus reducing the noise volume. Applying a curtain of bubbles for protection has been shown to halve the sound intensity of pile driving. However, this measure is dependent on weak water currents to be applicable[27].

Reducing impacts on birds

There are a number of potential negative impacts of offshore wind power development on birds. These include displacement from existing habitats, risk of collisions with wind turbine blades, and wind farms as migration barriers for birds[28].

To avoid displacement, certain areas should not be developed. Even though some bird species have been shown to adapt to wind parks, many vulnerable species may be severely impacted if wind parks are established in their traditional feeding or breeding areas. However, such areas can be challenging to identify. Developing a science-based vulnerability index of birds may serve to meet this challenge[29]. Building offshore wind farms in deeper waters and further offshore may reduce the loss of habitat for birds, as such areas often constitute more meagre feeding opportunities[30].

IMPORTANT MIGRATION CORRIDORS MUST BE LEFT OPEN AS “BLUE CORRIDORS”

Wind farms may also constitute a barrier between nesting sites and foraging areas, leading to a fragmentation of the birds' habitat. To reduce negative impacts on diurnal migrating birds wind farms should not be developed in migration flyways of vulnerable bird species. Additionally, the risk of overlap with such areas may be mitigated by keeping several kilometer-wide corridors open adjacent to or within the wind farms[31]. Several studies have shown avoidance behavior by migrating birds after the construction of offshore wind farms. It has been suggested that the detour caused by wind turbines is insignificant compared to the total length of migration[32].

While some studies show that loss of birds due to collisions with offshore wind turbines do not have significant impacts on current populations, the cumulative impacts over time of such loss on bird populations is more uncertain[33]. Fully utilizing currently available mitigation measures, as well as integrating cumulative impact into environmental assessments are two measures recommended to reduce the rate and scale of bird loss over time due to collisions with offshore wind turbines.

To further reduce bird collisions, proper spatial planning that takes into account important migration corridors is important[34]. Lastly, it has been shown that reducing the level of illumination[35] or adjusting the color spectrum of lighting used may reduce the attraction of birds to offshore wind farms[36].

Potential synergies

The large expansion expected for offshore wind-power development in the near future has spurred innovative ideas on how to take advantage of marine space more efficiently. One of these multi-use concepts involves the production of human food or animal feed in offshore wind farms[37].

Aquaculture has seen substantial growth in recent years and now accounts for more than 47 percent of the global supply of sea food[38]. However, there are a number of environmental and human health concerns related to aquaculture. Almost all of current sites used for aquaculture are situated along the coast, within 3 nautical miles of the shore[39]. In many countries regulations and restrictions have limited the expansion of aquaculture in near-shore areas[40]. Options to move aquaculture further offshore, to avoid coastal vulnerabilities and competition for space, are therefore being explored, including in Norway. However, as in coastal areas, aquaculture in offshore areas will also have to compete for space with other activities

and stakeholders[41]. Additionally, the high-energy environments at offshore wind-power sites pose significant technical challenges to currently employed aquaculture structures and techniques[42].

The integration of aquaculture in offshore wind farms may have a number of positive benefits. Offshore wind turbines and the corresponding scour protection take on the function of an artificial reef when deployed at sea. The natural ecological progression witnessed at many offshore wind farms following construction suggests that a favorable environment for invertebrates as well as fish is prevalent[43], which should also prove beneficial to aquaculture development.

OFFSHORE WIND-POWER MAY BE COMBINED WITH FOOD PRODUCTION OR OTHER MULTI-USE CONCEPTS. BLUE MUSSELS CULTIVATED OFFSHORE HAVE LESS PARASITE INFECTIONS THAN AT NEAR-SHORE SITES.

A major issue for aquaculture operations is water quality. Compared to near-shore areas the water quality further offshore is generally better[44]. Blue mussels cultivated offshore have been shown to have significantly less parasite infections than at near-shore sites[45].

The development of assemblages of benthic species on the wind turbine foundations may constitute a significant operational hazard. The total weight and mass added by marine organisms puts the towers under additional pressure from the water movement in addition to facilitating corrosion[46]. However, the biomass on structures such as bridge pilings, offshore wind, and buoys does generally not increase to any significant extent after 1-2 years of construction[47]. The foundations must periodically be cleaned[48]. However, if cleaning is combined with cultivating and harvesting, costs of maintaining the structures can be reduced and economic benefit may be gained by taking advantage of the highly productive environment for marine species.

To implement the needed expansion of renewable energy production, while minimizing negative impacts on the environment, spatial planning and the use of environmental impact assessments must be improved and better coordinated.

Mussels *(Mytilus edulis)* grown near-shore in Bohuslän, Sweden.

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INTRODUCTION

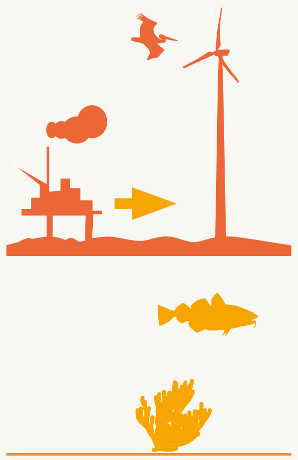
Transitioning from fossil to renewable energy is key to reducing the emission of greenhouse gasses and curbing the impacts of climate change.

Climate change is one of the main challenges facing the world today. According to the United Nations International Panel on Climate Change (IPCC) the emission of greenhouse gasses (GHG) throughout the last century constitutes a serious threat to infrastructure, human health and the survival of species and ecosystems on account of its disruptive effect on the world's climate system[1].

Wind power is generally recognized as one of the leading renewable energy technologies. However, allocating space for additional wind parks inland has proven to be challenging in many countries, as numbers of wind parks already exist, and accessible space is a limitation. While competition for suitable sites exists at sea as well, it is not as pressing as on land. Additionally, because of prevailing wind regimes, offshore sites generally provide more favorable conditions for wind power production. Offshore weather extremes however also pose challenges to construction and operation.

WWF firmly supports the development of offshore wind and views the technology as an essential part of the future 100 percent renewable energy mix[2]. The offshore wind market has shown high annual growth in the past several years and this growth is expected to continue. One of the biggest challenges to the global energy transition is to minimize the negative environmental impacts of new energy projects. For WWF it is essential to ensure that the transition does not destroy the natural ecosystems it was put in motion to protect. This report seeks to provide an overview of the latest research on the environmental impacts of offshore wind in order to inform decision-makers, planning authorities, and private developers, to support selection of the best projects, and to thus limit the negative impacts of such projects on the environment.

THE TRANSITION MUST NOT DESTROY THE ECOSYSTEMS IT WAS PUT IN MOTION TO PROTECT.



There are a number of potential environmental impacts of offshore wind development. This report provides an overview of the impacts on benthic species, fish, marine mammals, and birds that have been discussed in relation to offshore wind farms. The geographic scope of this report is the North Sea, but the report may also contain information of value to stakeholders in other geographic regions. The report presents a number of measures for reducing the environmental impacts, and highlights several benefits of offshore wind. Finally, three policy recommendations are suggested to stakeholders at EU and state level.

A vast amount of research has already been published, or is currently being conducted on issues related to environmental impacts of offshore wind. This report should not be treated as an exhaustive summary of the current state of knowledge. Rather, it may be seen as a continuation of and addition to earlier summaries, encompassing new, updated information.

Potential impacts on the marine environment

Currently, the majority of offshore wind turbines are installed on the sea bed using monopiles, a jacket, a tripod structure or suction buckets. Questions have been raised whether the sea bed disturbances during construction may have an impact on benthic communities. If this is the case, fish stocks may potentially suffer from a loss of food sources and as a consequence ecosystems may experience alterations in their productivity and composition[3].

INFORMATION CONCERNING THE EFFECTS ON WHOLE ECOSYSTEMS IS GENERALLY QUITE LIMITED

Noise generated during construction is also an issue of concern, especially the noise stemming from pile driving. It has been suggested that noise generated during construction may kill or injure fish and marine mammals, as well as cause temporary or permanent hearing loss and disorientation. Species may abandon areas ranging up to several kilometers from the construction site due to noise. This may in turn affect spawning and juvenile stages of many species[4].

Concern has also been raised about the risk of collisions with the wind turbine blades[5]. Additionally, questions have been raised about the potential risk of offshore wind farms posing a migration barrier for birds, as well as for marine mammals. While the turbines themselves may cause migrating birds to shy away from their usual routes, it has also been suggested that the sound from the turbines in operation may disturb the communication and navigation of marine mammals. Another risk that has caused concern is displacement of birds due to habitat loss. Studies have shown that several bird species avoid wind farm areas after construction[6].

