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SAFEGUARDING MARINE PROTECTED AREAS IN THE GROWING MEDITERRANEAN BLUE ECONOMY

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CAPITALIZATION REPORT FOR THE OFFSHORE WIND ENERGY SECTOR

PHAROS4MPAs

A REVIEW OF SOLUTIONS TO AVOID AND MITIGATE ENVIRONMENTAL IMPACTS OF OFFSHORE WINDFARMS

Capitalization report

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ACCOBAMS	Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area
AC	Altering electric currents
ADD	Acoustic Deterrent Devices
AHD	Acoustic Harassment Devices
AIS	Automatic Identification System
BACI	Before-After/Control-Impact, a monitoring approach
(D)BBC	(double) Big Bubble Curtain
BfN	Bundesamt für Naturschutz, Federal Agency for Nature Conservation
BioConsult SH	Independent, ecological/ environmental research and consulting office in Schleswig-Holstein (Northern Germany)
BMU	Bundesministerium für Umwelt, Federal Ministry for the Environment
BSH	Bundesamt für Seeschifffahrt und Hydrographie, Federal Maritime and Shipping Authority, Germany
CAE	Cumulative Adverse Effects
CRM	Collision Risk Models
C-POD	Cetacean-Porpoise Detector
dB	Decibel, used within the acoustics as a ratio to describe the sound pressure level
DC	Direct electric currents
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
EU	European Union
FAO	Food and Agriculture Organisation
FFH	Fauna-Flora-Habitat. Areas which were selected for the European protected areas system Natura2000
FINO	Forschungsplattformen In Nord- und Ostsee, Research platforms in North and Baltic Sea
GES	Good Environmental Status
GW	Gigawatt
HDD	Horizontal Directional Drilling
HELCOM	HELsinki COMmission, monitoring concept for the Baltic Sea
HiDef	High-Definition digital flight monitoring surveys
HRA	Habitats Regulations Assessment
HSD	Hydro Sound Damper
HVDC	High-Voltage Direct-Current
IAC	Inner-Array Cables
IBA	Important Bird Area
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICCP	Impressed Current Cathodic Protection
IfAÖ	Institut für Angewandte Ökosystemforschung, Institute for Applied Ecosystem Research
IHC-NMS	Noise Mitigation System of the company IHC B.V.
IMMA	Important Marine Mammal Areas
IUCN	International Union for Conservation of Nature
IWC	International Whaling Commission
kHz	Kilohertz

kJ	Kilojoule
kV	KiloVolt
LED	Light Emitting Diode
MAP	Mediterranean Action Plan
MedPAN	Network of Marine Protected Areas managers in the Mediterranean
MMO	Marine Mammal Observer
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine spatial planning
MW	Megawatt
NGO	Non-Governmental Organisation
NM	Nautical Miles
NMS	Noise Mitigation System
NW	Northwest
ORJIP	Offshore Renewables Joint Industry Programme
OSPAR	OSlo-PARis Convention, monitoring concept for the North Sea
OWECS	Offshore Wind Energy Conversion Systems
OWF	Offshore Windfarm
PAM	Passive-Acoustic-Monitoring
PHAROS4MPAs	Lighthouse project for Offshore Windfarms in Marine Protected Areas
POD	POrpoise Detector
PTS	Permanent Threshold Shift
R&D	Research and Development project
SAC	Special Area of Conservation
SBC	Small Bubble Curtain
SCADA	Supervisory Control and Data Acquisition
SCI	Site of Community Importance
SCUBA	Self-Contained Underwater Breathing Apparatus
SEA	Strategic Environmental Assessment
SEL / S-SEL	Sound Exposure Level
SPA	Special Protected Area
SPAMIs	Specially Protected Areas of Mediterranean Importance
SPL	Sound Pressure Level
StUK4	4th version of the German Standard Investigation concept of the BSH (standard Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment), Standard UntersuchungsKonzept
SW	Southwest
T-POD	Timing Porpoise Detector
TTS	Temporal/ Temporary Threshold Shift
UAV	Unmanned Aerial Vehicle (drone)
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
V	Volt
VWS	Vessel Monitoring System
WWF	World Wide Fund for Nature

1 GENERAL INTRODUCTION

Purpose and methodology of the Capitalisation report - Background

The steadily rising concentration of Greenhouse Gases (GHG) in the Earth's atmosphere is a consequence of the increased emission by anthropogenic activities. These emissions and the consequential climate change have caused and are continuously causing serious threats to ecosystems, single species as well as human health. To reduce these emissions and hence diminish the consequences of climate change, several international (e.g. UNEP) and national institutions have established programs and projects to mitigate, reduce, or integrate effects of climate change. Among others, the European Union has developed programs and targets to replace energy from fossil sources by energy from renewable sources. The renewable energy targets developed by the EU in 2008 and renewed in 2014, aim for

- a 40% cut in greenhouse gas emissions compared to 1990 levels
- at least a 27% share of renewable energy consumption by 2030

Energy generated from wind power is one of the most promising tools to reach this EU targets and make energy production more sustainable. Besides generating energy from wind with land-based turbines, the field of offshore windfarms located in the oceans is developing since more than 25 years and gains raising awareness. Windfarms located offshore benefit from favourable wind conditions for efficient energy production and seem to profit from almost "infinite" space. However, OWFs impact on the surrounding environment and the more OWFs are developed, the greater the competition for space with the environment and other anthropogenic activities is becoming.

Since 1991, when Denmark built the first OWF, 17 countries have constructed OWFs, most of them located in Northern Europe (GLOBAL WIND ENERGY COUNCIL 2018). In the Mediterranean there is no OWF present so far. Turbines of OWFs usually have greater dimensions compared to the turbines onshore, and reach higher efficiency and yielding more energy per installation. Across Europe there have been about 4000 turbines installed so far (WIND EUROPE 2018). The present turbines are designed for relatively shallow waters (±40 m), as can be found in the North Sea and the Baltic Sea. To ensure resistance to severe weather conditions the foundations of those turbines are piled 30 m and more into the sea bed. Recent projects and developments also take possible locations further offshore, in deeper waters or on ground not suitable for piling, into account. However, major constraints, like the efficient transmission of the produced energy to the shore, are still under research and development. Floating turbines have been developed, which do not require a solid foundation, but are instead anchored in the ground. Until now several test sites and pilot projects have been constructed (e.g. OWF 'Hywind' in Scotland). Nevertheless, there are several projects in the early or advanced planning phase, for instance in the Mediterranean, where this construction technique is seen as most promising for the prevailing conditions (e.g. 'Les éoliennes flottantes du Golfe du Lion" in France) (4C OFFSHORE LTD 2018).

The construction, operation and decommissioning of OWF are impacting on the surrounding marine environment and also have consequences on a socio-economic level. It is proven that OWFs impact on the hydrographic conditions in their vicinity and that certain animal groups and habitats can severely be affected by an OWF. Potential impacts of OWF are investigated for instance for benthic communities, fishes, birds and marine mammals. Chemical pollutants, e.g. from sacrificial anodes can accumulate in the sediment with currently unknown consequences for the marine environment. Benthic communities can suffer from habitat loss due to the space the OWF requires and the seabed that is moved during construction of the turbines and associated constructions (e.g.

cables) (HUDDLESTON 2010). The impact of electromagnetic fields emitted by the cables transporting the energy from the turbines to the shore on benthic animals and invertebrates in general is not very well known. On the other hand benthic communities can use the newly introduced structures as additional habitat and this way contribute to generating an artificial reef (LINLEY et al. 2007). Such an artificial reef may be attractive for mobile animals, such as fish or marine mammals, which may use the reef as a feeding ground or, in case fishing is prohibited in the OWF, as a refuge (DEGRAER et al. 2013). Whether these secondary impacts of an OWF are beneficial for an ecosystem depends on several factors, such as the native habitat structure or the organisms, mainly colonizing the artificial reef. As some fish species have excellent hearing capabilities fish may also be harmed by the noise introduced to the marine realm by the piling of the foundations into the ground or by the pressure associated with the piling events (MUELLER-BLENKLE et al. 2010).

Marine mammals are known to respond at large distances to noise levels generated during construction. The main concern is that the sensitive auditory systems can be seriously harmed by pulsed noise generated during piling activities (e.g., eliciting a temporary or permanent threshold shift (BRANDT et al. 2014)). Also temporary or permanent displacement (habitat loss) is seen as a major pressure on marine mammals, because it can be followed by negative effects on the individual as well as on the population level. For birds several negative impacts are known. The physical presence of the OWF can lead to habitat loss as some species tend to avoid the windfarm area (Garthe et al. 2018). Furthermore the OWF can act as a barrier on migration routes of migrating birds and force the birds to change their original route. Furthermore birds face a potential risk of mortality due to an elevated collision risk with the turbines (DEGRAER et al. 2013).

In order to minimize negative impacts of OWF on the marine environment, it is recommended to follow the principles of 1. Avoidance 2.Mitigation and 3.Compensation. Negative impacts should be generally avoided. If this is not possible, these impacts should be mitigated following best-practice strategies and, as the least preferred option, the impacts should be compensated adequately. Possible strategies for avoidance and mitigation of negative pressures of most concern are presented in this report, including case studies of OWF, where these methods have been applied. Furthermore monitoring methods and research projects are highlighted, focussing on Northern European countries and how those can be adapted to future projects in the Mediterranean Sea.

Rising anthropogenic activities by increasing offshore wind developments will also cause spatial competition with other economic sectors (e.g., fisheries or tourism) as well as ecologic interests and targets, such as existing/planned Marine Protected Areas (MPAs) or sites of special ecological value. Since the 1950 there has been consistent progress in establishing protected areas in the Mediterranean Sea and in 2016 there were 1231 sites designated as MPAs, which equals 7.14% of the area of the Mediterranean Sea (MedPAN et al. 2016) (Figure 1.1).

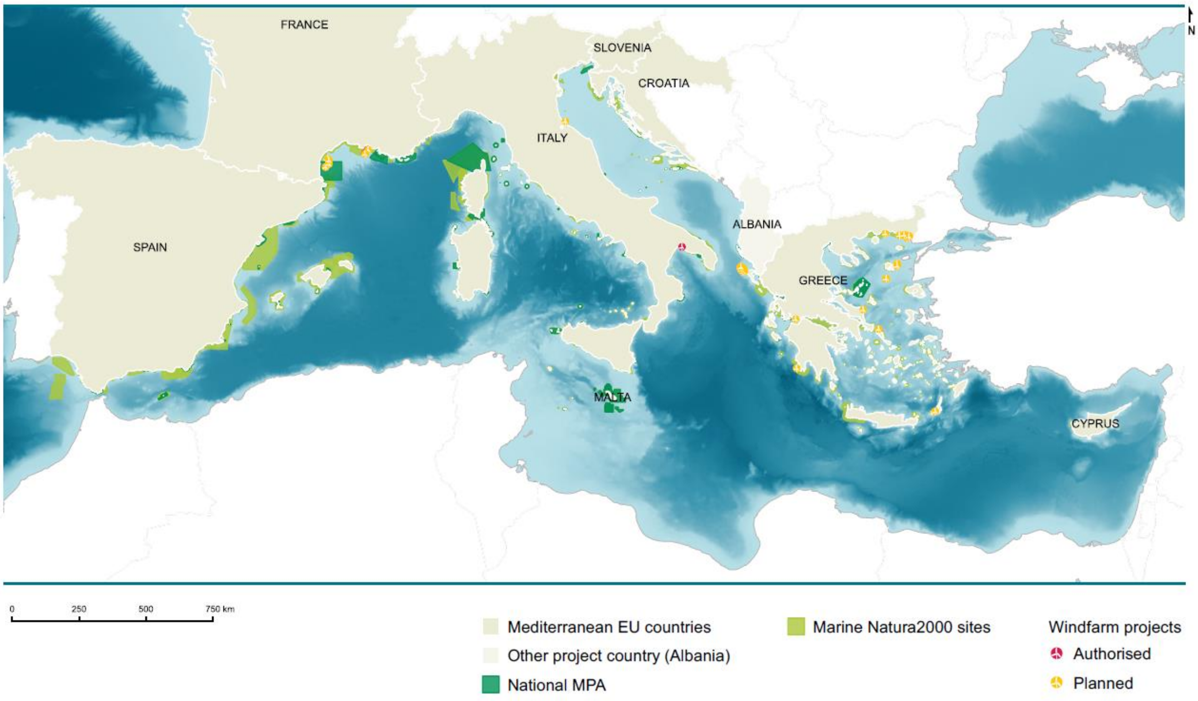

Figure 1.1 MPAs in the European Part of the Mediterranean Sea and planned OWFs. National (dark green) as well as MPAs under the framework of Natura 2000 (bright green) are displayed. (Source: WWF France, 2018)

According to the Aichi targets of the 'Convention on Biological Diversity' and 'Sustainable Developments Goals' of the United Nations (UN) the overall goal is to have at least 10% of coastal and marine areas conserved "consistent with national and international law" (MedPAN et al. 2016) by 2020. There is no clear definition of the term 'Marine Protected Area' and thus there are various different types of MPAs with varying protection status in the Mediterranean Sea. Only 0.04% of the Mediterranean belongs to no-take zones, where e.g. fishing is strictly prohibited. In the Mediterranean there are national or regional designated MPAs, e.g. within the Natura2000 network and Specially Protected Areas of Mediterranean Importance (SPAMIs). Internationally designations exist for instance from the UNESCO (UNESCO World Heritage Sites). The actual management of these MPAs is often not fully developed and knowledge about the existing management measures and their effectiveness is scarce. In addition the legislation is often not adequately defined to deal with existing pressures and provide mitigation or compensations measures or to initiate research projects (questionnaire within the MedPAN framework). It is assumed that doubling the share of renewable energy in general on a global scale to 36% by 2030, would give the opportunity to keep global warming from failing the 2°C threshold (IRENA 2019). Offshore wind power is seen as one of the most promising tools of producing renewable energy to reach these goals. At the same time the Aichi targets are crucial to be fulfilled to maintain and/or recover biological diversity in the marine realm and sustain a functioning and healthy marine environment. To ensure that these two important goals of the near future can be successfully fulfilled, a discussion on whether and how these goals can co-exist is inevitable.

Ecologic interests, for renewable energy production on the one hand and conservation goals on the other hand, may compete for space and most suitable locations, but are also seen as areas of potential co-use, if managed sustainably (Lacroix & Pioch 2011). In order to establish future guidelines if and how anthropogenic activities and MPAs can co-exist, this report aims to review the best available knowledge on the impacts, mitigation and monitoring methods of different types and phases of OWF to enable stakeholders and decision makers in the MPA sector as well as in the offshore wind industry and politics to establish regulations or recommendations for sustainable OWF projects in the Mediterranean Sea. Within the framework of the PHAROS4MPAs projects BioConsult SH was assigned to draft a Capitalization report reviewing literature assessing marine environmental issues related to the developing offshore windfarm industry. According to the guidelines given by WWF France within the PHAROS4MPAs project the present report is "[…] based on methodologies, practices, intervention tools already tested and implemented by stakeholders at local or regional level that represent a strong interest for wider targeted dissemination in the Mediterranean area". The capitalization report focuses on impacts of the offshore windfarm sector on the marine environment and relevant mitigation and monitoring techniques. Due to the existing experiences and research projects dating back to the early 1990s, the present report focuses mainly on knowledge gained in the North Sea, Baltic Sea and North-East Atlantic. It is based on an extensive and thorough literature research, only considering scientifically sound research, databases and literature. The detailed aims and objectives targeted by this report are as follows.

Aims & Objectives

- Overview of techniques and trends in the Offshore Windfarm (OWF) sector with focus on Northern Europe
- Review and consolidate existing information about impacts of OWFs on marine environment
- Define the most important threats and review and consolidate existing information about mitigation techniques
- Review and consolidate existing information about monitoring techniques and programs
- Extrapolate existing knowledge to the situation in the Mediterranean Sea
- Describe examples of currently existing regulations, guidance and advice that is applicable to the marine environment and OWF development
- Review and list existing legal regulations and regulatory frameworks that could be used to support recommendations for the sector in the Mediterranean Sea
- Discuss how the current knowledge, experiences, mitigation and monitoring methods can be used in the light of increasing OWF development in the Mediterranean Sea with the emphasis on marine protected areas.

2 CHARACTERISTICS OF OFFSHORE WINDFARMS (OWF)

2.1 Components of OWF

In this chapter relevant components are outlined and procedures for the construction are highlighted.

2.1.1 Foundation types (fixed)

For offshore construction works, the water depth is generally divided into three classes: Shallow waters (0–30 m), transitional waters (30-50 m), and deep waters (50–200m) (MUSIAL & BUTTERFIELD 2004). The sea depth is the most important factor for the capital market viability of offshore winfarms because the cost for foundations significantly increases with increasing depth. Hence, several types of foundations are already developed, and some types are under development considering varying factors such as sea depth and e.g., soil conditions (Figure 2.1) (OH et al. 2018).

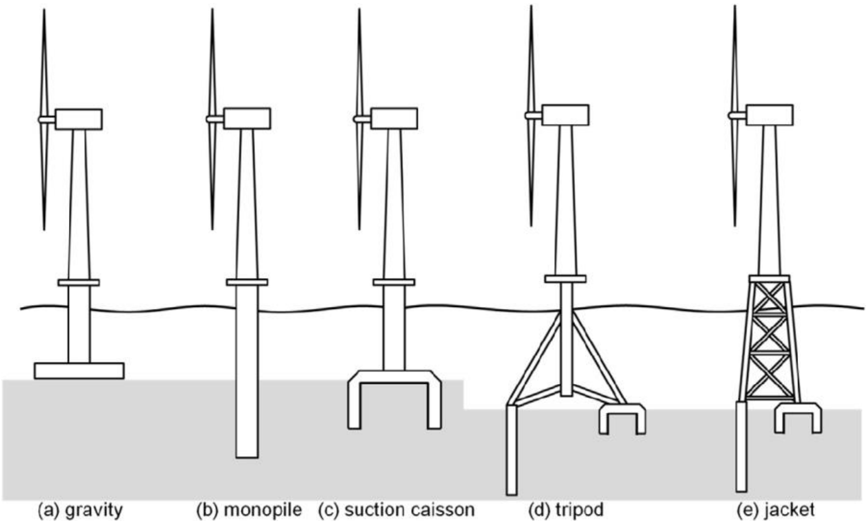

Figure 2.1 Types of foundations for offshore wind turbines (OH 2018).

Figure 2.2a shows the current types of foundations used in commercial OWF with respect to the sea depth and the distance from shore. This figure provides insights into trends for foundation types with respect to the sea depth and the distance from shore. Figure 2.2b also shows the trend of foundations for OWF over the sea depth and the capacity: gravity – monopile – multipod. As the site is deeper and is farther from shore, multipod is more widely used than gravity and monopile foundations.

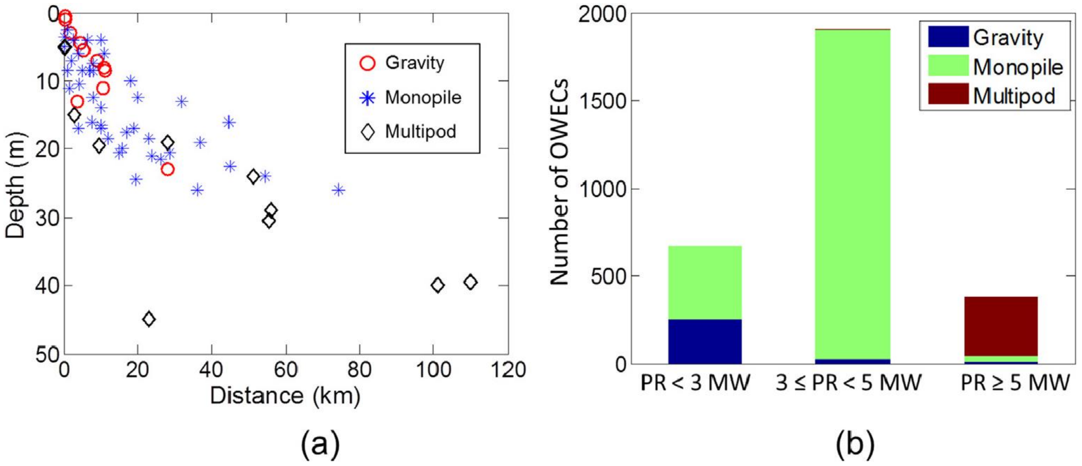

Figure 2.2 Comparisons of installed foundations for offshore wind energy conversion systems (OWECs); symbols in figure (a) represent windfarms constructed with each foundation type; bars in figure (b) represent the number of OWECs with respect to the capacity of OWECs (Power Rating, PR) (OH 2018)

In shallow waters, gravity type (Figure 2.2 a) and monopile type foundations (Figure 2.2 b) are mainly used. Especially, monopiles are most frequently used because of the suitable sea depth at available locations and a quick and safe construction sequence including market-ready equipment and installation vessels. Gravity basements have been used seldom and experience is limited to a few locations. However plans for future OWF include gravity basement structures in water depth up to 60m with base slab diameters around 40m and a capacity to carry generators of maximal 8-10 MW and more. Gravity basements have been used e.g., for the Danish windfarm ‘Rodsand 2’ (2.3 MW turbine capacity) and the Swedish windfarm ‘Karehamn’ (3,0 MW turbine capacity). In transitional and deep waters, monopiles, tripods and jacket foundations are mainly deployed until water depths are too high for grounded foundations.

The current status of applications for different fixed foundations are discussed in the following sub-sections

Gravity based support structures

A gravity-type foundation consists of a large circular pile with a concrete plate structure resting on the seabed (Figure 2.3). Initial offshore windfarms in Denmark were installed by using this type of foundation close to shore, where the water depth is very shallow. Moreover, several demonstration projects such as the ‘Avedøre Holme’, ‘Breitling’, ‘Thornton Bank (Phase I)’ offshore windfarms used this type of foundation because this type of support structure combines some essential advantages such as production on-shore, lowering on the seaground instead of piling, filling with ballast from the seaground, durability in marine environments and structures can be easily removed by replacing the ballast with air. The deepest gravity foundations in operation are in Thornton Bank (27 m). In Europe, gravity foundations will likely continue to fill an important niche for shallow to moderate water depth regions where drivability is a concern (including plans for offshore windfarms in the French channel waters).

Figure 2.3 Gravity foundations under construction for Thornton Bank (source: LUC VAN BRAEKEL).

Monopile

Monopiles are typically large diameter, steel cylinders that are piled or drilled into the seabed (Figure 2.4). Outer diameters usually range from 3 to 10 m, their length, of which about 50% is driven into the seabed, varies between 30-80 meters.

Monopile foundations are the most commonly deployed foundation structure used in the offshore wind energy industry to date and especially in European offshore windfarms. Most European offshore windfarms have been constructed in shallow waters with less than or around 40 m depth, with soil mainly consisting of sand and gravel, which requires relatively low effort on piling of piles. Nevertheless, this technology requires heavy duty equipment like jack-up barges or moon-bay barges for installation, which cause considerable footprints, piling noise, and suspended sediment. Hence, marine mammals are exposed to high noise levels and in addition. Fisheries and other environmental issues must be considered for installing offshore windfarms with this substructure.

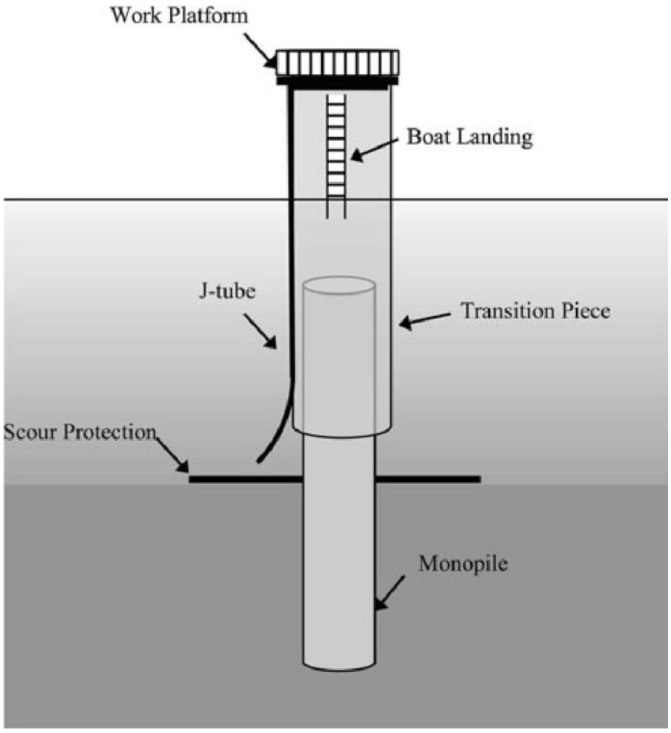

Figure 2.4 Components of a monopile foundation (Kaiser & Snyder 2012)

Suction bucket

Suction buckets are steel fabrications that look like upturned buckets embedded in the marine sediment (Figure 2.5). The installation is relatively quick with low level of vibration, noise, and suspended sediment. Moreover, this type of foundations is economic because of the simple and fast installation procedure (Musial et al. 2006).

Several North Sea trial installations were performed including a full scale test of a wind turbine at the German 'Borkum Riffgrund I' site, carrying a Siemens SWT-4.0. This trial was carried out by Dong energy in water depth of 25m with dense sand beds as installation ground. Footprint of the buckets was 8x8m, with a total installation weight of more than 700 tons. At the 'Borkum Riffgrund 2' site, 20 Suction Bucket Jackets were installed in 2018 carrying 8 MW generators.

Figure 2.5 *Installation of a suction bucket jacket at 'Borkum Riffgrund 2' in 2018 (copyright Örstedt/Matthias Ibeler, source: https://orsted.de/presse-media/news/2018/07/bkr02-letztes-sbj-installiert 06.12.2018).*

Multipod (tripod and jacket)

Space frame substructures such as tripod and jacket structures can provide the required strength and stiffness for transitional water depths (Figure 2.1(d) and (e)).

Tripods consist of a central steel shaft connected to three cylindrical steel tubes through which piles are driven into the seabed (Figure 2.6).Tripods are heavier and more expensive to manufacture than monopiles, but can be more reliable in deep water.

Figure 2.6 Tripod foundations (left) and jacket foundation (right) (source: 'Alpha Ventus')

A jacket foundation is a very large multi-chord base formed of multiple sections of structural tubing or pipe that are welded together. Jacket foundations are an open lattice steel truss template consisting of a welded frame of tubular members extending from the mudline to above the water surface (Figure 2.6). Jacket structures have gone under intense modelling and testing and can be installed in waters as far as 60 meters deep. Tripod and jacket structures provide sufficient bearing capacity in transitional water depths with relative short penetration length.

2.1.2 Foundation types (floating)

Most OWFs with floating type foundations are demo and test versions. The test floating OWF foundations target very deep sites (e.g., 100–200 m) and have high rated capacity (e.g., 5–8 MW). Floating support structures can be classified into three main classes (Center of Wind Energy at James Madison University 2012, Rhodri and Costa Ros, 2015) each having their advantages and disadvantages:

- Semi-submersible platform: uses the water plane area to achieve stability, similar to tway a barge does. Simple moorings are used to keep the structure in place. Buoyancy stabilised platform which floats semi-submerged on the surface of the ocean whilst anchored to the seabed with catenary mooring lines. Often requires a large and heavy structure to maintain stability, but a low draft allows for more flexible application and simpler installation. Examples: WindFloat (by Principle Power); Damping Pool (by IDEOL); SeaReed (by DCNS).
- Spar-buoy: Ballast stabilized – uses a very large weight deep under water, providing a counterbalance to the loads. Simple moorings are used to keep the structure in place. A cylindrical ballast-stabilised structure which gains its stability from having the centre of gravity lower in the water than the centre of buoyancy. Thus, while the lower parts of the structure are heavy, the upper parts are usually lighter, thereby raising the centre of buoyancy. The simple structure of the spar-buoy is typically fairy easy to fabricate and

provides good stability, but the large draft requirement can create logistical challenges during assembly, transportation, and installation, and can constrain deployment to waters >100m depth. Examples: Hywind (by Statoil); Sway (by Sway); Advanced Spar (by Japan Marine United).

- Tension leg platform (TLP): – uses tensioned mooring arrangements to keep the structure stable. A semi-submerged buoyant structure, anchored to the seabed with tensioned mooring lines, which provide stability. The shallow draft and tension stability allows for a smaller and lighter structure, but this design increases stresses on the tendon and anchor system. There are also challenges with the installation process and increased operational risks if a tendon fails. Examples: PelaStar (by Glosten)

In most types (spar-buoy, barge and semi-submerged) the mooring chains are not under tension but consist of steel of high tenacity and 4-6 times the water depth in length. This needs stable or heavy anchorages, also in high water depth. On the other hand, mooring structures under tension exist, anchoring the floater directly to the ground – (tension leg platform, or "TLP") (Figure 2.7 and Figure 2.8). Floating foundation types include floating steel structures that can be imported as well as concrete structures (floating barge FLOATGEN) that can be manufactured close to the deployment site.

Floating windfarms have the potential to significantly increase the sea area available for offshore windfarms, especially in countries with limited shallow waters, such as Mediterranean countries which face bathymetry restrictions for installation of fixed foundations due to the rapid drop off of the continental shelf. Another beneficial aspect of floating offshore windfarms is that they can be placed farther offshore and minimize landscape alteration. Also they can potentially reduce the conflicts with other marine activities (such as fishing, recreation and coastal navigation) and can reach stronger and more consistent wind resources. In case of the offshore windfarm development in France this type of foundations was proposed as most appropriate considering that near the coast there are dense marine human activities (trawling, small coastal fishing, nautical activities, seaside tourism etc.), relatively modest wind fields compared to ones further offshore as well as water depths reaching more than 40 m near the shore that do not allow the installation of fixed offshore windfarms (DIRECTION INTERRÉGIONALE DE LA MER MÉDITERRANÉE 2015). All structures have the advantage of a high degree of prefabrication (if deep sea harbours are at hand) and quick and easy transport to the construction site. Impact on the marine environment is reduced because the practices for floating OWFs in Europe so far use techniches without piling of foundations. Floating foundations and wind turbines are built on land then towed offshore to be anchored at the selected site. A good example is the 'Hywind' concept. Many parts of the five floaters were prefabricated in Spain, and then placed in waters off Norway for assembly and transport horizontally to Scotland. The foundation consists of an 8.3 m diameter, 100 m long submerged cylinder secured to the seabed by three mooring cables.in 95 to 120 m water depth.

Although pioneer countries have focused on fixed bottom foundations taking advantage of the mild bathymetry of the North and Baltic Sea, floating designs, although promising, constitute a recent development and so far few cases of floating OWFs have been documented in Europe:

Hywind: Hywind Scotland is the world's first commercial windfarm using floating wind turbines, situated 29 km off Peterhead, Scotland. The farm has 5 Hywind floating turbines with a total capacity of 30 MW. Equinor (then: Statoil) launched the world's first operational deep-water floating large-capacity wind turbine, Hywind, in 2009. The pilot windturbine (tower: 120 m, 2.3 MW) turbine was towed 10 km offshore into the Amoy Fjord in 220 m deep water, off of Stavanger, Norway on 9 June 2009 for a two-year test run (mooring with drag embedded anchor). In 2015, the company received permission to install the windfarm in Scotland. Three suction cup anchors hold each turbine. Hywind Scotland was commissioned in October 2017. Hywind is a floating wind turbine design based on a single floating cylindrical spar buoy moored by cables or chains to the sea bed. Its substructure is ballasted so that the entire construction floats upright. Hywind uses a ballasted catenary layout with three mooring cables with 60 t weights hanging from the midpoint of each anchor cable to provide additional tension[1].

Windfloat: In October, 2011, Principle Power deployed a full-scale 2 MW WindFloat prototype (WF1) 5km off the coast of Aguçadoura, Portugal[2]. The Windfloat stability system (also known as active ballast) distributes water ballast between the three columns of the semi-submerged floating structure to compensate for variable turbine thrust due to low frequency changes in wind velocity and direction. The system is closed-loop (no water moves in or out of the system. Drag embedment anchors were used, a mooring configuration similar to those on Oil and Gas platforms and permanently moored maritime structures. Decommissioning started in 2016 after a successful 5-year deployment.

Floatgen: In France the first pilot floating offshore wind turbine 'Floatgen' with a capacity of 2 MW located in the Bay of Biscay (Atlantic Ocean) was grid connected in 2018. The floating structure consists of concrete and the mooring systems include 6 anchors and mooring lines made from synthetic fiber (Nylon)[3].

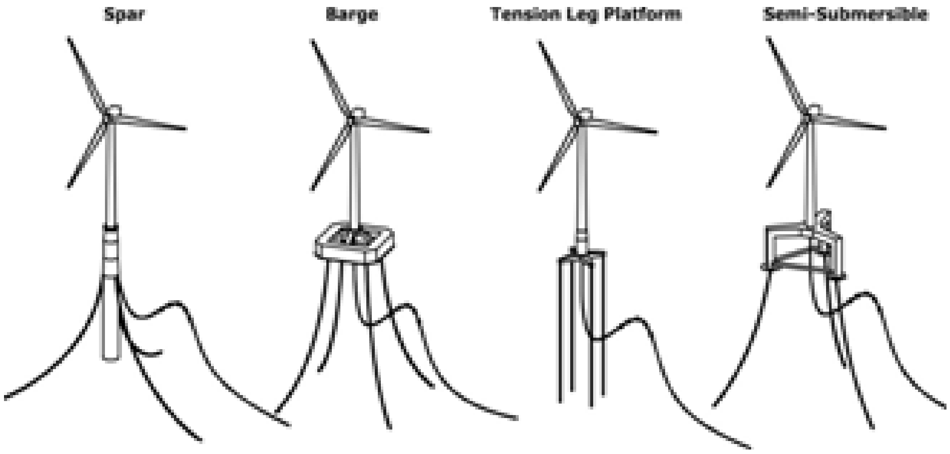

Figure 2.7 Examples of floating wind turbine components and mooring systems (DNV GL 2018)

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[1] https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us.html
[2] http://www.principlepowerinc.com/en/windfloat
[3] https://floatgen.eu/en/demonstration-and-benchmarking-floating-wind-turbine-system-power-generation-atlantic-deep-waters

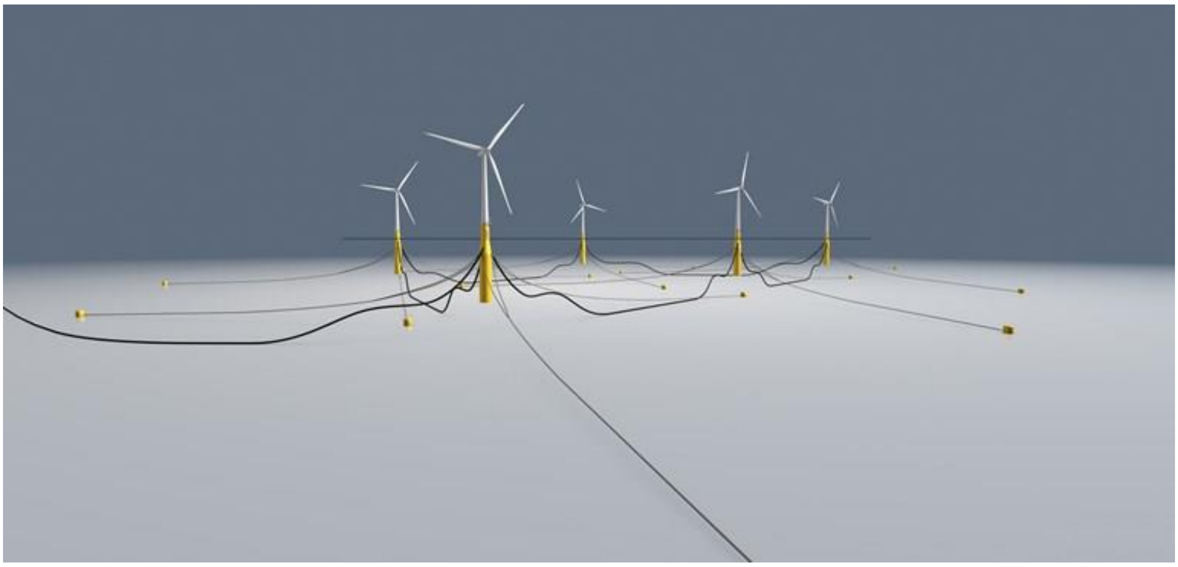
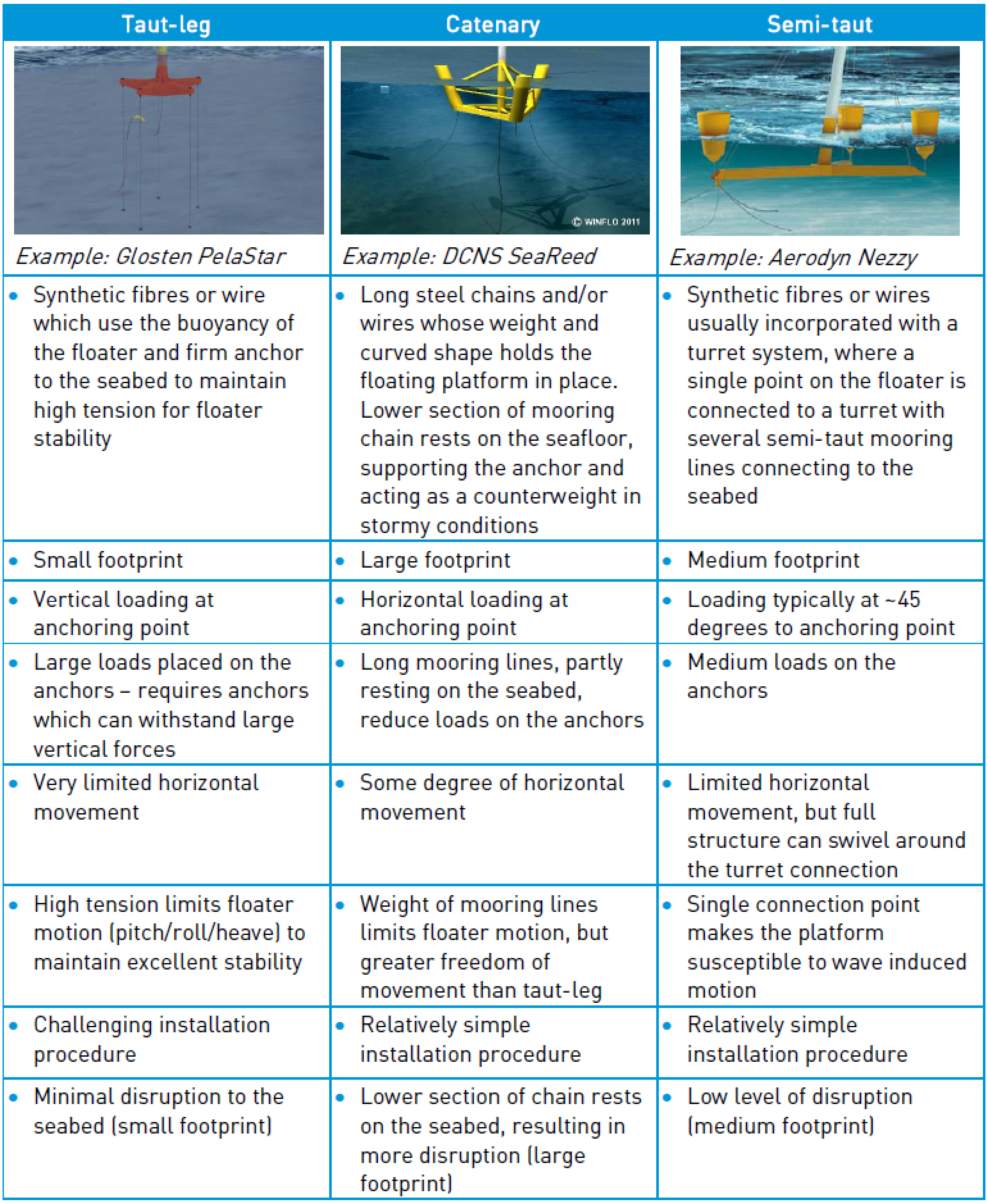


Figure 2.8 An exemple of a spar type loating platform for offshore wind turbines (source: https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us.html)

Mooring systems

According to RHODRI AND COSTA ROS, (2015) the most common mooring configurations are either taut-leg mooring systems, which are used with TLP concepts, or catenary mooring systems, which are used with spar-buoy and semi-submersible concepts. Some concepts will also adopt a semi-taut mooring system, which is a mix between both characteristics, though this is less common. An overview of these configurations is showed below (Figure 2.9).



Taut-leg	Catenary	Semi-taut
Example: Glosten PelaStar	*Example: DCNS SeaReed*	*Example: Aerodyn Nezzy*
• Synthetic fibres or wire which use the buoyancy of the floater and firm anchor to the seabed to maintain high tension for floater stability	• Long steel chains and/or wires whose weight and curved shape holds the floating platform in place. Lower section of mooring chain rests on the seafloor, supporting the anchor and acting as a counterweight in stormy conditions	• Synthetic fibres or wires usually incorporated with a turret system, where a single point on the floater is connected to a turret with several semi-taut mooring lines connecting to the seabed
• Small footprint	• Large footprint	• Medium footprint
• Vertical loading at anchoring point	• Horizontal loading at anchoring point	• Loading typically at ~45 degrees to anchoring point
• Large loads placed on the anchors – requires anchors which can withstand large vertical forces	• Long mooring lines, partly resting on the seabed, reduce loads on the anchors	• Medium loads on the anchors
• Very limited horizontal movement	• Some degree of horizontal movement	• Limited horizontal movement, but full structure can swivel around the turret connection
• High tension limits floater motion (pitch/roll/heave) to maintain excellent stability	• Weight of mooring lines limits floater motion, but greater freedom of movement than taut-leg	• Single connection point makes the platform susceptible to wave induced motion
• Challenging installation procedure	• Relatively simple installation procedure	• Relatively simple installation procedure
• Minimal disruption to the seabed (small footprint)	• Lower section of chain rests on the seabed, resulting in more disruption (large footprint)	• Low level of disruption (medium footprint)

Figure 2.9 Mooring systems for floating OWFs (Rhodri and Costa Ros 2015)

Anchoring systems

According to Rhodri and Costa Ros, (2015) there are a number of anchoring solutions available, depending on the mooring configuration, seabed conditions, and holding capacity required. Catenary mooring configurations will often use drag-embedded anchors to handle the horizontal loading, though piled and gravity anchors are still applicable, while taut-leg moorings will typically use either drive piles, suction piles, or gravity anchors to cope with the large vertical loads placed on the mooring and anchoring system. The size of the anchor is also variable, with larger and heavier anchors able to generate a greater holding capacity.

Ultimately, anchor choice will be project and site specific, often dictated by the seabed conditions. Higher holding capacities are usually generated in sands and hard clays than in soft clays, although where penetration is difficult in firm soils, gravity base or piled solutions might be required. A summary of the main anchor types is detailed below, but there is great variety even within these typologies (Figure 2.10). All are proven concepts which have been used extensively in the marine and oil & gas industries.

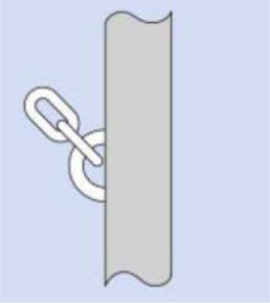
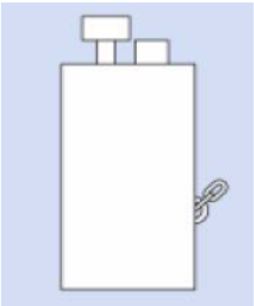
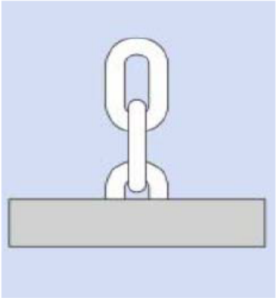
Drag-embedded	Driven pile	Suction pile	Gravity anchor
			
• Best suited to cohesive sediments, though not too stiff to impede penetration	• Applicable in a wide range of seabed conditions	• Application constrained by appropriate seabed conditions - not suitable in loose sandy soils or stiff soils where penetration is difficult	• Requires medium to hard soil conditions
• Horizontal loading	• Vertical or horizontal loading	• Vertical or horizontal loading	• Usually vertical loading, but horizontal also applicable
• Simple installation process	• Noise impact during installation (requires hammer piling)	• Relatively simple installation, less invasive than other methods	• Large size and weight can increase installation costs
• Recoverable during decommissioning	• Difficult to remove upon decommissioning	• Easy removal during decommissioning	• Difficult to remove upon decommissioning

Figure 2.10 Anchoring systems for floating OWFs (Rhodri and Costa Ros 2015)

2.1.3 Other OWF components

Turbines

The wind turbine is composed of a tower (usually starting from a transition piece at sea level), nacelle, hub, and blades (Figure 2.7). Offshore turbines range from 3 to 8 MW with 12 MW under research and prototype construction (for example the Haliade 12X of GE that could be tested in

Cherbourg in 2020/2021). Turbine' suppliers work also on 15 MW turbine development, that could be ready for projects installed before 2030[4].

Tower

Towers are tubular structures consisting of steel plate cut, rolled, and welded together into large sections. The tower provides support to the turbine assembly and the balance of plant components, including a transformer located in the base, and communication and power cables. Tower height is determined by the diameter of the rotor star and the clearance above the water level. Typical tower heights are 60–80 m giving a total hub height of 70–90 m when added to the foundation height above the water line. Tower diameter and strength depend on the weight of the nacelle and expected wind loads.

Figure 2.11 An assembled rotor being lifted onto a nacelle at Nysted windfarm (©DONG Energy)

Nacelle

The nacelle houses the generator and the gearbox. Nacelles are large prefabricated units and need the heaviest and highest lift. Thus their installation offshore has together with the rotor stars the highest constraints regarding wind and wave limits and thus plays a major role in the time-line of construction works (Figure 2.11).

Blades

Blades are airfoils made of composite material, usually reinforced glass-fibre composites. The blades are bolted to the hub either onshore or offshore.

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[4] http://newbedfordwindenergycenter.org/2017/09/dong-energy-predicts-13-15mw-wind-turbines-by-2024/

Generators

A wide range of turbines and generators regarding their power rating and their suitability to a certain rotor diameter is commercially available. Due to the technical development in the last years, many versions of a power rating of 2-4 MW are available, but recent trends enlarge as well rotor stars as nacelles with generators, making 6-8 MW turbines state of the art and up to 12 or 15 MW can be expected to be available in the near future (Figure 2.12 and Figure 2.13).

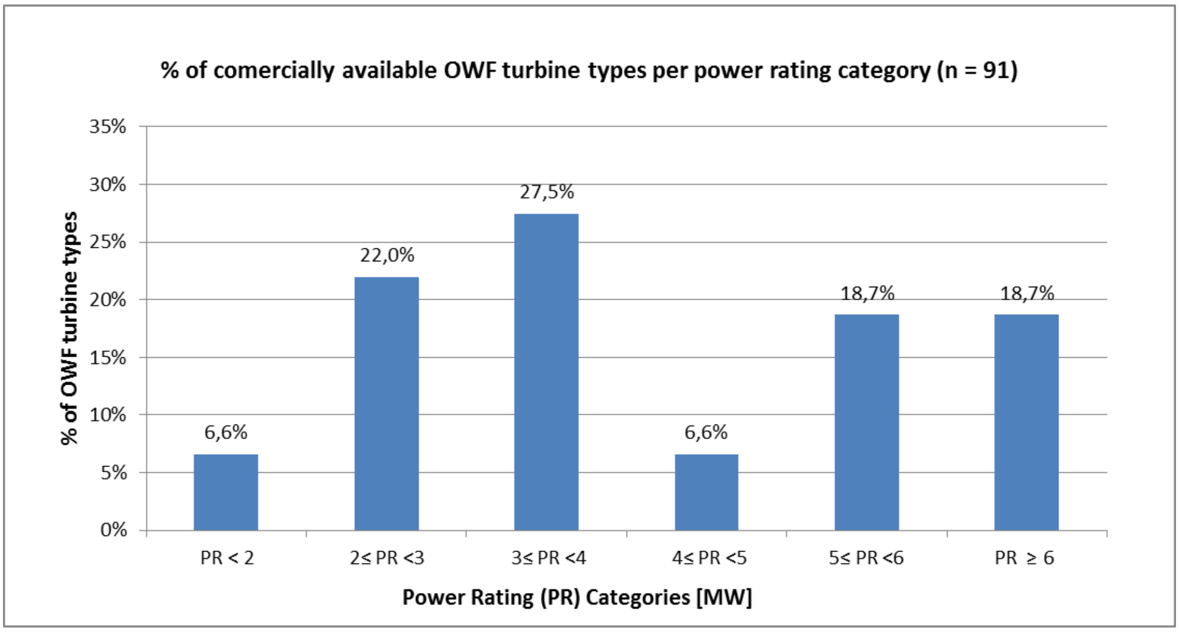


Figure 2.12 Percentage of Offshore Windfarm turbine types that are commercially available (n=90) or installed as prototypes (n = 1) per various Power Rating (PR) categories (source: Graph derived by processed data from 4coffshore database on wind turbines - October 2018, see Annex).

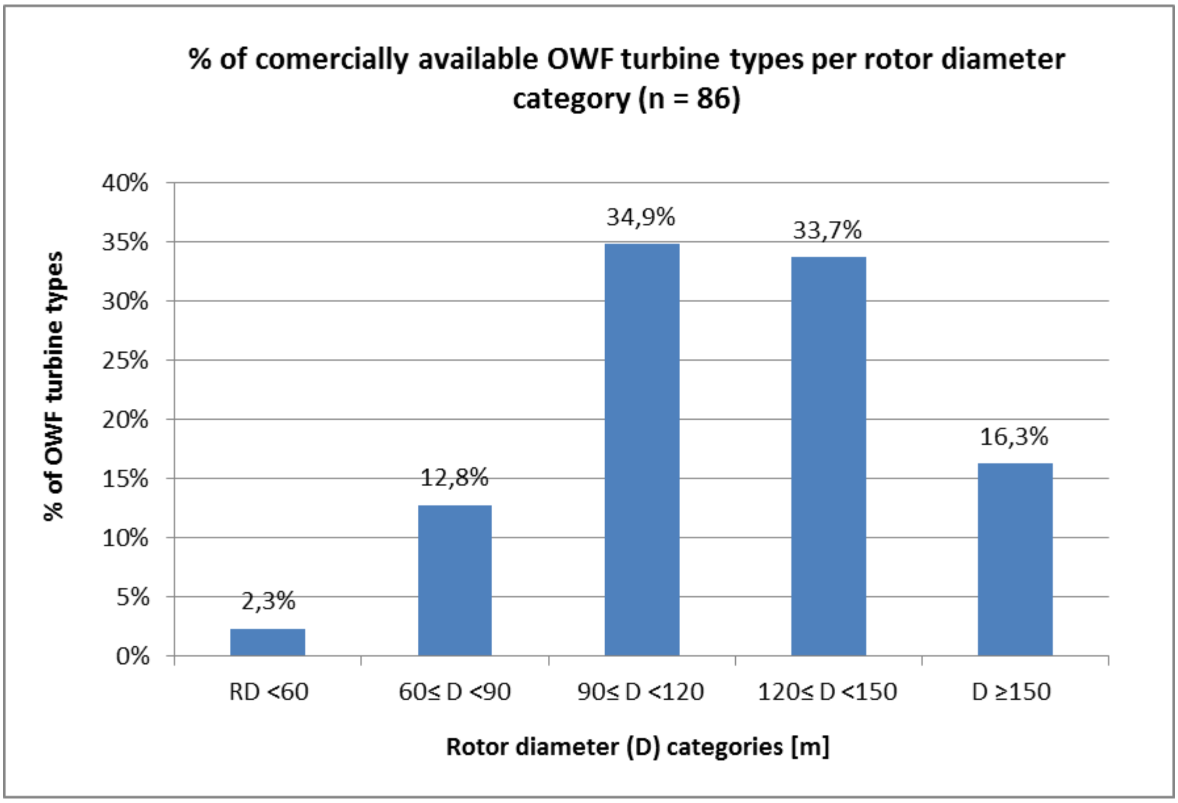


Figure 2.13 *Percentage of Offshore Windfarm turbine types that are commercially available (n=86) per various rotor diameter (D) categories (source: Graph derived by processed data from 4coffshore database on wind turbines - October 2018, see Annex).*

2.1.4 Electricity Collection and Transmission

Cables

Cables are needed to connect the offshore components starting from energy production at the wind turbines over the sub-stations to the final destination at the consumption points (Households, industry, infrastructure, transportation etc.). Cables connect the turbines and the windfarm to the electrical grid. Collection cables connect the output of strings (rows) of turbines depending on the configuration and layout of the windfarm. The output of multiple collection cables is combined at a common collection point or substation for transmission to shore.

Inner-Array Cables

The inner-array cables (IAC) connect the wind turbines within the array to each other and to an offshore substation. The turbine generator is low voltage (usually less than 1 kV, often 500–600 V) which is not high enough for direct interconnection to other turbines. A turbine transformer steps up the voltage to 10–36 kV for cable connection. Inner-array cables are connected to the turbine transformer and exit the foundation near the mudline. Cables are buried 1–2 m below the mudline and connected to the transformer of the next turbine in the string. The power carried by cables increases as more turbines are connected and the cable size or voltage may increase to handle the increased load: actually, 66 kV is becoming the base case for IAC voltage (EOLFI, WPD pers. communication). The amount of cabling required depends on the layout of the farm, the distance between turbines, and the number of turbines.

Export Cable

Export cables connect the windfarm to the onshore transmission system and are typically installed in one continuous operation. Export cables are buried to prevent exposure, and in some places, may require scour protection. At the shore, cables come onshore and may be spliced to a similar cable and/or connected to an onshore substation. Water depths along the cable route, soil type, coastline types, and many other factors determine the cable route, installation time, and cost. At the onshore substation or switchyard, energy from the offshore windfarm is delivered to the power grid.

Export cables are composed of three insulated conductors protected by galvanized steel wire. Medium voltage cables are used when no offshore substation is installed and usually range between 24 and 36 kV. High voltage cables are typically 110–225 kV (EOLFI, WPD pers. communication and are used with offshore substations. High voltage cables have the capacity to carry more power than a medium voltage cable but are heavier and wider in diameter (Figure 2.14).

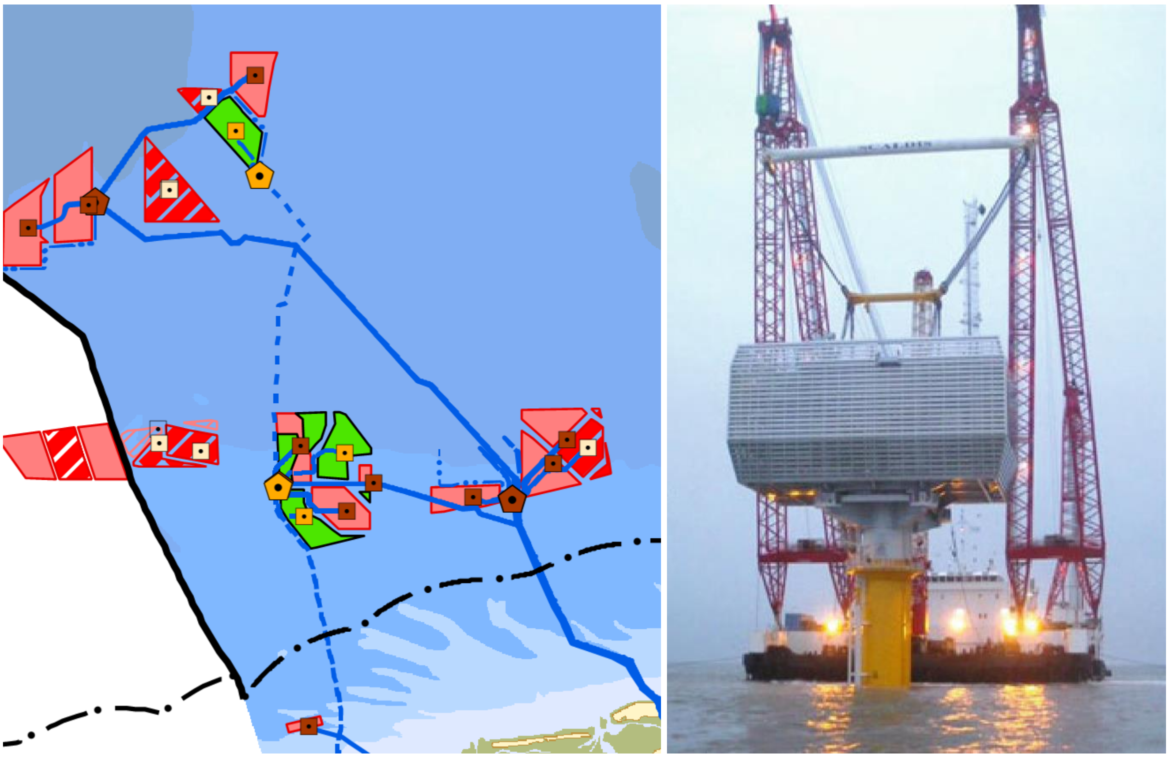


Figure 2.14 Export cable layout in the German EEZ collecting power of different OWF-Clusters and landing the power at two main shore landing points (left ©BSH 2018) and inner-park sub-station (right, at Gunfleet Sands © Offshore Wind Power MarineServices)

Due to the high distances of some offshore windfarms e.g., in the German EEZ (Exclusive Ecopnomic Zone) to the onshore interconnectors, a high-voltage direct-current (HVDC) transmission link is often installed to minimize transmission loss.

2.1.5 Offshore substation

The purpose of an offshore substation is to increase the voltage of the electricity generated at the wind turbine to minimize transmission losses. The substation is sized with the appropriate power rating (MVA) for the project capacity, and steps up the line voltage from the collection system voltage to a higher voltage level, usually that of the POI.

All offshore windfarms require substations but not all substations are located offshore. The need for offshore substations depends upon the power generated and the distance to shore which determines the tradeoffs between capital expenditures and transmission losses (KAISER & SNYDER 2012 and references therein). The components of offshore substations include voltage transformers, switchgear, back up diesel generator and tank, accommodation facilities, j-tubes, and medium- and high-voltage cables. Substations are positioned within the windfarm at a location that minimizes export and IAC distance. Substations are typically 500 tons or more and are placed on foundations similar to those used for turbines (Figure 2.15). Onshore substations also include equipment to monitor power quality, such as voltage stability and harmonic disturbances, and SCADA (Supervisory Control and Data Acquisition) systems allow the behaviour of the entire system to be monitored and controlled.

Figure 2.15 Substation at 'Alpha Ventus' (source: https://www.tennet.eu/our-grid/offshore-projects-germany/alpha-ventus/).

2.1.6 Associated components

Meteorological Systems

A met mast, to measure the meteorological environment is often among the first structures to be installed at the potential windfarm sites (Figure 2.16). A mast collects wind data at multiple heights to characterize the project area's meteorology. Sensors collect data on vertical profiles of wind speed and direction, air temperature and barometric pressure, ocean current velocity and direction profiles, and sea water temperature.

Other moored systems for acquiring data on environmental parameters such as wind speed at different heights above the water, wave heights and frequency, ocean currents include wind measurement and oceanographic buoys. These instruments are often equipped with measurement technology including LiDAR systems.

LiDAR (Light Detection and Ranging) is a surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. Lidar can be used to increase the energy output from windfarms by accurately measuring wind speeds and wind turbulence. Lidar systems can be mounted on the nacelle of a wind turbine or integrated into the rotating spinner to measure oncoming horizontal winds, winds in the wake of the wind turbine and proactively adjust blades to protect components and increase power. Floating LiDAR systems located at points across a windfarm zone is another alternative. Due to higher accuracy, cost reduction and less safety challenges associated with offshore mast installations there is a tendency to replace the met masts with LiDAR systems.

Figure 2.16 Met tower in the German EEZ (© BioConsult SH 2011)

A scour protection serves to fix the ground around a structure driven into the seabed. Scour often occurs where strong currents pass by an object with ground conditions being either sandy or muddy. Scour protections often have diameter of 20-50m and thus inherit a remarkable footprint with effect on the benthic community and by providing an alternative new habitat (e.g., by dumping rocks and gravel of different sizes).

2.2 Construction techniques

In this chapter we briefly cover the various techniques for constructing an OWF (piling, cable setting, assembling the wind turbines, floating or fixed etc.).

2.2.1 Assembling, transport and installation of offshore wind turbines

The parts of offshore wind turbines are assembled on land at suitable site facilities, which allows them to be quickly installed at sea. This process requires a high level of precision and can only be achieved when good weather conditions and low wind speeds prevail. In most installation sequences, all support structures (e.g., monopiles or jackets) are installed by a special equipped Offshore Heavy Lift vessel (OHL) a jack-up barge or semi-submersible crane vessels. A second crane vessel starts setting the rest of the tower, nacelle and rotor. This allows time and cost effective piling of all structures in a short time window.

2.2.2 Construction of foundations

Gravity Base

Gravity foundations are prefabricated onshore in one piece, then transported by barge or towed by an anchor handling tug and lowered into place (on bottom) using cranes or derrick barges. Sea bed preparation is required – silt must be removed and the sea bed must be smooth before the foundations can be lowered. During lowering, the foundation is filled with sand or gravel to achieve the required weight and stability (Figure 2.17).

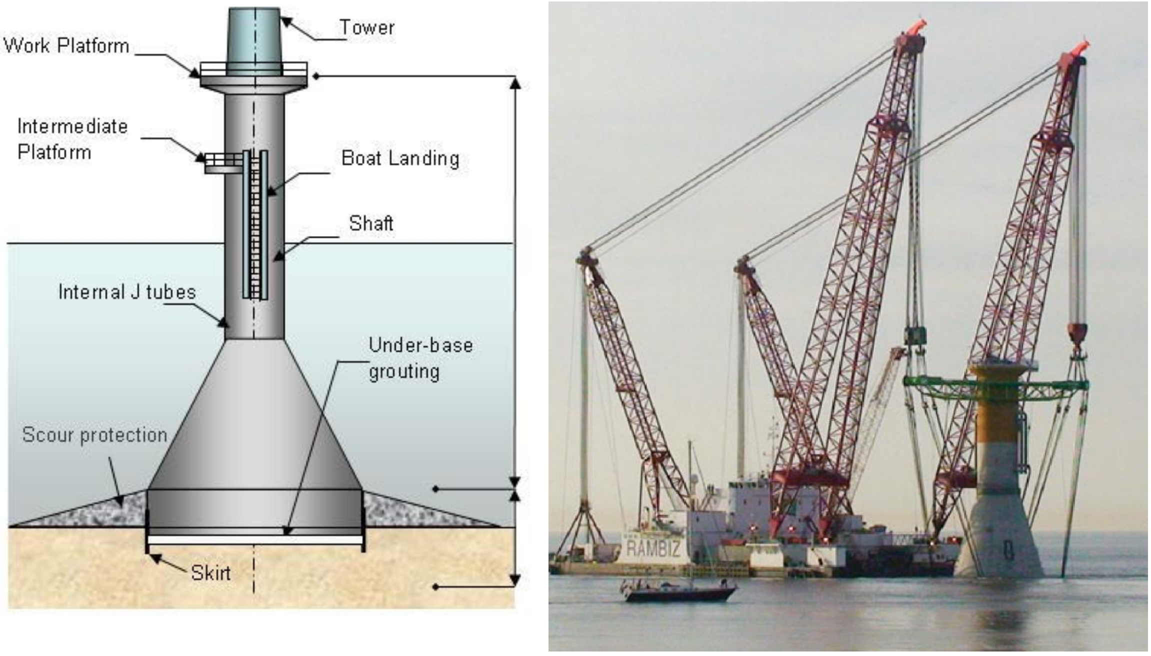


Figure 2.17 A typical gravity base caisson foundation for shallow depth (left © https://www.wind-energy-the-facts.org/offshore-support-structures.html) A gravity foundation being installed at Thornton Bank by the heavy lift vessel Rambiz (right, source & © LUC VAN BRAEKEL)

Monopile

For monopile foundations some seabed preparation might be required, such as removal of boulders or the (post construction) laying of gravel to prevent scour (Figure 2.18). After the pile has been driven, a transition piece is attached on top of the pile in a special concrete casting process. The transition piece is usually pre-installed with various features such as boat landing arrangement, cable ducts for the submarine cables, and turbine tower flanges for the bolting of the turbine tower.

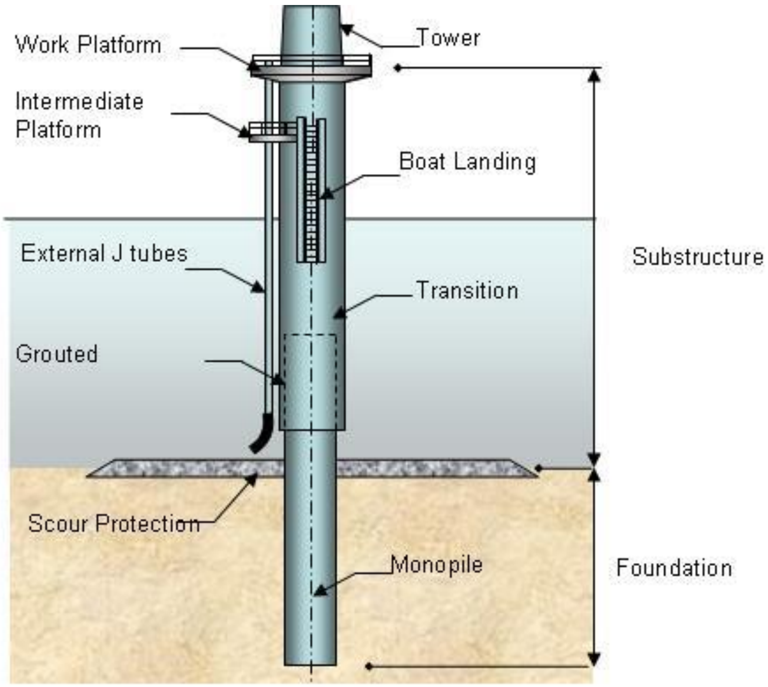


Figure 2.18 A typical monopile foundation used in the offshore wind energy industry (source & © https://www.wind-energy-the-facts.org/offshore-support-structures.html)

Suction Caisson/Bucket

The installation method is simple and quick – a single unit can be deployed and installed in a few hours as a single operation. The caisson is allowed to settle into the seabed and a pump is attached to the head. The pump is used to produce depression by removing the water from the bucket. This lowers the bucket deeper into the seabed. Auxiliary equipment and consumables such as hydraulic hammers and grouting spreads are not required. Finally, at the end of the turbine's life, a suction caisson can be removed completely from the sea bed by reattaching the pumps and pressing air inside the caisson. Suction caissons have several advantages over the monopile including higher durability, the ease of installation, the complete deconstruction and the structure's greater resistance to vertical and lateral loads due to their larger diameters.

Tripod

A tripod foundation is a transitional depth foundation for offshore wind turbines that is based off similar foundations used in the oil and gas industry. The turbine tower rests upon a steel pile, similar to a monopile foundation. A steel frame is attached to the pile which distributes the loads from the tower onto three steel bases. Through the bases, smaller piles (needle pins) are driven into the seabed to a certain depth, depending on the seabed geology and water depth to fix the structure on the ground. A typical tripod structure is shown in Figure 2.19.

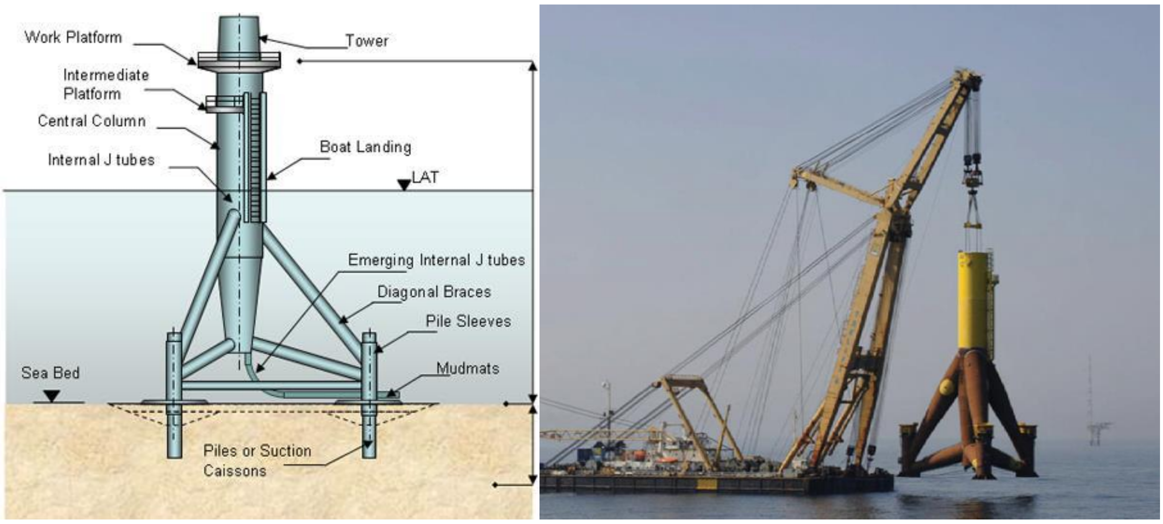


Figure 2.19 *A tripod support structure for offshore wind turbines in transitional water depths. (left, source & © https://www.wind-energy-the-facts.org/offshore-support-structures.html). The Taklift 4 placing a tripod foundation at 'Alpha Ventus' (right, source & © Alpha Ventus)*

Jacket

The jacket is prefabricated onshore and placed upon a large transport barge to be transported to the installation site. The jacket foundation structure is an adaptation from the oil and gas industry and has been installed at sites hundreds of meters deep. Piles are driven through each leg of the jacket and into the seabed or through skirt piles at the bottom of the foundation to secure the structure against lateral forces. Jackets are robust and heavy structures and require expensive equipment to transport and lift (Figure 2.20).

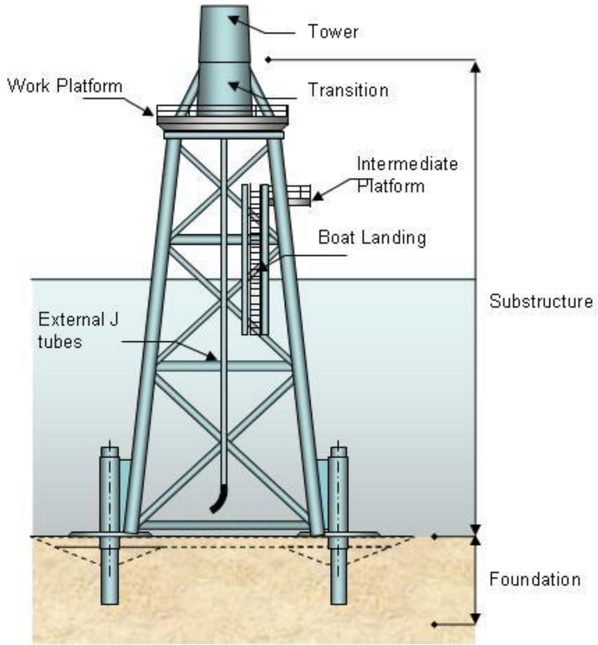


Figure 2.20 *A typical jacket-tubular foundation structure (source: https://www.wind-energy-the-facts.org/offshore-support-structures.html)*

Floating Deepwater Technologies

Floating structures must have enough buoyancy to support the weight of the turbine and to restrain pitch, roll, and heave motions within acceptable limits. The most important loads to consider are wind turbine thrust, wave loads, wind turbine torque and drift forces. There are some key differences in the load characteristics of floating wind turbines to that of floating oil rigs. While floating oil rigs and payload and wave driven, floating wind turbine loads are primarily wind-driven overturning moments. Floating structures are often prefabricated to a high degree onshore or near shore and then pulled to the installation site. Main challenges include the fixation of the structures on the sea bottom and the neutralisation of wave movements and lateral forces on turbines and blades. For moorings and anchoring, either classical drag anchors are needed or dead weights could be used in some specific type of soil (for instance suction cup anchors were used in Hywind OWF and drag embedment anchors for Windfloat project in Portugal, see chapter2.1.2).

2.2.3 Cable laying in the marine environment

The connecting cables have to be protected against scour, falling anchors or other damages. In most scenarios they will be buried in depth of one to two meters. The method of burial depends on the type of soil encountered. Three main techniques are possible (Figure 2.21):

- jetting, adapted to soft bottom: consists of blowing jets of water to dig a groove that can measure up to 2 m wide and 1 to 2.5 m deep,
- the pipe/cable laying plough, adapted to coarse soils or soft rocks: opens a furrow of 6 m wide and 3 m depth maximum,
- slicing, adapted to hard soils (rock or agglomerated gravel): allows the soil to be cut about 0.5 m wide for depth of 0.5 to 2.5 m.

Figure 2.21 Different methods of burying cables into the seaground

In case burying is not possible, the cable will be placed directly on the bottom and protected either by:

- a riprap: pieces of rocks of the order of 1 to 1.5 m high and 7 to 10 m wide are arranged on the cables,
  - the laying of a mattress consisting of articulated concrete blocks, approximately 3 m wide and high,
  - or the laying of shells: the cable is surrounded and protected by shells made of cast iron or polymer (Figure 2.22).

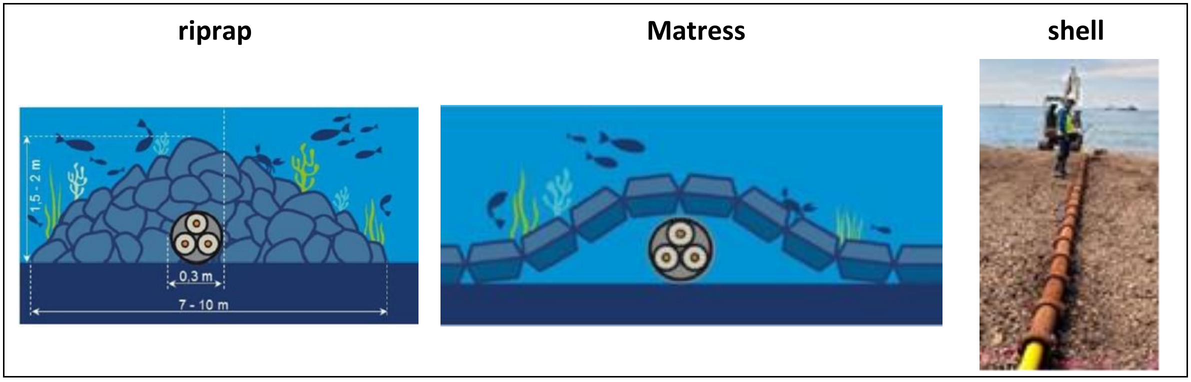


Figure 2.22 Different methods of protecting cables if layed onto the seabed

Laying cables on the seabed is performed in distinctive steps: First, the cables are rolled up by the manufacturer onto large drums, whereupon they are loaded onto a cable-laying ship/vessel and taken out to sea. Near the coast the cable is pulled onto land from the ship. Floats are used to keep the cable on the surface of the water for cable-laying purposes. This is to prevent damage from rocks or uneven surfaces on the seabed. When the cable is linked to its connecting point on land, the floats are removed and the cable gradually sinks down to the seabed. As the ship moves out, the cable is unravelled from the reel and settles on the seabed or in the trench. The end of the cable is connected to the end of the next cable via a sleeve.

Depending on the condition of the seabed, there are numerous different methods and tools for the laying of cables. If, for instance, the seabed is hard and rocky, it is common to use a plough-like tool slide. A sandy seabed, on the other hand, it is possible to use an underwater jet sled that runs across the entire length of the cable, creating a one-metre trench. The cable then sinks into the trench and is embedded on the seabed by the current. Apart from trenching there is the Horizontal Directional Drilling (HDD) method, or directional boring, which provides a trenchless method of installing conduits from offshore to shore. It is a steerable trenchless method of installing cables in a shallow arc along a prescribed bore path by using a surface-launched drilling rig, with minimal impact on the surrounding area. The system cable is then pulled through the conduit to shore for connection to the system's on-shore equipment. HDD is used when trenching or excavation is not practical or environmentally desirable. HDD is often the preferred method for landing submarine cables onto shore. In general burying cables or preparing the seabed for cable-laying can have severe effects on benthic habitats and should thus be planned with special attention.

2.2.4 Port facilities for assembly and storage

For the successful installation of an offshore windfarm, a key factor is the existence of appropriate port facilities in the adjacent land areas, as much of the construction work takes place on land.

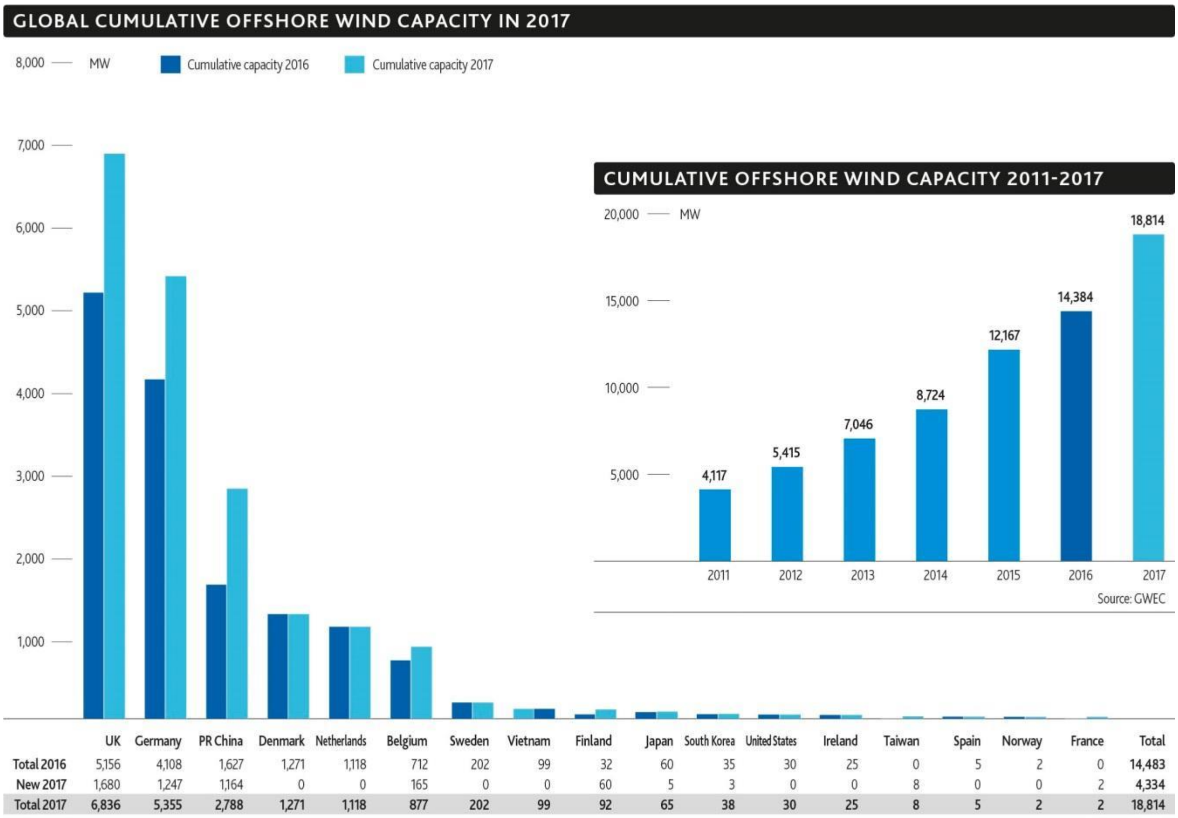
During the construction of offshore windfarms, terminal area for the storage and pre-assembly of the foundations and parts of wind turbines from various port facilities must be provided. A sufficient quay length for berthing ships of 140m length and more in combination with sufficient water depth in the basin must be provided. Short distances to the construction sites help to shorten turnover rates.

3 CURRENT SITUATION AND TRENDS

Since the renewable energy directive of the European Union was adopted in 2008 (renewed in 2014), reaching for 27% share of renewable energy consumption in 2030, energy generated by offshore wind power has gained increasing importance, as well in the EU as worldwide. Being aware of the fact that the offshore wind sector is rapidly increasing worldwide, this paragraph will mostly focus on the current situation, developments and future trends and projections in Europe.

The history of offshore windfarms started with the construction of the OWF 'Vindeby' in Denmark in 1991 and till present 16 countries have followed the Danish example (GLOBAL WIND ENERGY COUNCIL 2018) (Figure 3.1). The European Wind Energy Association (EWEA) projections suggest that the growth of the wind power sector will continue with fast pace. Between 2006 and 2017 the capacity of offshore wind has grown worldwide from less than 1 GW to over 19 GW (IRENA 2018), whereas European countries hold the biggest share with around 85%. In 2017 Europe had a total installed offshore wind capacity of almost 16 MW (Figure 3.1). This equals a total amount of 92 offshore windfarms in 11 European countries with more than 4000 turbines being installed and (partially) grid-connected (WIND EUROPE 2018) ().

Table 3.1). Within Europe five countries represent the biggest market share of 98%. United Kingdom is the market leader with 43% of all grid-connected turbines, Germany owns 28%, Denmark 12%, Netherlands 9% and Belgium 6%.



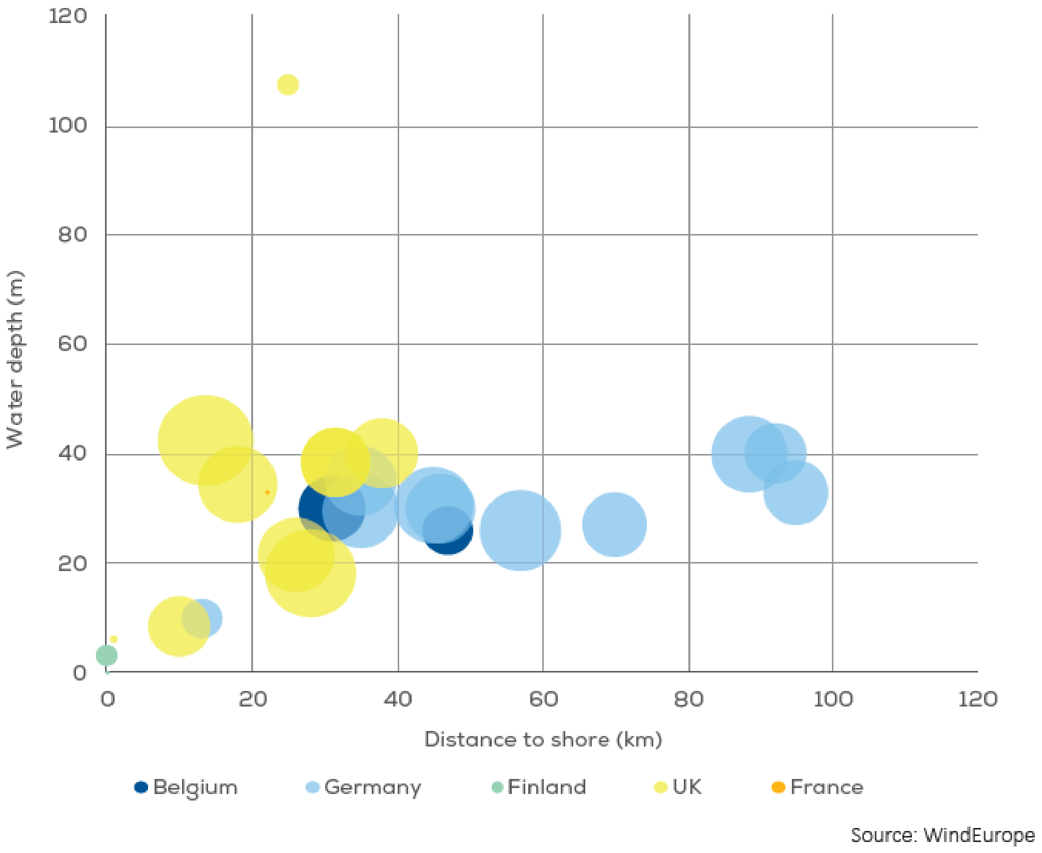
Source: GWEC

	UK	Germany	PR China	Denmark	Netherlands	Belgium	Sweden	Vietnam	Finland	Japan	South Korea	United States	Ireland	Taiwan	Spain	Norway	France	Total
Total 2016	5,156	4,108	1,627	1,271	1,118	712	202	99	32	60	35	30	25	0	5	2	0	14,483
New 2017	1,680	1,247	1,164	0	0	165	0	0	60	5	3	0	0	8	0	0	2	4,334
Total 2017	6,836	5,355	2,788	1,271	1,118	877	202	99	92	65	38	30	25	8	5	2	2	18,814

Source: GWEC

Figure 3.1 Cumulative offshore wind energy capacity worldwide by country in 2016 and 2017. Cumulative capacity is shown from 2011 – 2017. (GWEC, 2018)

The majority of the offshore wind power is produced in the North Sea (71%), followed by the Irish Sea (16%), the Baltic Sea (12%) and the Atlantic Ocean (1%). In these areas the OWF can be constructed in relatively shallow waters, the average water depth of OWFs is less than 30 m. Thus, the focus of the construction techniques was put on fixed structures, such as monopile foundations (> 80%). On the East coast of Scotland the first floating OWF 'Hywind' (30 MW) consisting of five floating turbines is in use since end of 2017 at water depths up to 110 m (initiated after the Hywind floating demo wind turbine in Norway). In France the first floating offshore wind turbine 'Floatgen' with a capacity of 2 MW located in the Atlantic was grid connected in 2018. Another example of pilot floating wind turbine comes from Portugal (WindFloat) with a 5-year successful deployment since 2011[5]. Floating turbines shall open the opportunity to build OWF in further distance of the coast in deeper waters. To date the average distance of an OWF to the coast is at around 40 km, also depending on the country and national regulations. OWF being constructed during 2017 in Europe, show the greatest distance from shore in German waters (up to 112 km) and in Finland there is a OWF constructed at a distance of only 4 km (FRAUNHOFER INSTITUT FÜR ENERGIEWIRTSCHAFT IMD ENERGIESYSTEMTECHNIK IEE & RHORIG 2018) (Figure 3.2). Despite the leading role of European countries in the offshore wind energy sector the development of OWF in the Mediterranean is still in its infancy and to date no OWF exists in the Mediterranean.



Source: WindEurope

Figure 3.2 Average depth (m) and distance to coast of OWF under construction in 2017 in the EU. The size of the bubbles represents the relative capacity of the OWF. (WIND EUROPE 2018).

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[5] http://www.principlepowerinc.com/en/windfloat

Table 3.1 *Number of offshore windfarms, turbines, installed capacity per European country. Modified after WindEurope (2018). Besides "Hywind" OWF in the UK and one turbine in France, there is no floating OWF operating and grid connected in the countries included in the table.*

Country	**No. of OWF**	**No. of turbines connected**	**Capacity installed (MW)**
UK	31	1,753	6,835
Germany	23	1,169	5,355
Denmark	12	506	1,266
Netherlands	7	365	1,118
Belgium	6	232	877
Sweden	5	86	202
Finland	3	28	92
Ireland	2	7	25
Spain	1	1	5
Norway	1	1	2
France	1	1	2
Total	92	4,149	15,780

Nevertheless, offshore windfarms are not only expanding globally, but also the size of the turbines itself and the capacity of a single turbine has undergone a drastic increase since the beginning of offshore wind power. The diameter of the rotor blades and the height of the hub have increased from 1991 (35 m and 37.5 m, respectively) to 136 m rotor blade diameter and 96 m hub height (Figure 3.3 and Figure 3.4). While 'Vindeby' started off with 0.45 MW capacity per turbine the standard capacity increased to 3 – 6 MW and is now moving to exceed 8 MW.