While the oceans may seem endless, the useable habitat for several marine species is actually quite limited. Therefore, it is necessary to explore and mitigate the possible negative impacts of offshore wind farms on the marine environment. At the same time, it is important to bear in mind the critical need for developing more renewable energy production in order to halt global climate change which is the ultimate threat to the world's ecosystems.

Research status

While most research programs relating to environmental impacts of offshore wind are just being initiated or are in the early stages, some monitoring programs in Denmark, Belgium and Great Britain are already starting to produce post-construction results. However, much research is still limited to developing proper methodological approaches. There is a general tendency of studies and experiments to focus on single-species systems. Information concerning the effects on whole ecosystems is generally quite limited. Research on environmental impacts related to offshore wind development is currently being carried out primarily in European countries such as Denmark, Sweden, Belgium, Netherlands, the UK and Germany. However, the methodologies being developed are expected to be applicable to other marine environments around the world[7].

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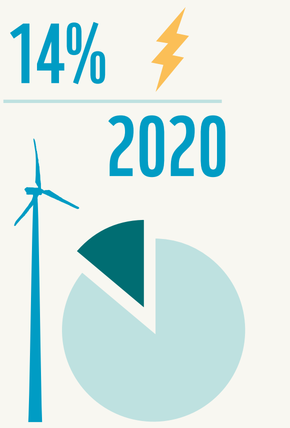
The oceans may seem endless, but the useable habitat for several marine species is quite limited. Norway lobster or Langoustine *(Nephrops norvegicus)*, Sognefjord, Norway

BACKGROUND

Use of wind power for electricity production has a long history in Europe, starting in the late 19th century Great Britain. However, it would take about 100 years before wind turbines became operational at sea.



Wind is believed to be able to contribute to 14 % of the electricity by 2020.

In 1991, the first offshore wind farm was inaugurated in Denmark featuring eleven 450 kW turbines comprising a total capacity of 4.95MW[8].

Throughout the 1990s, the offshore wind power sector grew at an irregular pace and consisted mainly of a small number of near-shore projects in Denmark and Holland with turbine capacity never exceeding 1 MW. After the turn of the century, the amount of new offshore wind capacity added to the European electricity grids has increased more rapidly every year[9].

European Climate Policy

In 2008 the European Union introduced policies to reduce greenhouse gas emissions by 20 percent, increase the share of renewable energy in the energy mix by 20 percent and increase energy efficiency by 20 percent by 2020. In order to meet the 20 percent renewable energy target the European Commission expects 34 percent of electricity to come from renewable energy sources by 2020[10] . Furthermore, wind is believed to be able to contribute 14 percent of the electricity by 2020[11].

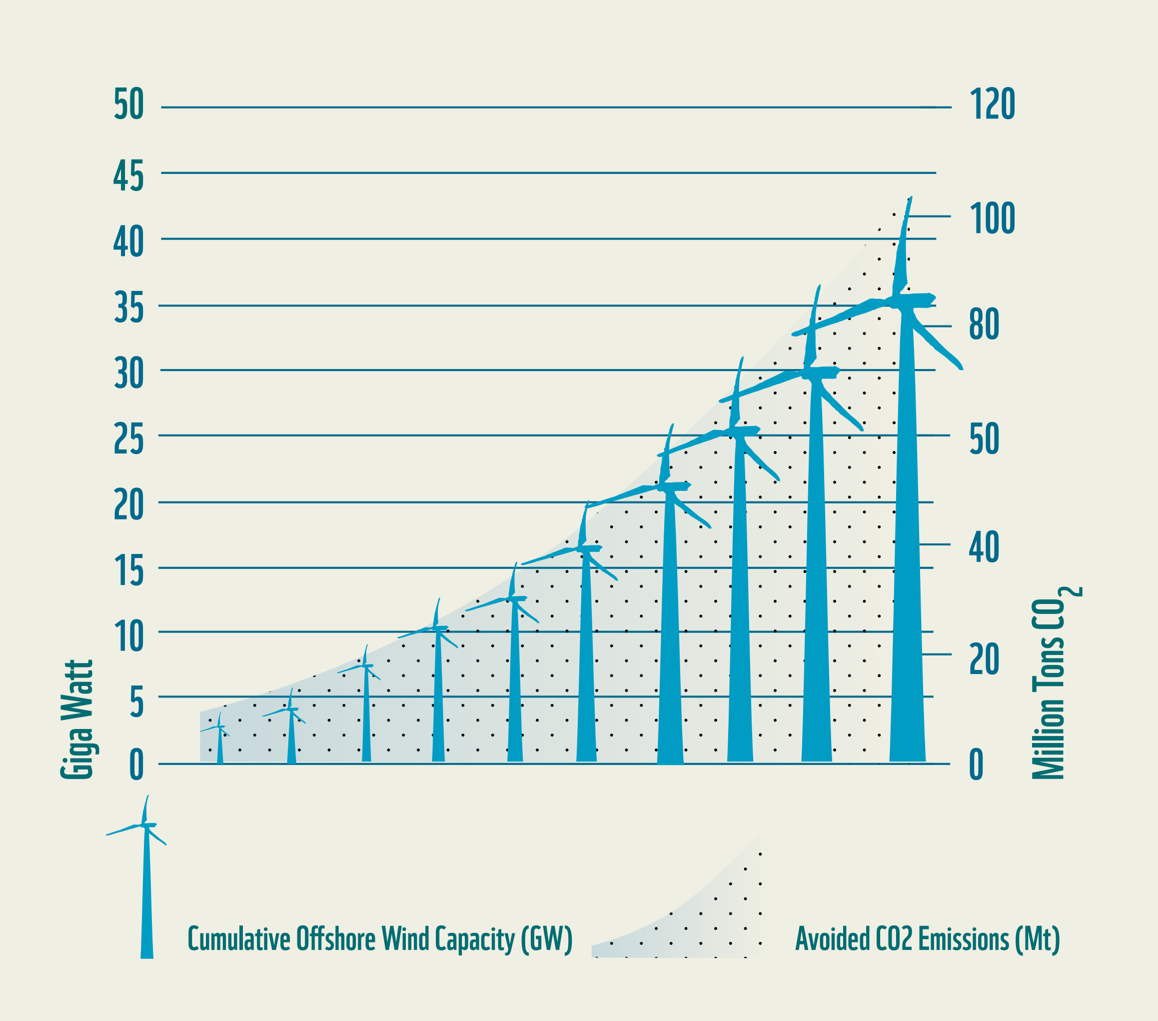
In 2013, the EU began the consultative process for negotiating a new climate and energy package for 2030. WWF has estimated that by 2030 Europe could use 38 percent less energy compared to a business as usual projection while generating more than 40 percent of its energy from renewable sources. In sum, this will allow for a 50 percent reduction in GHG emissions compared to 1990-levels[12]. By implementing these targets into the final climate and energy package, the European countries will make a strong commitment for reaching its goal of 80-95 percent reduction in GHG emissions by 2050 as set out in the European Energy Roadmap 2050.

Wind power market

Today the offshore wind market is booming. During the course of 2012, 293 new offshore wind turbines were installed in a total of nine fully grid-connected wind-farms. This newly added capacity of over 1000 MW represents an investment of 3.4 to 4.6 billion euros[13]. The offshore wind marked is expected to continue growing towards 2020.

As required by the EU's Renewable Energy Directive, all European countries have produced National Renewable Energy Action Plans (NREAPs), which provide an estimate of the share of each renewable technology in the energy mix from 2010 to 2020. According to the European Wind Energy Association (EWEA), the cumulative capacity of offshore wind in the NREAPs amounts to 43.3 GW by 2020[14] which represents a tenfold increase from the current level. In total, an estimated €65.9 billion will be invested in offshore wind turbines alone between 2011 and 2020[15].