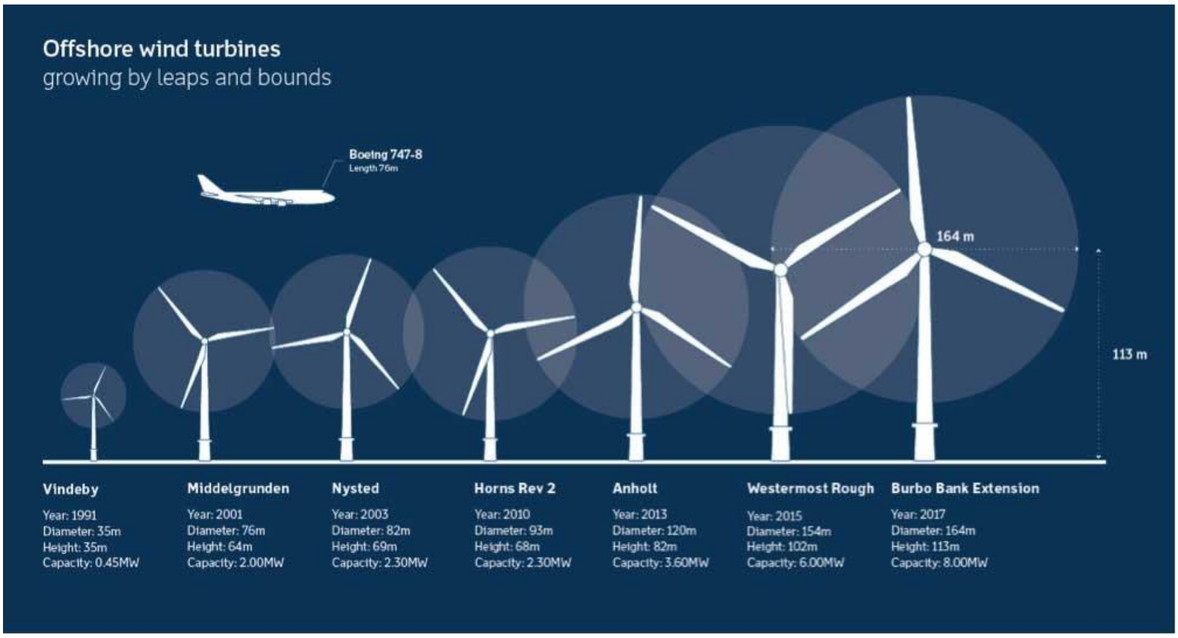


Figure 3.3 Schematic view of the development of rotor diameter (m) and hub height (m) worldwide of offshore turbines from 1991– 2017. (OPEN OCEAN 2017)

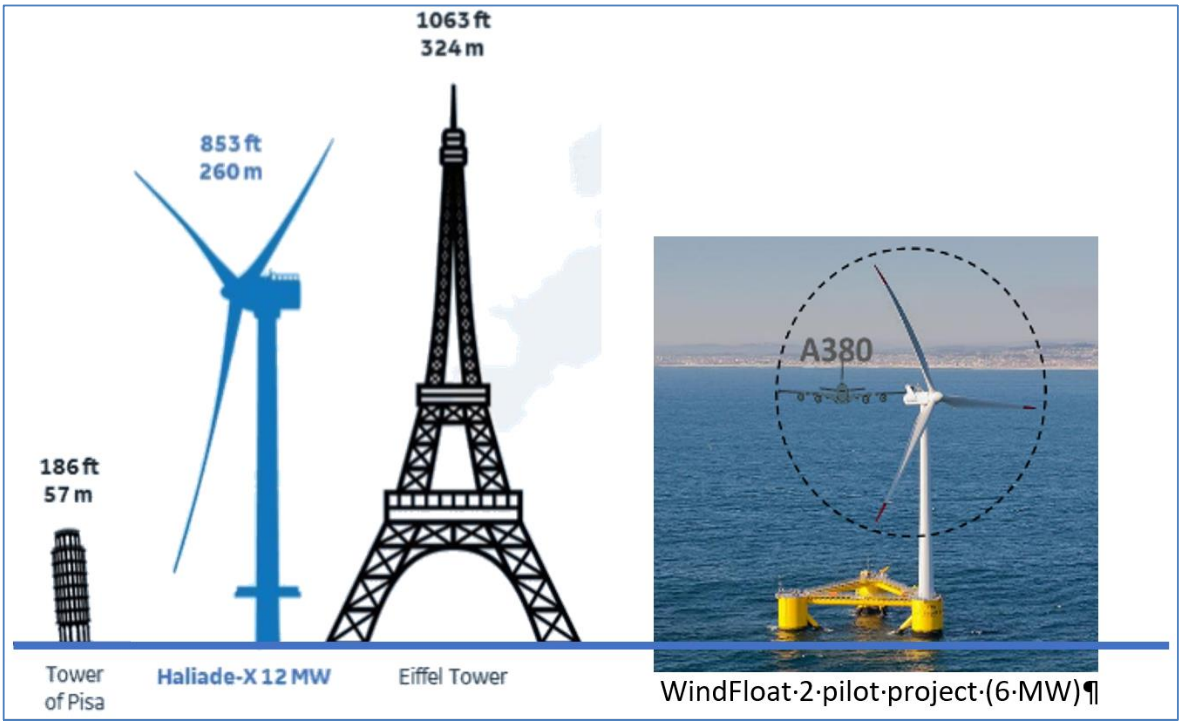
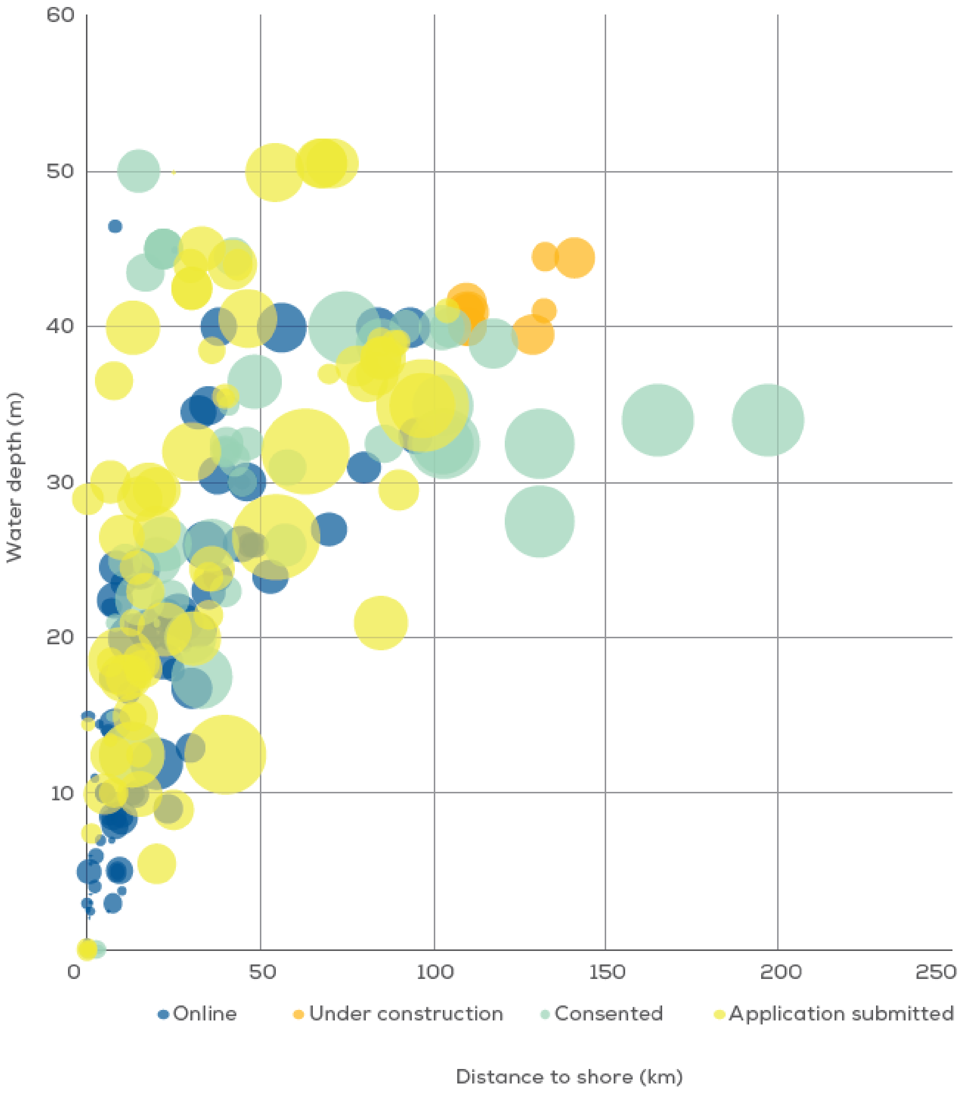


Figure 3.4 Comparative view of the size of the world's biggest turbine Haliade-X and the floating turbines of the WindFloat 2 pilot project, Portugal (source: modified after General Electric Renewable Energy - https://www.ge.com/renewableenergy/wind-energy/turbines/haliade-x-offshore-turbine).

For the future development of the offshore wind power sector the projections suggest, that the global capacity will increase up to 521 GW in 2050 (IRENA 2018) and the total European offshore wind capacity will reach 70 GW by 2030 (according to the Central scenario WindEurope). According to the latter scenario with regards to the spatial distribution of OWF in Europe the North Sea will remain the region with the highest capacity, followed by the Baltic Sea (projects in Germany, Denmark, Sweden, Poland and Estonia). In the Atlantic (UK, France and Portugal) and the Mediterranean Sea (France and Italy) the projected capacity will reach 8 and 0.5 GW, respectively.

In general the progress in technical development makes planning and installing of OWF with an increasing capacity at greater depth and further offshore possible. Projects are consented in distances from the coast of greater than 150 km and up to depths of 50 m (only bottom-fixed installations are considered here) (Figure 3.5).

The progress in technical development will also promote the installation of more floating turbines. To date nine floating offshore wind projects (total capacity: 338 MW) are planned to be commissioned by 2021 in France, the UK, Ireland and Portugal and further projects worldwide (e.g. Japan, US and Korea) are already commissioned or planned and are expected to exceed 5 GW by 2030 (GLOBAL WIND ENERGY COUNCIL 2018) (Figure 3.6).



Source: WindEurope

Figure 3.5 Average depth and distance to shore of bottom-fixed OWFs in Europe. The colour of the bubbles represents the status of the OWF (blue = online, orange = under construction, green = consented and yellow = application submitted). The size of the bubbles indicates the overall capacity of the site. (WindEurope, 2018)

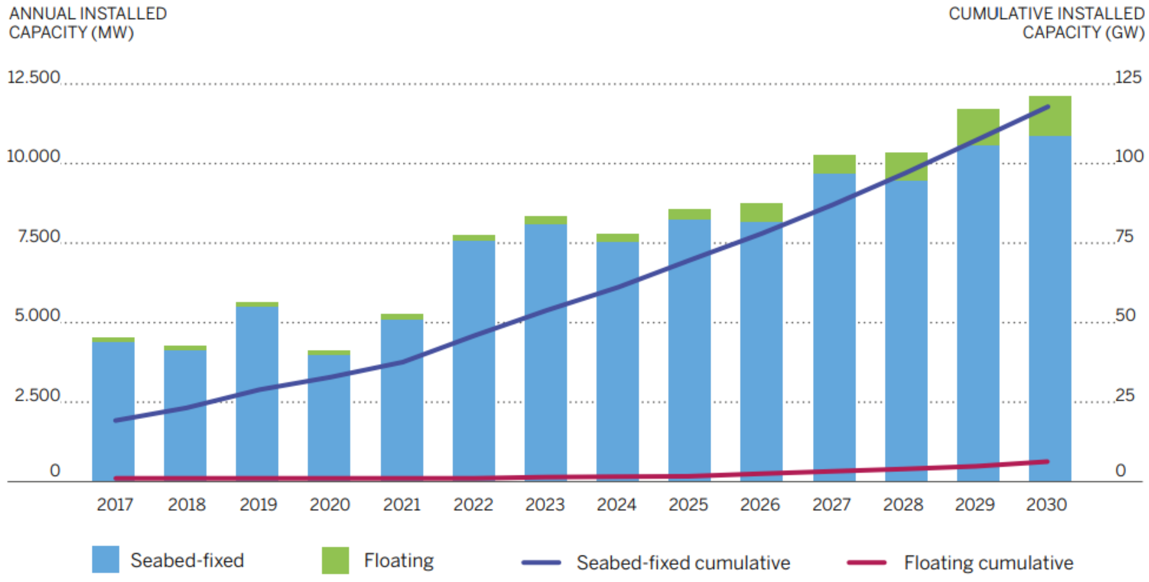


Figure 3.6 Global projections for development of worldwide offshore wind capacity. In green the projected share of floating OWFs. (GWEC report, 2017)

Specific forecasts for the Mediterranean region energy generated from offshore wind power is the most favoured and promising source of renewable energy, also in the light of an expected cost reduction of up to 50% for new OWFs by 2021 (SOUKISSIAN et al. 2017). For the Mediterranean the installation of floating turbines is suggested to be the most favourable option regarding the geomorphology in many Mediterranean regions (SOUKISSIAN et al. 2017). Therefore sites with floating turbines in the French Mediterranean are in planning or in progress (e.g. 'Les éoliennes flottantes du Golfe du Lion' and 'Les éoliennes flottantes de Provence Grand Large') (4C OFFSHORE LTD 2018). Other Mediterranean countries are facing cancellation of OWF projects (e.g. Spain and Italy) due to financial or governmental reasons. In Greece several projects with capacities between 50 MW ('Dikella' in the Thracian Sea) and 585 MW ('Thrace Sea' in Thraki region) are in the planning phase already since 2010 and 2007 respectively (4C OFFSHORE LTD 2018), making it difficult to predict any progress for these projects. For current status of OWF in the Mediterranean and worldwide, see for instance: https://www.4coffshore.com/offshorewind/.

4 MEDITERRANEAN MARINE HABITATS & SPECIES AND INTERNATIONAL CONVENTIONS

The Mediterranean Sea is characterized by high-level biodiversity, with a high percentage of endemic species. The variable topography of the basin and the climatic and hydrologic conditions of its ecosystems allow the presence of both temperate and subtropical species. Specifically, the basin hosts between 4% and 18% of the world's marine species, many of which are endemic to the Mediterranean. The Western Mediterranean hosts the greatest diversity of sea turtles, marine mammals, and seabird life. The Mediterranean Sea contains sensitive deep-sea, pelagic, and coastal habitats, intact shorelines, estuaries, underwater canyons, coralligenous assemblages, along with 150 important wetlands for birds, and around 5000 islands and islets. The most important coastal habitats are sea grass ecosystems with the endemic *Posidonia oceanica* meadows having the highest economic and ecologic value. They cover about 50,000 km^2 of both sandy and rocky areas of the Mediterranean Sea; reaching depths up to 45 m. Meadows of *Posidonia oceanica* are important nursery areas for fish, supporting 25% of the Mediterranean Sea fish species. They also have a major role in maintaining seashore stability. Along with *Zostera marina, Posidonia oceanica* sea grass is considered endangered species, facing a number of pressures from human activities (SOUKISSIAN et al. 2017 and references therein).

Explicit information about the most important marine Mediterranean habitats and species in terms of conservation can be found in the following chapters:

- 5.3.7 Important marine habitats in the Mediterranean (invertebrate species included)
- 5.4.6 Situation in the Mediterranean Sea (fish related)
- 5.5.5 Sea turtles in the Mediterranean Sea
- 5.6.5 Mediterranean marine avifauna
- 5.7.7 Marine mammals in the Mediterranean sea

Regarding the occurrence of marine habitats listed under Annex I of the EU Habitat Directive 92/43/EEC (EUROPEAN COMMISSION DG ENVIRONMENT 2007) and associate sessile species and their relation to the offshore windfarms in various water depths and related infrastructure one can highlight the following:

'1110 - Sandbanks which are slightly covered by sea water all the time': Above a sandbank the water depth is seldom more than 20 m below chart datum. This habitat is related to offshore windfarms with fixed foundations and the electricity transfer grid (cable laying and operation)

1120* - Posidonia beds (*Posidonion oceanicae*)': It is a priority habitat according to Annex I of the EU Habitats Directive 92/43/EEC. *Posidonion oceanicae* can form meadows or beds extending from the surface to 40–45 m depth. Situating offshore windfarms in a priority habitat raise strong oppositions during the permit process because of conservation obligations stemmed from the Habitats directive. Therefore offshore windfarms and associate infrastructure (cables) should be generally considered incompatible with this kind of habitats.

1130 - Estuaries: Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. This habitat is potentially related to the electricity transfer grid (cable landing).

1140 - Mudflats and sandflats not covered by seawater at low tide': Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms. This habitat is potentially related to the electricity transfer grid (cable landing).

‘1150* - Coastal lagoons’: Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. This habitat is potentially related to the electricity transfer grid (cable landing) but it must be noted that it is also a priority habitat and may raise strong oppositions during the permit process because of conservation obligations stemmed from the Habitats directive.

‘1160 - Large shallow inlets and bays’: Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. This habitat is potentially related to the electricity transfer grid (cable landing).

‘1170 – Reefs’: Rocky reefs are extremely variable, both in structure and in the communities they support. A wide range of topographical reef forms meet the EU definition of this habitat type. These range from vertical rock walls to horizontal ledges, sloping or flat bed rock, broken rock, boulder fields, and aggregations of cobbles. They can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions. Reefs can be found in a wide spectrum of water depths from coast up to >200 m depth (deep zone of habitat 1170). This habitat is related to offshore windfarms with fixed or floating foundations and the electricity transfer grid (cable laying and operation).

Invertebrates important in terms of conservation according to Habitats directive include the species *Pinna nobilis* (depth range: 0,5 to 60 m), *Centrostephanus longispinus* (depth range: 40 to 210 m), *Lithophaga lithophaga* (they can reach depths of 125 to 200 m), *Petromyzon marinus* (at depths down to 4.000 m), *Scyllarides latus* (depth range: 4 to 100 m), *Corallium rubrum* (depth range: 15 to 1016 m), *Gibbula nivosa* (depth range: 5 to 12 m), *Lithothamnium coralloides* (depth range: 1 to 30 m), *Patella ferruginea, Phymatolithon calcareum* (depth range: 1 to 30 m), and can be affected if their habitat is occupied or disturbed by offshore windfarm foundations, cables laying and operation and anchoring of survey, construction or maintenance vessels.

Regarding the presence of marine mobile species such as fish, marine mammals, and sea turtles, these can be present throughout the offshore windfarm site regardless the foundation type. Sea caves used as nesting and resting sites by Monk seals *Monachus monachus* as well as sandy beaches used as nest sites of sea turtles are of high ecological importance and potential cable laying activities, cable landings and disturbance from construction and operational activities should be restricted. Avifauna related to the marine environment (seabirds, some raptors etc) or migratory birds could also be found throughout the study area of an offshore windfarm.

Main anthropogenic pressures that species and habitats face in the Mediterranean include the following (PIANTE & ODY 2015) and more detailed information can be found in the chapters mentioned above:

- Extraction of living resources (Fisheries & Aquaculture)
- Extraction of non-living resources (Mining)
- Energy production
- Land-based pollution
- Maritime transport
- Tourism
- Climate change

To protect the seas surrounding Europe three conventions exist. The conventions are area specific (Mediterranean, North-Atlantic and the Baltic) and aim for similar goals within the specific ranges and needs of the respective seas. In the following the three conventions are described shortly.

Barcelona Convention - Mediterranean

The Barcelona Convention (or Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean) was adopted in 1976 within the framework of the Mediterranean Action Plan (MAP) of the UNEP (United Nations Environment Program), which aims to further protect the Mediterranean marine environment through cross-border cooperation. The Barcelona convention has 21 contracting parties (and the EU) and covers issues from biodiversity, coastal management and sustainable development. One major focus of the Barcelona convention is the achievement of Good Environmental Status (GES). For this purpose an extensive monitoring and assessment program (IMAP) was adopted in 2016 (UNEP/MAP 2017).

The MAP promotes in its Mid-Term-Strategy the “planning and management mechanisms ensuring that economic, social and cultural development is in harmony with natural environment and landscape” as well as formulates the strategic objective “to facilitate sustainable development of coastal and marine areas by ensuring planning mechanisms that address both natural processes and anthropogenic pressure impacting on them” (UNEP/MAP 2018). Both objectives give way to support ecosystem-based management of the Mediterranean Sea under a strong framework as the Barcelona Convention.

OSPAR – North-East Atlantic

The Oslo-Paris-Convention (OSPAR) in its recent form was established in 1992. A cooperation of 15 nations and the EU aims for the protection of the marine environment of the North-East Atlantic. Within the OSPAR framework areas the environmental status of the North-East Atlantic seas is assessed, areas of threat are identified and appropriate programs and measures developed, which are agreed internationally by the participating parties. This way the OSPAR Commission acts as a platform for cooperation between governments, requires commitment of the contracting parties and gives hands-on recommendations e.g. on monitoring to improve the protection of the North-East Atlantic (OSPAR 2019).

HELCOM – Baltic

The Helsinki Commission (HELCOM) was initiated in 1992 and acts as an environmental policy maker for the Baltic Sea area by developing common environmental objectives and actions and is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention). All countries located on the Baltic Sea and the EU form the 10 contracting parties. HELCOM aims to protect the marine environment of the Baltic Sea from all sorts of pollution with strong cross-border cooperation. Within the HELCOM framework recommendations are developed based on assessments on the ecological state of the Baltic Sea. The standards developed by HELCOM are agreed on from all contracting governments. (HELCOM 2019).

5 IMPACTS OF OWFS ON THE MARINE ENVIRONMENT

5.1 Introduction

Potential impacts of OWF

There are various different pressures associated with offshore windfarms which can possibly have an impact on the marine environment. These risks can either apply for the entire life cycle of an OWF or only during a specific phase. The main pressures associated with the three main phases of an OWF (construction, operation and decommissioning) are the following (BSH 2013; AGENCE FRANÇAISE POUR LA BIODIVERSITÉ 2018):

Construction phase

- **Visual** and **acoustic** stress due to construction activities
- **Sound** and **light** emissions by vehicles/vessels and machinery during construction
- Temporary/permanent **loss of habitats**
- **Pollutant** emissions
- **Turbidity** of water due to sediment disturbance

Operation phase

- **Visual impact** and annoyance due to **noise emission** of turbines during operation
- **Shadow flicker** from rotor blades
- **Vibration**
- Additional **electric and magnetic fields**
- **Land use** by the required infrastructure (anchors, foundations, cables etc.)
- Potential discharge of **pollutants**
- **Changed sediment** distribution and dynamics
- **Changed current** patterns
- Potential impact on **water quality**
- **Collision risk** of birds with wind turbines
- **Barrier** effect on fauna
- **Disturbances** (e.g. birds, long-term loss of resting and feeding areas)
- **Creation of artificial reefs by the turbines**
- Adverse impacts of maintenance and repair operations.

Decommissioning phase

- **Visual and acoustic annoyance** due to dismantling activities
- **Annoyance from vehicle and machinery operation** during dismantling activities
- **Loss of habitats** (resting and feeding areas) due to decommissioning activities
- **Pollutant** emissions
- **Turbidity of water** due to sediment disturbance

The following sections will mainly focus on the impacts of noise, habitat loss, pollution & waste, sediment alternation, electromagnetic fields, temperature, direct impacts of the construction and indirect impacts of the presence of the OWF. It will be discussed how these pressures are defined and which impacts these pressures have or may have on different factors and animals in the marine environment. It has to be borne in mind, the impacts, e.g. on the climate, of the entire lifecycle of an OWF (from production of the individual components until the recycling of the decommissioned structures) and the Corporate Social Responsibility are important topics that need to be taken into account when discussing the further development of offshore wind power. This report is limited to cover current knowledge on solutions to avoid and mitigate environmental impacts of offshore windfarms during construction, operation and decommissioning.

5.1.1 Noise

Virtually all species use sound to communicate, search and identify prey or orientate themselves in their habitats. Within the last decades, the emission of anthropogenic noise into the Mediterranean Sea and the other oceans has increased rapidly, mainly by vessel noise from marine traffic, coastal and offshore constructions (harbour extension, marine renewable energy, oil platforms), seismic surveys and military operations (MAGLIO et al. 2016).

For marine wildlife, and especially marine mammals noise can pose a massive impact, starting with masking of communication, deterrence from their optimal habitats and physical stress (including e.g., injuries of the auditory systems), all having an impact on individual fitness and thus eventually on population dynamics. For noise is one of the most severe impacts on marine wildlife, it is crucial to analyse and understand what sound is and how its effects can be assessed.

Underwater sound

Sound in general is generated by a vibrating object and propagates as a wave through a specific medium, like a solid (e.g. seafloor), liquid (e.g. water), or gas (e.g. air). As the sound spreads through the medium, its energy diminishes because of propagation loss e.g., by reflection at surfaces or the sea ground.

Sound can be measured by its Amplitude/ intensity (loudness), for example in Watt per square meter (W/m^2), or decibels (dB). Decibel (dB) is a relative unit and must always be referenced to a pressure and distance to the source. Table 5.1 provides estimates of underwater noise of different sources.

Table 5.1 Overview of sound levels underwater of common events

Ships underway	**Broadband Source Level (underwater dB at 1m)**
Bulg/Cargo Vessel (173m, 16 knots) (ARVESON & VENDITTIS 2000)	174
Cable-Layer / Trenching (NEDWELL et al. 2003)	178 (152to 192 when measuring smaller and larger vessel including active machinery)
Large Tanker (NATIONAL RESEARCH COUNCIL 2003)	183-200
Military Sonars	
AN/SQS-53C (U. S. Navy tactical mid-frequency sonar, center frequencies 2.6 and 3.3 kHz) (NORMAN et al. 2004)	235
AN/SQS-56 (U. S. Navy tactical mid-frequency sonar, center frequencies 6.8 to 8.2 kHz) (U.S. DEPARTMENT OF COMMERCE & SECRETARY OF THE NAVY 2001)	223
SURTASS-LFA (100-500 Hz) (U. S. DEPARTMENT OF THE NAVY 2001)	215 underwater dB for a single projector, with up to 18 projectors operating simultaneously in a vertical array
Ocean Acoustic Studies	
Heard Island Feasibility Test (HIFT) (Center frequency 57 Hz) (MUNK et al. 1994)	206 underwater dB for a single projector, with up to 5 projectors operating simultaneously in a vertical array (maximum transmit level: 221dB)
Acoustic Thermometry of Ocean Climate (ATOC)/North Pacific Acoustic Laboratory (NPAL) (Center frequency 75 Hz) (MUNK et al. 1995)	195
Construction Activities	
Piling of 4-6m Monopiles Piling at Horns Rev (NEDWELL et al. 2007)	Peak-to-peak >250 dB Peak: 196 dB (in a distance of 720m) and SEL of 176 dB

The high dB values of military sonars and ocean acoustic studies are noticeable in Table 5.1, but even moving ships produce high dB values in water.

Pulsed sound pressures are created by sound sources like the piling of larger monopiles and may lead to severe injuries in marine mammals. Noise of pile driving is measured standardized in 750 m distance to the source (or normalized to this distance following ISO 180406:2017 (ROBINSON & THEOBALD 2017)) and well exceeds with growing pile diameters sound levels in which injuries to marine mammals are likely.

Noise levels from pile driving are one of the loudest noise sources in the sea. Noise levels depend on various factors, the most important being piling energy, pile diameter and water depth (Figure 5.1). Pile diameter and water depth which define the surface emitting noise into the water column. As piling energy is related to pile diameter (larger piles need higher energy), pile diameter is a good predictor for actual noise immission, but as piling energy may be kept low in order to reduce noise immission, there is quite some variability between projects, though a clear positive relationship between pile diameter and noise levels is apparent.

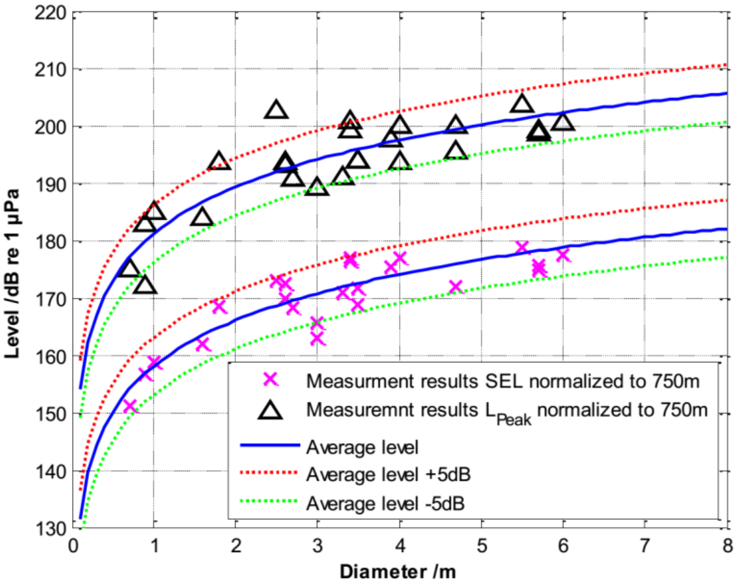


Figure 5.1 Relationship between pile diameter and noise immission expressed as SEL and Lpeak from offshore pile driving (BELLMANN 2014).

5.1.2 Pollution and waste

When talking about marine waste and pollution one has to distinguish between macroscopic pollution, such as plastic bags or other debris from households and industry, and chemical pollution generated by dispersion of chemicals or toxic substances. During construction and operation of an OWF macroscopic waste can be released into the marine environment by inappropriate waste disposal, e.g. on the construction vessels. These waste items can harm animals, such as birds, turtles, fish and marine mammals, either via entangling in the waste item or by swallowing it.

Chemicals or potentially toxic substances can be released e.g. by oil leakages due to improper handling of construction machines or coating and sealing material containing polyurethane or epoxy resin. The latter is classified as environmentally hazardous prior to be fully hardened. Another potential source of chemical leaching is the use of anti-fouling paints, which minimize biological fouling of devices (BOEHLERT & GILL 2010). Furthermore submarine corrosion control can be a source of chemical pollution of the surrounding marine environment. Submerged metallic structures can be protected by sacrificial anodes (Cathodic protection). These anodes consist in most cases of Aluminium (Al) or Zinc (Zn), but may also contain heavy metals like Indium (In), Cadmium (Cd) or Lead (Pb) (KIRCHGEORG et al. 2018). This technique is based on the progressive dissolution of the sacrificial anode, which leads to a release of the containing metals to the marine environment. Studies on Zinc released from sacrificial anodes showed that the concentration in the surrounding water and the seabed surface was increased (GABELLE et al. 2012; DEBORDE et al. 2015 and references therein). Aluminium itself is not considered as toxic or rather has a high no-observed-effect concentration (DERIVATION OF A WATER QUALITY GUIDELINE FOR ALUMINIUM IN MARINE WATERS 2015), but can form toxic bounds with other elements and can also be enriched in the seabed surrounding a construction using sacrificial anodes for corrosion control (GABELLE et al. 2012). The potential impact and predicted release of metals from sacrificial anodes in the OWF sector remain unclear and are discussed controversially. KIRCHGEORG ET AL. (2018) give a good review on the current knowledge and knowledge-gaps and suggest a low environmental impact. However, monitoring data is scarce and it remains difficult to assess its environmental impact (KIRCHGEORG et al. 2018).

5.1.3 Electromagnetic fields

Electromagnetic fields (EMFs) are magnetic fields that are generated by an electrical current running through an electric wire. There are natural generated EMFs, like the earth geomagnetic field, and human induced sources of EMFs. Strength of an EMF is given in the unit Tesla (T). Offshore windfarms generate EMFs by subsea power cables transporting the generated electricity over a long distance to the coast. Strength of an EMF decreases with distance from the wire (Figure 5.2) and depends on the strength of the current, meaning that stronger EMFs can be generated as a consequence of heavy winds. Cable sheating prevents electric fields from reaching the marine environment, however movement through the electromagnetic field, e.g. by water currents ore passing animals, can induce electric fields (BOEHLERT & GILL 2010). Therefore, both electromagnetic (EMF) and induced electric fields (iEF) can be expected to be generated by subsea power cables (Figure 5.3).

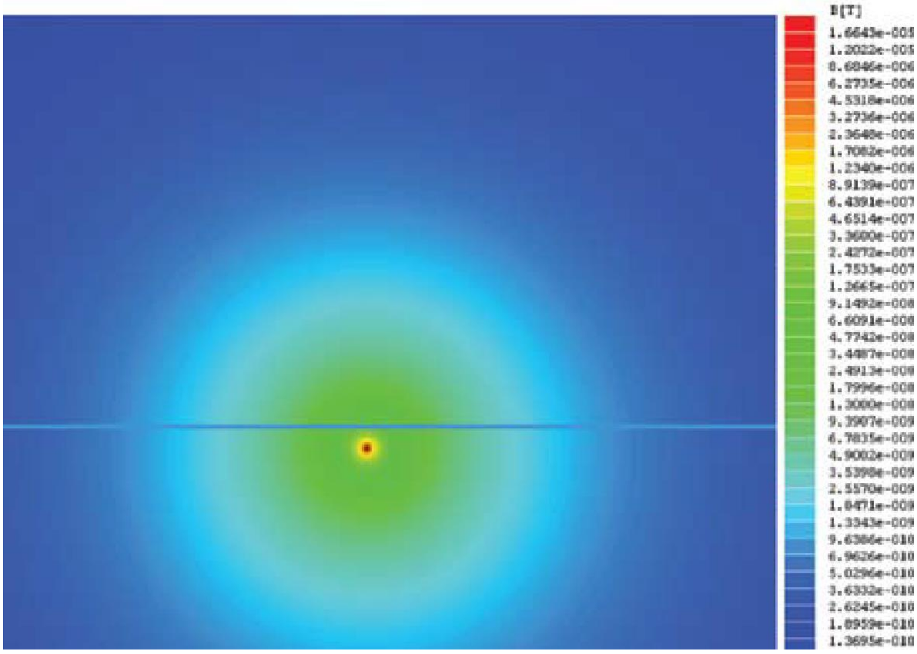


Figure 5.2 Schematic presentation of the magnetic field (T) generated by an industry standard 13 kV subsea cable buried at 1 m depth. Blue line represents the seabed surface. (BOEHLERT AND GILL, 2010)

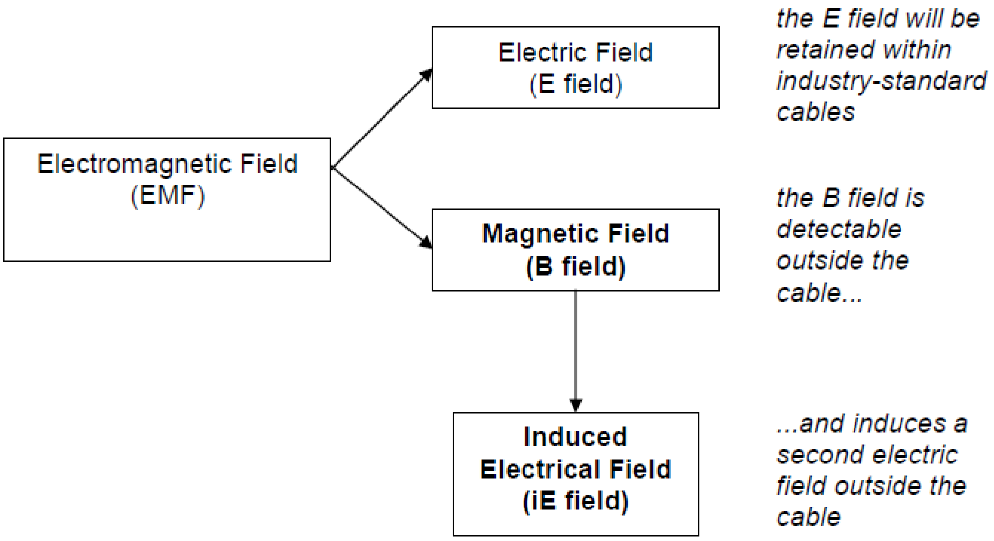


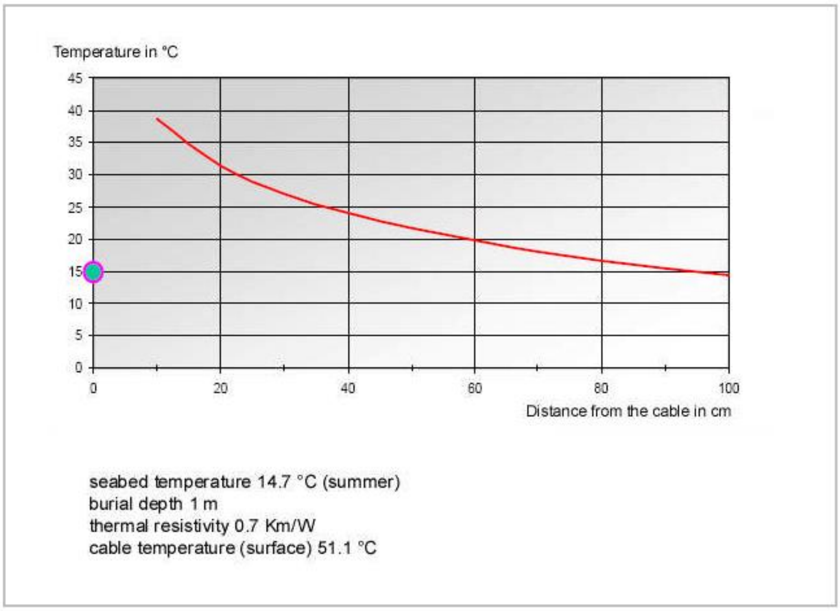
Figure 5.3 *Schematic overview of the fields associated with subsea power cables, whereas the magnetic (B field) and induced electrical field (iE field) can potentially impact on the marine environment. (Gill, 2005)*

EMFs and induced electrical fields are generated through the entire operational phase of an OWF. Two different kinds of electric currents have to be distinguished: Direct electric currents (DC) generate static electromagnetic fields, whereas altering electric currents (AC) generate variable electromagnetic fields, the EMF of DC cables being generally stronger than of AC cables. Both AC and DC power cables are used in OWFs (Bureau Waardenburg Ecology & landscape & WaterProof Marine Consultancy & Services B. V. 2016).

EMFs and induced electrical fields are generated through the entire operational phase of an OWF. Impacts of EMFs induced by OWFs are so far not well studied. However, the greatest impacts are expected for animals which use the Earth’s natural geomagnetic field for orientation (such as some migrating fish species, cetaceans and sea turtles) or which depend on electroreception for prey hunting (e.g. some elasmobranchs).

5.1.4 Temperature

Energy transmission in the cables produces heat, causing a heating of the cable itself of up to 70°C (Emeana et al. 2016) and a rise in temperature in the surrounding environment, which decreases with the distance from the cable (Figure 5.4). In case the cable is placed above the seabed the produced heat is emitted via convection to the passing seawater and this way rapidly dispersed. Various additional factors can determine the degree of temperature increase in the vicinity of the cable: Cable type and transmission rate, sediment characteristics (in case the cable is buried) and the ambient abiotic conditions (water temperature, currents etc.). At equal transmission rates AC cables have a higher heat dissipation than DC cables (IfAÖ 2006).



seabed temperature 14.7 °C (summer)
burial depth 1 m
thermal resistivity 0.7 Km/W
cable temperature (surface) 51.1 °C

Figure 5.4 Example of a modelled seabed temperature in the surrounding of a medium voltage AC cable in an OWF buried at 1m depth. (IFAÖ 2006)

The heat produced by the submarine cables is thought to have a potential impact on the surrounding seafloor, the microbial community as well as benthic and demersal animals.

5.1.5 Artificial light

There are variable sources of artificial light during construction, operation and maintenance phase. Lighting would be necessary for illuminating the work area on land, at the berth, and on the vessels while at berth

During construction temporary work lighting would illuminate work areas on vessel decks or service platforms of wind turbines or associated infrastructure on platforms. In addition, cable laying may occur 24 hours a day during certain periods, and these vessels would be illuminated at night for safe operation. Also storing of equipment and preparatory activities during construction are expected at existing industrialized ports however with not substantial increase in lighting above what is normally expected. In addition, all vessels operating between dusk and dawn are required to have navigation lights turned on. Similar artificial light sources are expected during decommissioning.

During operation, besides lighting coming from maintenance vessels, shipping safety lights and safety aviation lights are placed at the base and top of the wind turbines respectively. International and national regulations regarding ship and air safety require that wind mills, either individually or collectively as a windfarm have to be marked with obstruction lights during night-time. The lighting specifications differ between countries. In addition converter station platforms are supposed to be permanently illuminated for safety and operational reasons.

A number of factors can affect light transmission, both in air and water. In air, the transmission of light can be affected by atmospheric moisture levels, cloud cover, and type and orientation of lights. In water, turbidity levels and waves, as well as type of light, can affect transmission distance and intensity.

As discussed in following chapters birds and sea turtles are potentially affected by the presence of light. More precisely birds migrating during nights with bad weather conditions may be attracted by light in offshore structures which can lead to direct mortality from collision. High numbers of migrating birds are known to cross large water bodies – e.g. the North Sea – during night-time; orientation of these migrating birds relies on a number of mechanisms from magnetic compass over polarized light to night cues such as sunset and stars. The disturbances of night-migrating birds by artificial lights range from des-orientation to exhaustion and/or collisions. Regarding lighting sea turtle hatchlings have shown attraction to artificial light in the sea risking indirect mortality from disorientation, energy loss and increased predation in the vicinity of the light source.

5.1.6 Collision risk

As discussed in the following chapter one of the potential effects of offshore windfarms on marine birds is due to collision mortality. Collision is more likely to occur if seabirds/migratory birds fail to avoid wind turbines and fly through the rotors swept area. As actual collision fatalities cannot be identified in the marine areas a lot of effort has been given to evaluate the collision and avoidance rates in order to get estimations of collision risk, a process which is species and site specific.

Besides the turbines, ship traffic associated with OWF construction and maintenance work pose a risk to marine fauna such as marine mammals and sea turtles. Impacts and mitigation measures of ship strikes are discussed in chapter 5.7 and 6.5.

5.1.7 Secondary impacts of OWF components

Impacts that are not directly associated with the OWF itself, but result from a situation caused by the OWF are known as secondary impacts. Two main secondary impacts were identified to impact on the marine environment: The reef effect and the reserve effect.

Reef effect

The introduction of underwater constructions associated with offshore wind power will create new artificial substrate. The foundations of the turbines, scour protection, concrete mats or any other submerged construction part of a turbine can act as artificial reefs (LINLEY et al. 2007; LANGHAMER 2012)) which will increase the heterogeneity in that area and inevitably be colonized by marine flora and fauna. If turbines are built in a naturally sandy habitat, the newly introduced hard-structures provide an alternative habitat and may be attractive for species associated with hard-substrates (Figure 5.5). This can support an increase in local biodiversity as seen at the OWF 'Alpha Ventus' in the North Sea in the benthic community (BSH & BMU 2014) and may change the characteristics of the species composition. After the construction of the Danish OWF "Horns Rev" it was found that the newly introduced hard substrates were colonised mainly by species which were not recorded at pre-construction surveys in the sandy seabed community (NIELSEN 2006). A similar pattern was observed at gas platforms in the Mediterranean (Ionian and Aegean Sea), where the increased fish abundance found on the rigs was related to a higher occurrence of reef-dwelling species, which normally do not occur in open waters (CONSOLI et al. 2013). In general studies show a high number of species associated with the rigs in the Mediterranean, especially a high density of mussels and oysters, with decreasing species richness at depths below 23 m and richness and compositions depending on the directional side of the structure (PONTI et al. 2002). Site dependent factors such as proximity to rocky shores and hydrographic conditions including degree of scour influence the presence of some species and the absence of others. The structures may also extend the distributions of some mobile species of e.g. crabs, lobsters or fish, as a result of new habitat opportunities. Although the scientific literature is broadly in agreement that there is likely to be an enhancement effect for fish and crustaceans, the extent and nature of the effect, it appears, is heavily dependent on the nature of the reef created, and the characteristics of the indigenous populations at the time of introducing the artificial reef.