Figure 1 Estimated Offshore Wind Capacity & Avoided CO2 Emissions



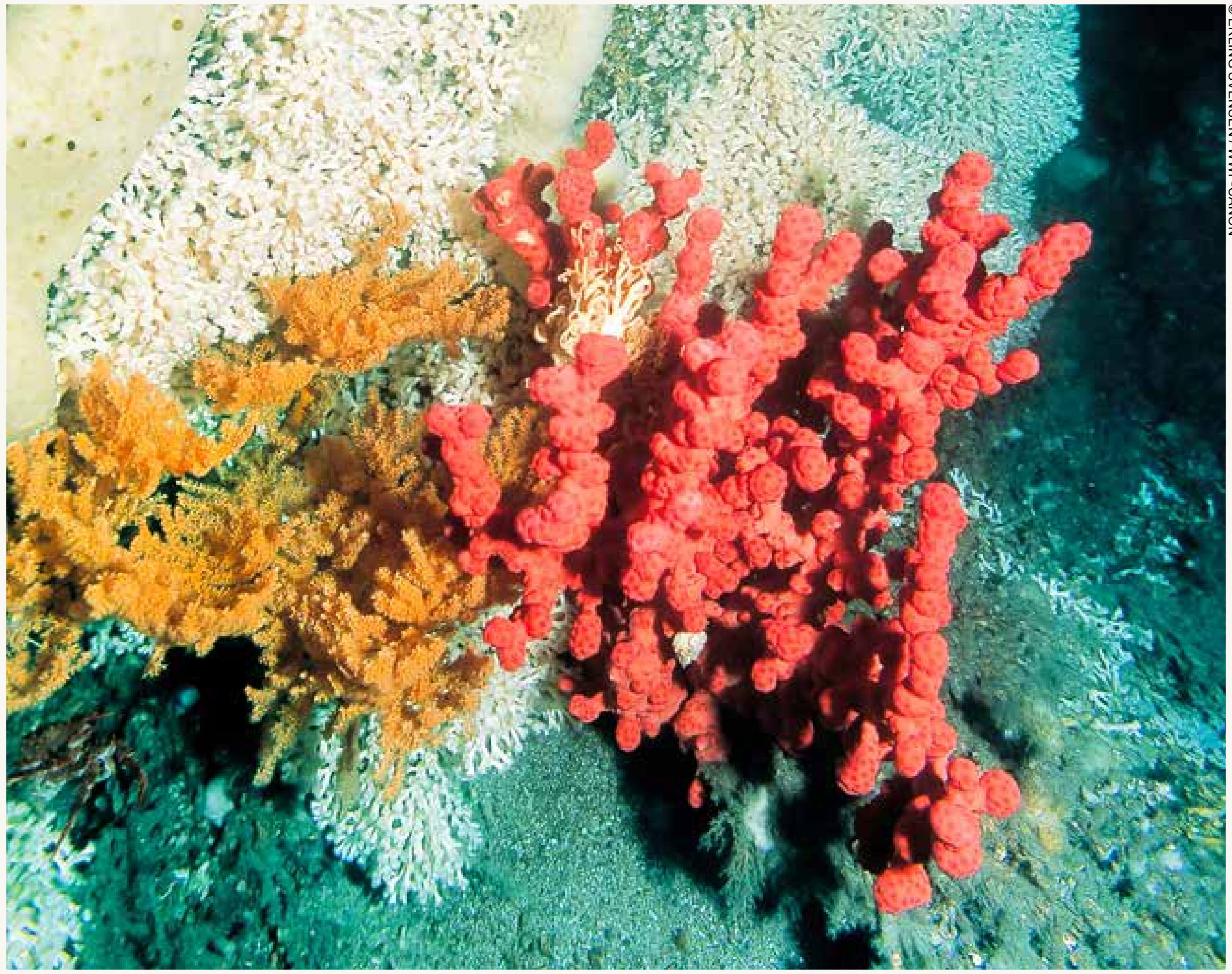
In 2011, offshore wind power avoided the emissions of 9.8 million tons of CO_2. Assuming the projected increase of installed capacity is realized, offshore wind will avoid 102.1 million tons of CO_2 in 2020. This reduction constitutes nearly twice the amount of Norway's yearly GHG emissions[16].
(Developed from Renewable Energy Action Plans presented in EWEA 2011: Wind in our sails – The coming of Europe's offshore wind energy industry)

Development trends in offshore wind

The offshore wind market is developing at a rapid pace. As the technologies mature and valuable experience is gained from the projects that have been implemented, the offshore wind industry is planning bigger farms in deeper water further from shore than ever before. While the majority of current wind farms have been installed up to 20 kilometers from shore in depths up to 20 meters, a large number of offshore wind farms consented or currently under construction are located in water depths up to 60 meters and up to 60 kilometers from shore[17]. As offshore wind turbines are currently being installed directly on the seabed, it is important to consider the potential environmental impacts on benthic communities.

BENTHIC SPECIES

Offshore banks are technically suitable for wind power development, but these habitats are also attractive for a vast variety of benthic communities.



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Deep-water coral *(Lophelia pertusa)* and Sea fan *(Paragorgia arborea)* in the "Selligrunnen", a protected cold-water coral reef in the Trongheimsfjorden, Norway. *Lophelia pertusa* is a colonial bank-forming species of ahermatypic coral, found in deep, dark, cold waters.

Because of technical and economic considerations, the preferred seabed types for construction of offshore wind farms are those consisting of sand or gravel with only dispersed boulders close to the site[49]. Such species seek refuge outwards from shore on account of pollution, eutrophication or other harmful human development. Potentially, offshore wind farms may thus provide a refuge for affected species. Furthermore, benthic species constitute an important food source for birds and fish[50].

The potential disruptive effects of wind farms are not thought to be confined to the specific areas encompassing wind turbines, but will impact a wider surrounding area, which may comprise a range of habitats from coral reefs and rocky bottoms to sandy shores and kelp forests[51].

Report

Construction noise

To date there is an overall lack of understanding of the effects of noise on invertebrates[52]. For fish and marine mammals concern has been raised about the construction and operational noise, but this has not been extended to include the various species of invertebrates. Despite the limited availability of empirical knowledge several reports have concluded that invertebrates are robust to noise from explosions or seismic shooting. However, while some molluscs like oyster *(Crassostrea virginica)* seem to be highly tolerant to severe noise, it has been noted that abalones *(Haliotis corrugate & Haliotis fulgens)* are more sensitive[53]. A recent study established the hearing capabilities of the longfin squid *(Loligo pealeii)*. The squid seems susceptible to stimuli from predators and prey as well as other natural sounds that aid navigation by this species[54]. Noise disturbing these natural sound cues may have a negative impact. Marine invertebrates constitute an important part of ecosystems and habitats. Also, they are a highly diversified group of organisms which makes generalizations about potential impacts difficult[55].

Hydrodynamics

The submerged parts of offshore wind substructures cause changes in the current regime, which may have long-lasting effects on the seabed sediment. The wind turbines are generally situated in shallow waters on soft bottom sea beds. Due to scouring effects around the turbines, localized erosion may occur where the seabed sediment is naturally mobile. Depending on a range of tidal and seasonal variations in currents, wave action and water level the scour may develop as deep as 1.38 times the monopile's diameter. On account of this effect, scour protection is often installed for structural stability and cable protection. However, the scour protection itself may cause secondary scour in the seabed at its margins. At some sites, the secondary scour has been deeper than at unprotected sites[56]. The altered hydrodynamics may in turn impact marine organisms by influencing larval recruitment, sedimentation, the availability of food and oxygen, and waste removal[57]. Effects on benthic species have been recorded some 15 meters from the turbines[58]. On the other hand, no distance-related effects on benthic species could be detected in the monitoring program at Horns Rev offshore wind farm in Denmark[59].

MARINE INVERTEBRATES CONSTITUTE AN IMPORTANT PART OF ECOSYSTEMS AND HABITATS

Sedimentation

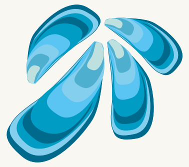
The construction of wind farms may cause particles to suspend and disperse. The concentration and radius will depend on the grain size, hydrodynamics and type of foundations deployed[60]. Increased sedimentation has been shown to decrease the biological diversity of an area[61]. For example, heightened levels of sedimentation have been shown to decrease fertilization in scleractinian corals *(Acropora digitifera)* as well as decreasing larval survival and settlement. Potentially, effects on coral communities could extend to adjacent locations as larva may be affected while passing through an impacted area[62]. Changes in the species composition may have significant effects on the functional traits of the ecosystems such as productivity, resistance to disturbance and susceptibility to biological invasion[63]. The effect of sedimentation will have varying impacts depending on a number of factors including intensity, spatial dispersal, particle size and life history of species[64]. It is also important to view the impact of sedimentation in the light of larger changes in the marine habitat.

Habitat change

The development of offshore wind entails some loss of natural seabed areas. It has been estimated that installing wind turbines and corresponding scour protection will result in the loss of 0.14-3 percent of seabed areas[65] with each turbine demanding around 450 square meters[66]. However, the introduction of hard substructures

1-2 TON

EACH TURBINE MAY SUPPORT AROUND 1-2 TONS OF BLUE MUSSELS



into the sea has shown that they function very much like artificial reefs, creating biological hotspots.

The settlement of microorganisms begins within a matter of hours, leading to the subsequent establishment of larger species in the ensuing weeks and months[67]. While the early phase of colonization is fairly predictable[68], the exact ecological development is more unpredictable, depending on seasonal variation in environmental conditions as well as levels of predation[69]. In the long term the timing of submersion does not seem to have any significant influence on the development of these communities[70]. While some suggest that age or type of substrate may influence the development of sessile communities[71], others suggest that the position of the structure in the water column is more important than age or type of substrate[72]. Comparisons between gravity foundations and monopiles have shown that of the total epifouling community over 50 percent of the species were shared between the two types of foundation[73].

Assemblages typically developing on wind turbine foundations are the same as those found on piers, namely filter feeding invertebrates. Several post-construction studies in Sweden, Denmark and the UK have observed two dominant assemblages: barnacles *(Balanus improvisus)* or blue mussels *(Mytilus edulis)*. The biomass of blue mussels was 10 times higher on wind turbine foundations than on bridge pilings and similarly for barnacles. This suggests wind turbines provide a particularly attractive substrate for blue mussels and barnacles. In fact, each turbine may support around 1-2 tons of blue mussels[74].

The mussels attached to the turbines provide refuge and food for small crustaceans and contribute to the biodiversity of macro-invertebrates. Furthermore, the waste material produced increases the abundance of other species. For example, small crustaceans may feed on the waste material of blue mussels while they in turn constitute prey for fish and other predators[75]. At the Egmond aan Zee offshore wind farm, significant development of hard substrate species were recorded. A total of 7.4 tons of mussels and 100 kilograms of small crustaceans and polychaete worms were estimated to have developed at the wind farm[76]. This constitutes a significant increase in food availability and may be seen as habitat enhancement.

The development of assemblages on the wind turbine structures may also pose a significant operational risk. The total weight and mass added by marine organisms adds additional pressure on the structure from water currents, in addition to facilitating corrosion[77]. Several studies suggest that the biomass on structures like

Fouling communities:

Fouling communities are assemblages of organisms living on solid substrates and fouling species can easily colonise newly deployed substrate. Typically there is a succession in species composition and abundance as the age of the deployed substrate increases. This succession is a result of species competing for space and equilibrium in fouling communities is generally not established within less than five years.

(From Danish Energy Agency, 2013. Danish Offshore Wind. Key Environmental Issues – a Follow-up.)

ARTIFICIAL SUBSTRUCTURES MAY ALSO FUNCTION AS STEPPING STONES FOR THE INVASION OF ALIEN SPECIES

bridge pilings, wind turbines and buoys does not increase to any significant extent after 1-2 years of construction[78]. On account of food and space limitations in addition to gravity and wave action, excess mussels may dislodge from the structures. Antifouling paints are usually not used on wind turbines, but periodic cleaning of the structures may take place, typically every two years[79]. An interesting idea noted in relation to this challenge is integrating aquaculture in offshore wind farms[80]. By taking advantage of the highly productive environment inside the wind farm marine organisms may be frequently harvested with a profit by aquaculture farmers while maintenance costs may be reduced for wind developers[81].

Research has shown that artificial reefs may have a restorative effect on degraded natural habitats. On the eastern Korean peninsula the loss of macroalgal habitat has been significant in later years. Efforts have been made to mitigate the losses. By deploying pyramid-shaped concrete blocks with kelp attached, artificial macroalgal beds have successfully been created, aiding recovery of the macroalgal community[82]. More research is currently being conducted to investigate species-specific habitat preferences in the design of foundations for offshore wind turbines in order to increase the biomass of desired species[83]. At Robin Rigg offshore wind farm in Scotland, the environmental impact assessment showed low levels of biological diversity. The post-construction monitoring analysis showed that biological diversity remained low one year after construction ended[84]. However, at Egmond aan Zee offshore wind farm in Dutch waters there was a recorded establishment of new species[85]. Furthermore, while no significant change in benthic community types was recorded at Robin Rigg during any of the survey periods the number of invertebrates did see a decrease after construction. However, this has been interpreted to be caused by natural changes and not by the construction of the wind farm[86]. At Egmond aan Zee there was no recorded short-term impact on the sandy bottom benthos[87]. This goes to show that even though the introduction of hard substructures often will enhance the biological diversity of soft bottom areas there is much variance in how this change will progress. Moreover, concern has been expressed that the hard bottom benthic species attracted to the wind farm will invade new territory adjacent to the wind farms.

ARTIFICIAL REEFS MAY HAVE A RESTORATIVE EFFECT ON DEGRADED NATURAL HABITATS

Stepping stones for new species

By introducing hard substructures into areas with soft bottom habitats, the species composition may be changed in an entire region because the hard structures function as stepping stones linking to natural hard bottom habitats[88]. Studies conducted on pier pilings and oil platforms suggest that artificially submersed structures may provide entry points for the invasion of alien species[89]. This may pose a risk to the local fauna as it has been shown that artificial structures changes the competitive interaction between species. As a result alien species have been found in higher numbers at artificial reefs[90].

While a general enrichment effect has been documented in the area surrounding the gravity-based wind turbines at Thortonbank offshore wind farm[91], a recent study has recorded such a spatial expansion effect onto the soft sediment benthos up to 50 meters from the erosion protection layers. Furthermore, this expansion may not subside as the fining of the sediment and the increase in food availability continues in the years to come. Bearing in mind that the distance between the protection layers are only 350 meters a total coverage between the turbines may not be ruled out[92].

In studies from Denmark and Sweden, two out of three non-indigenous species recorded on wind turbines dominated their respective sub-habitat[93]. Concern has been raised for the impact of new hard bottom species on the native hard bottom species in habitats adjacent to offshore wind farms[94]. While the significance of this

ARTIFICIAL REEFS

The introduction of hard substructures into the sea has shown that they function very much like artificial reefs, creating biological hotspots. Artificial reefs may have a restorative effect on degraded natural habitats, but artificially submersed structures may provide entry points for the invasion of alien species. Artificial reefs have been deployed all over the world for a number of different reasons. To a limited extent, artificial habitats have been constructed to restore degraded natural habitats and fisheries. To a higher extent artificial reefs have served to promote aquaculture, enhancement of recreational activities, eco-tourism, commercial fisheries production, protection of benthic habitats against illegal trawling, and research. Moreover, the artificial structures deployed are often designed in a manner seeking to cater to specific species.

This is artificial reef balls about 10 years old underwater. Buyat Bay, North Sulawesi, Indonesia. 16 October 2009.

potential impact will differ considerably between different regions, geographies, hydrologic regimes, species composition and seabed types etc., there is a general lack of research to fully evaluate its potential impact[95].

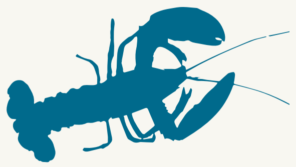
NO SIGNIFICANT REACTIONS WERE RECORDED AFTER EXPOSING PRAWNS TO THE ELECTRICAL MAGNETIC FIELD

Electromagnetic fields

In relation to offshore wind farms there are two major sets of electricity cables: the internal grid between the turbines, and the export cable (usually one but sometimes more) transmitting the electricity generated from the wind farm to the electricity network on land. The orientation of fish may be impaired by the magnetic fields surrounding electric cables and thus impact migration patterns[96].

Electricity produced at offshore wind farms is usually transmitted to shore through high voltage alternating or direct current cables. The current in these cables creates electric and magnetic fields (EMF). While the electric field generated by the current is isolated within the cable, the magnetic field is measurable around the cable. The magnetic field in turn induces an electric field in the environment. Such electric fields are also induced by water and marine organisms within the magnetic field[97]. An increase in voltage will cause a stronger electric field. Similarly, an increase in current will give a stronger magnetic field. While the field created by an alternating current (AC) system will reverse itself at the same frequency as the current, the field created by a direct current (DC) system will be constant. Regarding the environmental effects of EMF there is not enough information to sufficiently evaluate the differences between AC and DC systems[98]. Little has been done to investigate electromagnetic reception in invertebrates[99]. While several vertebrate species have been shown to possess the ability of geomagnetic navigation, experiments with lobsters have now demonstrated a similar ability in invertebrates[100]. Concern has been expressed about crustaceans' sensibility to EMF influencing their ability to locate food, and causing avoidance or attraction responses. Preliminary results from a recent study indicate that subtle changes in behavior do occur, but that these are not statistically significant[101]. Another study investigated the impact of EMF on mussels *(Mytilus edulis)*, prawns *(Crangon crangon)*, isopods *(Saduria entomon)* and crabs *(Rhithropanopeus harrisii)*. However, no significant reactions were recorded after exposure to the electrical magnetic field[102].