Figure 5.5 Common starfish on scour protection of the Danish OWF "Horns Rev". Photo: Maks Klaustrup. Source: NIELSEN (2006)

According to a guidance document of the European commission on wind energy developments and Natura 2000 sites (EUROPEAN COMMISSION 2010) states that within protected areas, such as Natura 2000 sites, any potential reef effect, whether positive or negative, "must not affect the integrity and conservation status of habitats or species for which the site has been designed". The artificial reef might also act as "stepping stone" for species not native to this area and increase the possibilities for these invasive species to spread further. A positive reef effect can be achieved highly depending on the natural community composition, the location and the structure of the reef. LANGHAMER (2012) suggest OWF associated structures, which may possibly enhance a positive effect of the artificial reefs, such as different kinds and materials of scour protection as it has to be noted that every artificial substrate introduced in an ecosystem will change the substrate composition and consequently the biocoenosis.

Reserve effect

Animals may be attracted to the constructions associated with an OWF not only because of an increase of potential prey sources generated by a reef effect. The construction itself might give them shelter and protection, which is known as the so called "reserve effect". These is often the case for fish, which can form large aggregations around the devices (LANGHAMER 2012 and references therein).

Since some fishing methods (e.g. bottom trawl fisheries) are impossible (and often forbidden) within and in the direct vicinity of a windfarm area to avoid any destruction of either the fishing gear or wind park devices (e.g. subsea cables), the windfarms or single turbines will lead to increased survival of fish in that area. This in turn bears the risk of increased fishing pressure in the vicinity of the park, cancelling out a potential "spill-over effect" from the No-fishing zone (LACROIX & PIOCH 2011). The attraction of the turbines could also cause negative side-effects, if for instance the fish are concentrated around these devices, which might not exhibit adequate shelter or protection against predators.

However, it is not yet possible to predict long-term effects of secondary impacts by OWFs since there is no research or monitoring program at an OWF exceeding seven years post construction. Further research and long term monitoring effort need to be conducted to gain knowledge about the impacts of underwater OWF components on the marine environment.

5.2 Impacts on abiotic environment

There are several potential impacts on the abiotic environment, which as a consequence may lead to impacts on marine wildlife. These impacts on the abiotic environment have not yet been investigated adequately. Only very few studies are dealing with this topic, maybe due to difficulties in appropriate and explicit measurements. In the following a summary on the current knowledge of these potential impacts will be given.

Offshore wind turbines function as an artificial barrier for wind and ocean currents. Thus, OWFs produce a wind-wake effect, i.e. a downstream wind speed reduction and enhancing of turbulences, which impact on atmospheric layers, resulting in modified wind characteristics and ocean dynamics (LUDEWIG 2015). The dimension of these wind-wakes and turbulences, depending on atmospheric stability, can persist in a distance between 10 to 20 times the rotor diameter (BRAND et al. 2011; HASAGER et al. 2017) as shown in Figure 5.6. While turbulences and wind-wakes on the one hand are well studied in concern to energy efficiency of an OWF as they may induce power deficit for downstream turbines (MOSKALENKO et al. 2010; BRAND et al. 2011), wind-wakes also have the potential to alternate the circulation pattern around the foundations and can be responsible for upwelling and downwelling patterns around the windfarm (BROSTRÖM 2008). In addition to wind-wake effects, fixed foundations of the turbines may impact the local hydrodynamics significantly (FLOETER et al. 2017). Water turbulences for instance, significantly increase suspended sediments resulting in 30-150 m wide plumes, extending for several kilometres (VANHELLEMONT & RUDDICK 2014). To which extend the newly developed floating turbines will impact on hydrodynamics has not been investigated yet. It is anticipated that the placement of artificial structures on the seabed can lead to increased concentrations of contaminants in the water column and their accumulation in the marine food web. Regarding floating OWFs the resuspension of contaminated sediments may occur by the anchoring systems on the sea bottom (e.g. chains, anchors) and the new introduction of contaminants through the structures themselves (e.g. anti-corrosion coatings, sacrificial anodes) (AGENCE FRANÇAISE POUR LA BIODIVERSITÉ 2018).

The further consequences of alternated hydrography and plumes for other marine aspects are currently unknown, but the spatial extent is considerable and the turbidity change may be persistent (VANHELLEMONT & RUDDICK 2014; FLOETER et al. 2017). However, FLOETER ET AL. (2017) suggested, that there is a potential impact on the stratification which eventually lead to an alteration in nutrient and plankton composition. In addition, VANHELLEMONT & RUDDICK (2014) suggest changes in sedimentation patterns and sediment spill that could potentially cause bathymetric modification.

Figure 5.6 Exemplary photograph of the wind-wake effect at Horns Rev II after (HASAGER, 2017)

Additionally to alternation in sedimentation patterns and sediment plumes, intentional or unintended pollution of the turbine itself may affect the water quality. While unintended pollution like oil leakage remains difficult to quantify chemical input of sacrificial anodes can account for about 0.5 to 1 tons of metals (mostly Al and Zn) and heavy metals (mostly In) per year per turbine, which results to 45 tons of Al and 2 tons of Zn for an OWF consisting of 80 turbines per year (KIRCHGEORG et al. 2018). While this input on the outside of the turbine may be negligible due to dilution effects, inside the foundations water and sediment will be enriched with these metals and may have a negative impact on the marine environment (KIRCHGEORG et al. 2018). As this may be a minor problem during the operation of the turbine, it needs to be taken into account during decommission (TOPHAM & MCMILLAN 2017).

Even though the single impacts on the abiotic environment may be known or neglected, the major challenge remains to achieve a reliable assessment of the cumulative impacts (LINDEBOOM et al. 2015).

5.3 Impacts on benthic communities and habitats

Marine habitats and benthic communities will be subject to habitat loss from occupation of seabed by turbine foundations, foundations from associated infrastructure (such as offshore converter station platforms, offshore masts etc.) scour protection and cable laying on the seafloor. Additional impacts come from cable trenching, anchoring and other physical disturbances of the seafloor including sediment suspension and remobilisation of nutrients and contaminants. Eventually heat emission and electromagnetic fields can alter habitats or communities on a very local scale.

5.3.1 Occupation of seabed areas and habitats

The direct impact during the construction and operation phase of an offshore windfarm results from the permanent occupation of a part of the benthic areas where the foundations of wind turbines, related infrastructure (offshore platforms, scour protection structures etc.) and submarine cables will be located, leading to permanent habitat loss during the lifetime of a windfarm. While the footprint of each turbine foundation is relatively small (except for example gravity foundations), scour protection may cover the seafloor at 20 – 30 m around the turbines. Where cables are laid on the seafloor permanent habitat loss is not restricted to the windfarms itself but extends along the cable connection to the mainland.

5.3.2 Physical disturbance, damage, displacement and removal of vegetation and fauna

Physical disturbance, damage, displacement and removal of flora and fauna occur during trenching, cable burial and cable removal, anchoring of vessels and installing the foundations on the seabed (IFAÖ 2006). Investigations in the North Sea and the Baltic Sea indicated that effects are mostly reversible and the affected areas are recolonized within a certain period, however, recovery time will not only depend on the strength of the impacts but also on the structure of the seabed and the local benthic communities. It needs to be noted that some benthic communities may need long recovery times and specific assessments are recommended.

During the construction phase the installation of foundations and cables (as well as their removal during decommission) lead to turbulence and sedimentation nearby, depending on the seabed type. Usually because of technical and economic considerations, the preferred seabed types for construction of offshore windfarms are so far those consisting of sand or gravel with only dispersed boulders close to the site. This is the case in offshore windfarms in North Sea and Baltic Sea but may not be the case within the Mediterranean basin which has a rather narrow continental shelf and is characterised by steep bathymetry.

The large construction vessels are often jacked-up on hydraulic legs or utilize spuds for positioning, which would result in some direct impact to the seabed. Also anchoring causes disturbance to the seafloor and benthic communities. Over time, a dynamic environment would level the seafloor but effects can last long where dynamics are low.

In the case of the cable laying/jetting vessel, anchoring is a common method used to move the barge along the cable route, and an anchor handling tug is employed to reposition anchors as the barge advances along the route. The vessel is positioned using a series of heavy anchors deployed in an array around the vessel. Anchors tend to dig into sandy sediments to a depth of 0.91 to 1.5 m depending upon sediment type.

In addition, as the vessel position is adjusted, a portion of the anchor cable nearest the anchor slowly drags across the seafloor surface, causing a shallow sediment disturbance. This action is minimized by the use of mid-line buoys on the anchor lines, which raise a greater amount of anchor chain off the bottom, reducing the amount of chain that is swept along the bottom as the vessel moves. The setting and repositioning of anchors in this manner has the potential to injure relatively sedentary benthic organisms.

When operating in shallow water areas, typically less than 6 m deep, the propeller wash from large vessels could contact the bottom and cause scouring, sediment suspension and increase water turbidity. This can impair some types of benthic organisms, or make them more susceptible to predation.

Vegetation

Cable installation (as well as removal during decommissioning phase) besides direct loss of vegetation within the trench area may lead to reduced shoot density and rhizome biomass close to the trench, because of the combined effect of excavation and back filling and temporary burial below sediment deposited alongside the cable trench (IFAÖ 2006). Marine vegetation may be affected by sediment suspension and increased water turbidity. Special attention should be given to the *Posidonia oceanica* meadows which consist the priority habitat type *1120 according to EU Habitats Directive. The species is endemic to the Mediterranean and the adjacent coasts of the Atlantic, grows on sandy substrate and recovery is slow when disturbed. The turbidity caused by construction is also harmful to *Posidonia* oceanica beds and should also be considered. Detailed information for *Posidonia* seabeds are presented in chapter 5.3.7 of this document.

Benthic communities

The physical loss of seabed will lead to a loss of the benthic communities at the impact area. Additional potential impacts include the disturbance and damage to the benthic communities due to construction, changes in sediment transport pathways and remobilisation of nutrients or contaminants.

Mobile species of the benthic communities such as fish are expected to avoid disturbance and not be subject to direct mortality. A principal risk to sessile species exists where sensitive habitats hosting vulnerable species characterised by slow growth rates are disturbed. Faunal communities populating exposed bedrock, chalk, gravel, coarse sand, silty sand and intertidal mudflats are prone to long-term (> 6 months) damage. Fauna of stiff clay, sands of high mobility and clay was considered less vulnerable and will recover in shorter times (IFAÖ 2006).

Benthic fauna could be subject to effects of sediment suspension and deposition and filter feeding organisms may experience clogging of feeding and respiration organs. In most cases such sedimentation effects are reversible either through resuspension or by benthic communities recolonizing the area. However, depending on the volume of sediment suspended a layer of deposited sediments could cover hard substrate areas over longer periods.

Potential impacts on soft bottom communities relate to areas of the seafloor that are temporarily disturbed by geotechnical investigation methods such as coring and boring, and construction/ decommissioning activities such as cable jetting, foundations installation and scour protection installation.

Disturbance of habitats is most obvious if biogenic structures like mussel beds, sea grass beds, *Sabellaria* reefs or maerl beds are affected.

'Maerl' is a collective term for several species of calcified red seaweed. Maerl beds are mixed sediments built by a surface layer of slow-growing, unattached coralline algae creating a habitat for rich fauna. In the West Mediterranean they are found down to 90–100 m, while in the East they occur down to depths of ca 180m (BARBERA et al. 2003). The high sensitivity of maerl beds is explained by the slow growth and poor recruitment of maerl species. Maerl beds have considerable conservation value because they harbour a disproportionately high diversity and abundance of associated organisms in comparison with surrounding biotopes; some of these species are confined to the maerl habitat or rarely found elsewhere. Animals that burrow in the maerl gravel beneath the living bed include: bivalves, urchins, sea cucumbers, anemones, worms, decapods etc. and also provide good shelter for invertebrate predators from larger predators. Some of the organisms that live within maerl beds are rare, unusual or poorly known. They also act as nursery areas for the juvenile stages of commercial species such as cod, edible crabs and scallops which are attracted to the complex 3-dimensional unconsolidated structure. Mediterranean maerl beds are often targeted for demersal fish and cephalopods. Furthermore coralline algae may be one of the largest stores of carbon in the biosphere. All plants take up carbon during photosynthesis, but coralline algae deposit large amounts of carbon in their cell walls in the form of calcium carbonate. Two of the more common maerl-forming species, *Lithothamnion corallioides* and *Phymatolithon calcareum*, are also included in Annex V of the Habitats Directive.

Maerl biotopes, which are relatively scarce, are currently threatened by several types of human activity. The effects of habitat removal through offshore construction activities or the commercial extraction of maerl are irreversible over timescales relevant to humans. Other severe threats to maerl habitats include poor water quality (chemical pollution by organic matter and excess nutrients) and the use of demersal fishing gear. In addition fragile and slow growing, maerl can be damaged by dredging, heavy anchors and mooring chains. Maerl is expected to be adversely affected by rising temperatures and ocean acidification caused by climate change. The coralline algae that form the maerl are amongst the slowest-growing species; that any damage to the maerl beds may take decades to repair so Maerl is considered to be a non-renewable resource.

Focus should be also given to seagrass beds due to their important ecological services. They are diverse and productive ecosystems (net primary production of seagrasses may be extremely high (300–1500 g C m-2 year-1), making them among the most productive marine and terrestrial ecosystems and can harbour hundreds of associated species from all phyla, for example juvenile and adult fish, epiphytic and free-living macroalgae and microalgae, molluscs, polychaetes etc. (MAERL 1998). Seagrass herbivory is an important link in the food chain, feeding hundreds of species, including green turtles, fish, geese, swans, sea urchins and crabs. Some fish species that visit/feed on seagrasses raise their young in adjacent sites or coral reefs. Seagrasses trap sediment and slow down water movement, causing suspended sediment to settle out. Trapping sediment benefits coral by reducing sediment loads, improving photosynthesis for both coral and seagrass. Seagrass conservation is one of the most important challenges for marine scienceand an increasing concern for coastal managers. This concern has been particularly noteworthy in temperate areas, such as the Mediterranean Sea, where primary production of seagrasses and its associated algal assemblages (epiphytes and benthic algae) represents a major driving force of ecological processes in the coastal system.

Disturbance effects related to submarine cables are in general expected to be temporary and localized if cables are buried in the sediments. Areas along the cable route affected by coverage with protective structures will usually be restricted to a narrow strip of a few metres along the cable.

According to the document from French Biodiversity Agency regarding the development of 3 floating OWF (in the Gulf of Lion, off Fos-sur-Mer, Gruissan and Leucate - Le Barcarès) and marine biodiversity it is mentioned that for floating OWF during the installation phase, the impacts are essentially the destruction of habitat under the anchors (anchors and chains) and along the trench of the electrical connection cable from the farm to the ground. During operation the impacts are dependent on the type of anchorage installed: direct by ragging and abrasion, clogging, asphyxiation of the bottoms under the chains, indirect by a chronic resuspension of the sediments by the action of the chains on the background. Very few impact studies evaluate in a fine way (modeling) the dispersal cones of the sediments linked to the action of the chains during operation. It can be argued that tension-line anchor systems limit impacts on benthic habitats in the operating phase compared to catenary type anchors (AGENCE FRANÇAISE POUR LA BIODIVERSITÉ 2018).

5.3.3 Reef effect

There is ongoing debate about the possible ecosystem impacts of wind turbine foundations and their scour prevention structures, which provide artificial reefs.

According to LINLEY et al. (2007), turbine towers together with their associated scour protection, constitute an artificial reef, and the surfaces are readily colonised by a typical and broadly predictable assemblage of organisms, reflecting zonation patterns observed in adjacent rocky shore communities. Site dependent factors such as proximity to rocky shores and hydrographic conditions including degree of scour influence the presence of some species and the absence of others at specific OWF sites. The structures may also extend the distributions of some mobile species such as crabs, lobsters and fin fish, as a result of new habitat opportunities. Although the scientific literature is broadly in agreement that there IS likely to be an enhancement effect for finfish and Crustacea, the extent and nature of the effect, it appears, is heavily dependent on the nature of the reef created, and the characteristics of the indigenous populations at the time of introducing the artificial reef.

Depending on the colonisation this can be a positive/neutral effect if the colonisation comes from autochthonous species and serve as a biodiversity niche or negative effect if invasive species benefit from the new colonisation opportunities. On the positive aspects potentially, offshore windfarms may thus provide a refuge for affected species. Furthermore, benthic species constitute an important food source for birds and fish.

Studies on the ‘Alpha Ventus’ test site showed a local increase in diversity due to growth on wind turbine foundations. In the North Sea especially, which is dominated by soft sediment and associated benthic communities, the foundations and scour prevention structures create artificial surfaces for colonisation by hard substrate species that do not occur naturally at all in these locations. So far, however, there has evidently been no colonisation by species not native to the German North Sea, meaning that the increase in diversity is indeed only local. It is not yet possible to predict the long-term effects of this change in natural local ecological communities as a result of large-scale windfarms.

During RECON project (COOLEN & JAK 2017) the following issues were investigated:

1. What is the species composition of marine growth on offshore structures in the North Sea?

2. To what extent is this composition explained by abiotic factors (e.g. depth, temperature, location, platforms age, marine growth cleaning frequency, et cetera) and biotic factors (e.g. food availability, proximity to marine growth on other offshore structures, distance to coastal populations, et cetera)?

3. To what extent are the communities on the structures isolated from or connected to each other and how is this explained by the factors noted earlier?

The composition and richness patterns on studied artificial structures were strongly influenced by geographic location, depth, and substrate type. In addition, a set of keystone species had a significant impact on other species in the community. Installations in similar hydrodynamic regions showed a higher similarity when compared to objects in other regions. Furthermore, communities at similar depth and attached to similar substrates (e.g. rocks or steel) were alike.

Windfarms, oil and gas platforms structures harbour a high biodiversity and connect populations. The RECON study showed that species composition of marine growth on offshore structures (i.e the studied platforms, windfarms, wrecks and buoys) was over 200 hard substrate associated species.

Communities on scour protections are similar to natural reefs and therefore leaving in place these rocks and potentially other parts of installations should be considered in decommissioning decisions. Depending on life cycles and species status (e.g. OSPAR protected or non-native), different leave-in-place options should be considered during decommissioning. These options should include leaving in place the foundations as they are, removing part of the foundations to depths with limited risk of non-indigenous colonisation, or full removal (COOLEN & JAK 2017).

In general, detecting changes in species composition when various influences are present, is challenging and there is the need for further monitoring of additional locations outside the regions investigated to gain better perspective. The connectivity analysis showed that connectivity depends on the species studied but additional locations between the studied locations should be inspected and monitored to understand connectivity patterns.

5.3.4 Electromagnetic fields (EMFs)

Little is known regarding electroreception of marine invertebrates. It has to be noted, that the term “invertebrates” covers a variety of animals of different taxonomic groups such as arthropods (for instance crustaceans in marine environment), molluscs (for instance chitons, bivalves, squids, and octopuses), annelids (for instance polychaetes), and cnidarians (hydras, jellyfishes, sea anemones, and corals). In the light of OWF these are benthic organisms as well as pelagic organisms and pelagic life stages of benthic animals which are thought to be potentially impacted by construction and operation of an OWF. Invertebrates can fulfil important ecological functions (Sea hare, zooplankton) and/or have a commercial value (Scallops, squids).

It is assumed that EMFs associated with OWF cables can potentially affect some benthic invertebrates. Experiments on the response of crustaceans to EMF show contrasting results. A recent study on the edible crab *Cancer pagurus* revealed no change in physiological responses (e.g. respiration rate, haemocyanin concentration) when exposed to EMF emitted from sub-sea power cables (SCOTT et al. 2018). However, the crabs were attracted to the EMF of the cables, but as well responded by behavioural changes and spend more time resting in their shelter than outside. Love et al. (2015) exposed Rock crabs to energized and unenergized cables and could not detect any preferences or behavioural differences between the treatments.

5.3.5 Heat emissions

The cable collecting the electricity of the turbines to the transformer stations and the cables connecting the windfarms to the mainland are designed for maximum core temperatures of about 90 °C and sheath temperatures of up to 60 °C during full load events and heat the surrounding sediment and water (MÜLLER et al. 2016). When cables are placed on the seafloor the surrounding water will easily transport the heat emissions and heating of the seafloor is only expected very close to the cable. When cables are buried in the sediment, heat transfer is much slower. Temperature rise, especially of the upper layers of seabed sediments, can be reduced to an acceptable level if cables are buried to sufficient depths.

5.3.6 Impact of noise on invertebrates

The impacts of noise on invertebrates have not yet been considered in the context of OWF produced noise. However, a recent review focusing on the impacts of human induced noise on aquatic invertebrates summarized serious threats from noise (WEILGART 2018 and references therein). In the planktonic community larvae of scallop were found to exhibit malformations after laboratory exposure of artificial human noise (seismic airgun pulses) (WEILGART 2018 and references therein) and boat-noise induced increased larval mortality of the sea hare (*Aplysia californica*), which is an important grazer on coral fouling and removes toxic bacteria (WEILGART 2018 and references therein). Contradictory impacts have been found for other invertebrate larvae (e.g Pacific oysters (*Magallana gigas*) and bryozoans (*Bugula neritina*)), where ship-noised induced an enhanced settlement behaviour and some of them grew larger in size when exposed to ship-induced noise (WEILGART 2018 and references therein). It remains unknown which ecological consequences this altered larval behaviour will cause. Zooplankton in general can be imposed to severly increased mortality due to the noise impact of a seismic survey. It has to be kept in mind, that zooplankton is the basis of the food web and contains early life stages of many ecological and commercially important species.

5.3.7 Important marine habitats in the Mediterranean Sea

Within the marine Mediterranean region the following habitats Listed under Annex I of the EU Habitat Directive 92/43/EEC are present and their descriptions are shown below (EUROPEAN COMMISSION DG ENVIRONMENT 2007):

‘1110 - Sandbanks which are slightly covered by sea water all the time’: Sandbanks are elevated, elongated, rounded or irregular topographic features, permanently submerged and predominantly surrounded by deeper water. They consist mainly of sandy sediments, but larger grain sizes, including boulders and cobbles, or smaller grain sizes including mud may also be present on a sandbank. Above a sandbank the water depth is seldom more than 20 m below chart datum. The habitat is also associated with *Posidonia* beds. On many sandbanks macrophytes do not occur. This marine habitat occurs widely on the European coasts. It is characterized by various types of communities/assemblages because it encompasses various sediment types characterised by different physical, chemical and hydrographic factors. Within Meditarrenean this habitat type has forms ranging from fine sand on shallow waters, to sands with *Cymodocea nodosa* and deeper to maerl beds / sediment surfaces of coarse stable material, such as shells, stones. The latter two sub-types are particularly distinctive and are of high conservation value because of the diversity of species they may support and the low development rates. Main pressures and threats reported for the habitat involve pollution including eutrophication effects, overfishing, invasive non-native species, and mechanical damage such as marine constructions, coastal touristic installations, benthic trawling, and dredging. This habitat is related to offshore windfarms with fixed foundations that may technically be installed in shallow waters (0-30m). Effects from OWF components include the occupation of habitat areas from foundations, occupation/disturbance due to the electricity transfer grid as (cable laying activities and operation).

‘1120* - Posidonia beds (*Posidonion oceanicae*)’: It is a priority habitat according to Annex I of the EU Habitats Directive 92/43/EEC. *Posidonia oceanica* (L.) Delile is the most important endemic seagrass species of the Mediterranean Sea6 and it can form meadows or beds extending from the surface to 40–45 m depth. Beds of *Posidonia oceanica* are characteristic of the sublittoral-infralittoral zone of the Mediterranean (Figure 5.7). This habitat type is very common in the Mediterranean coasts, and is absent only in cases of low salinity, poor water renewal or pollution. On hard or soft substrate, these beds constitute one of the main climax communities. They are sensitive to desalination, generally requiring a salinity of between 36 and 39‰.

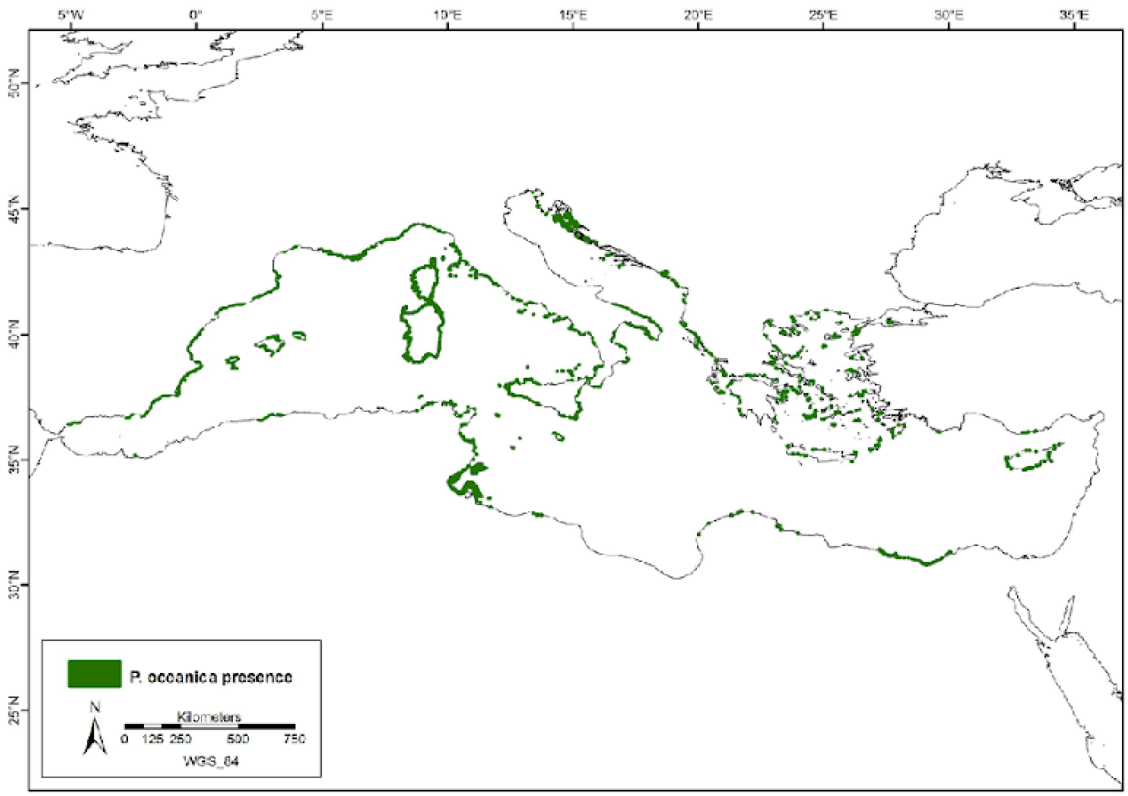


Figure 5.7 *Current distribution of Posidonia oceanica meadows. The current distribution of P. oceanica (green areas) along the Mediterranean Sea coastline (TELESCA, 2015).*

In the sublittoral zone, the ecosystem of the seabed is at optimal growth conditions: the bottom is always covered with seawater, the light is plentiful, and there is a great variety of substrates (rocky, sandy and muddy). Thus, the ecosystem has several compartments. The first compartment includes animals and plants (especially Green algae, Red algae, Brown algae and marine Angiosperms), living attached to the bottom. The second compartment includes animals (mainly Arthropods, Echinoderms and Gastropods) living on the bottom without being attached and often move among the plants and animals of the seabed. Finally, the third compartment includes animals that swim above the seabed and the attached plants and animals. Here can be found mainly fishes and nudibranchs.

In sandy areas of sublittoral zone *Posidonia oceanica* meadows prevail. When the hydrodynamic and light conditions are favourable, *Posidonia oceanica* meadows cover the entire sea bottom from 1 down to 40 meters deep. From ecological aspect, the seagrass meadow plays the role of the terrestrial forest. The rhizomes of *P. oceanica* are perennial, retain sediment and protect the sea bottom from erosion. The leaves of *P. oceanica* are continuously updated offering huge amounts of organic matter in the ecosystem. Finally, all the leaves and rhizomes host an incredibly large number of plant and animal species (approximately 1000 species in the most conservative estimates). These species feed, reproduce and find protection in the meadows. The role of *Posidonia oceanica* meadows in marine coastal environments is often correctly compared to that of the forest in terrestrial environments. These meadows constitute the basis of the richness of coastal waters in the Mediterranean, given the surface area they occupy (20-50% of the seabeds between 0 and 50m depth), and, in particular, given their essential biological role in maintaining the equilibrium of coastal waters and their concomitant economic activities (BOUDOURESQUE et al. 2012).

Seagrass meadows clearly rank amongst the most valuable coastal ecosystems on Earth in terms of goods and services they provide. Although their structural and functional roles have been largely understood, seagrasses are declining at alarming rates due to climate change (e.g. warming, ocean acidification), alien species invasion and direct human activities near the coasts (e.g. coastal urban development, fishing activities, aquaculture). According to TELESCA et al. (2015) the regression of meadows is a generalised phenomenon in the Mediterranean Sea, even though some exceptions exist (e.g. Corsica, parts of the Sardinian coastline and the Valencia region in Spain). Regression percentages in some cases are as high as 30%.

Full recovery of *P. oceanica* meadows is usually considered irreversible in human time-scale, because it is a slow-growing species with a low recovery rate resulting to a rather permanent impact when part of this habitat is occupied by construction activities (for instance cable laying activities) or by installation of structures on the meadows (foundations, anchors etc.). The management of direct impacts, such as trawling, anchoring, dredging and pipeline refilling, can help recovery and promote resilience, although this can take an extremely long time. Transplantation of seagrass is often unsuccessful, largely due to the fact that habitats are still too deteriorated to allow planted seagrasses to survive (TELESCA et al. 2015). Situating offshore windfarms in a priority habitat raise strong oppositions during the permit process because of conservation obligations stemmed from the Habitats directive but also because of fundamental nature protection reasons. Therefore offshore windfarms and associate infrastructure (cables) should be generally considered incompatible with this kind of habitats.

1130 - Estuaries: Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike 'large shallow inlets and bays' there is generally a substantial freshwater influence. The mixing of freshwater and sea water and the reduced current flows in the shelter of the estuary lead to deposition of fine sediments, often forming extensive intertidal sand and mud flats. Where the tidal currents are faster than flood tides, most sediments deposit to form a delta at the mouth of the estuary. Plants: Benthic algal communities, Zostera beds e.g. *Zostera noltii* (Zosteretea) or vegetation of brackish water: *Ruppia maritima* (= *R. rostellata* (Ruppietea)); *Spartina maritima* (Spartinetea); *Sarcocornia perennis* (Arthrocnemetea); (*Carex spp., Myriophyllum spp., Phragmites australis, Potamogeton spp., Scirpus spp*.). Animals: Invertebrate benthic communities; important feeding areas for many birds. Threats and pressures are numerous, many linked to development, use of water (modification of water flow), water quality, and fishing. Due to its coastal characteristics this habitat is potentially related to the electricity transfer grid (cable landing) regardless the foundation type and water depth of the main OWF. Disturbance to the wildlife present in this habitat can potentially be caused by cable installation activities and occupation of areas used for feeding.

'1140 - Mudflats and sandflats not covered by seawater at low tide': Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms. They are of particular importance as feeding grounds for wildfowl and waders. Sandflats and mudflats are largely infrequent Habitat Types of highly variable nature and extent mostly contained within Estuarine and Lagoonal systems. It must be noted that during the reporting cycle 2000-2007 according to Article 17 of Habitats Directive, the habitat was not reported as present in the Mediterranean Biogeographic region, but was included in the next reporting cycle 2008-2013. Treats and pressures are numerous, but the major threats in all regions are coastal defence activities such as dyking and stabilization of sand. Water traffic in shallow areas close to the coast can damage the habitat through coastal erosion. Also dredging is a threat, and in some areas also intense recreational use of the shore. Eutrophication due to nutrient run-off from the catchment area also threatens the quality of the habitat. Run-off from urban areas introduces various hazardous substances, that can accumulate in the soft sediments. Oil spills at sea that are washed ashore on mudflats or sandflats pose a serious threat, as oil is very difficult to remove from this type of soft sediment. Similar to habitat 1130 due to its coastal characteristics this habitat is potentially related to the electricity transfer grid (cable landing) regardless the foundation type and water depth of the main OWF. Disturbance to the wildlife present in this habitat can potentially be caused by cable installation activities and occupation of areas used for feeding.

'1150* - Coastal lagoons': Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sand banks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall, evaporation and through the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae, Potametea, Zosteretea* or Charetea. Salt basins and salt ponds may also be considered as lagoons, providing they had their origin on a transformed natural old lagoon or on a saltmarsh, and are characterised by a minor impact from exploitation. Plants: *Callitriche spp., Chara canescens, C. baltica, C. connivens, Eleocharis parvula, Lamprothamnion papulosum, Potamogeton pectinatus, Ranunculus baudotii, Ruppia maritima, Tolypella n. nidifica. In flads and gloes also Chara ssp.(Chara tomentosa), Lemna trisulca, Najas marina, Phragmites australis, Potamogeton ssp., Stratiotes aloides, Typha spp*. Animals: Cnidaria- *Edwardsia ivelli*; Polychaeta- *Armandia cirrhosa*; Bryozoa- *Victorella pavida*; Rotifera - *Brachionus sp.*; Molluscs- *Abra sp., Murex sp.;* Crustaceans- *Artema sp.;* Fish- *Cyprinus sp., Mullus barbatus*; Reptiles- *Testudo sp.;* Amphibians- *Hyla sp*.

Threats and pressures are numerous, mainly various human impacts linked to development along the coasts. That affects water quality and directly destroying the habitat (building, dredging, anchoring, etc). Also fishing, aquaculture and invasive species are threats. This habitat is potentially related to the electricity transfer grid (cable landing) regardless the foundation type but it must be noted that it is also a priority habitat and may raise strong oppositions during the permit process because of conservation obligations stemmed from the Habitats directive.

'1160 - Large shallow inlets and bays': Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow 13 indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well-developed zonation of benthic communities. These communities have generally a high biodiversity. The limit of shallow water is sometimes defined by the distribution of the Zosteretea and Potametea associations. Several physiographic types may be included under this category providing the water is shallow over a major part of the area: embayments, fjards, rias and voes. Plants present: Zostera spp., Ruppia maritima, Potamogeton spp. (e.g. P. pectinatus, P. praelongus), benthic algae. Animals: Benthic invertebrate communities. Pressures and threats towards the habitat mainly involve various physical disturbance, and water quality with both eutrophication and various pollutions, but also locally extraction of oil or gas and aquaculture. Similar to habitats 1130 and 1140 due to its coastal characteristics this habitat is potentially related to the electricity transfer grid (cable landing) regardless the foundation type and water depth of the main OWF.

'1170 – Reefs': Rocky reefs are extremely variable, both in structure and in the communities they support. A wide range of topographical reef forms meet the EU definition of this habitat type. These range from vertical rock walls to horizontal ledges, sloping or flat bed rock, broken rock, boulder fields, and aggregations of cobbles. They can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone. Reefs may support a zonation of benthic communities of algae and animal species as well as concretions and corallogenic concretions.

It should be noted that although there has been an extended categorisation for terrestrial habitats, for marine habitats the definition was based primarily on geomorphological and other characteristics suitable for identifying the conservation purposes (*Posidonia oceanica* beds excluded). In case of the marine habitat '1170 – Reefs' some clarifications are necessary to distinguish the variate forms of this habitat.

- Two main types of reef can be recognised: those where animal and plant communities develop on rock or stable boulders and cobbles, and those where structure is created by the animals themselves (biogenic reefs).
- Reefs are characterised by communities of attached algae (where there is sufficient light – on the shore and in the shallow subtidal) and invertebrates, usually associated with a range of mobile animals, including invertebrates and fish.
- "Hard compact substrata" are: rocks (including soft rock, e.g. chalk), boulders and cobbles (generally >64 mm in diameter).
- "Biogenic concretions" are defined as: concretions, encrustations, corallogenic concretions and bivalve mussel beds originating from dead or living animals, i.e. biogenic hard bottoms which supply habitats for epibiotic species.
- "Geogenic origin" means: reefs formed by non-biogenic substrata.
- "Arise from the sea floor" means: the reef is topographically distinct from the surrounding seafloor.
- "Sublittoral and littoral zone" means: the reefs may as an unbroken transition extend from the sublittoral uninterrupted into the intertidal (littoral) zone where they are exposed to the air at low tide or may only occur in the sublittoral zone, including deep water areas such as the bathyal.

In the Mediterranean, this habitat is essentially subject to the light factor. The vertical distribution of the organisms within this habitat allows to recognize four stages, which gather environmental characteristics defined by the ecological factors that are the wetness, the duration of emersion, the exposure to the solar rays, the drying by the wind and the thermal and saline differences (leaching by the rain) between the low sea and the high sea levels. Within the Mediterranean Reefs are comprised of several elementary habitats (i.e. assemblages) (CAHIERS D'HABITATS NATURA 2000, 2004):

- the Supralittoral rock assemblage (code 1170-10): The supralittoral level (also known as splash or spray zone), located at the edge of the maritime domain (but not submerged by ocean water) represents drastic living conditions since the rock is moistened only by spray during storms. The plant life is represented by patches of dark lichens that can appear as crusts on rocks as well as epi- and endolithic cyanobacteria. The benthic animal life is very little diversified (two or three species). But the birdlife is well established, some breeding birds being strictly dependent on this type of environment. Detritus feeding Isopoda commonly inhabit the lower supralitoral. Effects on this particular assemblage of 1170 habitat are related the electricity transfer grid. Impacts on the Supralittoral rock assemblage result from occupation of areas within the construction zone, potentially increased sedimentation during cable burying or cable landing activities leading to removal of the organisms in these locations and secondary disturbance for the avifauna present. Depending on the spatial and temporal extent of the activities, the period of the construction, the area the habitat in the surrounding location, impacts' significance may vary to low until high.

- the Upper mediolittoral rock assemblage (code 1170-11) and the Lower mediolittoral rock assemblage (code 1170-12): The mediolittoral stage corresponds globally to the tidal balancing zone, between the mean low water level and the mean high water level. It hosts organisms that do not support desiccation, but can cope with harsh ecological conditions given the magnitude of variations in ecological factors, including desalination. For animals, the plant cover, usually abundant, buffers these ecological fluctuations. In the Mediterranean, this stage is narrow, but has two distinct horizons defined by the different levels of humectation. Similar to habitat type 1170-11 impacts on this rock assemblage result from occupation of areas during cable burying or cable landing activities but are expected to be very localised since in the Mediterranean, this stage is altitudinally very small. Impacts should therefore be evaluated in a broader context considering overall impacts affecting the upper and lower reef zones.

- The Infralittoral reef with photophilous macroalgae (code 1170-13): The infralittoral stage is still immersed, but its upper fringe can emerge during high spring tides. It is essentially the light factor that governs the distribution of photophilic and then sciaphile (ombrophilous) species. In all temperate tide seas, this stage is occupied by large brown algae such as Laminaria. Under the protective canopy of these "forests", which can be very dense up to 15-20 m, the living organisms find attenuated ecological fluctuations. The Infralittoral reefs assemblage is extremely rich as regards both quality and quantity, containing several hundred species. Its production is great and its biomass can attain several kilogrammes per square metre. Its seasonal dynamics are strong. The trophic network there is very complex and opens onto other habitats by exporting organisms and organic matter. Many fishes feed on the plants and animals living in this habitat. Effects on this particular assemblage of 1170 habitat are related to offshore windfarms with fixed foundations and the electricity transfer grid. Impacts can result from occupation of areas within the construction zones and foundation locations, from potentially increased sedimentation and turbidity during construction activities that decreases photosynthesis, and thus affects the algal population; sedimentation fills in the microcavities between the algae and eliminates the small cryptic fauna. Other impacts are related to the removal of the benthic organisms and vegetation in the OWF locations and secondary disturbance for the mobile benthic organisms present. Depending on the spatial and temporal extent of the activities and the methods used for installation of the OWF and also considering the ecological sensitivity of the benthic communities, impacts' significance may vary to low until high. Reef effects due to introduction of hard substrate in the water column may occur but it is unclear how they can interact with the natural occurring habitat 1170 in the surrounding areas (promotion of invasive species or enhancement of biodiversity).

- the Coralligenous assemblage (code 1170-14): The circalittoral stage extends to the survival limit of autotrophic multicellular algae. It is characterised by greater or lesser biogenous constructions on rock faces or as clumps on the bed and abundance of big erect invertebrates. This habitat is located mainly between 30 and 90 metres and forms landscapes of great aesthetic value. The coralligenous is considered to be an ecological crossroad that brings together, thanks to the habitat's extreme structural heterogeneity, a large number of cenotic compartments from the biocenosis of infralittoral algae to that of the bathyal muds. The growth of calcareous algae, consolidated and compacted by constructor invertebrates, shapes networks of cavities that shelter a rich and varied fauna with often very diverse relationships and needs. This richness and great diversity make the coralligenous one of the most ecologically valuable habitats in the Mediterranean. Although coralligenous sites are expected to be avoided through appropriate spatial planning in micro- and macroscale these ecosystems could potentially be indirectly affected by changes in water quality due to turbidity and sedimentation from OWF construction activities in adjacent sites.

The corresponding categories according to Barcelona Convention are as follows and more detailed information can be found in Interpretation Manual for marine Habitats© 2012 UNEP-MAP-RAC/SPA[6]:

- Biocenosis of supralittoral rock (I.4.1.) (Upper level, rarely submerged)
- Biocenosis of the upper mediolittoral rock (II.4.1.) (Above mid-level, subject to being uncovered by water and submerged)
- Biocenosis of the lower mediolittoral rock (II.4.2.) (Middle level, subject to being out of the water and then being submerged)
- Biocenosis of infralittoral algae (III.6.1.) (From the surface down to 35 to 40 m)
- Coralligenous (IV.3.1.) (10 to 90 m. When the water is very clear, the coralligenous begins and ends very deep: 60-130 m)
- Biocenosis of shelf-edge rock (IV.3.3) (200m)
- Biocenosis of deep sea corals present in the Mediterranean bathyal (V.3.1.) (>200m)

The main anthropogenic pressures include:

- Point source pollution (urban pollution, fish farming) or non-point source pollution (e.g. oil spills)
- Overfishing of fish species which regulate the balance of bottom-soil bio communities. Their absence could result to secondary impacts population bursts of urchins and vegetation overgrazing.
- The increase in invasive species which, although likely to be favored by climate change, they are secondary favored by the absence of natural predators due to overfishing.
- Coastal pollution, aquaculture and any other human activity which directly or indirectly increases the turbidity of the water column, given the already marginal light conditions in which these bio-communities live.
- Fishing with trawlers in muddy areas adjacent to coral formations is included as turbidity factor. Bad offshore fishing practices using bottom and longline nets that kill sessile organisms while also act as chronic traps of fish and other species. Moreover, very slow growth rates (~ 0.006-0.83 mm per year) and fragile structures make these organisms particularly vulnerable to any mechanical disturbance.
- Illegal collection of corals and other rare or threatened species for decorative or other use.
- Both the use of deep longliners and trawls has been recorded as the main threats to the deep zone of habitat ‘1170’ (Categories IV.3.1., IV.3.3, V.3.1.).

5.3.8 Conclusion

Construction of offshore windfarms in Mediterranean is expected to pose similar impacts as other offshore installations in the marine environment. Direct impact includes the occupation of seabed areas and habitat removal and indirect impacts are caused by disturbance of seabed communities, secondary degradation of the adjacent habitats and indirect sedimentation in the areas close to construction zones. Impacts on benthic communities due to elevated temperature, noise and electromagnetic emissions need to be further investigated in the future. Same stands for the reef effects formed in the foundations of wind turbines, platforms and scour protection structures.