CONCERN HAS BEEN EXPRESSED ABOUT CRUSTACEANS' SENSIBILITY TO EMF INFLUENCING THEIR ABILITY TO LOCATE FOOD, AND CAUSING AVOIDANCE OR ATTRACTION RESPONSES



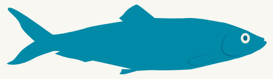
Preliminary results from a recent study indicate that subtle changes in behavior do occur, but that these are not statistically significant[101]. Langoustines (aka Norway lobsters, Dublin Bay lobsters, or Scottish prawns) landed in the newly developed creel pots with blue escape taches for young, small langoustines. MSC certified fishery. Sheldaig, West coast of Scotland.

FISH

Offshore wind farms may have both negative and positive impact on fish.

There are a number of potential impacts of offshore wind on fish. Concern has been raised about displacement due to operational noise during construction, disturbance from sedimentation, habitat changes, and avoidance and attraction effects due to electromagnetic fields. On the other hand, several studies have also pointed to potential benefits of offshore wind farms for fish. These include enhanced biological productivity and improved ecological connectivity on account of trawling exclusion and the functioning of wind turbines as artificial reefs.

VULNERABILITY TO NOISE VARY A LOT BETWEEN DIFFERENT SPECIES. HERRING HAS PREVIOUSLY BEEN IDENTIFIED AS BEING PARTICULARLY SENSITIVE TO NOISE



Construction noise

During the last few decades there has been a surge of human activity generating underwater noise[103]. The potential effect of anthropogenic sound on fish includes the disruption of communication abilities and detection of the acoustic surroundings[104]. Additionally, the impacts of intense sound sources like seismic air guns or pile driving may cause behavioral changes including displacement from foraging or reproductive areas, temporary hearing loss, tissue damage and imminent death. While hearing and the processing of sound may differ widely between different species[105], species differences in the detection and disturbance effect of wind power construction noise - as well as noise effects from boat traffic, pile-driving and seismic surveys - are largely unexplored[106].

The response of fish has been found to depend on a number of factors including life cycle stages, such as spawning periods, and body size. Variation between different species is especially high[107]. Sound levels increasing the hearing threshold of cod *(Gadus morhua)*, salmon *(Salmo salar)* and sole *(Solea solea)* have been shown to cause avoidance behavior[108]. However, there is also evidence of cod and sole adapting to pile-driving sounds over time[109]. Moreover, small-bodied demersal fish have been recorded in abundance near wind turbines two years after pile driving has taken place[110].

The large variance in noise vulnerability between fish species and the timing of construction activities may influence the impact of offshore wind farms. Herring *(Clupea harengus)* has previously been identified as being particularly sensitive to noise[111]. As potential spawning habitats for herring lie within a zone of harmful noise on the western part of Scroby Sands offshore wind farm, including about 30 percent of the wind turbines, the construction noise may have negatively affected a significant part of the herring population in this area. The herring population experienced reduced recruitment over several seasons after the construction of the offshore wind farm. Two possible explanations have been suggested; direct mortality of the adult stock during pile driving or displacement leading to longer-term abandonment of the spawning area[112].

Sedimentation

The construction of wind farms may cause sediment particles to suspend and disperse. The concentration and radius of the effects will depend on the grain size, hydrodynamics and type of foundations deployed[113]. Increased sedimentation has been shown to decrease the biological diversity of an area[114]. Changes in species composition may have significant effects on the functional traits of ecosystems such as productivity, resistance to disturbance and susceptibility to biological invasion[115]. The effects of sedimentation will have varying impacts depending on a number of factors including intensity, spatial dispersal, particle size and life history of species[116]. Another feature of sedimentation that constitutes a risk to fish is clogged gills leading to respiratory problems and inhibited feeding. However, this may be a particular concern for smaller species and larvae[117]. While turbidity may cause avoidance behavior by some fish species[118], other studies have shown that several species thrive in turbid waters, presumably on account of reduced predation[119]. Several recent studies related to sedimentation effects of offshore wind farm construction have shown similar results. In Sweden, at a distance of 150 meters from dredging activities no negative effects were found on juvenile or adult fish[120]. Furthermore, the Danish Monitoring Programme only recorded short-term and local impacts of sedimentation on benthos[121]. Moreover, case-specific models of the distribution and concentrations of sediments have shown no impact on adult fish while indicating limited impact on larvae with no large consequences[122].

Habitat change

By introducing hard substructures into the sea these take on the functions of artificial reefs. The introduction of hard materials into the sea will lead to the settlement of marine organisms within a short amount of time. In the ensuing weeks and months there is an ecological progression, increasing the species diversity[123].

While there are studies that have revealed no significant difference of fish assemblages around artificial reefs[124], a vast array of evidence suggest that artificial reefs generally support higher densities of fish and biomass than soft bottom habitats. In some cases, this is also the case when compared to adjacent natural reefs[125]. A number of factors have been pointed out as important for the success of submersed structures in forming artificial habitats. These include enhancing the protection and food availability for fish in addition to serving as reference points for spatial orientation[126].

While artificial reefs usually refer to structures designed to achieve this specific end, structures such as piers and oil platforms may be described as secondary artificial reefs[127]. Such secondary structures have proven to attract a variety of fish and invertebrate species[128]. Offshore wind turbines and the scour protection used to hold them in place may serve a similar function. Several studies suggest that these structures enhance the fauna community, virtually creating "hot-spots" of biological activity[129]. At Robin Rigg offshore wind farm in Scotland, a monitoring program showed a decrease in the number of fish during construction, but an increase to nearly pre-construction levels one year into operation[130]. However, whether artificial reefs actually enhance productivity and thus produce more fish or simply attract existing fish is still being discussed in the literature. Definitely, for certain species, and in certain regions, artificial reefs may simply redistribute existing fish biomass[131].

More research is being conducted to investigate species-specific habitat preferences in the design of foundations for offshore wind turbines in order to increase the biomass of desired species[132]. However, earlier research has suggested that the configuration of scour protection in terms of density and void space is important. For example, frond mats that function like sea grass beds have been shown to provide nursery habitats for juvenile fish. In fact, it has been suggested that the loss of habitat caused by the installation of wind turbines may be compensated up to 2.5 times by new habitats created in the process even though the new habitat will be of a different character[133]. Thus, while development of offshore wind farms may entail some habitat loss, the corresponding biological development may expand the habitat available for many species.

Report

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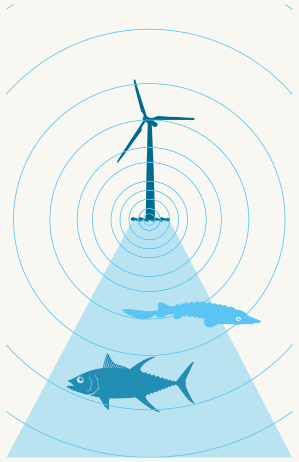
Herring *(Clupea harengus)*, an ecologically and commercially important species, has previously been identified as being particularly sensitive to noise. Swimming in a large ball provides safety in numbers against predators. The phenomenon is known as schooling. This group of herring in the Strait of Georgia, British Columbia, Canada has synchronized their swimming and formed a school.



FISH MAY DETECT NOISE FROM WIND TURBINES VARYING BETWEEN A FEW HUNDRED METERS TO 25 KILOMETERS

Operational noise

Less intensive than construction noise but longer lasting are the sounds from wind turbines in operation[136]. The operational noise stems from vibrations in the tower caused by the gearbox mesh in addition to the generator, causing underwater noise[137]. While this is not thought to be deadly for fish it has raised concern that it may be masking biologically important sounds, causing hearing loss and raising stress levels leading to reduced immune system functions[138]. The distance from which fish can detect wind turbine noise depends on a number of factors including the number and size of the turbines, the hearing capabilities of the fish species, other forms of background noise, wind speed, water depth and type of sea bottom[139]. Estimations from several studies suggest that different fish species may detect noise from wind turbines varying between a few hundred meters to 25 kilometers[140].

The experimental work that has been conducted on impacts of operational noise from wind turbines on fish has not found any indications of behavioral or psychological reactions[141]. However, increased respiration in flatfish has been registered in laboratory testing simulating the operational noise from wind turbines[142]. On the other hand, in harbour areas and in association with other human activities such as boat traffic it has been shown that fish have been able to acclimatize to continuous operational noise[143]. Another study has shown that even though fish may be disturbed by the noise from wind turbines, it does not constitute a sufficient distraction to abandon a preferred habitat[144].

Electromagnetic fields

Fish species that employ electrical currents for orientation such as sharks and rays, eels and electric fish are the most sensitive. It has been suggested that many such species may be able to detect EMF at a distance over 300 meters[145]. While the small spotted catshark (*Scyliorhinus canicula*) has been shown to keep away from induced electric fields at a certain level[146], more recent experiments have shown other forms of behavioral responses, including attraction to cables, for other types of sharks and rays[147]. Other studies have shown that EMF may affect migration behavior in salmonoids *(Salmonidae)*[148] and eels *(Anguilla anguilla)*[149]. However, it has also been suggested that this effect may constitute a relatively trivial temporary change in swimming direction[150].