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[6] http://sdf.medchm.net/web/mimh/en/index.html?iv_3_1_15.htm

Depending on the underlying characteristics of the seabed there can be a spectrum of impact magnitude, from severe ones due to destruction of sensitive habitats such as *Posidonia oceanica* beds, reefs, ecologically important coastal ecosystems and due to removal of sensitive sessile benthic communities until minor impacts, where construction is favoured due to the site characteristics. The sensitivity of a site can be a combination of various factors as the spatial distribution of habitats, their structure quality, the spatial distribution of species and their population status as well as morphological and hydrodynamic characteristics.

Although site selection for the positioning of the offshore wind turbines may be able to avoid sensitive habitats after proper mapping cable installation and routing may have an impact on the marine environment since it is not always possible to avoid patches of protected habitats and areas hosting sensitive or endangered invertebrate species.

Direct impacts on habitat types within the Mediterranean Basin that are situated along the coast (‘1140, 1130, 1150*and 1160) can potentially result from the cable laying activities through their areas and at connection points to feed the electricity grids in the mainland. Appropriate spatial planning should take under consideration the distribution of these habitats and in advance avoid these sensitive areas.

Due to diversity that characterises the habitat type ‘1170-Reefs’ along with bathymetry and morphology there can be a spectrum of impacts ranging from low significance (for instance from spatiotemporally limited cable landing in the supralittoral zone and in the absence of important avifauna) up to high significance (for instance potential direct and indirect impacts on coralligenous assemblages as described above). Therefore impacts seem to be site specific, depending on the sensitivity of the benthic communities to construction activities. During operation reef effects due to introduction of hard substrate in the water column may occur but it is unclear how they can interact with the natural occurring habitat 1170 in the surrounding areas (promotion of invasive species or enhancement of biodiversity).

The habitat types of ‘1180 - Submarine structures made by leaking gases’ and ‘8330 - Submerged or partially submerged sea caves’ are very localised and during spatial planning of offshore windfarms those locations are expected to be adequately avoided because of environmental, economic, cultural reasons, construction limitations and for not hampering the progress of the OWF approval process.

Emphasis has to be given to the impacts of cable installation within areas of the priority habitat 1120* *Posidonia oceanica* seabeds, an important habitat of the endemic species of the Mediterranean. Case studies have shown a persisting degradation of the habitat when trenches where applied, with lower population densities not only on the trench zone but also on the zones alongside to the trench. The creation of a trench in the *P. oceanica* bed with the aim of accommodating pipelines or cables (burial) is a technical choice that, as far as possible, should be avoided, considering the known negative impacts on the prairie. On the other hand the laying installation (without burial) of a cable on *P. oceanica* meadows is an operation that today can be carried out without significant interferences on seabed. In the case of healthy prairies the impact might even be reduced to zero, since the prairie tends to cover the cable incorporating it in the matte. However in this case, when laid on sea bottom one should consider the risk of cables being damaged by bottom trawls which in turn depends on whether there are banned fishing activities near the coast and whether this ban is respected (BOUDOURESQUE et al. 2012; BACCI et al. 2013). 2013). On the other hand, since any effect on the meadow is strictly relates to technical characteristics of the project (e.g. number and length of the cable) and state of health and extension of the prairie, if necessary, one might consider the possibility of burial in some particular situations, of course after a careful evaluation.

Another aspect difficult to assess as shown in chapter 5.9 are cumulative effects regarding cable installations. The subject might be most relevant if cables are aimed to be placed next to each other in designated corridors adjacent to other infrastructure such as pipelines. In current discussions such designated cable corridors are favoured by environmental agencies and nature protection organizations. Decisions are probably based on the prospect to limit disturbance during installation and repair work. However, since occurrence of electromagnetic fields and heat dissipation might pose the comparably bigger problem to the marine environment such recommendations should be critically examined. New facts could be revealed by conducting research and by the application of effective monitoring programs to on-going developments.

In conclusion monitoring is essential during the construction and cable laying activities as well as prior to construction to assess the previous health state of the habitats. Considering the great spatial variability at small scale (normally present in the biological systems) the results of the monitoring should be based on data for quantitative descriptors (i. e. shoot density, phenology, epiphyte communities) acquired in an adequate amount, and, in case of *Posidonia oceanica* beds possibly, processed under a nested sampling strategy, in order to state correctly the health level of the meadows.

5.4 Impacts on fish/elasmobranchs

Fish can occupy various habitats, from species living at the substrate or close to it (demersal species) to pelagic species, occupying the water column and high seas. Thus they interact with many other (marine) organisms, either as food for other fish, birds and mammals as well as important protein source of humans. Furthermore various species are predators themselves (e.g. some shark species or Tuna) and act as top predators in the marine food web. Fish have to be distinguished between bony fish and elasmobranchs (sharks, rays and chimaeras). Relevant impacts of OWF on fish are described in the following.

5.4.1 Noise

The impact of noise related to offshore windfarms can impact fish in several ways. Loud noise emissions from construction can impact the physiological integrity and alter the behaviour. In the long-term it is not yet understood if steady noise from windfarm operation can have an effect on population dynamics or in the fitness of individuals. In general the different life stages of (bony) fish - eggs, larvae and adults- need to be considered in noise impact studies. While adult fish of many species are able to move away from a source of noise and return after the disturbance has ended, the majority of the larvae are pelagic, so free-floating in the water column, and thus fated to the water currents. A recent summary of existing literature on measured noise levels causing (mortal) injuries or behavioural changes of different fish species can be found here: Andersson et al. (2017).

The studies undertaken to investigate the impact of OWF related noise so far are limited to the species from northern temperate waters in Europe, where OWF has a longer history than anywhere else. Nevertheless, the results gained so far in studies from e.g. the North Sea can be transferred to a certain extent to the Mediterranean, since for instance fish can be classified into different hearing groups based on their anatomical features. Current knowledge is based on studies referring to construction noise generated by the piling of fixed foundations. Reduced piling activity by installation of floating turbines may have differing responses of fish during construction.

The hearing sense is well developed in fish, but in contrast to marine mammals fish can register and respond to particle motion. Species without a swim bladder (e.g. many flatfish species, sharks and rays) are only sensitive to particle movement, while others are affected by particle motion as well as sound pressure (e.g. cod, *Gadus morhua*). Some species are known as "hearing specialists" (e.g. herring, *Clupea harengus*) and are very sensitive to noise in a relatively wide frequency range (HUDDLESTON 2010). Up to date only in 100 out of more than 29 000 fish species hearing has been tested. Thus, generalized statements have to be taken with caution. However, temporary threshold shift (TTS) has been demonstrated in some fishes (for further information on causes for TTS and thresholds for different species see POPPER et al. (2014) and ANDERSSON et al. (2017). Alternations in hearing thresholds may prevent fish from reaching spawning grounds, acoustically communicate or searching for food.

There is little known about masking of biologically important signals in fish by anthropogenic induced sound sources. Thus, there is little scientific studies investigating if sound during operation of an OWF or the associated increased ship traffic during construction and operation is preventing fish from interacting with their environment. A recent study of PINE et al. (2018) found that the noise of vessels inhibited predator-avoidance behaviour in fish and therefore lead to higher predation rates, as well as vessel noise masked the fishs' communication signals and decreased the communication distance.

Species with a swim bladder can be directly harmed by sound pressure (e.g. associated with pile driving sound). The so called barotrauma can cause the swim bladder to expand and contract rapidly, causing tissue damage or severe damage of the swim bladder itself, causing death of the animal (POPPER et al. 2014). If cod are in close vicinity of a pile driving event (400m) a field based study showed that 40% of the fish exhibited a rupture of the swim bladder. Furthermore individuals up to 100 m distance to the piling event showed abnormal swimming behaviour (DE BACKER et al. 2017). Also lab based experiments (e.g. MUELLER-BLENKLE et al. 2010) have studied the impact of pile driving sound on fish behaviour. Cod and sole (*Solea solea*) were exposed to low sound pressure levels (range: 140 – 161 dB re 1 µPa (peak)). Both species tried to move away from the source of sound. As a consequence swimming behaviour was altered. Swimming speed of sole increased until the recording of noise ended. Cod showed a similar, yet weaker, reaction. As the reaction was less pronounced after several exposures to the sound, this can indicate a certain kind of habituation.

At a noise level comparable to pile driving noise in 750 m distance (with noise mitigation ≤ 160 db) squid species showed stress responses by trying to escape from the noise source, alarm responses and ejecting ink (WEILGART 2018 and references therein). Probably as a consequence of a seismic survey, strandings of giant squids were reported on the Atlantic coast of Spain in 2001. The animals suffered from internal damages and damages to their statocysts, which are crucial for orientation (WEILGART 2018 and references therein), which indicates a certain sensitivity to underwater noise in cephalopod species.

5.4.2 Electromagnetic fields

Many fish and other marine vertebrates are able to detect underwater electromagnetic fields (EMF), for instance species that use the Earth's natural geomagnetic fields for orientation and migration (cetaceans, reptiles, bony fish). Sharks and rays (and other elasmobranchs) are known to be strongly electrosensitive as they use electroreception to locate the very low frequency electric fields produced by organisms.

In an operation windfarm the major source emitting EMFs are the subsea power cables that connect the OWF with the coast to transport the generated energy. There is limited knowledge so far on the impacts of EMFs produced by subsea cables in general on. Studies on highly migratory species, such as European eel (*Anguilla anguilla*) that they react to changes in EMF produced by subsea cables if their migration routes are passing subsea cables in shallow waters. In mesocosm studies it was shown that electrosensitive species, such as Thornback ray (*Raja claveta*) and Spurdog (*Squalus* *acanthias*), react on electromagnetic fields generated by the cables used in OWF, but so far it is not possible to draw final conclusion whether this might impact (positively or negatively) on these species. The potential effects range from very short-term change in moving direction to longer-term effects, such as delay of migration due to serious larger scale avoidance (GILL & BARTLETT 2010).

Shark's response to EMF are also assumed to involve changes in swimming behaviour (TRICAS & GILL 2011), but they might be as well attracted by the EMF (HUDDLESTON 2010) but so far there is no knowledge whether EMF does impact on habitat use, feeding behaviour or reproductive success of elasmobranch species.

Another potential impact associated with the electricity transmission through underwater cables is the emission of heat. Currently it is thought that the thermal effect is limited to a small radius (cm) around the cable (BOEHLERT & GILL 2010). It still remains unknown if this change in temperature is going to have major impact or stressor for benthic fish.

5.4.3 Pollution and waste

One aspect of marine pollution caused by OWF is the use of sacrificial anodes, a method to prevent submerged metallic structures from corrosion. In the offshore wind industry they often contain zinc (Zn) or aluminium (Al), for instance. As these anodes are constructed to dissolve, eventually these heavy metals are released constantly to the surrounding environment, where they might accumulate in the water or in the sediments. Up to now there is a lack of knowledge on the direct impacts of metals released by OWF components and there are no scientific evidences that they are causing any harm to the fish fauna.

In case of an oil spill fish could be harmed by the direct presence of the oil and the associated chemicals. Fish usually absorb oil through their skin or their gills (BSH 2012). Also other chemicals, such as fluorine compounds in firefighting foams, can be ingested by fish directly or through the food-web and cause serious harm (YEUNG & MABURY 2013). Therefore an accurate storage and disposal of oil and chemical containing waste on land is required.

5.4.4 Habitat loss/change

The change in seabed structure through construction of the foundation and sea cable laying during construction of OWFs can have severe impacts on the marine environment. It is assumed the increased turbulence, caused by the dispersal of sediment during the construction, is only temporary and will not affect the fish fauna negatively on a longer-term (Nehls, pers. comm.).

The life cycles of fish can be rather complex, requiring different habitats depending on their life stage. There are pelagic species with a benthic egg stage and or many benthic species spent their larval phase in the open water. Thus it is important to consider the entire life cycle of fish, not only the adult stage. Seagrass beds (e.g. *Posidonia oceanica*) for instance are acting as important nursery grounds for several fish species, while the adult stage has a pelagic life style (DEL PILAR RUSO & BAYLE-SEMPERE 2006). Constructions impacting on seagrass beds (see also chapter 5.3) may then lead to negative impacts on the population of pelagic fish.

A multiannual study conducted on offshore windfarms in the Belgium showed that density and numbers of soft sediment fish species had not significantly altered 6 years after the construction of the OWF (DEGRAER et al. 2017). This lets the authors of the study to indicate that the soft sediment ecosystem in between the turbines (at distance > 200 m) is comparable to pre-construction conditions as the species originally inhabiting the sandy bottom remain dominant.

Single species changed in abundance. Plaice (*Pleuronectes platessa*) for instance seemed to be attracted by the OWF and some species altered their feeding behaviour. They started to use prey items usually associated with hard substrates (see also the section about "Secondary impacts" in this chapter).

5.4.5 Secondary impacts

Impacts that are not directly associated with the OWF itself, but result from a situation caused by the OWF are known as secondary impacts. For fish communities two secondary impacts are known to date: The reef effect and the reserve effect.

As the (non-floating) foundation of an OWF provides artificial hard substrate, attracting invertebrates to settle, it has been shown that these enhancements in potential prey can have a positive impact on the fish community (GILL 2005). STENBERG et al. (2015) conducted a study at the Danish OWF 'Horns Rev' comparing abundance data of fish before construction of the Danish OWF 'Horns Rev' and seven years post-construction. They found, that the species diversity was significantly higher close to the turbines attracting fish with a preference for rocky habitats to the former homogenous sand habitat. The devices may also enhance movement and dispersal of species with planktonic larvae (e.g. corals) over a greater area, connecting habitats, which would otherwise be too far apart for larval drifts (HENRY et al. 2018). A study conducted in OWFs in the Belgian part of the North Sea between 2005 (pre-construction) and 2016 (operational phase) did not detect any change in species composition of benthic fish around the turbines (DEGRAER et al. 2017). So, despite the establishment of new artificial hard-substrate to the mainly soft-sediment environment, the species being dominant before construction where still dominating the community 5-6 years post-construction. Only the abundance of one species, Plaice (*Pleuronectes platessa*), was positively affected, which could indicate an attracting effect of the artificial reef and/or a positive effect due to fishery exclusion within the OWFs. The latter is known as the so-called reserve effect, which suggests, that due to the exclusion of fisheries inside an OWF (either a total prohibition as in Germany or an exclusion of specific fishing techniques, such as bottom trawling, due to the submarine OWF associated constructions) these areas can serve as a refuge for fish.

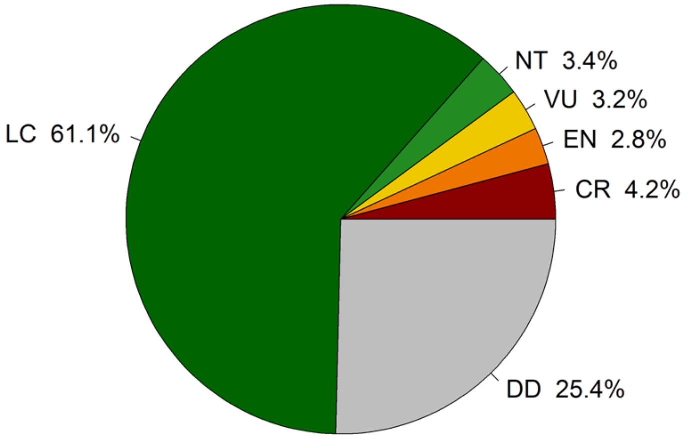
Contradictory to studies predicting a beneficial effect of the newly induced reef like structure, there are suggestions, that these new structures could have potentially a negative impact on a longer time-scale due to increased aggregation of fish (and other animals), which do not find adequate refuge when aggregated around turbines (LACROIX & PIOCH 2011). Furthermore there is the potential that not only native species but also invasive species can use the network of artificial reefs as stepping stones (ADAMS et al. 2014).

A potential reef-effect for fish eggs and larvae was also tested within the environmental monitoring in OWFs in Belgian waters (DEGRAER et al. 2017). It is expected that the artificial reefs will have a positive influence on fish species, which require hard substrate for spawning. The egg and larvae abundance did not differ in the OWF compared to the reference sampling stations outside the OWF. Nevertheless, the study terminated shortly after the OWF had been constructed and the authors (and references therein) assume that it will take 3 -5 years for a community to get fully established at an artificial reef. Time will tell if these artificial structures imply impacts for eggs and larval stages on a longer-term. Settlement processes and reef effects might differ in OWFs with floating turbines as the submerged surface area is lower than on fixed structures and the anchoring systems may be favourable for a different composition of reef forming organisms and provide altered refuge possibilities compared to fixed turbines.

5.4.6 Situation in the Mediterranean Sea

The Mediterranean Sea is a biodiversity "hotspot" for fish, containing around 7% of the total global marine fish species (Figure 5.9). A total of 519 native marine fish species are known to live in the Mediterranean Sea (446 bony species and 73 Elasmobranchs), of which 74 are uniquely occurring in this region (endemic species). About 60% of the Mediterranean fish species are classified as in the conservation category "Least concern" according to the IUCN (International Union for Conservation of Nature) (IUCN 2010) (Figure 5.8). But 4% are seen as Critically Endangered, most of which occur in the higher populated coastal areas of the Mediterranean. In total 30 species (40%) of Elasmobranchs are classified as threatened, but only eight of them receive some kind of protection.

As in many other areas, fish in the Mediterranean is subject to a variety of human pressures such as (over) fishing, climate change, pollution and habitat destruction which may have detrimental impacts on populations, whereas the fishery sector is the most severe threat to marine Mediterranean fish. According to the FAO (Food and Agriculture Organisation) (2018) the Mediterranean and Black Sea (representing a joint statistical area in FAO measurements) obtain the highest percentage (62.2%) of stocks fished at an unsustainable level worldwide. Pollution as well as habitat loss is thought to impact on approx.7.5% of species and human disturbance on 5% of species (IUCN 2010). Hence, any additional human induced intervention in the Mediterranean Sea has to consider the impacts on fishes and their habitats.



Category	No. of Species
CR Critically Endangered	21
EN Endangered	14
VU Vulnerable	16
NT Near Threatened	17
LC Least concern	308
DD Data Deficient	128

Figure 5.8 *Conservation status of fish in the Mediterranean Sea listed by the IUCN. (Datasource: IUCN 2018, unpubl.)*

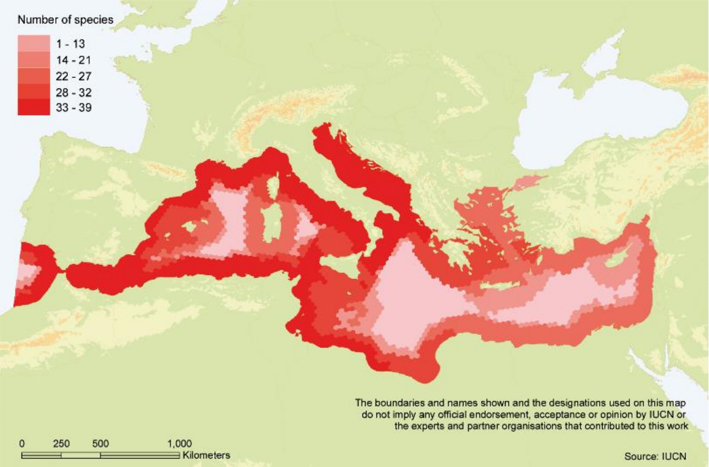


Figure 5.9 Species richness of threatened marine fish in the Mediterranean Sea. (IUCN, 2010)

Almost one third of the Mediterranean fish species lack a sufficient data basis to list them in any of the IUCN categories, which concerns many of the endemic species. This makes appropriate management of the fish fauna and of entire ecosystems very challenging.

5.5 Impacts on sea turtles

Little is known for impacts on sea turtles from offshore windfarms. Based on known impacts from other offshore projects and activities sea turtles may potentially be subject to:

- Noise impacts during construction phase
- Ship traffic impacts before, during and after construction phase
- Electromagnetic fields during operation phase
- Artificial light impacts before, during and after construction phase

5.5.1 Potential noise impacts on sea turtles

Despite increasing levels of anthropogenic noise throughout the oceans, there are few data about the hearing capabilities of sea turtles or how they might behaviourally and physiologically respond to potentially harmful sources of noise, their uses of sound, and their vulnerability to sound exposure.

It has thus been necessary to extrapolate from other animal groups and more precisely, based on anatomy, hearing range for turtles seems to better approximate that of fishes than of any marine mammal.

In general sound, at higher intensities, may have a diverse range of effects on the animal. Acoustic disturbance from seismic survey activities may lead to the interruption of normal behaviours (such as feeding or breeding) and avoidance, leading to displacement from the area and exclusion from critical habitats (Nelms et al. 2016)—an effect that has been documented for a number of cetacean species, particularly mysticetes (baleen whales) and delphinids and sea turtles. Additionally, startle responses, such as increased swim speeds and altered dive durations, have been observed in fish and marine mammals possibly leading in extreme cases to physical damage (and mortality) such as decompression sickness and strandings. A reduction in hearing sensitivity may be observed as a result of damage to auditory organs and structures, such as sensory hair cells. Noise may also cause stress which in turn can lead to a depressed immune function (NELMS et al. 2016 and references therein). Observed responses of sea turtles to low-frequency signals include: agitated behaviour, abrupt body movements, startle responses, changes in swimming patterns and orientation. Prolonged exposure could potentially affect sea turtles by encouraging avoidance behaviour, increasing stress and aggression levels causing physiological damage to the ears altering surfacing or diving rates or confounding orientation cues.

5.5.2 Ship traffic impacts

In areas where recreational boating and ship traffic is intense, propeller and collision injuries are common for marine wildlife. Sea turtles staying close to the sea surface to bask, mate or breathe are vulnerable to boats collisions or being struck by propellers. Vessel collision contributes to the mortality and maiming of sea turtles.

Higher vessel speed increases the probability that turtles would fail to flee from the approaching vessel while the majority of sea turtles hit by boats do not survive. Young turtles are very alert so less likely to be hit by vessels. Many sea turtles that experience severe trauma, such as boat collision, have buoyancy control issues from their injuries. There is also a risk to sea turtles due to disturbance from vessel movements associated with surveying, installation and maintenance activities.

5.5.3 Electromagnetic fields

Sea turtles are highly migratory, and depending on life stage, may be found in nearshore or oceanic waters, or transiting between habitats. Studies on loggerheads suggest that sea turtles use geomagnetic sensitivity (in addition to other non-magnetic cues) for orientation, navigation, and migration (LOHMANN et al. 2008). More specifically, studies have documented these turtles' ability to use the Earth's magnetic field for compass-type (i.e. directional, to maintain a heading in a particular direction), and the more complex, map-type orientation (i.e. positional, to assess position relative to a specific geographic location.

The mechanisms for sea turtles sensory abilities are not well known and to date so conclusions about the effects of magnetic fields from power cables are still hypothetical as it is not known how sea turtles detect or process fluctuations in the earth's magnetic field (NORMANDEU ASSOCIATES INC. & EXPONENT INC. 2011).

5.5.4 Artificial light impacts

The extent of the effects of artificial light from offshore windfarm construction and operation to sea turtles is highly unknown. The sources of artificial light related to offshore windfarms have already been described in chapter 5.1.5 and they include mainly light from vessels, ports and offshore platforms.

Artificial light is known to have detrimental effects on the ecology of sea turtles, particularly at the hatchling stage when they emerge from nests on natal beaches and head towards the sea. Under natural conditions turtles hatch predominantly at night (although some early morning and late afternoon emergences occur). After hatching they show an innate and well-directed orientation to the water, relying mostly on light cues that attract them toward the brighter horizon above the sea surface. Artificial lighting on beaches is strongly attractive to hatchlings. It can cause them to move away from the sea and interfere with their ability to orient in a constant direction. Ultimately, this disorientation can lead to death of hatchlings from exhaustion, dehydration and predation (THUMS et al. 2016 and references therein).

While the problems caused by light pollution during the journey of hatchlings from the nest to the water's edge are well recognized, the impact of artificial light on their behaviour once they reach the water is unknown. Upon arrival at the sea, turtle hatchlings swim to offshore waters to begin their oceanic life stage, orientating using wave direction and an internal magnetic compass. Nevertheless a study by THUMS et al. (2016) showed that light is also an important navigational cue once hatchlings enter the water. In addition if artificial light disrupts the orientation and swimming behaviour of hatchlings, causing them to linger or become disoriented in the near shore, it is likely to increase the chances of mortality by predation, with detrimental effects on the survivorship and resilience of populations (THUMS et al. 2016 and references therein).

5.5.5 Sea turtles in the Mediterranean Sea

The Mediterranean Sea hosts local populations of 2 sea turtle species, the loggerhead turtle *Caretta caretta* and the green turtle *Chelonia mydas*. The Mediterranean is also frequented by turtles originating from Atlantic rookeries, including leatherback turtles *Dermochelys coriacea*, olive ridley turtles *Lepidochelys olivacea* and Kemp's ridley turtles *L. kempii* (CASALE et al. 2018 and references therein). Both *Caretta caretta and Chelonia mydas* are listed in Annex IV and as priority species under Annex II of the EU Habitats directive 92/43/EEC.

Although loggerhead turtle nesting occurs across the Mediterranean Basin, more than 96% of clutches are laid in Greece, Turkey, Libya and Cyprus. Minor and infrequent nesting occurs also along the western basin coastlines of Spain, France, Italy and their offshore islands. No nesting activity of either species has been documented for Algeria, Morocco, Monaco or the eastern Adriatic (Albania, Bosnia and Herzegovina, Croatia, Montenegro, Slovenia).

The nesting sites with the highest number of clutches per year for loggerhead turtles are Zakynthos Island (with also the highest nest density), Kyparissia Bay (both in Greece), Belek, Anamur (Turkey) and Chrysochou Bay (Cyprus) (CASALE et al. 2018 and references therein).

The 13 major green turtle rookeries are located in Turkey, Cyprus and Syria, with minor nesting aggregations occurring in Egypt, Lebanon and Israel

Figure 5.10 shows "major" nesting sites of loggerhead turtle *Caretta caretta* and Figure 5.11 of green turtles *Chelonia mydas.*

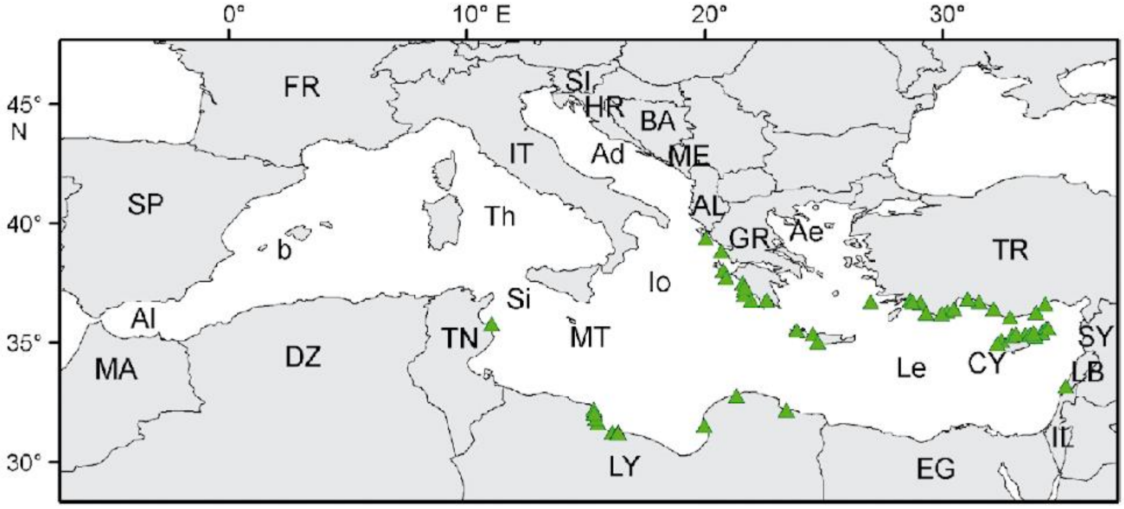


Figure 5.10 *Major nesting sites (i.e. ≥10 clutches yr−1 and ≥2.5 clutches km−1 yr−1) of loggerhead turtles Caretta caretta in the Mediterranean. Countries: AL: Albania; DZ: Algeria; BA: Bosnia and Herzegovina; HR: Croatia; CY: Cyprus; EG: Egypt; FR: France; GR: Greece; IL: Israel; IT: Italy; LB: Lebanon; LY: Libya; MT: Malta; ME: Montenegro; MA: Morocco; SI: Slovenia; SP: Spain; SY: Syria; TN: Tunisia; TR: Turkey. Marine areas: Ad: Adriatic Sea; Ae: Aegean Sea; Al: Alboran Sea; Io: Ionian Sea; Le: Levantine Basin; Si: Sicilian Strait; Th: Tyrrhenian Sea; b: Balearic Islands (Spain) (CASALE et al. 2018 and references therein).*

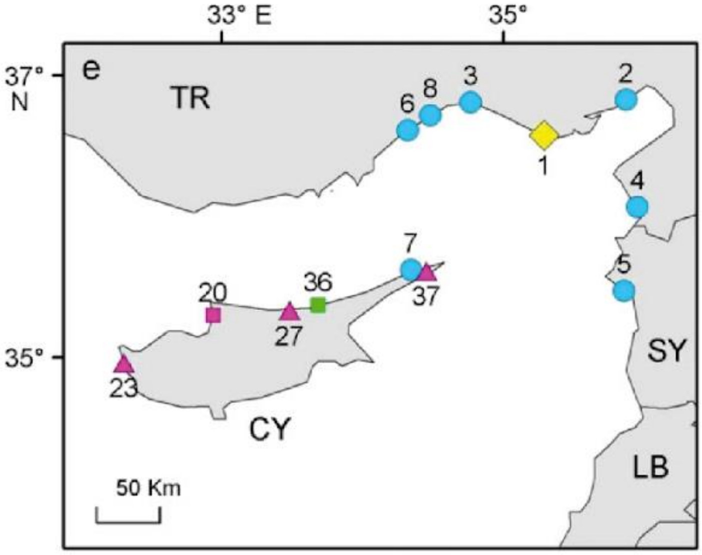


Figure 5.11 *Major nesting sites of green turtles Chelonia mydas. Classes of nesting activity: Very high (>300 clutches yr*$^{-1}$*): yellow, High (100–300 clutches yr*$^{-1}$*): blue, Moderate-dense (20–99 clutches yr*$^{-1}$*; ≥6.5 clutches km*$^{-1}$ *yr*$^{-1}$*): pink triangle, Moderate-not dense (20–99 clutches yr*$^{-1}$*; 2.5–6.5 clutches km*$^{-1}$ *yr*$^{-1}$*) pink square, Low-not dense (10–19 clutches yr*$^{-1}$*; 2.5–6.5 clutches km*$^{-1}$ *yr*$^{-1}$*): green. CY: Cyprus; LB: Lebanon; SY: Syria; TR: Turkey. Numbers represent nesting locations (CASALE et al. 2018 and references therein).*

5.5.6 Conclusion

Offshore windfarm sector is not developed in Mediterranean Basin and at the same time experience with sea turtles from the Northern European countries, is lacking because of the rare presence of the sea turtles in these geographic regions. Impacts of offshore windfarms on sea turtles are therefore unknown and could only be extrapolated or speculated from the already known threats to these species or from case studies in the North American coast where there may be sea turtle nesting or breeding grounds in the vicinity of proposed sites (BAILEY et al. 2014).

In this sense, noise could disturb sea turtles with the intensity and duration of affect diminishing with distance from the source. Potential sources include piling activities as well as motorized vessels involved in the construction, maintenance and decommissioning phase which transmit noise through both air and water. Also construction activities such as cable laying and other pile driving activities could impact sea turtles in the vicinity of the project.

Collisions of sea turtles with vessels cannot be excluded based on former documented incidents from other human marine activities. There is also a risk to sea turtles due to disturbance from vessel movements associated with surveying, installation and maintenance activities.

So far artificial light pollution onshore has been documented as a disorientation factor for hatchlings trying to enter the sea and can affect the mortality rates during hatchling emergence and their entrance into the sea. However effects of permanent artificial light due to offshore windfarms as well as of artificial light related to construction, maintenance and decommissioning activities to sea turtles hatchlings and the response of the sea turtle population in general are still unclear.

5.6 Impacts on birds

Birds can be affected by offshore wind turbines in four ways (DIERSCHKE & GARTHE 2006; DREWITT & LANGSTON 2006): Collision, habitat loss due to displacement, attraction and barrier effects.

5.6.1 Collision

Although collisions with wind turbines appear to kill fewer birds compared to other man-made structures such as power lines, buildings or traffic (LOSS et al. 2015), bird mortality due to collisions with wind turbines is one of the major ecological concerns associated with windfarms.

For onshore windfarms, estimates of the number of bird collisions range from 0 to almost 40 fatalities per turbine per year (SOVACOOL 2009; LOSS et al. 2013; GRÜNKORN et al. 2016). These estimates are usually derived by intensive carcass searches and numbers need to be corrected for imperfect searcher efficiency, carcass persistence, search radius etc. (WARREN-HICKS et al. 2013; KORNER-NIEVERGELT et al. 2015).

At offshore windfarms estimation of collision fatalities by carcass searches is impossible. Furthermore, systematic recordings of collisions with technical devices such as cameras, radar or sound recording systems (DIRKSEN 2017) have so far not been successful. Consequently, no direct estimates of bird mortality at offshore windfarms exist. All efforts to gauge collision risk at offshore wind turbines are therefore based on collision risk models or conceptual comparisons with evidence from onshore windfarms or offshore structures such as platforms where collision victims can be found (BAND 2012; HÜPPOP et al. 2016; KLEYHEEG-HARTMAN et al. 2018).

There is a wide range of factors influencing bird collisions at wind turbines (MARQUES et al. 2014). At offshore sites the factors considered most important are:

- Avoidance behaviour
- Flight height/flight behaviour

- Bird abundance/siting of windfarm.

Avoidance behaviour

Avoidance behaviour is regarded as the single most important factor affecting the collision risk of birds at offshore windfarms (OWF). Only individuals that do not avoid turbine even at close range and cross the rotor-swept area are at risk to collide with the rotor blades. Assumed avoidance rates also play a pivotal role in collision risk models (CRM) as they have a strong impact on estimated collision numbers (BAND 2012; KLEYHEEG-HARTMAN et al. 2018; SKOV et al. 2018).

Usually, three types of avoidance behaviours are considered:

- Macro-avoidance: behavioural response to the presence of the windfarm occurring beyond its perimeter, resulting in a redistribution of birds inside and outside the windfarm.
- Meso-avoidance: behavioural response within the windfarm footprint to individual turbines, resulting in a redistribution of the birds within the windfarm footprint.
- Micro-avoidance: behavioural response to single blade(s) within 10 m of the rotor-swept zone, considered as the bird's 'last-second action' taken to avoid collision.

A number of studies have attempted to estimate avoidance rates at OWF (reviewed in COOK et al. 2018; SKOV et al. 2018), yet data especially on meso- and micro-avoidance rates is still scarce. However, recent estimates of total avoidance rates show that the vast majority of birds flying in the vicinity of OWFs avoid the rotor-swept area. While previous guidance on the use of avoidance rates in CMRs suggested 0.98 as the default rate to be used for seabirds, current studies suggest total avoidance rates in excess of 0.99 for all species considered (COOK et al. 2018; SKOV et al. 2018). While this difference at first sight seems to be trivial, it will result in the predicted collision rate being more than halved (COOK et al. 2018) emphasising the importance of avoidance behaviour for collision risk.

Flight height

Flight behaviour, particularly flight height, is an important factor as it determines the proportion of bird movements at rotor height. Evidently, birds flying below or above the rotor-swept area are not required to exhibit avoidance behaviour in order to avoid collision.

The flight height distribution is species specific and also depends on external conditions, primarily weather and wind conditions (ERNI et al. 2002; VAN BELLE et al. 2007; KEMP et al. 2013). For nocturnally migrating species at sea, previous studies have consistently shown a high proportion (usually 20% - 40%) of movements within 200 m altitude and thus within the general height range of offshore wind turbines (HÜPPOP et al. 2006; FEBI 2013; FIJN et al. 2015; BRUDERER et al. 2018).

In recent years, a number of studies have estimated flight heights of marine birds to assess their susceptibility to collisions at OWFs (FURNESS et al. 2013 and references therein; JOHNSTON et al. 2014). They have shown that flight heights vary widely across species. For some species such as alcids (e.g. common guillemot, razorbill) and procellariforms (e.g. shearwaters and storm petrels) flight heights are almost exclusively below the rotor zone of typical offshore wind turbines and hence, the collision risk of these species seems negligible. In other species like northern gannet, gulls (*Larus* spec.), divers (*Gavia* spec.) as well as ducks and geese, a higher proportion of birds were recorded within rotor height increasing their theoretical collision risk (GARTHE & HÜPPOP 2004; FURNESS et al. 2013; JOHNSTON et al. 2014).

Flight type may also play an important role in collision risk, especially when associated with hunting and foraging strategies. Otherwise preferentially low flying species increase flight height while foraging (e.g. plunge-diving gannets and terns). Additionally, when birds are hunting and focused on prey, they might lose track of WT position. However, while this has been shown for several onshore species, especially raptors (MARQUES et al. 2014), evidence for the role of flight behaviour on collision risk at offshore sites is still lacking.

Bird abundance/siting of windfarm

At OWF located in areas with high concentrations of bird movements collision risk is likely to be higher than at sites with low bird abundance (DREWITT & LANGSTON 2006). In CRMs estimated fatalities increase proportionally with the number of birds flying at the windfarm site.

At offshore locations an increased number of flying birds can be expected at migration corridors. Particularly species migrating during the day avoid crossing large expanses of open water (BERTHOLD et al. 2003) and therefore concentrate in areas where the distance between shorelines is short. Therefore, at locations such as straits, islands and peninsulas high numbers of diurnally migrating landbirds (mostly passerines) and soaring birds such as raptors can be expected. In contrast, nocturnal migrants usually exhibit broad-front migration. These species do cross larger sea areas and concentrate much less at topographical features (ÅKESSON 1993; FORTIN et al. 1999; NILSSON et al. 2014).

Other areas with concentrations of bird movements are related to highly frequented wintering or stop-over sites of marine birds or areas regularly used by (sea) birds commuting between breeding and foraging sites. For example, EVERAERT & STIENEN (2007) found a particularly high collision rate of terns at a windfarm located between a breeding colony and main foraging areas of these birds.

Collision risk models (CRM)

In the absence of direct data on bird collisions at OWF, collision risk models are currently the only possibility to derive estimates of the number of collision victims. Although several different models exist (KLEYHEEG-HARTMAN et al. 2018), the so-called Band model (BAND et al. 2007; BAND 2012; HIDEF AERIAL SURVEYING LIMITED & BIOCONSULT SH 2018) is the one most often applied, particularly within environmental impact assessments for OWF in the UK. The Band model is based on the technical specifications of the turbines (e.g. rotor blade dimensions, rotation speed, pitch of blades etc.) as well as the flight speed and other characteristics of the species in question. Models then take into account the flux rate and the behavioural response of birds to the presence of windfarm and the turbines within. Sensitivity analyses have shown that model outcomes are most sensitive to the assumed avoidance rates, particularly to the predicted response of the birds within the windfarm (KLEYHEEG-HARTMAN et al. 2018; SKOV et al. 2018).

As mentioned above, a recent study within the Offshore Renewables Joint Industry Programme (ORJIP) using recent technological developments for the monitoring of seabird movements at an operational offshore windfarm quantified avoidance rates of five target seabird species (SKOV et al. 2018). In line with a recent review of avoidance studies (COOK et al. 2018) they concluded that total avoidance rates of the study species are likely to be higher than previously thought which, in turn, has important repercussions for the estimated number of collisions.

For an onshore location, KLEYHEEG-HARTMAN et al. (2018) could show that assuming sufficiently high avoidance rates the predicted number of collisions by the Band model was similar to estimates based on carcass searches.

Collision risk of different species groups

Seabirds: Several studies have tried to develop vulnerability indices for marine birds to impacts from offshore wind developments (GARTHE & HÜPPOP 2004; FURNESS et al. 2013). Specifically, FURNESS et al. (2013) combined information on flight altitude, flight manoeuvrability, percentage of time flying and nocturnal flight activity together with a conservation importance score to derive a total collision risk score for a large number of marine species. This initiative confirmed a large inter-specific variability in theoretical collision risk. Gulls (primarily Herring gull, Great and Lesser black-backed gull), Northern gannet and White-tailed eagle (the only raptor considered in this study) were assigned the highest risk scores, while the collision risk of alcids and procellariformes was thought to be low. For gulls an elevated collision risk has been proven on land (GRÜNKORN et al. 2016).

While this study concentrated on species of the North Sea and northern Atlantic, indication about the collision risk of Mediterranean species can be inferred as flight behaviour within species groups is likely to be similar. However, such considerations cannot substitute direct observations of focal species in a Mediterranean setting.

Raptors: At many onshore windfarms, birds of prey are regarded the species group most vulnerable to collision (BARRIOS & RODRIGUEZ 2004; MARQUES et al. 2014; WATSON et al. 2018). This seems mostly related to their mode of flight, low manoeuvrability and habitat use. At offshore locations, raptors can mostly be expected during migration. In the Mediterranean, the largest concentrations of raptors are expected at the Strait of Gibraltar, the Bosporus and between the Italian mainland and the islands of Sicily and Malta (BILDSTEIN 2006). However, lower numbers of migrating raptors are likely to occur at other areas as well (MEYER et al. 2000).

First results from OWFs have shown that migrating raptors at sea might be attracted to windfarms (SKOV et al. 2016). Raptors have also been observed using the offshore wind turbines and associated structures as roosting sites (own unpubl. data). Hence, in areas where they occur in larger numbers, the collision risk of raptors at offshore sites may be comparatively high.

Nocturnal migrants: Most of the migratory species, particularly passerines, migrate during the night. Nocturnal migration is largely independent of the landscape. Instead, nocturnal migrants follow a general migration direction unguided by the coastline or other topographical features. This migration pattern is referred to as “broad-front migration” (BERTHOLD et al. 2003). On their broad front migration nocturnal migrants regularly cross larger bodies of water (FORTIN et al. 1999) and, hence, are observed in large numbers at offshore locations (VAN BELLE et al. 2007; FIJN et al. 2015; WELCKER & VILELA 2018).

Nocturnal migrants are often thought to be particularly vulnerable to collisions with wind turbines (ERICKSON et al. 2001; STRICKLAND et al. 2011). This assumption may be related to the fact that nocturnally migrating passerines often represent the majority of fatalities at man-made structures such as buildings, communication towers or offshore facilities such as platforms (HÜPPOP et al. 2006, 2016; LONGCORE et al. 2008; ARNOLD & ZINK 2011).

The assumed higher collision risk of nocturnal migrants at offshore structures is thought to be related to poorer visibility of obstacles during the night, which may be aggravated during periods of inclement weather (AVERY et al. 1977; BALLASUS et al. 2009). In addition, and perhaps most importantly, collision risk may further increase if structures are illuminated and, hence, attract birds (EVANS OGDEN 1996; LONGCORE et al. 2008; VAN DOREN et al. 2017). For example, at an illuminated offshore platform in the German Bight, over half of the bird strikes occurred in just two nights that were characterized by very poor visibility (HÜPPOP et al. 2006).

However, in contrast to results from offshore platforms, there is evidence that the collision risk of nocturnal migrants at onshore wind turbines is relatively low (KRIJGSVELD et al. 2009; GRÜNKORN et al. 2016; WELCKER et al. 2017). For example, obligate nocturnal migrants constituted only 8.6% of all fatalities at onshore windfarms located within a major migration flyway between Scandinavia and the European mainland (WELCKER et al. 2017).

Whether the collision risk of nocturnal migrants is similar to onshore windfarms (probably low collision risk) or comparable to other offshore structures (high collision risk), remains to be demonstrated. One principle difference between onshore and offshore migration is that onshore migrants can interrupt migration activity almost immediately when weather conditions deteriorate. When faced with inclement weather offshore, birds need to continue their flight until they reach land and possible stop-over sites. This may play an important role as in these situation birds are likely to be attracted to light sources at sea and thus incur a higher risk of collision (AUMÜLLER et al. 2011). Therefore, studies on the impact of flashing red lights at onshore windfarms which did not reveal significant differences between fatality rates at wind turbines with or without flashing red lights (KERLINGER et al. 2010) may not be representative for OWFs.