The monitoring program at Horns Rev in Denmark did indicate some effects on migration patterns for eelpout *(Zoarces viviparus)*, cod *(Gadus morhua)* and flounder *(Platichthys flesus)*[151]. Moreover, field studies have shown changes in behavior and migration of marine animals[152]. On the other hand, it has been suggested that the survey design for this study was not adequate to firmly link these effects to EMF[153].

At Robin Rigg offshore wind farm in Scotland, surveys conducted before and after construction as well as during operation showed an increase in the number of electro-sensitive species along the cable route. This may suggest an attraction effect of EMF. However, surveys from control sites displayed a similar increase, suggesting an overall population increase of elasmobranches in the area[154].

© ERLING SVENSEN / WWF-CANON

European eel *(Anguilla anguilla)*, Hardanger, Norway

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A helicopter lowering a technician to maintain the Horns Rev wind farm, Esbjerg, Denmark.

CASE EXAMPLE: HORNS REV, DENMARK

In Denmark the first long-term studies of fish development after the construction of offshore wind farms have been conducted by the Danish Energy Agency. After the construction of Horns Rev offshore wind farm in 2003 changes and differences in the composition of fish species and abundance has occurred. While 41 species were registered inside Horns Rev, only 30 different species were registered at the reference area outside the wind farm. Moreover, before the construction of the wind farm, fish abundance was usually higher in deeper waters. However, as the abundance of fish inside the wind farm increased, the fish distributions in deeper and shallower water became more similar[134].

The fouling communities that colonized the wind turbines and the surrounding scour protection provided good feeding opportunities for a number of foraging fish. For example, pouting (*Trisopterus luscus)* has been found around the turbines feeding on small crustaceans, and the goldsinny wrasse (*Ctenolabrus rupestris*) is known to feed on common mussels, both of which are found in billions inside the wind farms at Horns Rev. Moreover, it has been registered that fish often migrate out of the wind farm into deeper water in search of food during the night, while staying inside the wind farm during the day. Even though the wind farm provides a diverse habitat, this migratory pattern suggests that fish are still dependent on areas outside the wind farm[135].

MARINE MAMMALS

There are a number of potential impacts of offshore wind on marine mammals. The main concern is related to habitat change, displacement or injury on account of construction and operational noise, as well as avoidance or attraction to electromagnetic fields. On the other hand, several studies have also pointed to potential benefits of offshore wind farms for marine mammals. These include enhanced biological productivity and improved ecological connectivity.

Construction noise

There has been a surge of human activity generating underwater noise during the last few decades[155]. Studies have shown that construction noise related to offshore wind farms (especially pile driving) may cause behavioral changes in seals *(Phoca vitulina* and *Halichoerus grypus)*[156], porpoises *(Phocoena phocoena)*[157] and dolphins *(Tursiops truncatus)*[158]. Disruption effects have been measured up to 20 kilometers from the pile driving site[159]. Most countries surrounding the North Sea have therefore introduced strict regulations about pile-driving, designed to protect any marine mammals that may be present.

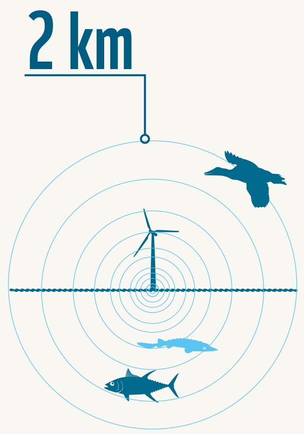
The construction of the first large-scale offshore wind farm, Nysted, in the Danish part of the North Sea was started in 2002. A study was conducted to investigate whether the Harbour porpoise *(Phocoena phocoena)* occupying the area would remain or leave the area as noise levels increased considerably. The study recorded less echolocation activity during construction and concluded that the porpoises abandoned the area, with effects being recorded up to 15 kilometers away[160].

At another offshore wind farm in Denmark different results have been recorded during the construction period. At Horns Rev harbour porpoise *(Phocoena phocoena)* were recorded returning after only a few hours[161]. While harbour seal *(Phoca vitulina)* also left the area during pile driving activities, individuals were recorded foraging inside the wind farm after construction in relatively the same numbers as adjacent areas[162]. However, the Monitoring Program at Horns Rev concluded that while pile driving activities had clear yet short-term effects on the porpoises the overall construction phase had no or weak effects[163]. However, if construction does not take appropriate seasonal prohibitions into consideration, any species relocation may have a severe impact on nursery habitats[164]

At Robin Rigg offshore wind farm in Scotland, the monitoring program notes a short-term displacement effect on Harbour porpoise. Furthermore, observations of grey seal *(Halichoerus grypus)* across the study area decreased during construction, but because of the low numbers of observations any displacement effect could not be attributed to construction activities even though this may be likely[165]. Moreover, at Scroby Sands offshore wind farm in England a general decline of harbour seals *(Phoca vitulina)* was recorded. The wind farm is situated close to a haul-out and breeding area for harbour seal. The study states that the decline could not be explained by environmental factors or a general population decline. Furthermore,

Bryde's whale *(Balaenoptera brydei/edeni)* swimming over a bait ball of Sardines, three ridges on forehead that distinguish the Bryde's whale from other mysticetes are prominently visible. Off Baja California, Mexico *(Eastern Pacific Ocean)* visible in this photo

The Krakken, a jack up barge, that is constructing the wind turbines of the Walney offshore windfarm. The farm consists of 102, 3.6 MW turbines, giving a total capacity of the Walney project of 367.2 MW, enough to power 320,000 homes. The rotor diameter of the turbines is 107m for Walney 1 and 120 m for Walney 2. The wind farm is owned and constructed by Dong Energy. Cumbria, UK.



DISRUPTION EFFECTS HAVE BEEN MEASURED UP TO 20 KILOMETERS FROM THE PILE DRIVINGSITE

the study suggests that the noise from pile-driving displaced the harbour seals while rapid colonization by the competing grey seal as well as increased noise from vessels prevented the harbour seal from re-establishing at the site[166].

Operational Noise

The estimates for the distance at which seals and porpoises can detect the operational noise from offshore wind turbines ranges from 100 meters to several kilometers for seals and 20 to 70 meters for porpoises[167]. Another study states that the reported noise levels from offshore wind turbines are low especially considering the current levels of noise caused by other human activities such as shipping. Furthermore, based on the existing knowledge of hearing threshold of four representative species of porpoises *(Phocoena phocoena)*, dolphins *(Tursiops truncatus)*, whales *(Eubalaena glacialis)* and seals *(Phoca vitulina)* the impact of operational noise from turbines is likely to be none or low[168].

While seals and porpoises have displayed distinct reactions to simulated sounds from 2MW wind turbines this was not considered to be fear-driven behavior. In fact, echolocation activity increased when simulated sound sources were active suggesting exploratory behavior by the porpoises[169].

At Robin Rigg offshore wind farm in Scotland, no changes were found in numbers of harbour porpoise and grey seal between development phases. However, the preliminary monitoring report states that there is insufficient data to conclude on the wind farm's effect on marine mammals[170].

Another study has investigated the long-term effects at Nysted offshore wind farm. After ten years of operation, the density of porpoise activity had not increased to more than 30 percent of its baseline level[171]. While this study may provide information on the density of porpoises before and after construction it cannot causally link avoidance behavior to noise related to the wind farm. As suggested by the authors and indicated by another study[172], the porpoises may simply not be very interested in the area to begin with. Thus, when noise is introduced they will choose to leave. On the other hand, in other areas porpoises may choose to stay despite the disruption of wind farm noise[173].

At Horns Rev Offshore wind farm, the results were different. The average density of porpoises decreased during construction and semi-operation (period following construction with intensive maintenance and service operation). However, porpoises were recorded inside the wind farm after only a few hours following construction. During operation the average density of porpoises returned to baseline levels[174].

CONSTRUCTION MUST TAKE APPROPRIATE SEASONAL PROHIBITIONS INTO CONSIDERATION

While porpoises may become accustomed to the operational noise of offshore wind and have small to no effect on the population at large the cumulative effects of human activities may result in large reductions in the population. In a simulated model of population size in inner Danish waters the effects of wind farms, by-catch in commercial fisheries and noise from shipping were evaluated. The population size dropped 10 percent in the scenario including wind farms compared to the reference scenario. The population size did not decrease further by the inclusion of shipping, but the factoring of 1.7 percent by-catch annually prompted another 10 percent decrease. This study demonstrates the importance of considering the cumulative impact of different human activities when evaluating the impacts on marine mammals. While none of the activities had any significant impact of the simulated population level in isolation, there was a large population decline when considered together. However, these results should be treated with caution bearing in mind that some of the key input parameters were based on limited data[175].

MARINE MAMMALS MAY BE ATTRACTED TO WIND FARMS ON ACCOUNT OF THE CONTINUED AVAIL-ABILITY OF PREY

Habitat change

Porpoise have been recorded feeding near oil rigs[176]. As the foundations and scour protection related to wind farms have been shown to share similar features of biological development as offshore oil rigs it is reasonable to expect that marine mammals may be attracted to wind farm areas. Other studies have suggested that seals *(Phoca vitulina)* [177] and porpoises *(Phocoena phocoena)*[178] may be attracted to wind farms provided that disturbance factors do not deter this behavior.

At Robin Rigg offshore wind farm in Scotland, the survey of fish populations did not reveal any significant negative impact on fish stocks. It is suggested that marine mammals may be attracted to the wind farm on account of the continued availability of prey[179].

A study from the Egmond aan Zee Offshore wind farm in Dutch waters compared baseline status of porpoise activity before construction and during operational state five years later. Monitoring was not conducted during the construction phase. This study shows that the abundance of porpoises has actually increased since the wind farm became operational. This is in line with an overall increase of porpoises over the last couple of decades in this area, but comparisons with control area points to a higher abundance within the wind farm than outside. A couple of factors explaining this increase are suggested by the authors. The development of biological hotspots inside the wind farm has increased the food availability while also providing shelter from the noise of vessels that traffic this part of the North Sea[180].

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A young harbour or common seal *(Phoca vitulina)* head portrait in kelp. Lundy Island, Devon, England, UK. Bristol Channel, North East Atlantic Ocean.

BIRDS

There are a number of potential impacts of offshore wind on birds. Concern has been raised about displacement on account of habitat change, risk of collisions with wind turbines and wind farms as barriers for diurnal as well as long-distance bird migration.

On the other hand, several studies have also pointed to potential benefits of offshore wind farms for birds such as enhanced biological productivity inside the offshore wind farm and provision of resting areas for certain species.

Habitat change

Behavioral responses to offshore wind farms may cause birds to avoid previously-used habitats. This phenomenon has been dubbed displacement. Additionally, the construction and operation of wind turbines may directly impact the availability of food, thus limiting the functioning of the birds' habitat[182]. One study looking into the displacement effect over time found evidence of habituation. Over the period of several years, pink-footed geese *(Anser brachyrhynchus)* were recorded foraging inside the wind farm after keeping a distance of several hundred meters[183].

At Robin Rigg offshore wind farm in Scotland, the monitoring program showed evidence of a decrease in the number of common scoter *(Melanitta nigra)* one year after construction. Furthermore, raw data for year one of operations suggests a 50 percent displacement rate of northern gannet *(Morus bassanus)* while an increase was recorded for great cormorant *(Phalacrocorax carbo)*. For all gulls *(Larus argentatus* & *Larus marinus)* combined, there was no recorded change in numbers. However, it is stressed that more data is needed to confirm all of these results[184].

At Nysted and Horns Rev offshore wind farms the most numerous bird species generally displayed avoidance behavior. The results also showed great variety in the responses between different types of bird[185]. On the other hand, it has been suggested that this study has not taken into consideration natural changes in the food supply thus weakening the conclusions of the study[186]. Furthermore, there were no signs of the wind farm leading to an increased use of the area for birds even though little gulls (*Hydrocoloeus minutus)* were recorded in higher numbers post construction than before[187].

In order to interpret the magnitude of potential habitat loss at population level it is important to evaluate the relative loss in relation to the potential feeding habitat outside the wind farm. For the Nysted and Horns Rev offshore wind farms the monitoring programs conclude that the impact of habitat loss is relatively small for most species of bird. However, it is necessary to take into consideration the cumulative effects of additional wind farms in nearby areas to avoid a significantly larger impact on bird populations[188].

A recent article looking to develop more concise methodology for assessing the impact of offshore wind on sea bird populations in Scottish waters presents a vulnerability index on displacement or habitat loss. The index takes into account the conservation importance of each species, disturbance by ship or helicopter

Breeding and wintering birds

European seas support large populations of breeding and wintering birds which makes these offshore areas important in an international context. As these areas are part of a global flyway system, every year tens of millions of birds follow these routes from breeding areas to wintering areas and back. Additionally, these waters harbour important foraging areas for many species of birds while also being in close proximity to large roosting areas .

Northern gannets *(Sula bassana)* colony, Saltee Islands, County Wexford, Ireland, June 2009.European

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Knot (*Calidris canutus)* flock flying in front of East Hoyle Windfarm, Wirral, UK. The knot has one of the longest migrations of any bird.

INDIRECT ECOSYSTEM EFFECTS ARE DIFFICULT TO CAPTURE

and flexibility of habitat use. Populations of divers as well as common scoter were identified as the most vulnerable[189]. These results are in line with previous findings on the vulnerability to habitat displacement[190]. On the other hand, such indexes comprise a limited set of factors that may neglect other potential impacts. For example, the impact of Scroby Sands offshore wind farm led to a shortage of young herring. As a consequence, a successful colony of little terns *(Sternula albifrons)* was negatively impacted[191]. While this vulnerability may have been compensated by habitat flexibility, indirect ecosystem effects are difficult to capture in this manner.

Risk of Collision

The impact of wind turbines on birds is the most researched area relating to wind power and the environment. The concern for birds colliding with the turbines prompted a special focus on the extent of this phenomenon and its related effects on population dynamics and migration[192]. The risk of collision will vary greatly depending on the site, species and season. In order to fully evaluate the biological impact of birds colliding with wind turbines the data must be seen in relation to population size of the specific species and the demographic characteristics of that particular species[193].

Onshore studies have suggested that raptors are more prone to collisions than other species on account of the abundance of individuals in close proximity to wind farms. However, other factors such as species-specific flight behavior, weather conditions and topography specific to each wind farm site have been suggested as more important[195]. Additionally, demographic characteristics of certain bird species, such as raptors, that lay few eggs, mature late and have a long life span, will lead to enhanced vulnerability to higher mortality rates at population level[196]. While raptor mortality may be of less concern at offshore sites, because raptors are not very common out at sea, this example shows the necessity of proper spatial planning taking into account the differing vulnerabilities of various species of bird.

An index has recently been created for estimating the collision risks for various bird species. The factors assessed included flight height, flight agility, time spent flying, night flight and conservation importance. The index identifies populations of gulls *(Larus argentatus, Larus marinus, Larus fuscus & Larus canus)*, white-tailed eagle *(Haliaeetus albicilla),* northern gannet *(Morus bassanus)* and skuas *(Stercorarius skua & Stercorarius parasiticus)* as the most vulnerable birds in Scottish waters[197]. However, several other factors that may play an important part in assessing the impact on birds were not captured by this index. For example, the potential for weather conditions affecting the collision risks for birds seems probable. Heavy rain or fog may be even more important explanatory factors of vulnerability than species-specific variance. On the other hand, it has been suggested that collisions resulting in deaths influenced by difficult weather conditions may not be as concerning as one might think because birds tend not to fly when weather conditions are poor. Migrating birds may be an exception since they do not know the weather conditions along the whole migration route when setting off – this is a subject of discussion at present. At Horns Rev offshore wind farm it was noted that waterbirds tended not to fly inside the wind farm at night or during difficult weather conditions[198]. While it is important to gain knowledge on specific species and the impact of individual offshore wind farms it is crucial to understand more about the cumulative impacts of additional offshore wind farms. A recent study has modeled the impact of multiple offshore wind farms on birds in the Dutch North Sea. For almost all species included, a tenfold extrapolation of the effects at Egmond aan Zee offshore wind farm did not have a negative impact at population levels. While the Dutch breeding population of herring gull *(Larus argentatus)* did show

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In Norway, at the Smøla wind power farm, experiments are currently being conducted on increasing the rotor blade visibility to birds by painting parts of the rotor blades black[194].

SPATIAL PLANNING THAT ACCOUNT FOR THE DIFFERENT VULNERABILITIES OF BIRD SPECIES IS ESSENTIAL

a strong decline this was suggested to have been caused by changes in the ecological conditions and not to be directly related to the wind farms[199].

Migration Barriers

Several studies have shown that many migrating birds avoid offshore wind farms during migration[200]. It is recognized that onshore wind farms represent a barrier for landbirds such as raptors and cranes. At offshore wind farms this effect has not been similarly studied[201].