Recent studies estimated the number of collisions of nocturnal migrants at OWFs at about 20 fatalities per turbine and year based on CRMs (SCHULZ et al. 2014; BRABANT et al. 2015; KRIJGSVELD et al. 2015).

5.6.2 Barrier effect

Barrier effects occur where a windfarm acts as a ‘barrier’ for a bird getting from A to B and where the bird alters its flight trajectory in response to the windfarm presence. As a consequence, birds may use more circuitous routes to fly between, for example, breeding and foraging grounds, and thus use up more energy to acquire food (MASDEN et al. 2009, 2010b; SPEAKMAN et al. 2009; BAND 2012). It is also possible that the habitat fragmentation caused by such physical barriers will lead to avoidance of certain sea areas that previously have been utilized as foraging habitat.

Barrier effects may arise for migrating bird as well as for breeding and resting birds. With respect to bird migration, barrier effects may lead to extended migration distances and consequently increased energy expenditure. According to SPEAKMAN et al. (2009) the modelled impact on energy expenditure of migrating birds having to fly around a single windfarm facility are likely to be marginal and for most species would result in depletion of less than 2% of their available fat reserves, even if the birds travelled 30 km out of their way to avoid the facility. They concluded that even cumulative effects of several OWFs are unlikely to have profound negative effect on migrants. MASDEN et al. (2009) estimated the additional distance travelled by common eiders at a Danish OWF at about 500 m which was trivial compared to the total migration distance of about 1,400 km of this population.

The impact on resident birds having to make regular deviations around a facility because it is located between roosting and feeding sites, or between nesting and feeding sites, is more significant. An extra 15 km of flying each day would increase daily energy demands by between 4.8 and 6% (SPEAKMAN et al. 2009). The effect of distance is linear, so having to detour twice the distance each day would double the corresponding energy demands and thus could have long-term impacts on the birds. But predicting this impact is complex because the ways that birds respond to such increases in energy demand are not yet known, and birds show great flexibility in their responses to variation in energy demands (SPEAKMAN et al. 2009). Similarly, MASDEN et al. (2010b) estimated the additional energetic costs of a number of seabird species of avoiding one OWF to be lower than those imposed by low food abundance or adverse weather. However, they also concluded that cumulative effects of several windfarms may increase these additional costs significantly.

5.6.3 Displacement/Habitat loss – Attraction

Displacement can be considered as the avoidance of the windfarm footprint (and its vicinity) by birds that would utilize that area as a foraging site or staging/wintering area. Permanent displacement leads to habitat loss (DIERSCHKE & GARTHE 2006). Displacement and attraction applies only to bird species using the area as resting or foraging habitat but not to birds on migration. It needs to be noted that the avoidance behaviour of birds has contrasting consequences for collision risk and displacement. While birds that fail to avoid OWFs incur a high collision risk, displacement from foraging habitat is greatest for birds that do avoid windfarms (FURNESS et al. 2013; DIERSCHKE et al. 2016).

Regarding displacement, changes in abundance of birds at windfarms maybe caused by noise and visual disturbance (moving rotor blades) or merely by the presence of these vertical structures. The disturbance may be intensified by maintenance activities such as increased vessel movement, helicopter traffic and human activity at the turbines. On the other hand, attraction has been also documented for some seabird species (DIERSCHKE et al. 2016) associated with artificial resting sites or potentially increased food availability that may be attributed to new substrate at turbine bases and fishing bans.

The classification of the behavioural response of seabirds to OWFs according to DIERSCHKE et al. (2016) (based on 20 case studies from North Sea, Baltic Sea and Irish Sea) shows a complete range of behaviours from strong avoidance to attraction, but with many species showing little behavioural response (Table 5.2, Table 5.3 and Table 5.4).

Strong avoidance

Strong avoidance, defined as a complete absence or very strong decrease in abundance, has repeatedly been shown in divers and northern gannets (VANERMEN et al. 2015; DIERSCHKE et al. 2016; WELCKER & NEHLS 2016). Limited evidence suggests this may also be true for grebes and northern fulmars.

Recent studies investigating the effects of OWF and associated ship traffic on the distribution of divers in the German North Sea showed significant large-scale shifts in the species distribution after construction of the windfarms (MENDEL et al. 2019). Divers aggregated between two OWF clusters, indicating the remaining suitable habitat. The decrease in the abundance of divers was significant as far as about 16 km from the closest OWF (Figure 5.12). Similar results were found by HEINÄNEN et al. (in preparation) using digital aerial survey and satellite telemetry data of red-throated divers.

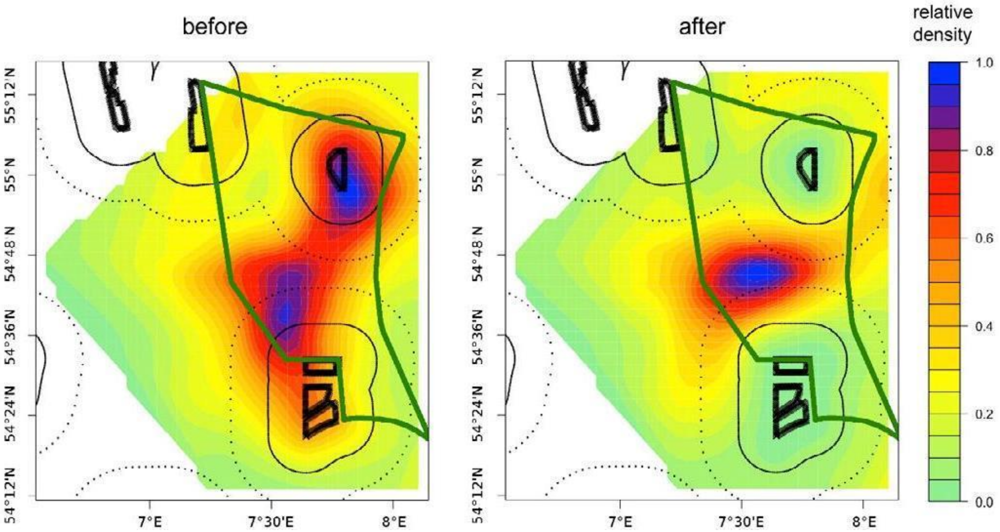


Figure 5.12 Spatial density plots of the predicted diver distribution 'before' vs. 'after' the construction of OWFs. Bold black lines: OWFs; thin black lines: 10 km distance buffer; dotted black lines: 20 km distance buffer; bold green line: Specially Protected Area (SPA), (MENDEL 2019).

Avoidance

Species in this category continue to use the marine area after construction of an OWF but do so to a lesser degree or at a lower abundance. Such a response has regularly been documented in long-tailed ducks, common scoters, common guillemots, razorbills, little gulls and sandwich terns, and with limited evidence also in manx shearwaters. Some studies have also reported avoidance in kittiwakes and common/arctic terns. Results on avoidance of these species are often ambiguous across studies (DIERSCHKE et al. 2016). This may indicate that the extent of displacement from OWFs varies among sites, possibly driven by differences in windfarm configuration, turbine size or the availability of suitable habitat in the area. However, due to the large spatiotemporal variability of seabird abundance at sea, contrasting results from different studies may also be attributed to a low power to detect effects (MACLEAN et al. 2012).

Attraction

Attraction, i.e. an increase in numbers of a species post-construction, has been reported for great cormorants and European shags. Also, increased numbers of several gull species (herring gull, great and lesser black-backed gull, common gull, black-headed gull) have been shown in several operational OWFs, but results were more variable across studies (DIERSCHKE et al. 2016).

Factors causing displacement

Movements of the rotor blades, the vertical structures itself and service traffic are the main factors leading to displacement. However, the contributions of these factors are difficult to discern. Anecdotal evidence from the OWF 'Horns Rev 1' suggested that birds entered the windfarm at positions with turbines being inactive (PETERSEN et al. 2006), and the OWF 'Egmond aan Zee' was crossed two to three times more often when turbines were inactive (KRIJGSVELD et al. 2009; GRÜNKORN et al. 2016; WELCKER et al. 2017).

Common eiders appeared to be less reluctant to cross a row of turbines at Utgrunden when non-operative (DIERSCHKE et al. 2016). Data from studies during the construction of OWFs suggest that birds also respond to the vertical structures alone. However, the avoidance behaviour before the installation of the rotor blades was often less strong (BIOCONSULT SH & IFAÖ 2014 and own unpubl. data).

The operation of offshore turbines involves nearly daily activity of ships and helicopters (to a lesser degree) inside and around the windfarms. Some seabird species, especially divers and seaducks, are known to be sensitive to ship and air traffic avoiding areas with high traffic intensity (SCHWEMMER et al. 2011). Maintenance traffic should therefore be regarded as an integral part of OWFs contributing to the avoidance response of birds.

Factors leading to attraction

For those birds that do not avoid OWFs, the platforms at the base of the tower as well as related structures offer roosting opportunities. Cormorants (great cormorant, European shag) and large gulls (herring, lesser black-backed and great black-backed gull) have regularly been observed to sit on these structures. Whereas it is uncertain whether large gulls intentionally visit windfarms for roosting, the availability of roosting sites is likely to contribute to the attraction effect on great cormorants and European shags. Because both species need roosting sites for regular drying of their feathers between foraging bouts, they usually cannot forage in marine areas far offshore. Windfarm structures allow these species to extend their foraging range further off the coast into areas previously unavailable (IMARES 2011).

OWFs are likely to cause changes in the pelagic and benthic fauna in that area. Foundations and scour protections create new hard substrate on formerly soft bottom, which is rapidly colonized by various epibenthic invertebrates (DE MESEL et al. 2015). These artificial reefs and the lack of fisheries can alter the fish fauna with respect to species composition, abundance and size classes. Moreover, turbulence at turbines may bring food particles to the sea surface, which then become available to surface-feeding species. These factors may have positive effects on food availability within OWF and this could lead to higher densities of seabird species that do not avoid OWFs. However, evidence for such an effect is still lacking.

5.6.4 Consequences of collisions and displacement

For the individual, collisions with wind turbines are considered fatal in essentially all cases. Information on consequences of collisions on population level, however, is still scarce. Potential population effects depend on various factors, such as life history traits (longevity, reproductive rates, age at first breeding etc.), density dependent processes, or whether additional mortality through collisions is additive or compensatory. Seabird populations may be more vulnerable to collision mortality as these are long-lived species with slow maturation and low reproductive rates and hence a potentially high impact of adult mortality on population dynamics. This applies especially to rarer species of high conservation concern. Migrating raptors (e.g. Egyptian Vulture, Short-toed Eagle, Black Kite etc.) are quite vulnerable as well. Thus migration routes and bottle-necks mapping is crucial. Passerines, on the other hand, are mostly short-lived with high annual reproductive output and thus may be more resilient to impacts.

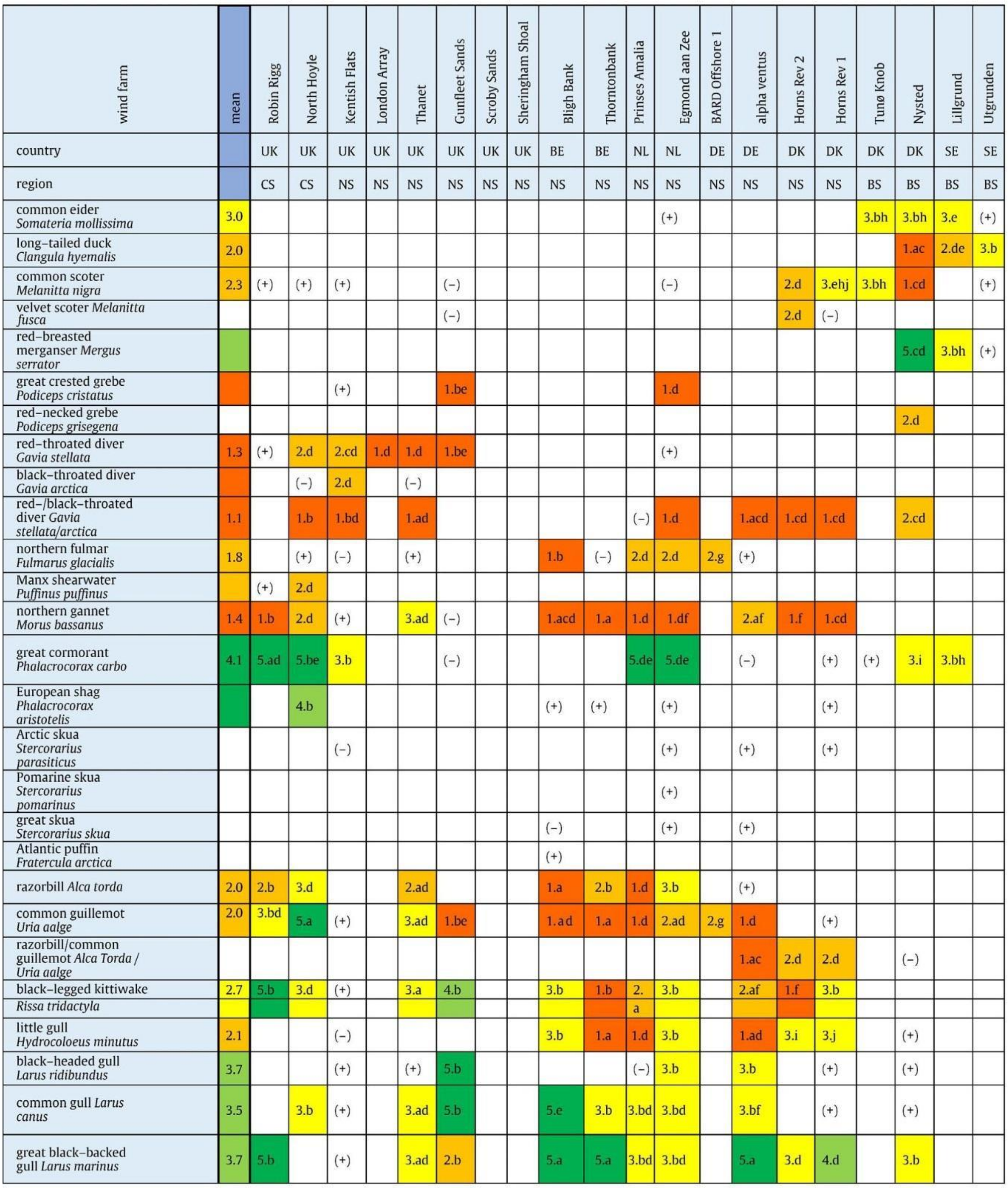
To gauge population effects it is important to consider not only the impact of a single OWF but cumulative effects of all OWFs in an area. Recent efforts to estimate cumulative impacts of collisions at OWFs have concluded that the risk of adverse population effects is generally low (POOT et al. 2011; LEOPOLD et al. 2014; BRABANT et al. 2015; GOODALE & MILMAN 2016). Only for lesser and great black-backed gulls in the southern North Sea and for Cranes in the Baltic a significant negative effect at population level could not be ruled out (BRABANT et al. 2015; SKOV et al. 2015). Yet, due to large uncertainties in collision and population models (COOK & ROBINSON 2017), assessments of impacts on bird populations have been strongly criticised (VOTIER 2016).

To determine the impact of displacement and habitat loss is even more difficult. Consequences may depend on the availability of suitable habitat outside OWFs and the degree of specialization or site fidelity of the different species. Displacement of birds may have little ramifications when habitat and food resources in the remaining area are not limiting factors to the species.

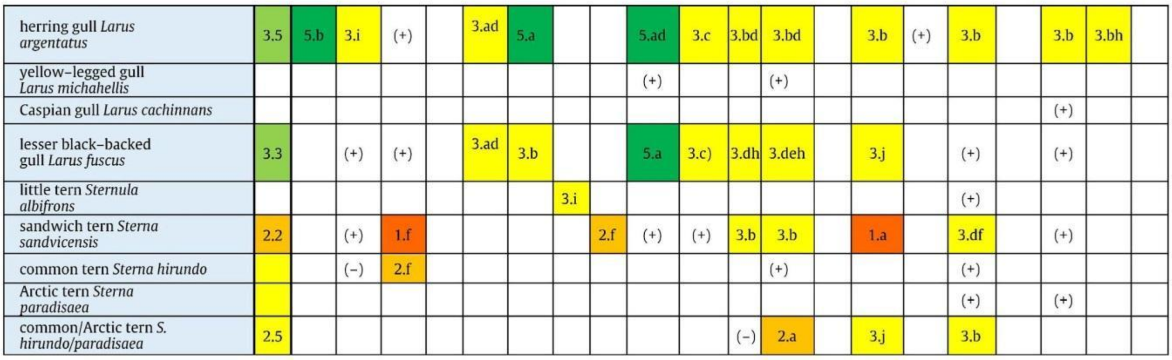
As displacement is unlikely to lead to direct mortality, indirect effects may play a more important role for population processes. Loss of foraging habitat may lead to reduced foraging success and increased intra- or inter-specific competition, and, subsequently, to reduced body condition which in turn may lead to carry-over effects on reproduction and survival.

To date no data is available quantifying effects of displacement on seabirds either on the individual or population level. Modelling exercises so far have suggested that the probability of negative impacts on populations is low although uncertainty related to these models is very high (POOT et al. 2011; TOPPING & PETERSEN 2011; LEOPOLD et al. 2014; GOODALE & MILMAN 2016).

Table 5.2 Response of seabirds to the presence of operating offshore windfarms according to results of post-construction studies. Windfarms are listed from west to east. Numbers and colours indicate the allocated class of response from strong avoidance (1, red) to strong attraction (5, dark green), with letter codes indicating the criteria used (see Table 5.3 for details). The second column gives the calculated arithmetic mean of the studies, but note that the final classification (colour) can slightly deviate owing to species-specific considerations. Regions: CS Celtic Seas, NS North Sea, BS Baltic Sea (DIERSCHKE 2016).

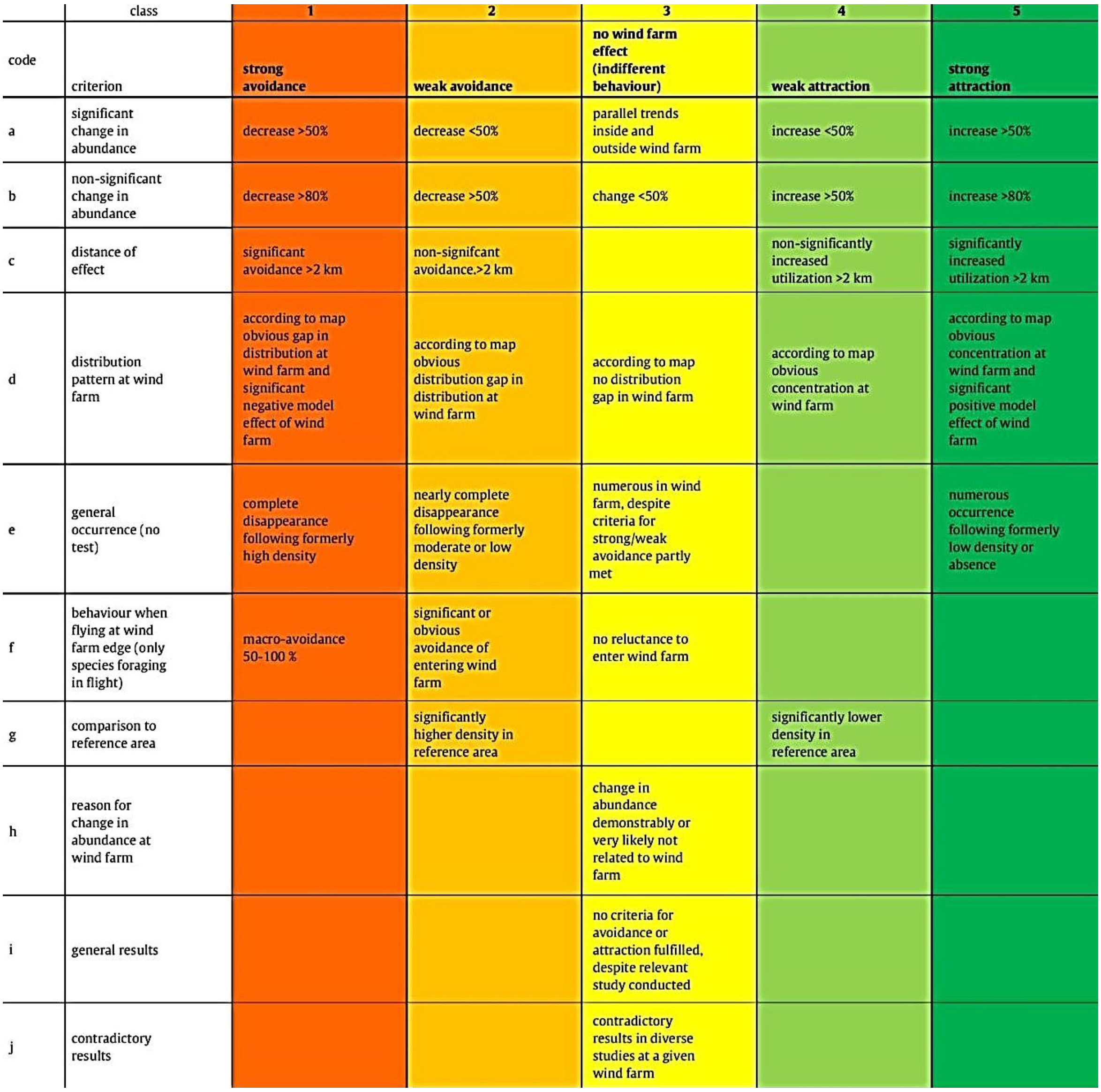


wind farm	mean	Robin Rigg	North Hoyle	Kentish Flats	London Array	Thanet	Gunfleet Sands	Scroby Sands	Sheringham Shoal	Bligh Bank	Thorntonbank	Prinses Amalia	Egmond aan Zee	BARD Offshore 1	alpha ventus	Horns Rev 2	Horns Rev 1	Tunø Knob	Nysted	Lillgrund	Utgrunden
country		UK	UK	UK	UK	UK	UK	UK	UK	BE	BE	NL	NL	DE	DE	DK	DK	DK	DK	SE	SE
region		CS	CS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	BS	BS	BS	BS
common eider *Somateria mollissima*	3.0												(+)					3.bh	3.bh	3.e	(+)
long–tailed duck *Clangula hyemalis*	2.0																		1.ac	2.de	3.b
common scoter *Melanitta nigra*	2.3	(+)	(+)	(+)			(–)						(–)			2.d	3.ehj	3.bh	1.cd		(+)
velvet scoter *Melanitta fusca*							(–)									2.d	(–)				
red–breasted merganser *Mergus serrator*																			5.cd	3.bh	(+)
great crested grebe *Podiceps cristatus*				(+)			1.be						1.d								
red–necked grebe *Podiceps grisegena*																			2.d		
red–throated diver *Gavia stellata*	1.3	(+)	2.d	2.cd	1.d	1.d	1.be						(+)								
black–throated diver *Gavia arctica*			(–)	2.d		(–)															
red–/black–throated diver *Gavia stellata/arctica*	1.1		1.b	1.bd		1.ad						(–)	1.d		1.acd	1.cd	1.cd		2.cd		
northern fulmar *Fulmarus glacialis*	1.8		(+)	(–)		(+)				1.b	(–)	2.d	2.d	2.g	(+)						
Manx shearwater *Puffinus puffinus*		(+)	2.d																		
northern gannet *Morus bassanus*	1.4	1.b	2.d	(+)		3.ad	(–)			1.acd	1.a	1.d	1.df		2.af	1.f	1.cd				
great cormorant *Phalacrocorax carbo*	4.1	5.ad	5.be	3.b			(–)					5.de	5.de		(–)		(+)	(+)	3.i	3.bh	
European shag *Phalacrocorax aristotelis*			4.b							(+)	(+)		(+)				(+)				
Arctic skua *Stercorarius parasiticus*				(–)									(+)		(+)		(+)				
Pomarine skua *Stercorarius pomarinus*													(+)								
great skua *Stercorarius skua*										(–)			(+)		(+)						
Atlantic puffin *Fratercula arctica*										(+)											
razorbill *Alca torda*	2.0	2.b	3.d			2.ad				1.a	2.b	1.d	3.b		(+)						
common guillemot *Uria aalge*	2.0	3.bd	5.a	(+)		3.ad	1.be			1.a d	1.a	1.d	2.ad	2.g	1.d		(+)				
razorbill/common guillemot *Alca Torda / Uria aalge*															1.ac	2.d	2.d		(–)		
black–legged kittiwake *Rissa tridactyla*	2.7	5.b	3.d	(+)		3.a	4.b			3.b	1.b	2.a	3.b		2.af	1.f	3.b				
little gull *Hydrocoloeus minutus*	2.1			(–)						3.b	1.a	1.d	3.b		1.ad	3.i	3.j		(+)		
black–headed gull *Larus ridibundus*	3.7			(+)		(+)	5.b					(–)	3.b		3.b		(+)		(+)		
common gull *Larus canus*	3.5		3.b	(+)		3.ad	5.b			5.e	3.b	3.bd	3.bd		3.bf		(+)		(+)		
great black–backed gull *Larus marinus*	3.7	5.b		(+)		3.ad	2.b			5.a	5.a	3.bd	3.bd		5.a	3.d	4.d		3.b		



herring gull *Larus argentatus*	3.5	5.b	3.i	(+)		3.ad	5.a			5.ad	3.c	3.bd	3.bd		3.b	(+)	3.b		3.b	3.bh	
yellow-legged gull *Larus michahellis*										(+)			(+)								
Caspian gull *Larus cachinnans*																			(+)		
lesser black-backed gull *Larus fuscus*	3.3		(+)	(+)		3.ad	3.b			5.a	3.c)	3.dh	3.deh		3.j		(+)		(+)		
little tern *Sternula albifrons*								3.i									(+)				
sandwich tern *Sterna sandvicensis*	2.2		(+)	1.f					2.f	(+)	(+)	3.b	3.b		1.a		3.df		(+)		
common tern *Sterna hirundo*			(–)	2.f									(+)				(+)				
Arctic tern *Sterna paradisaea*																	(+)		(+)		
common/Arctic tern *S. hirundo/paradisaea*	2.5											(–)	2.a		3.j		3.b				

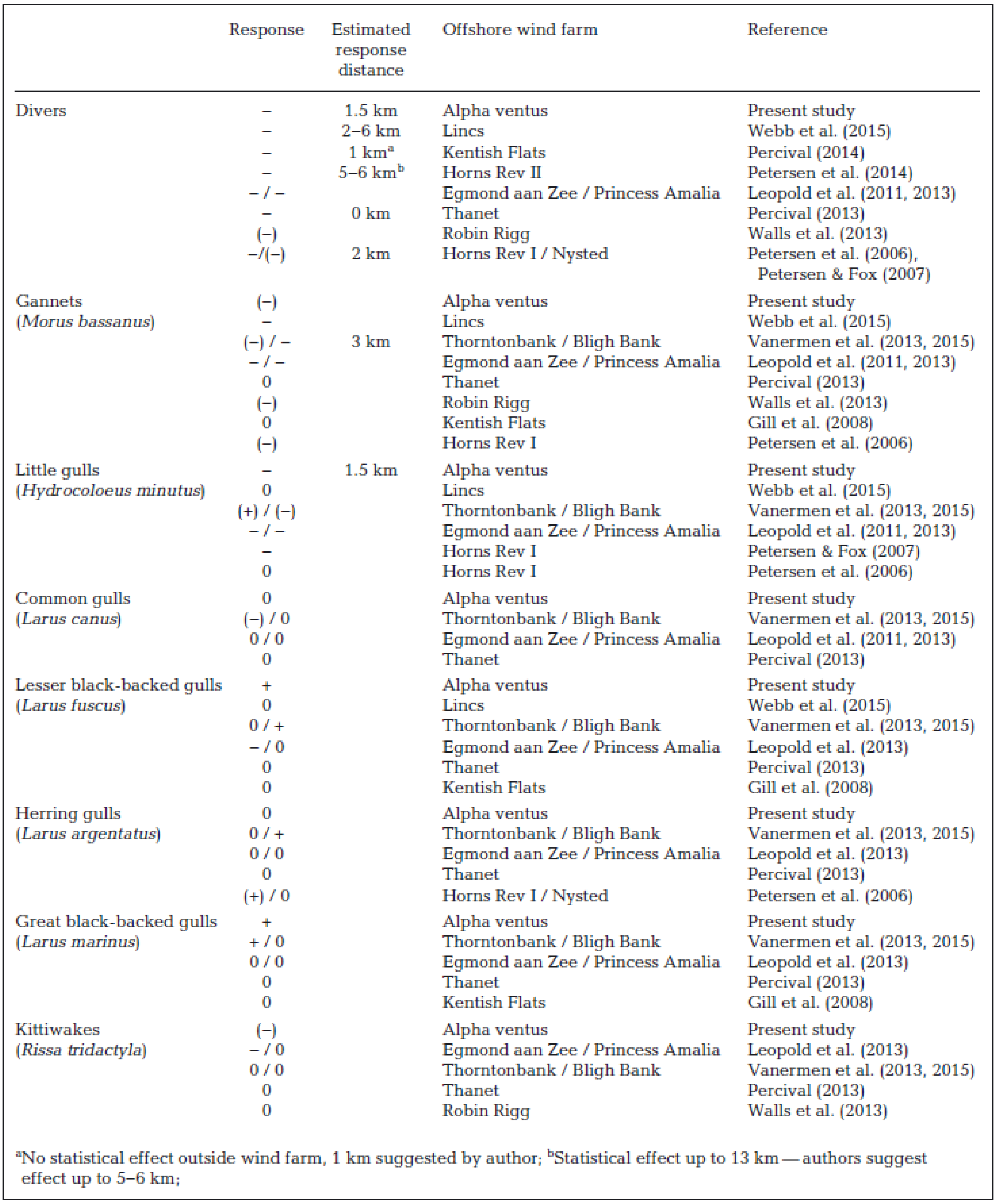
Table 5.3 Definition of classes regarding spatial behaviour of seabirds in response to offshore windfarms (DIERSCHKE 2016).



	class	1	2	3	4	5
code	criterion	**strong avoidance**	**weak avoidance**	**no wind farm effect (indifferent behaviour)**	**weak attraction**	**strong attraction**
a	significant change in abundance	decrease >50%	decrease <50%	parallel trends inside and outside wind farm	increase <50%	increase >50%
b	non-significant change in abundance	decrease >80%	decrease >50%	change <50%	increase >50%	increase >80%
c	distance of effect	significant avoidance >2 km	non-signifcant avoidance.>2 km		non-significantly increased utilization >2 km	significantly increased utilization >2 km
d	distribution pattern at wind farm	according to map obvious gap in distribution at wind farm and significant negative model effect of wind farm	according to map obvious distribution gap in distribution at wind farm	according to map no distribution gap in wind farm	according to map obvious concentration at wind farm	according to map obvious concentration at wind farm and significant positive model effect of wind farm
e	general occurrence (no test)	complete disappearance following formerly high density	nearly complete disappearance following formerly moderate or low density	numerous in wind farm, despite criteria for strong/weak avoidance partly met		numerous occurrence following formerly low density or absence
f	behaviour when flying at wind farm edge (only species foraging in flight)	macro-avoidance 50-100 %	significant or obvious avoidance of entering wind farm	no reluctance to enter wind farm		
g	comparison to reference area		significantly higher density in reference area		significantly lower density in reference area	
h	reason for change in abundance at wind farm			change in abundance demonstrably or very likely not related to wind farm		
i	general results			no criteria for avoidance or attraction fulfilled, despite relevant study conducted		
j	contradictory results			contradictory results in diverse studies at a given wind farm		

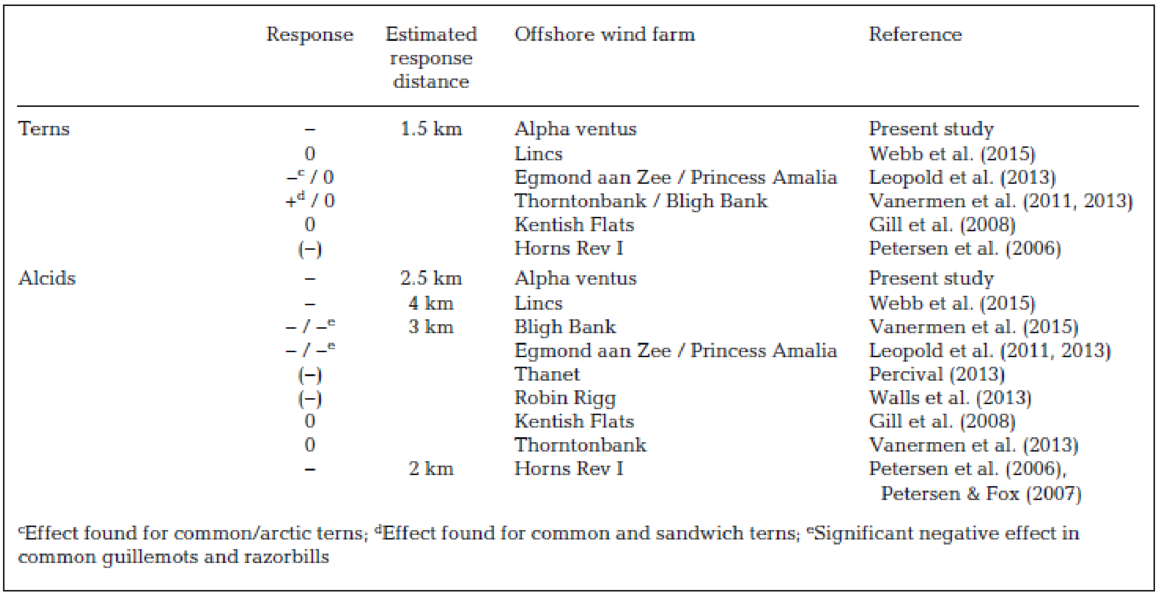
(+) observed inside windfarm (single row windfarms: observation close to turbine)
(-) not observed inside windfarm, despite occurring in the respective marine area

Table 5.4 Response of seabirds to offshore windfarms and estimated response distance (i.e. distance from the windfarm to which birds are affected). '–' and '+' signs indicate statistically significant negative and positive effects on abundance, respectively; '0' indicates no detected effect. Symbols in parentheses indicate no statistical effect, but response suggested by the authors (WELCKER & NEHLS, 2016).



	Response	Estimated response distance	Offshore wind farm	Reference
Divers	–	1.5 km	Alpha ventus	Present study
	–	2–6 km	Lincs	Webb et al. (2015)
	–	1 km[a]	Kentish Flats	Percival (2014)
	–	5–6 km[b]	Horns Rev II	Petersen et al. (2014)
	– / –		Egmond aan Zee / Princess Amalia	Leopold et al. (2011, 2013)
	–	0 km	Thanet	Percival (2013)
	(–)		Robin Rigg	Walls et al. (2013)
	–/(–)	2 km	Horns Rev I / Nysted	Petersen et al. (2006), Petersen & Fox (2007)
Gannets (*Morus bassanus*)	(–)		Alpha ventus	Present study
	–		Lincs	Webb et al. (2015)
	(–) / –	3 km	Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	– / –		Egmond aan Zee / Princess Amalia	Leopold et al. (2011, 2013)
	0		Thanet	Percival (2013)
	(–)		Robin Rigg	Walls et al. (2013)
	0		Kentish Flats	Gill et al. (2008)
	(–)		Horns Rev I	Petersen et al. (2006)
Little gulls (*Hydrocoloeus minutus*)	–	1.5 km	Alpha ventus	Present study
	0		Lincs	Webb et al. (2015)
	(+) / (–)		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	– / –		Egmond aan Zee / Princess Amalia	Leopold et al. (2011, 2013)
	–		Horns Rev I	Petersen & Fox (2007)
	0		Horns Rev I	Petersen et al. (2006)
Common gulls (*Larus canus*)	0		Alpha ventus	Present study
	(–) / 0		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	0 / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2011, 2013)
	0		Thanet	Percival (2013)
Lesser black-backed gulls (*Larus fuscus*)	+		Alpha ventus	Present study
	0		Lincs	Webb et al. (2015)
	0 / +		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	– / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2013)
	0		Thanet	Percival (2013)
	0		Kentish Flats	Gill et al. (2008)
Herring gulls (*Larus argentatus*)	0		Alpha ventus	Present study
	0 / +		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	0 / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2013)
	0		Thanet	Percival (2013)
	(+) / 0		Horns Rev I / Nysted	Petersen et al. (2006)
Great black-backed gulls (*Larus marinus*)	+		Alpha ventus	Present study
	+ / 0		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	0 / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2013)
	0		Thanet	Percival (2013)
	0		Kentish Flats	Gill et al. (2008)
Kittiwakes (*Rissa tridactyla*)	(–)		Alpha ventus	Present study
	– / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2013)
	0 / 0		Thorntonbank / Bligh Bank	Vanermen et al. (2013, 2015)
	0		Thanet	Percival (2013)
	0		Robin Rigg	Walls et al. (2013)

[a] No statistical effect outside wind farm, 1 km suggested by author; [b] Statistical effect up to 13 km — authors suggest effect up to 5–6 km;



	Response	Estimated response distance	Offshore wind farm	Reference
Terns	–	1.5 km	Alpha ventus	Present study
	0		Lincs	Webb et al. (2015)
	–[c] / 0		Egmond aan Zee / Princess Amalia	Leopold et al. (2013)
	+[d] / 0		Thorntonbank / Bligh Bank	Vanermen et al. (2011, 2013)
	0		Kentish Flats	Gill et al. (2008)
	(–)		Horns Rev I	Petersen et al. (2006)
Alcids	–	2.5 km	Alpha ventus	Present study
	–	4 km	Lincs	Webb et al. (2015)
	– / –[e]	3 km	Bligh Bank	Vanermen et al. (2015)
	– / –[e]		Egmond aan Zee / Princess Amalia	Leopold et al. (2011, 2013)
	(–)		Thanet	Percival (2013)
	(–)		Robin Rigg	Walls et al. (2013)
	0		Kentish Flats	Gill et al. (2008)
	0		Thorntonbank	Vanermen et al. (2013)
	–	2 km	Horns Rev I	Petersen et al. (2006), Petersen & Fox (2007)

[c] Effect found for common/arctic terns; [d] Effect found for common and sandwich terns; [e] Significant negative effect in common guillemots and razorbills

5.6.5 Mediterranean marine avifauna

One of the main characteristics of the Mediterranean marine avifauna is the high number of endemic taxa, despite the low diversity and small population densities. This is consistent with a low productivity ecosystem compared to open oceans (COLL et al. 2010).

Our knowledge on the vulnerability of seabirds to impacts from OWFs stems almost exclusively from species of the North and Baltic Sea. The sensitivity of Mediterranean seabirds, particularly endemic species, is unknown. Sensitivity indices published by the European Commission Document „EU Guidance on wind energy development in accordance with the EU nature legislation“ (EUROPEAN COMMISSION 2010) also include Mediterranean species but they are outdated as most of the information on windfarm impacts comes from more recent studies.

In the following Table 5.5 the seabird species present in Mediterranean (according to the Birdlife International official site) are shown as well as Global, European and EU Red list status and Annex category according to EU Birds Directive 2009/147/EC. Furthermore an indicative percentage of the global population of each species situated in Europe is also shown (BIRDLIFE INTERNATIONAL 2004). The sensitivity of Mediterranean seabird species to the different impact factors of OWFs has been inferred from similar species in the North and Baltic Sea for which information is available. It is important to note that this only gives a first indication of the possible risk for these species and cannot substitute the collection of the relevant data.

Table 5.5 Seabird species present in Mediterranean with Global, European and EU27 IUCN Red list status, Annex I category according to EU Birds Directive 2009/147/EC, the updated list of endangered or threatened species found in the Mediterranean established under the Specially Protected Areas and Biological Diversity Protocol (SPA/BD Protocol) of the Barcelona Convention, and indicative percentage of the global population of each species situated in Europe25. Bird species considered to be particularly vulnerable to windfarms. XXX = Evidence on substantial risk of impact, XX = Evidence or indications of risk or impact, X = Potential risk or impact, x = small or non-significant risk or impact, but still to be considered in assessments. This is an indicative list for guidance, and any potential impacts will be site-specific (source[7]).

Scientific name	English name	IUCN Red List Category			SPA/ BD Protocol	Birds Directive	% Global population in EU25 (breeding)	Habitat displacement	Collision	Barrier effect	Potential positive impact
		Global	Europe	EU 27		Annex I					
Alcidae (Auks)											
Fratercula arctica	Atlantic Puffin	VU	EN	NT		-	5-24	X	x	x	
Anatidae (Ducks, Geese, Swans)											
Aythya marila	Greater Scaup	LC	VU	VU		-	<5	X	X	x	
Bucephala clangula	Common Goldeneye	LC	LC	LC		-	25-49	X	X	x	
Melanitta fusca	Velvet Scoter	VU	VU	VU		-	<5	XX	X	x	
Mergus merganser	Goosander	LC	LC	LC		-	5-24	x	X	x	
Mergus serrator	Red-breasted Merganser	LC	NT	VU		-	25-49	x	X	x	x
Somateria mollissima	Common Eider	NT	VU	EN		-	25-49	X	X	x	
Gaviidae (Divers)											
Gavia arctica	Arctic Diver	LC	LC	LC		I	5-24	XXX	X	X	
Gavia stellata	Red-throated Diver	LC	LC	LC		I	<5	XXX	X	X	
Hydrobatidae (Northern Storm-petrels)											
Hydrobates pelagicus	European Storm-petrel	LC	LC	LC	X	I	25-49	X	x	X	
Laridae (Gulls, Terns, Skimmers)											
Chlidonias niger	Black Tern	LC	LC	LC		I	5-24	X	X	x	
Gelochelidon nilotica	Gull-billed Tern	LC	LC	LC	X	I	5-24	X	X	x	
Hydrocoloeus minutus	Little Gull	LC	NT	LC		I	5-24	XX	x	x	
Hydroprogne caspia	Caspian Tern	LC	LC	NT	X	I	<5	X	X	x	
Larus armenicus	Armenian Gull	NT	NT	NE	X	-	Unknown	x	XX	x	
Larus audouinii	**Audouin's Gull**	**LC**	**LC**	**LC**	**X**	**I**	**>95**	x	XX	x	
Larus cachinnans	Caspian Gull	LC	LC	LC		-	25-49	x	XX	x	

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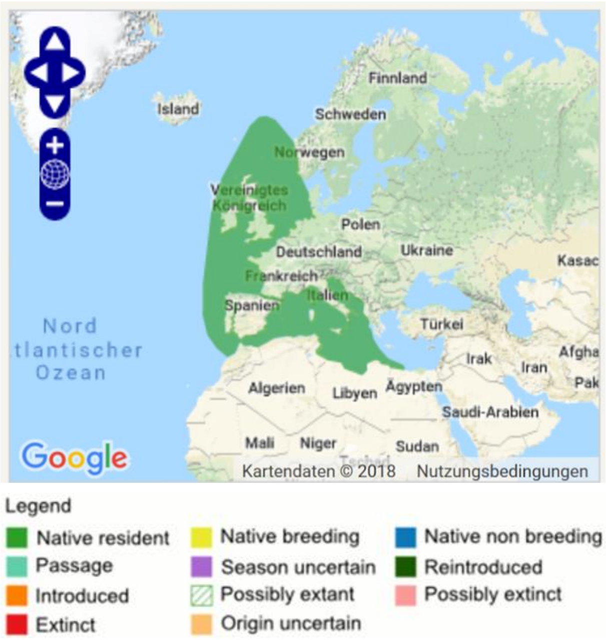
[7] http://datazone.birdlife.org/country; http://datazone.birdlife.org/info/euroredlist; *https://maps.birdlife.org/marineIBAs/default.html*, http://web.unep.org/unepmap/ten-seabirds-added-mediterranean-list-endangered-or-threatened-species

Scientific name	English name	IUCN Red List Category			SPA/ BD Protocol	Birds Directive	% Global population in EU25 (breeding)	Habitat displacement	Collision	Barrier effect	Potential positive impact
		Global	Europe	EU 27		Annex I					
Larus canus	Mew Gull	LC	LC	LC		-	25-49	x	XX	x	
Larus fuscus	Lesser Black-backed Gull	LC	LC	LC		-	50-74	x	XX	x	
Larus genei	Slender-billed Gull	LC	LC	LC	X	I	5-24	x	XX	x	
Larus melanocephalus	Mediterranean Gull	LC	LC	LC	X	I	<5	x	XX	x	
Larus michahellis	Yellow-legged Gull	LC	LC	LC		-	Unknown	x	XX	x	
Larus ridibundus	Black-headed Gull	LC	LC	LC		-	25-49	x	XX	x	
Rissa tridactyla	Black-legged Kittiwake	VU	VU	EN		-	5-24	x	XX	x	
Sterna hirundo	Common Tern	LC	LC	LC		I	5-24	X	X	x	
Sternula albifrons	Little Tern	LC	LC	LC	X	I	5-24	X	X	x	
Thalasseus bengalensis	Lesser Crested Tern	LC			X	-	<5	X	X	x	
Thalasseus sandvicensis	Sandwich Tern	LC	LC	LC	X	I	25-49	XX	X	x	
Pelecanidae (Pelicans)											
Pelecanus crispus	Dalmatian Pelican	NT	LC	LC	X	I	5-24	x	X	x	
Pelecanus onocrotalus	Great White Pelican	LC	LC	LC	X	I	<5	x	X	x	
Phalacrocoracidae (Cormorants)											
Microcarbo pygmaeus	Pygmy Cormorant	LC	LC	LC	X	I	5-24	x	X	x	
Phalacrocorax aristotelis desmarestii	**European Shag**	**LC**	**LC**	**NT**	**X**	**I**	**50-74**	x	X	x	X
Phalacrocorax carbo	Great Cormorant	LC	LC	LC		-	25-49	x	X	x	X
Podicipedidae (Grebes)											
Podiceps auritus	Horned Grebe	VU	NT	VU		I	<5	XX	X	x	
Podiceps cristatus	Great Crested Grebe	LC	LC	LC		-	25-49	XX	X	x	
Procellariidae (Petrels, Shearwaters)											
Calonectris borealis	Cory's Shearwater	LC	LC	LC		-	Unknown	XX	x	X	
Calonectris diomedea	**Scopoli's Shearwater**	**LC**	**LC**	**LC**	**X**	**I**	**75-94**	XX	x	X	
Puffinus mauretanicus	**Balearic Shearwater**	**CR**	**CR**	**CR**	**X**	**I**	**100**	XX	x	X	
Puffinus puffinus	**Manx Shearwater**	**LC**	**LC**	**LC**		**-**	**75-94**	XX	x	X	
Puffinus yelkouan	**Yelkouan Shearwater**	**VU**	**LC**	**LC**	**X**	**I**	**75-94**	XX	x	X	
Stercorariidae (Skuas)											
Catharacta skua	Great Skua	LC	LC	LC		-	50-74	X	x	x	
Stercorarius parasiticus	Arctic Jaeger	LC	LC	EN		-	<5	X	x	x	
Sulidae (Gannets, Boobies)											
Morus bassanus	**Northern Gannet**	**LC**	**LC**	**LC**		**-**	**75-94**	XXX	XX	X	
Charadriidae (Plovers)											

Scientific name	**English name**	**IUCN Red List Category**			**SPA/ BD Protocol**	**Birds Directive**	**% Global population in EU25 (breeding)**	**Habitat displacement**	**Collision**	**Barrier effect**	**Potential positive impact**
		Global	**Europe**	**EU 27**		**Annex I**					
Charadrius alexandrinus	Kentish Plover	LC	LC	LC	X	I	5-24	x	x	x	
Charadrius leschenaultii ssp. columbinus	Greater Sand Plover	LC	VU	CR	X	-	Unknown	x	x	x	
Kingfishers (Alcedinidae)											
Ceryle rudis	Pied Kingfisher	LC	EN	NE	X	-	**<5**	x	x	x	
Halcyon smyrnensis	White-breasted Kingfisher	LC	VU	NE	X	-	Unknown	x	x	x	
Flamingos (Phoenicopteridae)											
Phoenicopterus roseus	Greater Flamingo	LC	LC	LC	X	I	5-24	x	X	x	
Sandpipers (Scolopacidae)											
Numenius tenuirostris	Slender-billed Curlew	CR	CR (PE)	CR (PE)	X	I	-	x	X	x	
Birds of prey (Pandionidae)											
Pandion haliaetus	Osprey	LC	LC	LC	X	I	<5	x	X	x	
Birds of prey - Falcons (Falconidae)											
Falco eleonorae	**Eleonora's Falcon**	**LC**	**LC**	**LC**	**X**	**I**	**75-94**	X	X	X	

Additional information regarding seabird species presented in Table 5.5 whose large part of their global breeding population is situated within the Mediterranean are listed below.

Balearic shearwater (*Puffinus mauretanicus*)[8]



Ecology: The Balearic shearwater breeds in caves, burrows and crevices on islets and coastal cliffs in the Balearic Islands. Breeding colonies are relatively small, from isolated nests to loose aggregations of 10s or even a few hundreds of breeding pairs. The species is very philopatric, as is the rule with Procellariiformes. The nesting colonies of Puffinus mauretanicus are situated in caves and cliff cavities.

Adults do not commence breeding until their third year at the earliest, although most breeding recruitment tends to occur between 4 and 6 years. Birds lay eggs in early-mid March (exceptionally late February); hatching occurs in late April-early May; and adults leave the colonies around late June, a few days before the chicks fledge (early July).

Pelagic prey (especially small pelagic fish) seem to be the main prey for the species, but it also makes extensive use of discards both in the Mediterranean and when in the Atlantic, and can also feed on planktonic organisms. The species has been recorded diving to more than 35m. At sea, it has a rather coastal distribution, and tends to select productive shelf areas most often related to oceanographic frontal systems. During breeding, they tend to forage over the closest productive grounds to their breeding colonies coinciding with favourable winds during the outward stages of foraging trips, but some individuals also head to productive areas at the extreme of their distribution, assisted by optimal winds during short time windows. These productive waters are rich in small pelagic, where different types of fishing activity also co-occur and can provide substantial amounts of discards to shearwaters. The species appears to be more coastal during the non-breeding period, forming large aggregations that vary in location between (and within) years, presumably due to fluctuations in the availability of schools of small pelagic fish.

Fishing discards influence aspects of their ecology such as trophic and movement ecology. Fishing discards have also positive and negative impacts on life history traits such as breeding performance and survival, respectively. Regarding mortality in fisheries, a notable finding has been the increase of bycatch probability on longlines in the absence of trawling and purse-seining activity, in addition to other factors such as the annual cycle and the time of setting the fishing gear.

Population and distribution: The species breeds exclusively in the Balearic Islands, Spain, occupying the five major island groups: Menorca, Mallorca, Cabrera, Ibiza and Formentera. During the breeding period (late February - early July) the main foraging areas are located along the Mediterranean shelf of the Iberian Peninsula, mainly around the central Catalan coast, the Ebro Delta-Columbretes area and the Cape Nao, potentially exploiting the closest productive areas with respect to their breeding colonies. Some birds also exploit foraging grounds at the extreme of their

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[8] BirdLife International (2018) Species factsheet: Puffinus mauretanicus. Downloaded from http://www.birdlife.org on 19/11/2018.

distribution in the continental shelf off Algeria and Morocco as well as in the Gulf of Lions, in addition to the waters around the Balearic archipelago. The bulk of the population leaves the Mediterranean after breeding, and concentrates off the Atlantic coasts of SW Europe in summer-autumn, mainly in Spain, Portugal and France, and also SW UK and NW Morocco. Birds return to the western Mediterranean in autumn (mainly October), and spend the winter months roughly in the same foraging areas used during the breeding.

Global population based on a sea research (2014) was estimated to 25,000 individuals, suggesting that the breeding population could be larger than previously assumed (estimated breeding population size of about 7,200 pairs). The species is highly gregarious so sometimes a significant proportion of the global population is concentrated in a single flock.

This species has a small breeding range and a relatively small population which is undergoing an extremely rapid decline, largely related to low adult (and immature) survival rates. Main threats are fisheries by-catch at sea and predation at breeding colonies by introduced mammals, factors that would explain the added mortality of the species. Population models predict over 90% decline in three generations with an average extinction time of about 60 years, hence qualifying the species as Critically Endangered.

Yelkouan shearwater (*Puffinus yelkouan*)[9]

The Yelkouan shearwater is a medium-size procellarid strictly endemic to the Mediterranean Basin (including the Black Sea).

Ecology: It breeds in burrows, rocky cavities or big caves on rocky coastal and offshore islets, and on steep, inaccessible cliffs on the mainland. In the non-breeding season it disperses widely within the Mediterranean and Black Seas, often congregating in large flocks.

Population and distribution: Its precise distribution is not well known and numbers are disputed. The main breeding colonies are concentrated in the central and eastern Mediterranean. The species is known to breed in France (627-1044), Italy (9,000-20,000 pairs), Malta (1,370-2,000 pairs), Algeria (8-10 pairs), Tunisia (176-200 pairs), Croatia (300-500 pairs), Albania (1-10 pairs), Greece (4,000-7,000 pairs) and Bulgaria (0-10 pairs) giving a global estimate of 19,400-31,200 pairs according to BirdLife International (2015). Breeding is assumed in Turkey on offshore islands or mainland cliffs in the Aegean and Mediterranean, but so far no colonies have been identified.

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[9] BirdLife International (2018) Species factsheet: Puffinus yelkouan. Downloaded from http://www.birdlife.org on 19/11/2018.

Population trends in Albania, Algeria, Bulgaria, Greece, Tunisia, Croatia, France and Turkey are currently unknown. The population has been estimated to be declining rapidly in Italy, however trends reported for the European Red List of Birds suggest the population may be increasing. Declines have previously been reported for France and Malta. Nine colonies have gone extinct over the last 60 years and since 2009, one breeding colony off Sardinia (San Pietro Island) has been reported as absent, possibly extinct and no breeding has been recorded anymore in Corsica. Breeding success at many colonies appears to be extremely low and adult survival probabilities across the western Mediterranean have been reported as too low to maintain stable populations.

This species is precautionarily maintained as Vulnerable. Existing demographic studies of populations in France and Malta indicate a population decline, caused by low breeding success due to predation by introduced mammals and low adult survival owing to fisheries bycatch and predation.

The Gulf of Lion and the waters of the Calanques National park are regular feeding areas for the puffins and they regularly frequent areas technicaly appropriate for development of OWFs in France. In addition, the populations of the Gulf of Lion are considered vulnerable because they are already under heavy pressure (particularly by accidental catch in fishing gear). The priority issue for Puffins in this area is to protect breeding adults (individuals aged 5 or over) from any additional mortality (AGENCE FRANÇAISE POUR LA BIODIVERSITÉ 2018).

Audouin's gull (*Larus audouinii*)[10]

Audouin's Gull is a gull species endemic of the Mediterranean, easily identified by its scarlet red bill and greyish-black legs.

Ecology: Colonies are located on exposed rocky cliffs and on offshore islands or islets, normally not more than 50 m above sea level. The Ebro delta colony is located on saltmarsh and a sandy peninsula. In the Aegean it breeds on uninhabited islands sloping gently to the sea. Medium vegetation cover is preferred, and this probably provides chicks with shelter from heat and predators. During the non-breeding season the species prefers sheltered bays.

It is a coastal species, rarely occurring inland and generally not travelling far offshore, it feeds regularly along the coast. The diet consists mostly of epipelagic fish, and of commercial fishing. Diet during the breeding season has been found to vary between colonies due to fishing practices that target different species in the respective areas.

During the non-breeding season generally <40 km from the colony seems to be the norm (maximum recorded foraging range from a colony was 160 km). The species primarily forages

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[10] BirdLife International (2018) Species factsheet: *Larus audouinii*. Downloaded from http://www.birdlife.org on 19/11/2018.

in coastal and continental shelf areas between 5 and 15 nautical miles (NM) offshore. Juveniles tend to forage in upwelling zones, whereas subadults and adults are more independent of these sites.

It is partially migratory and dispersive. It breeds in large monospecific colonies ranging from 10 up to 10,000 pairs at a density of up to one nest/ m^2. Egg-laying takes place in the second half of April until the beginning of May, and peak hatching occurs in late May, with fledging mainly in the first two weeks of July. It has a large foraging range while breeding, and has been recorded up to 200 km from the colony. After breeding the birds disperse widely around the Mediterranean coast. Almost all juveniles and some adults migrate past Gibraltar during July-October, peaking in to winter on the North African coast. During the winter it roosts in flocks of several thousand. It returns to its breeding sites between late February and mid-April.

Very high colony-site fidelity is probably related to previous breeding success. However, in the Aegean Islands, birds return to the same island group but not necessarily to the same islet. At the Ebro Delta, Spain, c. 1.400 breeders disperse to other colonies every year, generating marked fluctuations at those sites. The Audouin's Gull is one of the few species of Larid to show nocturnal foraging patterns, which may be linked to fisheries activities, arrivals and departures from the Ebro Delta colony are in accordance with the trawling timetable. The species scavenges around fishing vessels, and uses discards extensively and very efficiently. The species's association with fisheries is more pronounced in the western than in the central and eastern Mediterranean and the trawler moratorium off the Ebro Delta established in 1991 reduced food availability to birds and impacted breeding success, possibly by increasing foraging ranges.

Distribution and Population: This species breeds in (all data for pairs) Spain (19.461), mainly the Chafarinas Islands and the Ebro Delta, Algeria (100-600), Greece (350-500), and Sardinia and Tuscan Archipelago, Italy (1.153-1.286), with smaller colonies in Portugal (400-460), Corsica, France (82), Cyprus (14-28), islets and rocks in the southern Adriatic Sea near Korcula and Peljesac Peninsula, Croatia (60-70), Turkey (47-90), Tunisia (70-115) and Morocco (50-300). It winters on the coast of North and West Africa from Libya west to Morocco and south to Mauritania, Gambia, Senegal and Gabon and there is a small wintering population in the east Mediterranean along the Aegean coast of Turkey.

The global population has been estimated at 21.161 pairs (2008) and an assessment estimated the European population (encompassing over 90% of the global population) to be stable or increasing throughout. This represents a significant increase from an estimated population of 1.000 pairs in 1975 and is thought to be a result of the increased availability mainly of effectively protected areas during the 1980s, and secondly of discarded fish from the trawlers, particularly around the Ebro Delta where the colony has grown rapidly since 1981. The large expansion of this species in the western Mediterranean has probably caused the breeding population in other parts of the Mediterranean to increase and new colonies have been found in Croatia and even out of the Mediterranean in southern Portugal. Nevertheless more than 90% of the European breeding population occurs at just four sites and only a single site (the Ebro Delta) held 67% of the global breeding numbers in 2007. Recruitment can be extremely rapid when food availability is high, resulting in high population growth rates. It is a long-lived species with high adult survival and relatively low fertility. Adult annual survival is estimated at 0,95.

Cory's shearwater (*Calonectris diomedea*)[11] [12]

Cory's shearwater is the largest Procellariiform species in the Mediterranean Sea. The Mediterranean race *C. d. diomedea* is endemic and is currently declining over the whole range.

Ecology: Pelagic movements include frequent foraging trips around the breeding areas, rapid, long-distance migrations, and smaller-scale movements within a well-defined wintering ground. Cory's shearwaters make the longest foraging trips of all Mediterranean seabirds, and birds from distant breeding colonies often converge spatially.

Breeding starts in April on barren offshore islands, occupying cliffs, caves and boulder fields. The Cory's shearwater is a long-distance migrant that leaves the Mediterranean to spend the non-breeding season in Atlantic waters off Africa and South America. It is present in the Mediterranean between March and October. There, it favours areas of wide continental shelf and the areas of influence of large rivers, where productivity is highest. It regularly attends trawlers and longlining vessels, and is the species suffering the heaviest mortality toll. In the Mediterranean, Cory's shearwater feeds on medium-sized to small fish (regularly, sardine and anchovy), alone or in association with tuna and cetaceans. Squid is also an important component of its diet. Fishing discards, a predictable source of food, have become a growing foraging option for Cory's shearwaters in the Mediterranean after the population decline of tuna and cetaceans, and the reduced availability of natural prey caused by overfishing. This increases the dependence of shearwaters on human activities, as the birds become attracted to fishing vessels, and modifies their foraging behaviour.

Population and distribution: This species breeds in Algeria, Croatia, France, Greece, Italy, Malta, Spain (excluding the Canary Islands), Tunisia and Turkey. The majority of the population spends the non-breeding season in the Atlantic, including areas off the west coast of Africa and east coast of Brazil. The most recent assessment of the European population provided an estimate of 30.500-48.100 pairs and he overall population has been estimated at 142.478-222.886 pairs.

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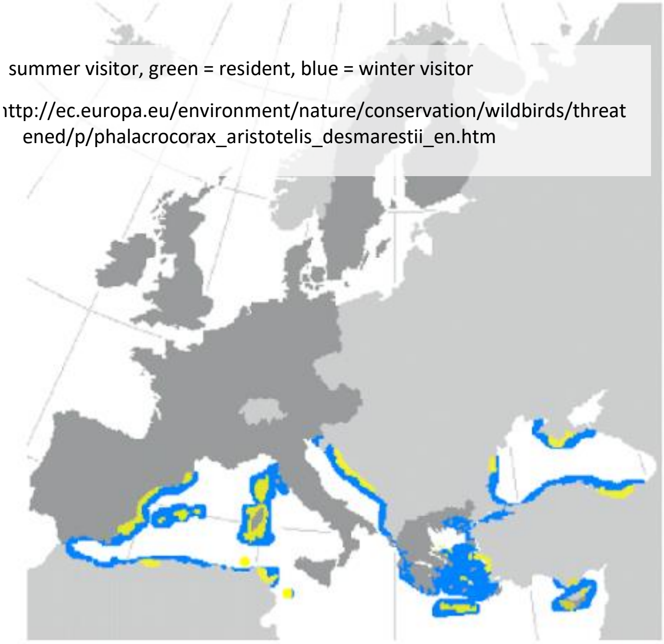
[11] BirdLife International (2018) Species factsheet: Calonectris diomedea. Downloaded from http://www.birdlife.org on 19/11/2018.

[12] UNEP-MAP-RAC/SPA. 2013. Seabirds in the Gulf of Lions shelf and slope area. By Carboneras, C.Ed. RAC/SPA, Tunis. 26pp.

Mediterranean shag (*Phalacrocorax aristotelis desmarestii*)

The Mediterranean Shag is the Mediterranean subspecies of the European Shag (*Phalacrocorax aristotelis*) which is endemic to the Mediterranean Basin and the Black Sea and is a flagship species for Mediterranean seabird conservation.

Ecology: In islands and rocky coasts. Shags breed colonially, forming small, loose (rarely dense) colonies, on cliff ledges or small caves or even under thick vegetation. Nesting sites are re-used in successive years by the same birds. They often roost in large groups. Accomplished swimmers and foot-propelled divers, shags feed on benthic and pelagic fish in waters which are usually located within a 20 km radius around their colony or roosting sites. The Shag feeds by diving underwater for fish (mostly, non-commercial species), it selects shallow waters (generally <80 m deep) and shows a preference for foraging over Posidonia seabeds. The species therefore remains mostly in coastal waters and does not venture far offshore[13].



summer visitor, green = resident, blue = winter visitor

http://ec.europa.eu/environment/nature/conservation/wildbirds/threatened/p/phalacrocorax_aristotelis_desmarestii_en.htm

Distribution and Population: The subspecies is endemic to the Mediterranean basin. The total population was estimated to be less than 10.000 pairs, half of them breeding in the EU (Eastern coast of Spain, Baleares, Corsica, Sardinia, Tuscany archipelago, Lampedusa, Crete and islets of the Ionian Sea). Very significant fluctuations in breeding numbers have been noted from year to year in several different Mediterranean colonies[14].

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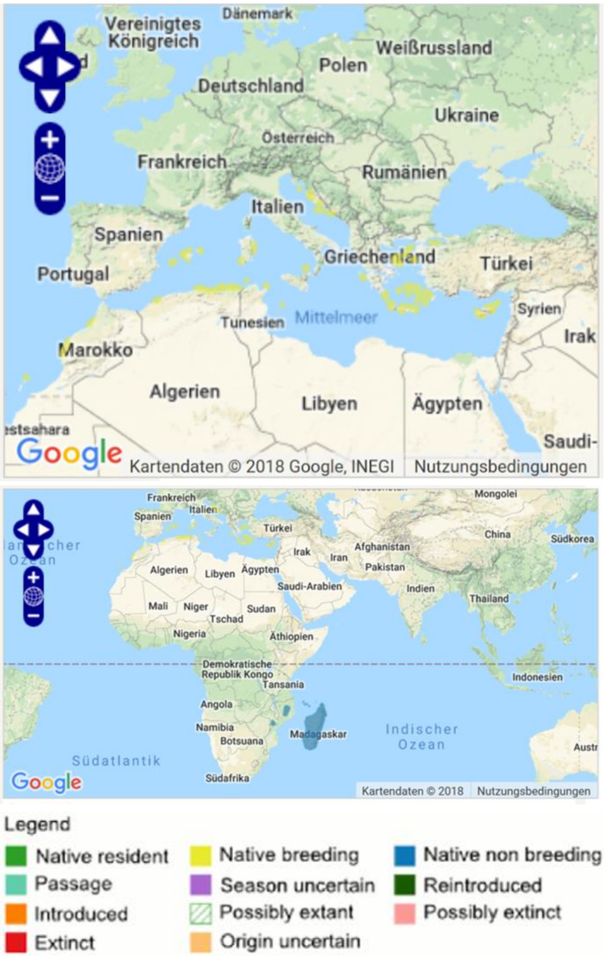
[13] Fric, J., Portolou, D., Manolopoulos, A. and T. Kastritis (2012). Important Areas for Seabirds in Greece. LIFE07 NAT/GR/000285 - Hellenic Ornithological Society (HOS / BirdLife Greece), Athens.

[14] BIRDLIFE INTERNATIONAL (1999): Species Action Plan for the Mediterranean Shag Phalacrocorax aristotelis desmarestii in Europe.

Eleonora's Falcon (Falco eleonorae)[15]



Amongst coastal bird species **Eleonora's Falcon (*Falco eleonorae*)** is also of great importance since more than 85% of its global population breeds in Greece and because of its foraging behaviour during the fledging season in autumn, where they prey on migrating birds approaching islands while traveling overseas (DIMALEXIS ET AL, 2007).

Ecology: The species is fully migratory, leaving its Mediterranean breeding grounds in October and November to winter in Madagascar, East Africa and the Mascarene Islands. The return journey begins in late April and May. Birds are known to fly as high as 1,000 m during the breeding season. They are generally gregarious (though sometimes solitary), tending to move in small and loose flocks at high altitudes.

Birds usually breed and stop over on small islands and islets, wintering mainly in open woodland on Madagascar. It feeds on large flying insects and small birds. Birds nest in the holes and ledges of sea cliffs, or on the ground preferably on isolated islets. The species appears to require very peaceful or uninhabited islands on which to breed, with direct exploitation and development both shown to be negative consequences of close proximity to people.

Population and distribution: In Europe (which covers >95% of the breeding range), the population is estimated at 14,300-14,500 pairs, which equates to 28,700-29,100 mature individuals. The North African population is estimated at approximately 250 pairs or 500 mature individuals. Therefore the overall population is estimated at 29,200-29,600 mature individuals. In Europe, which holds a large proportion of the global population, the population size is estimated to be increasing.

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[15] BirdLife International (2018) Species factsheet: Falco eleonorae. Downloaded from http://www.birdlife.org on 19/11/2018

Conclusion

The most important effects of offshore wind farming on birds are displacement of waterbirds and the collision risk of all birds flying over sea - on migration or other activities such as foraging - and thereby enter the windfarms. Although these effects have been observed through obvious shifts in bird distribution patterns and the bird collision incident at the research offshore Platform FINO) a quantified estimation for the long-term effects on various bird populations remains to be investigated.

In general, the effects of offshore windfarms on avifauna impacts are expected to be similar for the Mediterranean species as well, but the actual magnitude of these effects depend strongly on the site specific parameters like the marine area selected for the OWF, the composition of avifauna communities, the windfarm characteristics, the habitat use patterns, availability of similar habitats, the abundance of populations etc. From northern countries, where offshore wind farming is already more advanced, few information are available which can be used to assess possible impacts on some endemic Mediterranean species such as Balearic Shearwater and breeding migratory species Eleonora’s falcon and it is recommended to study the behaviour of these species in relation to offshore wind farming in detail as the development progresses. Site specific surveys are necessary integrating high standard monitoring techniques before, during and after construction of the windfarms and for sufficient periods.

5.7 Impacts on marine mammals

The most relevant impacts on marine mammals result from underwater noise emitted during the construction process, especially pile driving, which has received much attention over the last years. Further impacts result from habitat alterations and maintenance of the turbines and various other small-scaled impacts (Figure 5.13).

In the following chapter, emphasis is laid on the effects of noise and other impacts, as judged to be less important, are only briefly covered. Most of the current knowledge about offshore windfarms and cetaceans origins from studies on the harbour porpoise (*Phocoena phocoena*) a very abundant species in the North Sea and the Baltic Sea.

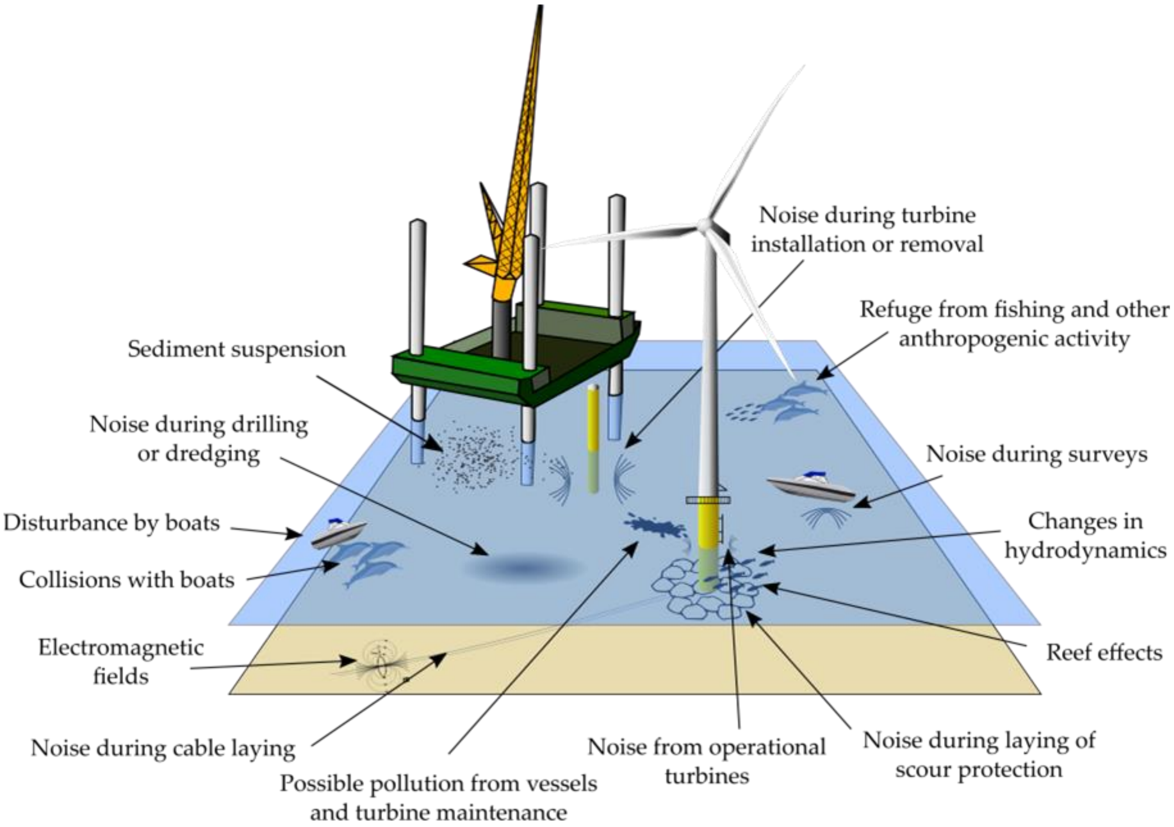


Figure 5.13 Effects that may influence marine mammals during the life of a windfarm (PERROW 2019)

5.7.1 Effects of noise on marine mammals

Since vast areas of the ocean are limited in light, marine mammals rely primarily on their acoustic sense to use sound for foraging, communication, social interaction and navigation. Both sounds being of natural or anthropogenic origin add significantly to ambient noise levels. Interference with detection of natural sounds has the ability to impact marine mammals to a certain degree. Anthropogenic noise may evoke behavioural reactions and communication alterations and at high levels even cause hearing damage. The ecological and life history traits of marine mammals (e.g. long lifespan, low reproductive potential, small population sizes, late maturity) makes them a vulnerable species group to noise against anthropogenic impacts. Figure 5.14 sketches the effects of noise and its ranges from the sound source having the strongest impact close to the sound source with injury diminishing with range due to propagations losses.

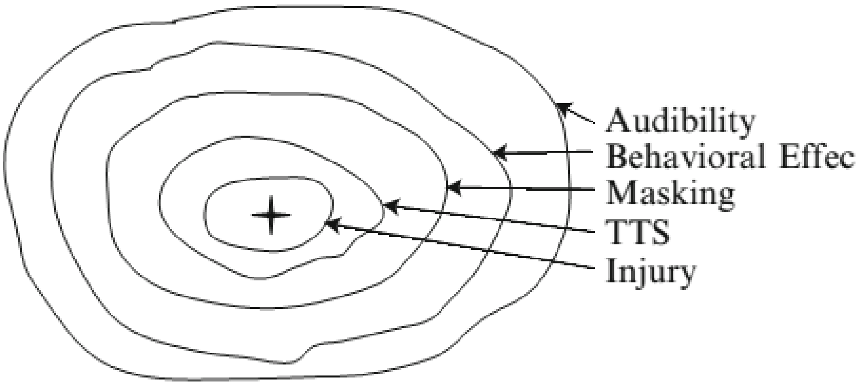


Figure 5.14 *Potential zones around the noise source divided in impact zones* (POPPER & HAWKINS 2012)

- **Audibility** - Audibility of a sound is limited by the sound dropping below either ambient noise levels or the animal's detection threshold.

- **Behavioural effects** – substantial change in behaviour for the animals exposed to anthropogenic noise. Reactions are situation-specific. Indicators of 'disturbance' include changes in swim direction and speed, dive duration, surfacing duration and interval, respiration (blow rate), movement towards or away from the noise, and changes in contextual and acoustic behaviour etc. Whether an animal reacts to a sound it hears depends on a number of factors including prior exposure (habituation vs. sensitization), current behavioural state, age, gender and health.

- **Masking** – Sounds which coincide with hearing ranges of marine mammals have the potential to mask important signals and reduce the distance over which individuals can communicate. The potential for masking is reduced by good frequency discrimination, temporal discrimination, and directional hearing abilities of the animal. Noise can mask signals such as communication sounds, echolocation, predator and prey sounds, and environmental sounds.

- **Auditory threshold shifts** – Noise exposure can result in a loss of hearing sensitivity, termed threshold shift. If hearing returns to normal after some quiet time, the effect is a temporary threshold shift (TTS); if the threshold stays shifted, it is a permanent threshold shift (PTS). TTS is considered auditory fatigue, whereas PTS is considered as injury - also in the legal context of the legal requirements for strictly protected species.
    - TTS: At some level and duration, sound can cause hair cells of the inner ear to fatigue, yielding an increase in auditory threshold. The amount of TTS depends on the noise level, rise time, duration, duty cycle, spectral characteristics etc. After some quiet time (minutes – days), hearing returns to normal. TTS has been measured in a few individual marine mammals.
    - PTS occurs when hearing does not fully return to normal after noise exposure and is considered an auditory injury. Noise-induced PTS has not been measured in marine mammals.

- **Mortality and mortal injury** – immediate or delayed death (e.g. strandings).

Marine mammal hearing

Sounds are processed within listeners' auditory systems, which vary in structure and function across marine mammal species (ERBE et al. 2016). Audiograms show the hearing threshold as a function of frequency. Audiograms are used to estimate whether an animal will be able to hear a given sound based on the hearing capabilities of the species. The audiogram is composed of a series of detection thresholds for narrowband signals obtained across a range of sound frequencies being depicted as a continuous sensitivity curve. Figure 5.15 assembles marine mammal audiograms grouped in families and interpolated for the center frequencies of 1/3 octave bands between 40 Hz and 200 kHz. Within each family, the lowest threshold of all species and individuals was plotted at each frequency. Marine mammal audiograms exhibit a characteristic U-shape, with a frequency region of best sensitivity that rolls off at distal frequencies, both lower and higher.

There are no underwater audiograms of sperm whales and baleen whales available. It is expected that their frequencies of best sensitivity overlap to some degree with the frequencies of their calls. Other indicators for what these animals can hear come from controlled exposure experiments looking for responses of animals to sound. Anatomical studies of baleen ears have suggested good hearing sensitivity between 10 Hz and 30 kHz. At the low-frequency end, sound detection by baleen whales might often be ambient noise limited rather than audiogram limited (Popper & Hawkins 2012).

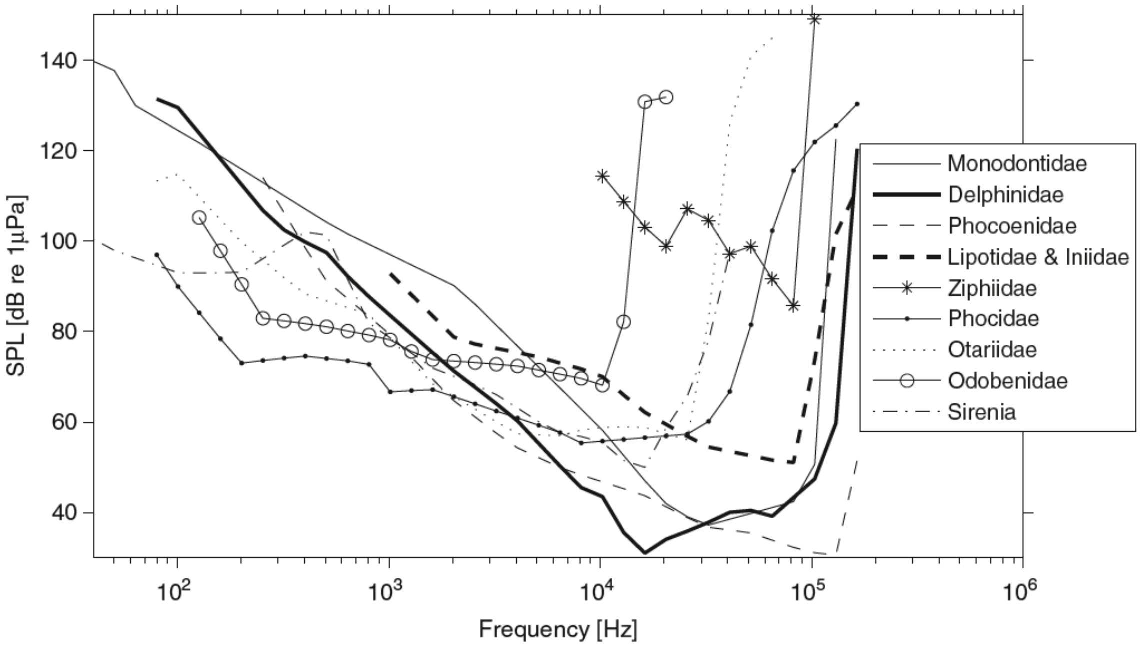


Figure 5.15 The audiogram of 9 marine mammal families (Popper & Hawkins 2012)

5.7.2 Effects of anthropogenic sounds on marine mammals

Noise is affecting marine mammals in different ways, depending on the marine mammals' conditions such as age, size, behavioural state, auditory capabilities. It is also dependent on the acoustic characteristics of the noise source regarding the noise level, duration, duty cycle, rise time, spectrum and the attributes of the bathymetry and the hydro- and geoacoustic parameters (Popper & Hawkins 2012). The (quantified) impacts described in this chapter refer to the construction of fixed foundations requiring pile driving. Knowledge on noise production of the construction and operating of floating turbines and the impact of it is still lacking as this technique is fairly recent.

Sources and dimensions of noise in OWF during construction phase

Offshore turbines are placed on a variety of foundations and their noise emissions differ accordingly. Until now monopiles, tripods or jacket foundations anchored in the seafloor by large steel piles have been the most widely used and it is these that generate significant noise. The size of turbines has also increased considerably from the first commercial large-scale windfarm Horns Rev 1 in 2002 employing 2 MW turbines, to the usual standard of 5 to 6 MW today. The first 8 MW turbines have now been installed and 10 MW turbines are expected in the near future. Foundation size has increased accordingly from a monopile diameter of 1 m in the first projects to 8 m in recent projects. Gravity base foundations and suctions buckets have now been installed in European windfarms and the development of floating foundations for use in deeper water is underway. These alternatives to monopiles have the important benefit of needing no or at least much reduced pile driving activity, thereby reducing the noise impact upon marine mammals and other marine fauna.

The construction of floating wind turbines requires no or reduced pile driving, hence, the noise emission during construction is assumed to be significantly reduced compared to pile driving for fixed foundations (Agence française pour la biodiversité 2018).

Noise immission from offshore pile driving are measured at standard distance of 750 m according to ISO 18406:2017 (Robinson & Theobald 2017). At 750 m, noise levels from large piles exceed values of 200 dB_{peak} and 180 dB_{SEL}.

Sources and dimensions of noise in OWF during operating phase

During operation, noise will be generated by maintenance activities and by the turbines themselves. Machinery noise is the main contributor to underwater noise, with vibrations transmitted from the nacelle to the foundations where they are radiated to the seabed and water. In contrast, airborne noise is almost completely reflected from the water surface. Turbine related noise will depend on the foundation type as well as on size and type of turbine but little information has been published on this so far. The operational noise immission from modern larger turbines does not exceed much (8-25 dB re 1µ Pa) above ambient noise (Degraer et al. 2016). Floating turbines may generate sound transmitted underwater by the floating platforms on the swell (transmission of vibrations in the water more relevant than for fixed foundations) and the interlocking of the chains of the anchoring systems (Agence française pour la biodiversité 2018). These noise sources remain to be quantified.

5.7.3 Impacts of noise in OWF during windfarm construction

Noise emission during OWF construction may lead to the following impacts on marine mammals:

Temporary hearing loss (BSH & BMU 2014) or permanent physical damage to their sensory system (Brandt et al. 2011; BSH & BMU 2014), so a loss of hearing sensitivity (Popper & Hawkins 2012).

Relating the noise exposure criteria to noise propagation modelling of offshore windfarm projects reveals that an onset hearing damage might be reached at distances of a few hundred metres for PTS and up to five kilometres for TTS (Brandt et al. 2014) from a single strike when large monopiles are driven into the seabed. It needs, however, to be taken into account that a full piling operation consists of a few thousand blows, thus cumulative exposures to the piling noise need to be considered. Under the assumption that harbour porpoises would remain stationary rather than moving away from a construction site a cumulative noise dose sufficient to cause PTS may be reached at distances of 5 – 10 km (Brandt et al. 2014). Harbour porpoise do, however, move away from loud noise sources and are usually deterred away from the vicinity of the constructions sites before start of piling. Taking uncertainties about swimming speed and direction into account, as well as uncertainties about noise propagation and possibly variable sensation levels (Nachtigall et al. 2016) it is currently not possible to accurately predict how many individuals receive noise levels inducing either form of hearing damage. An expert group formed to give advice to several Danish offshore windfarms concluded that the risk of hearing damage is considerably lower when taking soft-start of the piling operation, use of deterrents and porpoises fleeing from the noise source into account as compared to assessments assuming static exposures. However, the study could not rule out that pile driving will cause PTS to harbour porpoise without applying noise mitigation (Schack et al. 2015).

Studies of Bailey et al. (2010) detected noise levels produced by pile driving for OWF at a distance of 70 km above background noise, which could have been perceptible by marine mammals over the entire range. "Bottlenose dolphins and minke whales (and other mid- and low-frequency hearing cetaceans) may exhibit behavioural disturbance up to 50 km away. The measurements of piling noise indicate that any zones of auditory injury (PTS, and TTS) were likely to have been within a range of 100 m of the pile-driving operation, and such impacts should have been prevented by the use of MMOs (Marine Mammal Observers), who were there to ensure that there were no marine mammals within 1 km of the pile-driving." (BAILEY et al. 2010).

The sensitivity of seals against hearing impairments from underwater noise is considered to be much less as compared to cetaceans and in phocids such as harbour seal and grey seal the thresholds for the onset of TTS and PTS is estimated at 170 dB_{SEL} and 185 dB_{SEL} (M-weighted) respectively which is 30 dB higher as compared to High-frequency cetaceans (NMFS 2015). Such noise levels will only be recorded close to a piling operation. However, tracking of harbour seals and auditory modelling of HASTIE et al. (2015) predicted SELs resulting in high risks of auditory damage, with all seals predicted to potentially suffer TTS and 50% to gain PTS on a number of occasions, potentially influencing individual fitness and ability to function normally, with the prospect of population consequences.

Avoidance reaction leading to temporary habitat loss

Harbour porpoise and other marine mammals often respond aversively to anthropogenic noise with the response becoming stronger with increasing noise levels. Responses of marine mammals to anthropogenic noise sources are variable and not only depend on noise strength, but also on the characteristics of a noise source and the context of the disturbance (ELLISON et al. 2012). Although pile driving creates a relatively uniform noise, the different hearing abilities of marine mammals and likely different sensitivities means there is no uniform response of different species and cetaceans, specifically harbour porpoise, and seals are considered separately below.

Most knowledge on the response of cetaceans to pile driving originates from studies on harbour porpoise in the North Sea. The first offshore windfarms in Denmark and Germany caused rather large ranged effects on harbour porpoises. Reduced porpoise activity was recorded up to a distance of about 20 km during and shortly after piling (TOUGAARD et al. 2009; BRANDT et al. 2011; HAELTERS et al. 2012; DÄHNE et al. 2013; BIOCONSULT SH et al. 2014). This corresponds with the suggestion of BAILEY et al. (2010) that behavioural disturbance of Bottlenose Dolphins could similarly occur over large distances (up to 50 km) in relation to the pile-driving of two 5 MW turbines installed in the Moray Firth in northeast Scotland. However, the early projects involving harbour porpoise were constructed without noise mitigation and additional aspects of the construction work might have contributed to the strong response. For example, at 'Alpha Ventus' OWF in Germany, piles were first vibrated up to nine meters into the substrate before being piled with a hydraulic hammer, using between 11,383 and 25,208 strokes (lasting between 376 to 802 minutes) were required to install either three or four piles to a depth of 30 m.

In keeping with the results from other studies, BRANDT et al. (2011) found that porpoise acoustic activity fell by 100% in the hour after pile driving and did not return to normal for between 24 and 72 hours at a distance of 2.6 km from the site, with recovery time reducing with distance. An impact was detectable to 17.8 km from the site, but was not detectable at 22 km where activity increased. Up to around 5 km from the site, recovery times tended to exceed pauses in piling.