The barrier effect of offshore wind farms may have a negative impact of birds. The birds' behavioral avoidance response to the wind farm may lead to detours circumventing the structures ultimately extending the total flying distance and energy use. Furthermore, for species such as the common eider *(Somateria mollissima)* the reproductive success is related to the females' body reserves during the breeding period. By increasing the energy use for common eiders their body mass may drop, thus affecting the breeding output[202].

The results from the monitoring programs at Nysted and Horns Rev offshore wind farms showed that while all birds generally displayed avoidance behavior, the specific responses were highly variable depending on the species of bird. In general, waterbirds reacted to the wind farms at distances of 5 kilometers while deflecting at 3 kilometers. Over 50 percent of the birds avoided passing through the wind farms at a distance of 1 to 2 kilometers[203]. By comparing data pre- and post-construction at Nysted a study estimated that the common eiders altered their flight

50% OF THE BIRDS AVOIDED PASSING THROUGH THE WIND FARMS AT A DISTANCE OF 1 TO 2 KILOMETERS.

trajectory after construction of the wind farm. However, the additional 500 meter detour was considered trivial compared to the estimated migration distance of 1400 kilometers[204]. On the other hand, bearing in mind the plans for new offshore wind farms it is important to take the barrier effect into consideration as it will most likely increase the impact on migrating birds.

The presence of artificial lights at sea has been known to attract several bird species. There is recorded evidence of high number of bird fatalities after collisions with structures at sea on account of artificial lights[205]. However, it is not well established how artificial lights may affect different bird species nor their influence in causing bird collisions with wind turbines[206]. Based on experience from oil platforms the impact of light attraction may not be insignificant[207]. However, (manned) oil or gas platforms tend to be more lit up than (unmanned) wind farms where the only lights are those required as navigational warning lights.

Several studies have shown that the different spectral properties in lights may interfere with animals' behavior[208]. In relation to migrating birds an experiment conducted on an oil platform in the North Sea has provided some interesting findings. While migrating birds displayed disoriented behavior and attraction when exposed to white and red light sources, the birds showed little or no signs of attraction to green or blue lights. This study suggested that certain colors of lighting may interfere with the birds' magnetic compass causing disorientation and attraction[209]. If this is the case, changing the color of the lighting on offshore wind turbines may mitigate the risk of bird collisions. As there are a number of legislative requirements to the navigational lights required on offshore wind turbines efforts should be made at national or regional policy levels to allow for changing the color of lighting.

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Eider *(Somateria mollissima)* in flight. Spitsbergen (Svalbard) arctic archipelago, Norway.

RECOMMENDATIONS

1

Directive Establishing a Framework for Maritime Spatial Planning and Integrated Coastal Management[210]

WWF welcomes the European Commission's proposal for a directive establishing a framework for Maritime Spatial Planning (MSP) and Integrated Coastal Management (ICM). We believe it is essential to ensure a sustainable use of marine resources, such as offshore wind, and the protection of marine biodiversity and ecosystem services.

In the coming years the pressure and constraints placed on many sea areas will increase dramatically as a result of increased human activity. As this report has highlighted, offshore wind power development is expected to increase tenfold within 2020. Offshore wind power infrastructure will demand much more marine space, in competition with wildlife and traditional sea users. Many traditional sea users, such as shipping, cable- and pipeline companies, as well as emerging uses such as coastal tourism and areas for environmental protection are also expected to increase the demand for marine space. Thus, there is a growing need to manage sea areas in a more coordinated manner, both nationally as well as across country borders, in order to balance the need for development of various offshore activities while reducing the cumulative pressure on marine ecosystems.[211].

A common legally-binding framework for MSP and ICM will provide for:

- Better environmental protection by identifying the cumulative effects of proposed developments, safeguarding natural resources and assessing the risks associated with climate change;
- Enhanced resilience of marine ecosystems by identifying and protecting sensitive sea areas and connecting 'blue corridors' to enable ecological coherence between these areas;
- Effective cross-border co-ordination of plans and projects such as the development of offshore wind farms, the European integrated offshore power grid and the efficient development of Marine Protected Area networks;
- More efficient use of marine space by identifying synergies between compatible maritime activities that can be co-located, reducing the number of conflicts between different activities or sectors that are competing for space;
- Improved investment opportunities by increasing transparency, predictability and stability for investors as well as reducing co-ordination and transaction costs;
- Vibrant coastal communities and employment opportunities in long-established and emerging marine industries such as offshore wind that contribute to revitalize coastal areas.

WWF recommends all European countries and the European Parliament to act to ensure that the Directive:

- Provides coherent direction and clear goals and a time frame for these to be met, whilst safeguarding proportionality and subsidiarity by leaving Member States some flexibility with regard to the content of the plans and strategies to achieve objectives already set at European level;
- Requires Member States to cooperate and work together to ensure that plans and strategies are coherent across coastal zones and marine regions. This requires that competent authorities in each Member State are identified and are responsible for co-operating with other Member States or third countries;

Report

- Involves all relevant stakeholders and authorities in the production of maritime spatial plans and coastal strategies and provides public access to the results once available;
- Ensures that plans and strategies are based on the best available data that should be collected, as far as possible, by making use of existing instruments established under other EU initiatives;
- Provides for synergies between sectors by encouraging co-location of compatible activities or uses that can occupy the same spatial footprint;
- Requires all maritime plans and strategies to be subject to Strategic Environmental Assessment (SEA) in accordance with the provisions of Directive 2001/42/EC;
- Provides for coherence between marine planning and terrestrial planning regimes, using ICM to link and integrate the two.

2

Improve the Use of Environmental Impact Assessments[212]

EIAs are currently conducted at varying scales using different scopes and depths of studies, largely because of a lack of comparable national standards. There is a need for common international standards for EIAs to increase the use and value of comparative analyses and assessing cumulative effects over time.

WWF recommends improving the use of environmental impact assessments by:

- Applying common threshold values for assessments of impact.
- Clarifying the relevant criteria used for impact prognosis.
- Reaching an agreement on acceptable levels (i.e. assessing impact intensity) and scales of disturbance for species (e.g. reference populations to consider and biogeographic distribution affected).
- Setting up international guidelines and information exchange networks to minimize obstacles when conducting EIAs.

3

Pursue Opportunities to Develop More Offshore Wind Power Production in the North Sea

WWF recommends all European countries to pursue opportunities to develop more offshore wind power production in the North Sea in coherence with previous recommendations by:

- Giving priority to renewable energy production over fossil energy production.
- Introducing a national licensing system for offshore wind power production.
- Issuing licenses in a staged procedure allowing for new knowledge regarding environmental impacts to be taken on board before each round.
- Providing necessary economic incentives to allow commercial development of offshore wind farms.
- Countries around the North Sea Basin should coordinate their ambition and development of offshore wind and related infrastructure in order to reduce the total environmental impact as much as possible. This could for example be done through coordinated grid developments between countries reducing the total number of cables needed, or by coordinating the sequence of project implementation to reduce habitat stress in a given time.

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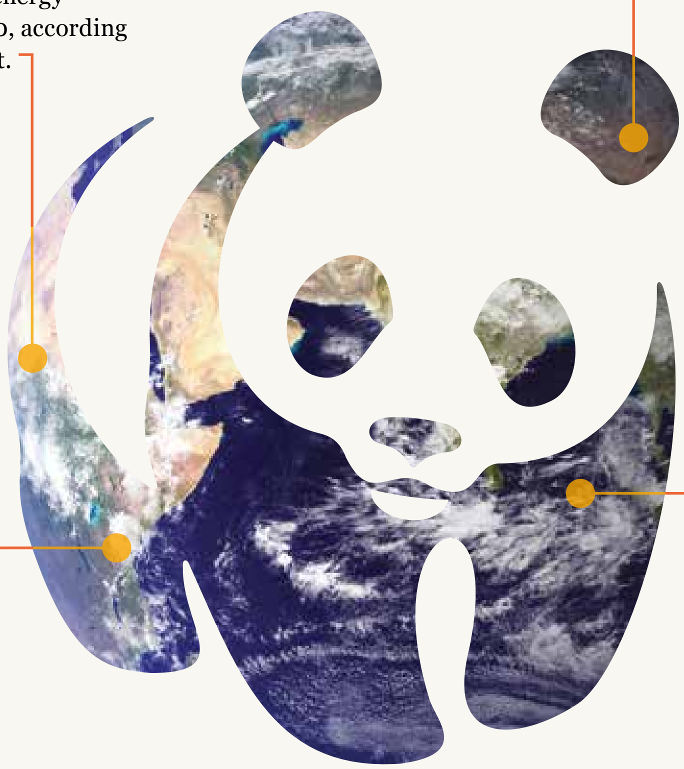

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