In a recent study, BIOCONSULT SH et al. (2016) investigated the response of harbour porpoises to pile driving during the construction of seven offshore windfarms in the German Bight of the North Sea. All projects applied noise mitigation measures but as these were still under development noise reduction was rather moderate. Non-parametric analyses revealed a clear gradient in how much porpoise detections declined at different noise level classes: Compared to a baseline period 25-48 h before piling, porpoise detections declined by over 90% at noise levels above 170 dB, but only by about 25% at noise levels between 145 and 150 dB_{SEL}. Below 145 dB this decline was smaller than 20% and may thus not clearly be related to noise emitted by the piling process. Effect duration after piling was about 20-31 h at the close vicinity of the construction site (up to 2 km) and decreased with increasing distance. Project-specific estimates ranged between 16 and 46 h.

The response of seals to piling activity is complicated in the sense that seals occur in and below the water surface as well as above it, with different sensitivities (see Introduction above). In support of the theoretical considerations of THOMSEN et al. (2006), early studies in Denmark showed a significant reduction of 31-60% in the numbers of seals using a haul-out some 10 km away during piling of Horns Rev (NERI 2004). At Scroby Sands in the UK, where the haul-out is <2 km from the OWF, aerial surveys showed a significant decline in the numbers of harbour seals that without full recovery two years after piling, suggesting displacement of animals to other areas outside of typical range from the haul-out. In contrast, grey seal showed a continued year-on-year increase in numbers after construction. The presence of this larger species competing with space and prey resources may have contributed to the failure of the smaller harbour seal to recover. Monitoring was not, however, linked to specific pile driving events and thus short-term disturbance and displacement could not be discounted in either species. Thus, where the two were linked, as at Horns Rev, boat-based surveys recorded a decline in the use of the windfarm area during the construction phase, with no harbour seals present inside it on days with pile driving (TEILMANN et al. 2006).

Where seals are individually tagged this increases the chance of detecting specific responses to short-lived events. Nevertheless, no clear changes in behaviour of tagged harbour seals either at-sea or on land were detected (TEILMANN et al. 2006), although this was thought to be partly because tagged seals rarely used either site, with only 0.41% of location fixes recorded within the Nysted OWF. In contrast, at Egmond aan Zee OWF in the Netherlands, it was suggested tagged harbour seals avoided the study area in the construction phase by at least 40 km (LINDEBOOM et al. 2011).

Similarly, in their study of 24 tagged harbour seals in the Greater Wash a key Round 2 development area for windfarms in the UK, HASTIE et al. (2015) showed the closest that seals came to active pile driving of the Lincs OWF UK varied between 4.7 and 40.5 km. Here, 31 monopiles (5.2 m diameter) were installed between May 2011 and 2012, with a ramp-up procedure followed for the first hour of piling over periods of 4-5 hours during which the median strike interval of the hydraulic hammer was two seconds.

In analysis of the response of tagged seals to construction of both Lincs and Sheringham Shoal OWFs, VOTIER (2016) compared at-sea telemetry data from 19 harbour seals prior to any construction with data from 23 individuals during the construction of Lincs and after piling was complete at Sheringham Shoal in 2012. Two spatial analyses were used to compare the historical data against the 2012 data and non-piling against piling data in 2012 alone. The results suggested a close-to-significant increase in the use of Sheringham Shoal in 2012 (up to May) compared to the baseline, although this was linked to a more general increase to the west of Sheringham Shoal rather than the windfarm driving the observed change. A significant increase in the use of the Lincs OWF site subject to piling was also attributed to a general increase in the use of the wider area. Lincs OWF is within 20 km of the main haul-outs and pupping grounds for harbour seals in the Wash and individuals continued to move in and out of the estuary during construction. However, during piling, VOTIER (2016) confirmed significant displacement of seals up to 25 km from the centre of the windfarm, but recovery time, defined as the time to return to an impacted area, was only two hours after piling. Thus, the gaps in piling of a few hours or days observed at Lincs (HASTIE et al. 2015) seemed to allow unhindered travel and foraging reflected by the lack of an impact on local population growth.

Other physiological impacts

In addition to the abovementioned impacts elevated underwater noise levels may lead to other, more subtle responses of marine mammals

- RICHARDSON et al. (1995) and other observed behavioural responses of cetaceans to anthropogenic noise as shorter surfacings and dives, fewer blows per surfacing, and a longer period of time between consecutive blows of bowhead whales during noise events.
- some cetacean species showed changes (reduction or cessation) (FRISK et al. 2003) of vocalization during noise events like
    - right whales and humpback whales during boat occurrence (FRISK et al. 2003)
    - bowhead whales during playbacks of industrial sounds (WARTZOK et al. 1989)
    - sperm whales during short sequences of pulses from acoustic pingers (WATKINS & SCHEVILL 1975)
    - sperm and pilot whales during the Heard Island Feasibility Test (BOWLES et al. 1994).

Especially anthropogenic induced mid- and low-frequency sounds is feared to cause severe impacts (disorientation, flight reactions including decompression sickness when come up to quickly at deep diving whales, and strandings) for marine mammals (BFN n.d.).

5.7.4 Impacts of noise during windfarm operation

A modelling exercise indicated that operational noise may be audible to marine mammals, especially to species with good hearing abilities at lower frequencies such as common minke whale *Balaenoptera acutorostrata*, over considerable distances of up to 20 km (MARINE SCOTLAND SCIENCE 2013), but there is no indication so far that this would lead to disturbance. However the chronic and potential masking effects of the sound produced by operating turbines has to be taken into account no matter which construction technique is used (floating or fixed).

During operation, commercial boat traffic will be excluded from the area, although maintenance vessels will service the windfarm throughout its life. Whilst larger heavy-lift vessels may be required to perform more complex maintenance tasks, such as swapping gearboxes, crew transfer vessels such as high-speed catamarans typically around 20-24 m in length will typically visit each turbine around six times per year during routine minor service activities (WINDPOWER OFFSHORE 2013).

The noise level generated by boats depends on their design and speeds at which they travel and further noise is emitted by their sonars. Vessel noise may be audible to many species of marine mammals at considerable distance with the potential to lead to a range of chronic effects including changes in behaviour, sound masking and displacement from important areas areas (RICHARDSON et al. 1995; MORTON & SYMONDS, H. 2002; JANSEN et al. 2015). Specific changes in behaviour and communication to increased vessel activity and noise have also been shown for Bottlenose Dolphin (NOWACEK et al. 2001; JENSEN et al. 2009; LA MANNA et al. 2013) and harbour porpoise.

For pinnipeds, JONES et al. (2017) evaluated co-occurrence of Grey and harbour seals and shipping traffic around the British Isles and modelled acoustic exposure to individual harbour seals that was validated with acoustic recorders. Co-occurrence rates were highest within 50 km of the coast, close to seal haul-outs and areas with high risk of exposure included 11 out of 25 SACs. Predicted cumulative M-weighted SELs for 70% of the harbour seals had upper bounds that exceeded levels that may induce TTS. Seals may also be disturbed from haul-outs by shipping that also appears to relate to visual as well as noise stimuli (ANDERSEN et al. 2012; JANSEN et al. 2015), with harbour seals seemingly more sensitive than grey seals where they occur sympatrically.

The increase in vessel traffic during the life of an OWF also increases the potential for marine mammals to be struck by vessels. Surprisingly perhaps, the review of VAN WAEREBEEK et al. (2007) of nearly 250 reported vessel collisions showed that 19 species of potentially small agile cetaceans including Bottlenose Dolphin and harbour porpoise had been involved in at least one incident. However, it is the larger cetaceans (DOLMAN et al. 2006), sirenians (BECK et al. 1982; PANIGADA et al. 2006) and some pinnipeds (GOLDSTEIN et al. 1999) that may be vulnerable. Windfarm service vessels are designed to travel relatively quickly and thus they may be expected to pose a higher risk than slower vessels. However, to date, there appears to be no known instances and no porpoises strandings have been reported which might hint at collisions with service vessels. The restriction of the use of vessels with ducted propellers in relation to windfarms in the UK over concern that these were contributing to harbour seal mortalities where animals had corkscrew wounds, proved to be unfounded as predation by grey seal was shown to be responsible (ONOUFRIOU 2016).

With respect to both disturbance through noise and collision risk it needs to be considered that windfarm service leads to additional ship traffic in an area between the windfarm and a nearby port. This ship traffic may pass areas of high value for marine mammals and marine protected areas. Until now, this factor is usually not addressed in environmental studies but should be considered in future.

In Canada, studies revealed that orca whales (*Orcinus orca*) are, amongst other anthropogenic impacts, especially affected by noise and physical disturbance of vessels (VANCOUVER FRASER PORT AUTHORITY 2018). Orca whales are vagrant in the Mediterranean. Even though there are several impacts on marine fauna occurring due to ship traffic, the long-term effects are still unknown for some specific species (e.g. the fin whale) (NOTARBARTOLO-DI-SCIARA et al. 2003). Consideration is also needed to the Mediterranean endemic species, e.g. the (critically) endangered ones, like the Mediterranean monk seal (*Monachus monachus*) since only less than 700 individuals are left (KARAMANLIDIS et al. 2016), as well as the ones where data is still deficient (e.g. Cuvier's beaked whales, long-finned pilot whales and Risso's dolphins) or "not Assessed" yet (e.g. orcas and rough-toothed dolphins) (NOTARBARTOLO DI SCIARA 2016).

5.7.5 Further impacts of OWFs on marine mammals caused by other pressures than noise

In additions to the pressures mentioned above construction and operation of offshore windfarms such as electromagnetic fields from cables, scour protection, active and passive corrosion protection of the foundations and also the lights of the turbines. In some areas turbines are equipped with sonar transponders as navigation aid for submarines. All such factors are so far not considered as causing more than subtle effects on marine mammals, if any, but contribute to a changing environment in areas where offshore windfarms are built.

In some countries, such as the Netherlands, Germany and Denmark commercial fishing is banned from windfarms (LINDEBOOM et al. 2011), although this is not the case in others such as the UK, but some fisheries may be limited due to safety restrictions or simply due to difficulties using specific gear within the confines of a windfarm. Where fisheries is excluded or significantly reduced, the abundance of fish within a farm may be expected to increase due to reduced mortality rates of target species and by-catch (LEONHARD et al. 2011; LINDEBOOM et al. 2011; WILHELMSSON & LANGHAMER 2014). However, outside the windfarm, the benefits of such refuges, including spill-over effects to adjacent areas, are more uncertain (GELL & ROBERTS 2003).

As with other factors, the ability of windfarms to act as reefs or refuges will depend on a wide variety of site-specific circumstances and it is most likely, that such effects will be strongly influenced by the size of the windfarm areas. The effects of reefs and refuges are likely to emerge stronger in larger windfarm areas and may thus play a more prominent role in the future.

Until today rather few studies have been published how harbour porpoise respond to the different factors and analysed whether porpoises occur in higher or lower numbers within operational offshore windfarms. In 2005 and 2006 BIOCONSULT SH (2008) investigated the presence of harbour porpoises in the Danish offshore windfarms Horns Rev 1 and Nysted 1 by passive acoustic measurements using T-PODs. During the study no differences could be detected in harbour porpoise presence between inside and outside the windfarm in both areas Nysted and Horns Rev. In Horns Rev no difference between porpoise detections at different distances to single turbines could be found. Here, the windfarm does not seem to influence the presence of harbour porpoises at all. In the Nysted windfarm a weak effect was found between different distances to single turbines with more porpoise recordings further than 700 m away from single turbines compared than 150 m to single turbines.

At the Dutch offshore windfarm Egmond aan Zee, harbour porpoise activity increased significantly inside the operational site, relative to the baseline conditions (LINDEBOOM et al. 2011; SCHEIDAT et al. 2011). SCHEIDAT et al. (2011) suggested this may be the result of a reef effect resulting from prey aggregations around turbine bases but also suggested the potential for a refuge effect from nearby shipping lanes consistent with the general impression that harbour porpoise tends to avoid or at least not be attracted to vessels.

For seals, RUSSELL et al. (2014) present telemetry data that suggested both grey and harbour seals trace windfarm structures as well as other anthropogenic structures such as in pipelines. An example of the track for one harbour seal that visited Sheringham Shoal windfarm in each of its of 13 foraging trips from haul-outs over 30 km away in the Greater Wash is shown in (Figure 5.16). This clearly shows movements directly between structures, many of which (77 of the 90 structures present) have extensive rocky scour protection extending up to 11 m from the bases, consistent with foraging activity.

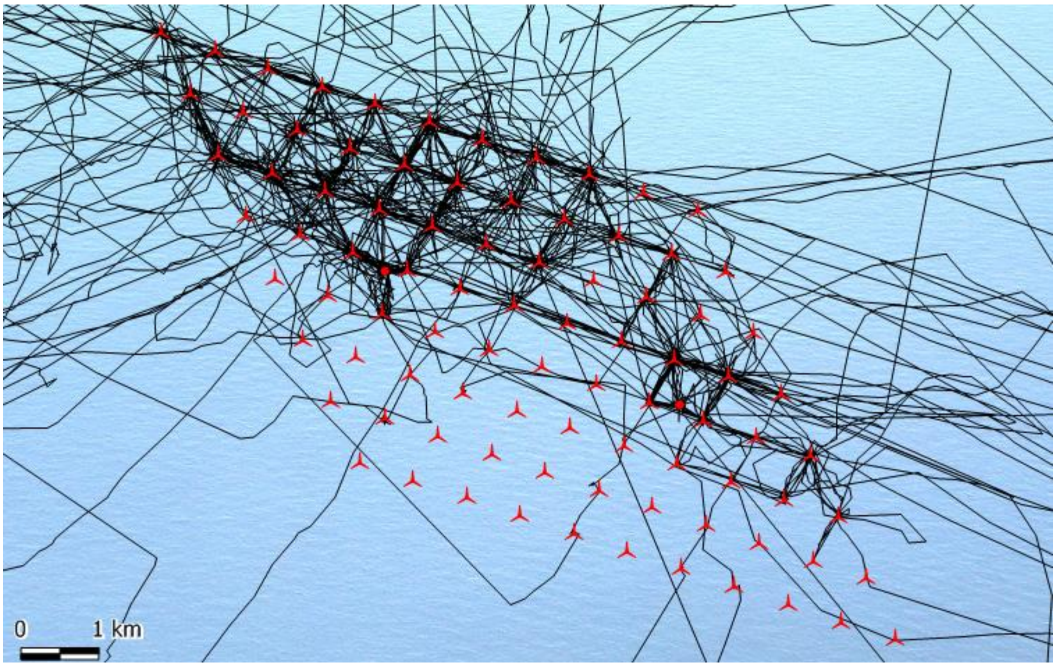


Figure 5.16 The tracks of a telemetry tagged harbour seal around Sheringham Shoal with the turbines and sub-stations (circles) shown in red. Whilst tagged, the seal visited the windfarm on each of its thirteen trips to sea (PERROW 2019).

5.7.6 Additional impacts on marine mammals present in the Mediterranean

Marine mammals in the Mediterranean are affected by existing anthropogenic pressures.

Table 5.6 lists the pressures that are present in the Mediterranean and the resulting impact on the marine mammal species.

Table 5.6 Overview of anthropogenic pressures with the type of impacts and the species being affected the most in the Mediterranean.

Anthropogenic pressure	Type of Impact	Species affected
Fisheries	Direct mortality through bycatch	Monk seal, all dolphin species (e.g. ÖZTÜRK 2015; NOTARBARTOLO DI SCIARA et al. 2016)
Vessel noise /traffic	Small scale redistribution	All (e.g. WILLIAMS et al. 2015)
Ship strikes / Collision	Direct mortality	Fin whale, sperm whale, long finned pilot whale (e.g. NOTARBARTOLO DI SCIARA 2016)
Seismic exploration	Short term habitat degradations	All (e.g. CASTELLOTE et al. 2012)
military/naval sonar	Direct mortality	Cuvier’s beaked whale (e.g. FRANTZIS 1998)

Ship traffic is one of the main impacts on marine mammals in the Mediterranean Sea, without any exceptions for the Pelagos Sanctuary, since many anthropogenic impacts are connected with maritime traffic (COOMBER et al. 2016). The northern Mediterranean Sea, and the Strait of Gibraltar (CARRILLO & RITTER 2010) are the two areas where most ship strikes with whales are encountered.

Baleen whales such as humpback whales, minke whales and fin whales, are frequently impacted by ship strikes (AVILA et al. 2018). Fin whales are the most frequently reported ship strike victim of all 11 cetacean species known to be affected by ship collisions within the Mediterranean Sea (Laist et al. 2001). Most of the Mediterranean deadly collisions were listed off Italy and France (Notarbartolo-Di-Sciara et al. 2003).

Due to the wide range of pressures and impacts on marine mammals, mitigation measures and techniques (see chapter 6) are strongly recommended to protect marine mammals from these impacts, especially the pile driving noise (BSH & BMU 2014). Additionally, further studies are suggested for improving the approaches (BSH & BMU 2014).

5.7.7 Marine mammals in the Mediterranean Sea

The Mediterranean Sea is considered as an outstanding hot spot of marine and coastal biodiversity (BIANCHI & MORRI 2000) and is characterized by diverse habitats reaching from complex topography with steep underwater canyon to narrow shelves (NOTARBARTOLO DI SCIARA 2016). Twelve marine mammal species are resident to the Mediterranean and are, according to the geographical heterogeneities of the subareas that are closely linked to the marine mammal’s biology, unevenly distributed throughout the Mediterranean. The Mediterranean can be divided in eight sub regions that host diverse features being important to habitat preferences of certain marine mammal species (NOTARBARTOLO DI SCIARA 2016): The Alboran Sea is a highly productive, oceanographically dynamic area, known as the hydrological motor serving and important feeding and breeding ground for cetaceans and their prey (CAÑADAS et al. 2005). The Algero-Provencal Basin encompasses a wide sub region, largely consisting of deep abyssal plains and narrow shelves, and with portions of its offshore waters that are amongst the Mediterranean’s most productive. The sub region contains critical habitat for many cetacean species. The Tyrrhenian Sea and Eastern Ligurian Sea connects the Italian mainland to the island of Corsica with a wide continental shelf in the north and Seamounts in the southern part. The Adriatic Sea is shaped with a heterogeneous geomorphology being shallow in its northern part and deepening to over 1200 m depth in the south. The continental shelf characterizes the Strait of Sicily, Tunisian Plateau and Gulf of Sirte as the most shallow sub region. The Ionian Sea and Central Mediterranean possess the deepest waters, with depth exceeding 5000 m in parts of the Hellenic Trench off south-western Greece. The Aegean Sea is shallow and interspersed with a large number of islands, islets and rocks. The Levantine Sea is highly influenced by geoengineering projects. Figure 5.17 depicts the most productive and diverse areas being of major importance to marine mammals (HOYT 2005).

28 marine mammal species are known to have occurred in the Mediterranean Sea. Of these, only twelve marine mammals –one pinniped and 11 cetacean species- inhabit the Mediterranean waters today (Table 5.7) and occur regularly in sub regions and various habitats. The remaining 16 marine mammal species were infrequently sighted.

*Figure 5.17 The Mediterranean Sea and its areas (*DEL MAR OTERO *&* CONIGLIARO *2012); blue ovals added to the figure label the most productive and diverse areas regarding marine mammals* (HOYT 2005).

*Table 5.7 Overview of the 12 resident marine mammals to the Mediterranean Sea with one pinnipedand 11 cetaceans (*NOTARBARTOLO DI SCIARA *2016).*

Species	IUCN status	Occurence	Habitat
Mediterranean Monk Seal, *(Monachus monachus)*	Endangered	Breeding in Greece, in parts of Turkey and Cyprus. Ionian and Aegean Sea	Neritic
Fin Whale (*Balaenoptera physalus)*	Vulnerable	Resident from Balearic Islands to the Ionian and southern Adriatic seas. Seasonal occurrence from the Atlantic population in the Strait of Gibraltar	Slope, oceanic
Sperm Whale *(Physeter macrocephalus)*	Endangered	Widely distributed in deep waters and slope	Slope, oceanic
Cuvier's Beaked Whale *(Ziphius cavirostris*)	Data deficient	Concentrated along deep continental slope and under water canyons	Slope, oceanic
Long-finned Pilot Whale (*Globicephala melas*)	Data deficient	One small population restricted to the Strait of Gibraltar. One population restricted to the western Basin, from the Alboran Sea to the Ligurian and Tyrrhenian seas	Neritic, slope, oceanic

Species	IUCN status	Occurence	Habitat
Risso's Dolphin (*Grampus griseus*)	Data deficient	Widespread in slope waters: Alboran, Ligurian, Tyrrhenian, Adriatic, Ionian, Aegean and Levantine seas and the Strait of Sicily.	Slope, oceanic
Killer Whale (*Orcinus orca)*	Not assessed (only subpopulation in the Strait of Gibraltar as "Endangered")	only in the Strait of Gibraltar	Neritic, slope, oceanic
Short-beaked Common Dolphin *(Delphinus delphis*)	Endangered	In the Alboran, Sardinian, the eastern Ionian, Aegean and the Levantine Sea off Palestine, the Sicily Strait.	Neritic, slope, oceanic
Striped Dolphin (*Stenella coeruleoalba*)	Vulnerable	Widespread offshore dolphin: in deep waters from Gibraltar to the Levantine Sea. A small number of striped dolphins live in isolation in the eastern portion of the Gulf of Corinth, Greece	Oceanic, slope
Rough-toothed dolphin (*Steno bredanensis*)	Not Assessed	Levantine Sea	Oceanic, slope, neritic
Bottlenose Dolphin (*Tursiops truncatus)*	Vulnerable (only subpopulation in the Gulf of Ambracia as "Endangered")	Widespread on continental shelf from Gibraltar to the Levantine Sea including the northern Adriatic and northern Aegean	Neritic
Black Sea harbour porpoise (*Phocoena phocoena relicta*)	Endangered	northern Aegean Sea, Black Sea proper and adjacent Turkish Straits System (Bosphorus, Marmara Sea, Dardanelles)	Neritic

5.8 Socio-economic impacts

Offshore windfarms do interact with other human activities in the marine environment. It can either be related to the visual presence of the construction, possibly impacting on wellbeing and touristic attraction of the coastal communities, or as competition for space of OWFs and other economic or social activities in the marine realm (Figure 5.18).

*Figure 5.18 Schematic overview of human activities and interests taking place, interacting and possibly competing for space in European Seas. (*MUSES-PROJECT 2018)

5.8.1 Fisheries and aquaculture

The fishing industry and OWFs are competing for space since in some countries, where OWF are already operating, fishing inside and around an OWF is prohibited (500-m restriction zone in Belgium and Germany) or restricted during times of construction or maintenance of the windfarm (UK) (SOUKISSIAN et al. 2017 and references therein). This leads to a reduction of the fishing area, as even if fishing is allowed inside the windfarm area only certain types of fishing gear are compatible for these conditions. A study conducted in the UK found that fishermen worry about a profit loss due to the fishing restriction (SOUKISSIAN et al. 2017 and references therein). Avoiding the windfarm area can lead to an increase in fuel costs and steaming time to reach fishing grounds (THE SCOTTISH GOVERNMENT 2013), if not only fishing but also passing of the OWF area is prohibited. On the other hand fishermen could profit from a potential spill-over effect, if the reef and reserve effects of OWF benefits the fish population of commercially important species. Similar to oil platforms floating wind turbines have the potential to act as so called fish aggregating devices (FAD). FADs can increase the catchability of some species (e.g. some tuna species) by 10-100 fold compared to open-water areas, which could lead to over-exploitation of FAD associated species around an OWF (FAYRAM & DE RISI 2007).

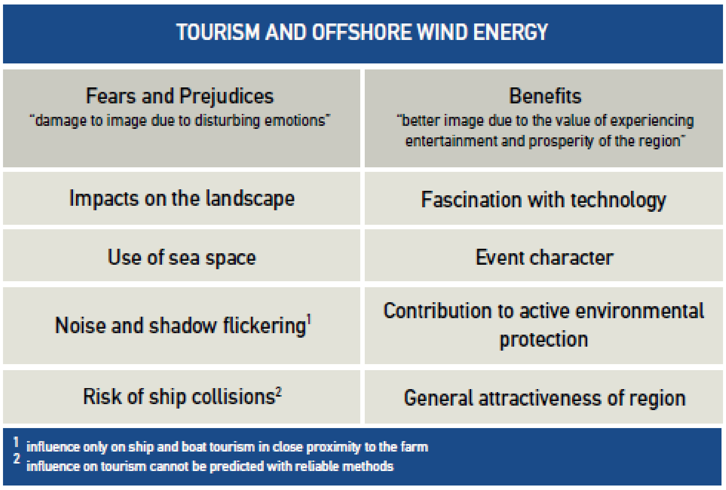
Regarding aquaculture there is a potential for shared space with OWFs. This topic receives increasing attention recently in the German part of the North Sea as the potential space for OWFs is covering 35% of the German EEZ (STELZENMÜLLER et al. 2016). Up to now building offshore aquaculture facilities is challenging due to the harsh conditions offshore compared to more coastal areas. This problem could be overcome by using the foundations or anchoring systems of an offshore wind turbine for securely attaching aquaculture devices (MICHLER-CIELUCH et al. 2009). In the Mediterranean Sea the aquaculture sector is growing approximately by 10% per year since 1970 (SOUKISSIAN et al. 2017) and thus growing in economic importance. Most aquaculture facilities are located in coastal areas avoiding the harsh weather conditions in areas further offshore, suggesting that the construction of OWF will rather offer beneficial opportunities for this sector than competition for space or resources.

5.8.2 Tourism

The touristic sector of a region can be impacted either by visual disturbance by the structure of an OWF itself, if built in visual distance to the shore. Other concerns of tourist or the tourist sector involve noise and shadow flickering as well as ship collisions with the turbines (Table 5.8). Noise and shadow flickering would affect leisure boating only in close vicinity of the turbines the noise impact will be of importance during the period when the windfarm is under construction (Stiftung Offshore-Windenergie 2013). In Denmark and Sweden OWF sites are close to the shore. Locals from the impacted area have a positive attitude towards offshore wind energy, but would rather prefer the constructions further offshore. In Denmark people were willing to pay more than 120 € per year for moving a hypothetical windfarm 50 km away from the coast (Snyder & Kaiser 2009).

Overall, neither in Denmark nor in the UK reduced touristic activity was observed in locations with OWFs close to shore (Westerberg et al. 2013). Overall it has been suggested, that the distance to shore has the greatest influence on whether the attitude is positive or negative. A modelling study on the coast of Languedoc-Roussillon revealed that an OWF could lead to an increase of tourist activity of a certain type of tourist especially if this is associated with a general “greening” of the tourist area/resort (Westerberg et al. 2013). Other potential benefits for the tourist sector are listed in Table 5.8.

Table 5.8 Potential impacts, positive and negative, of OWF on tourism in the Baltic Sea region. (STIFTUNG OFFSHORE-WINDENERGIE, 2013)



TOURISM AND OFFSHORE WIND ENERGY

Fears and Prejudices “damage to image due to disturbing emotions”	Benefits “better image due to the value of experiencing entertainment and prosperity of the region”
Impacts on the landscape	Fascination with technology
Use of sea space	Event character
Noise and shadow flickering[1]	Contribution to active environmental protection
Risk of ship collisions[2]	General attractiveness of region

[1] influence only on ship and boat tourism in close proximity to the farm
[2] influence on tourism cannot be predicted with reliable methods

5.8.3 Transport

Due to the space OWFs occupy, their presence and the restricted traffic permissions, the OWF sector is impacting the maritime transport, especially in frequently used shipping routes. In case of necessary rerouting of shipping lanes due to an OWF an increase in environmental pollution is a potential consequence as a prolonged steaming time will eventually cause higher ship air emissions besides an increase in costs for ship owners (Soukissian et al. 2017). In Germany for instance ships (except construction and maintenance vessels) are not allowed to cross an OWF. This, and a safety zone of 500 m around the entire OWF, can induce ships to choose a different passing route as known for sailors around the Danish OWF 'Nysted' in the Baltic Sea (STIFTUNG OFFSHORE-WINDENERGIE 2013).

If an OWF is located close to a shipping route, the windfarm acts as a potential risk factor for collision, either due to human errors, machine failures or bad weather conditions. A collision of a vessel with a turbine can have several consequences (ELLIS et al. 2008):

1. Environmental damages, such as oil spills or spills of other hazardous materials.
2. Human injuries, if the vessels sinks after the collision or parts of the turbine break and fall on board
3. Economic loss, either due to loss of cargo or damage of the ship

A study for the windfarm developer 'Nordzee Wind' conducted at the Dutch OWF 'Egmont aan Zee' (KLEISSEN 2006) found that the OWF had a negative impact on the radar performance of e.g. container ships, though the impacts were below a level, where other ships would become non-detectable. The radar performances improved in the simulator used in the study when the number of turbines between them decreased, which would be the case if they were moving towards each other. The Mediterranean contains some of the world's busiest marine traffic routes. Some of the areas with already high density of vessels (e.g. Gulf of Lion and North Adriatic Sea) overlap with locations for potential OWF development (BRAY et al. 2016), which may lead to spatial conflicts between these sectors.

5.8.4 Cultural heritage

According to the UNESCO (UNESCO 2017) OWF can impact on underwater cultural heritage, such as underwater archaeological sites: "The turbines themselves require foundations that may be relatively extensive or penetrate deep below the seabed. Large amounts of cabling are required between the turbines and sub-stations out at sea. Very long export cables have to be installed between the farms and their landfalls."

5.8.5 Seabed mining

The space an OWF requires for turbines or, cables etc. is consequently lost for other activities, such as the exploitation of marine mineral resources. Within the Mediterranean the Tyrrhenian and Aegean Seas for instance are areas known for their sulphide deposits, which have to be taken into account during site selection of an OWF as potential competitors for space (SOUKISSIAN et al. 2017).

5.8.6 Military use

The location of a planned OWF can overlap with areas used for military exercises in the EEZ of a country, such as shooting areas or submarine exercise areas. This can lead to space related conflicts between an OWF and national armed forces.

5.9 Cumulative effects

The production of electricity from offshore wind is expected to increase as a halting response of governents against climate change. However, there are concerns that the deployment of a larger number of offshore farms may affect wildlife (GOODALE & MILMAN 2016) due to cumulative effects which in turn cannot be fully considered in project specific impact assessments (such as individual EIAs). Mobile species such as seabirds and marine mammals may be exposed to offshore windfarms in several areas they visit during their annual cycle. For instance the overall collision risk of migratory birds depends on the total numbers of turbines present in the annual range of the individuals of a population, despite the fact that in individual OWFs collision risk models may provide low estimations for collisions.

While effects to wildlife from OWF are direct (e.g., mortality and injury) or indirect (e.g., general disturbance caused by the turbines and maintenance vessels), and are caused by pressures such as noise from pile driving, boat traffic, and lighting, yet, the greater concern is how multiple OWF will affect wildlife populations through time and space (GOODALE 2018). It is further important to consider that species and habitats exposed to pressures from OWF activities are often exposed to additional anthropogenic pressures which may cause cumulative impacts (see heterotypic effects in Figure 5.19).

Broadly defined, Cumulative Adverse Effects (CAE) is the accumulation of adverse effects of multiple anthropogenic actions over time and space. According to GOODALE & MILMAN (2016) "…*It represents a metric of total human impact to the ecosystem. First, the fitness of an individual in a population is reduced via its interaction with* a *hazard* (pressure) *posed by OWF. Second, the effects of multiple OWF on that individual and others accumulate into population level declines".* (Figure 5.19).

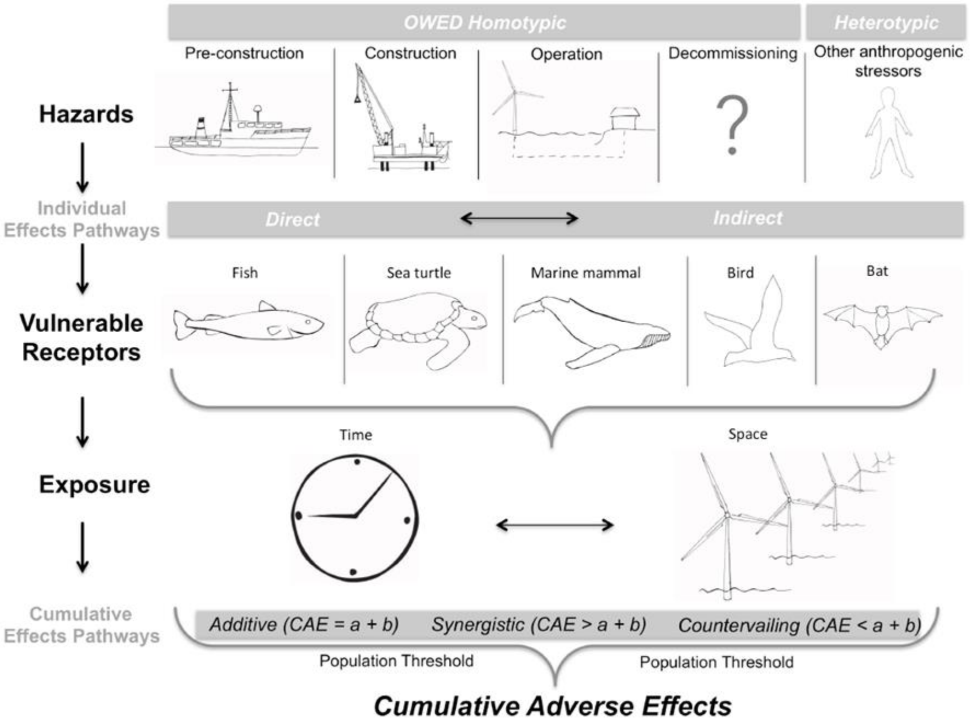


Figure 5.19 The process of the cumulative adverse effects of offshore wind energy development on wildlife. Homotypic OWF hazards, as well as other heterotypic sources, directly/indirectly adversely affect vulnerable receptors. These adverse effects accumulate as vulnerable receptors are repeatedly exposed through time and space to the OWF hazards via additive, synergistic, and countervailing pathways. The adverse effects of the exposure of vulnerable receptors to OWED hazards can then accumulate to a degree that a population threshold is passed (GOODALE & MILMAN 2016).

Adverse effects on an individual can occur primarily through direct and indirect pathways. Direct effects result from a clear cause-effect relationship between the effects on wildlife and an anthropogenic action such as mortality from colliding with a turbine. Indirect effects are second- or third-level effects, and occur away from the project or through multiple effects pathways (GOODALE 2018).

A lack of empirical evidence on the interactions between adverse effects hampers accurate assessment of cumulative effects and therefore a precautionary approach presumes effects are additive (GOODALE 2018).

Three inter-related elements should also be considered for estimating CAE of OWED on wildlife:

1. Identification of impacts (hazards)
2. Evaluation of species' vulnerability, including baselines, effects pathways, and effects thresholds
3. Delineation of exposure, including spatial and temporal boundaries

Understanding cumulative effects requires targeted investigation for the most vulnerable receptors. Once the receptors have been defined, a baseline (such as population level) needs to be determined for each. For instance a decline of population levels post implementation of OWF relative to the baseline could indicate an adverse effect of the OWF on the receptor. Temporal and spatial boundaries are also important components to understanding CAE.

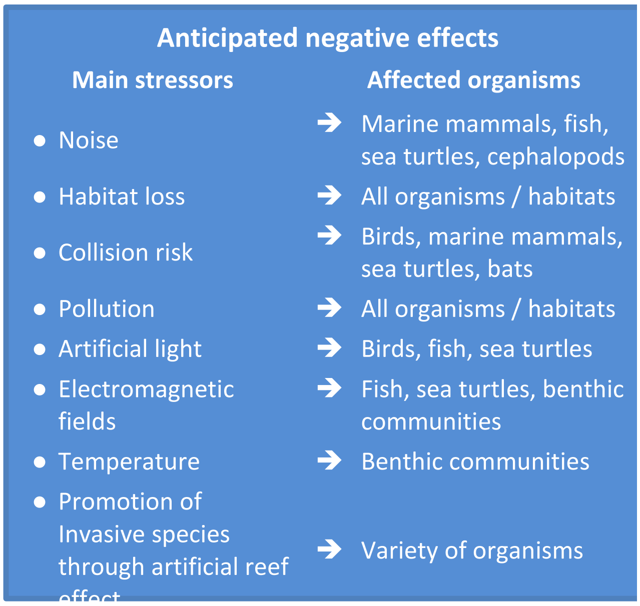
Regarding the impacts on marine mammals, first attempts have been made to analyse the impacts on population level considering cumulative impacts from construction of multiple windfarms (PIROTTA et al. 2018) and several studies currently address impacts on bird populations in relation to the collision risk. Further, first studies have been undertaken to investigate the cumulative effects of several stressors, for example disturbance from offshore windfarms and disturbance from ships (MENDEL et al. 2019). The risk of CAE of offshore windfarms on wildlife is poorly researched and assessment processes are underdeveloped. Assessment of CAE is difficult because the adverse effects of an individual windfarm need to be combined with past, present, and future stressors to determine population level impacts (GOODALE 2018). Recently methods and models are evolving to analyse the cumulative effects of OWF development on wildlife. More precisely potential OWF siting scenarios compared with wind engineering and biological data sets were applied in a deterministic model to evaluate cumulative exposure to wildlife. Aim of the tool is to provide standardized means by which decision makers can identify the species most at risk of CAE and the best management actions to reduce CAE (GOODALE & MILMAN 2019).

Cumulative impacts may best be managed in marine spatial planning (MSP) processes and as part of Strategic Environmental Assessments (SEA) which look beyond single projects. By default MSP and SEA consider maritime activities and their environmental effects at a broader scale. In marine habitats it is important to note that cumulative impacts should be considered in transboundary contexts, because many species are mobile and may be exposed to offshore windfarms in various places they use during their annual cycle. As offshore wind energy exploitation is expected to further increase in the near future it becomes more apparent to develop efficient marine spatial planning and to assess how the development of multiple offshore windfarms leads to cumulative effects on populations.

5.10 General conclusion on impacts

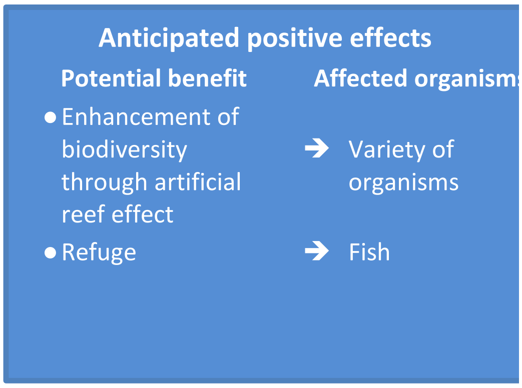
There are various factors associated with the development of OWFs that can potentially impact on the surrounding ecosystem. The occurrence and strength of any impact depends on the phase (siting, construction, operation or decommissioning) and on the environmental charecteristics of the OWF location. The main stressors impact on different marine habitats and organisms. Construction noise will impact strongest on marine organisms, such as cetaceans, while the risk of collision with the OWF facility is restricted to birds and bats. However, not only the turbines themselves, but also associated facilities, such as cables or the increased traffic caused by the construction and maintenance vessel can directly impact on habitats and species by emitting heat and EMFs (cables), producing noise and/or pose a potential collision risk/disturbance factor by their presence (vessel traffic).

Additionally OWF may potentially have beneficial effects on some organisms, for instance they can act as artificial reefs, provide refuge for fish or benthic organisms, when bottom-diturbing fishing gear is prohibited. The newly introduced artificial structures may enhance biodiversity and biomass and in consequence increase food sources.



Anticipated negative effects

Main stressors		Affected organisms
Noise	→	Marine mammals, fish, sea turtles, cephalopods
Habitat loss	→	All organisms / habitats
Collision risk	→	Birds, marine mammals, sea turtles, bats
Pollution	→	All organisms / habitats
Artificial light	→	Birds, fish, sea turtles
Electromagnetic fields	→	Fish, sea turtles, benthic communities
Temperature	→	Benthic communities
Promotion of Invasive species through artificial reef effect	→	Variety of organisms



Anticipated positive effects

Potential benefit		Affected organism
Enhancement of biodiversity through artificial reef effect	→	Variety of organisms
Refuge	→	Fish

The most relevant impacts on marine mammals result from underwater noise emitted during the construction process especially pile driving, which has received much attention over the previous years. So far studies have not demonstrated that marine mammal abundance is reduced in operational windfarms, while some attraction has been shown especially for seals. As the only seal species resident in the Mediterranean, the Mediterranean monk seal, has a very low population size, the benefit of the turbines as additional feeding ground is of minor relevance in the Mediterranean.

Vessel traffic during any stage of OWF can increase the risk for marine mammal/boat collisions and this needs to be considered especially when planning in areas in the Mediterranean Sea where larger whale species may be resident or migrate through. Another relevant issue in the Mediterranean is the overall high vessel density (Figure 5.20). Adding additional vessel traffic due to the OWF construction and maintenance vessels will potentially increase collisions as well as noise levels. The latter may lead to cumulative noise impacts on marine mammals, fish and sea turtles. As sea turtles were so far not considered in OWF related impacts studies, the impacts of construction vessels, turbines and related infrastructure is poorly understood.

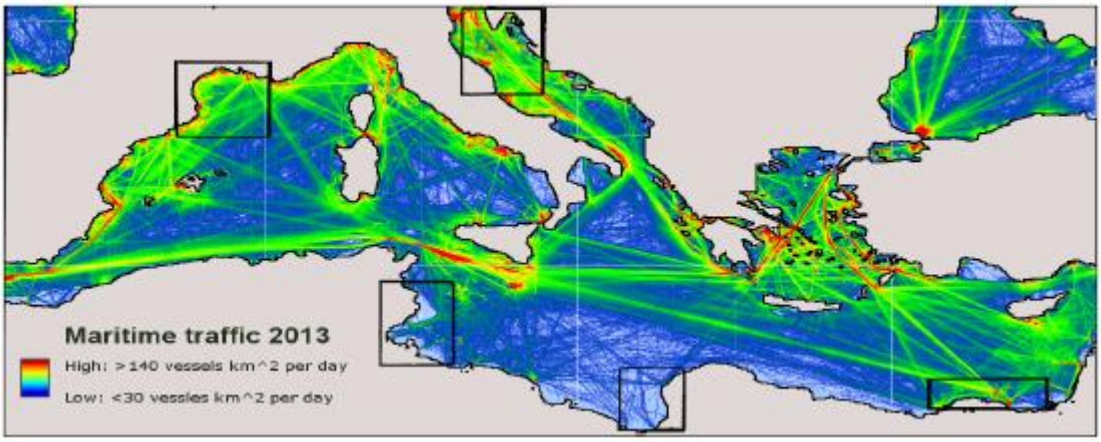


Figure 5.20 Density of commercial vessels (2013) in the Mediterranean obtained via AIS data. Potential OWF hotspot areas are displayed as black rectangles (BRAY et al. 2016)

Birds that avoid the area experience a de facto habitat loss. For some bird species showing avoidance behaviour to vessels as well as to OWFs, as known for the red-throated diver in the German North Sea, cumulative impacts of increased traffic and operating turbines may lead to large-scale shifts in the species distribution. The effects of offshore windfarms for Mediterranean species as are expected to be similar, but the actual magnitude of these effects depend strongly on the site specific parameters like the marine area selected for the OWF, the composition of avifauna communities, the windfarm characteristics, the habitat use patterns, availability of similar habitats, the abundance of populations etc. Possible impacts on some endemic Mediterranean species such as Balearic Shearwater and breeding migratory species Eleonora's falcon should be studied in relation to OWFs in detail as the development of offshore wind energy progresses. There are no indications that collision risk at sea is higher as for onshore windfarms, but this does not rule out that certain species are vulnerable due to their flight behaviour. For nocturnal migrants it is assumed that night-lighting of the turbines might attract birds under bad weather conditions and increase the collision risk. Bats can also be present in offshore area, mainly during seasonal migration times and potentiall collide with turbines or suffer from barotrauma. Within the Mediterranean Basin the migratory regime of bat species should be further investigated to understand activities and migration patterns over the open sea.

The significance of the impacts is highly dependent on the habitat characteristics of a site, the types of turbines and foundations and the installation techniques. Floating windfarms will likely have some different impacts than fixed windfarms, however, floating constructions as a recent development have not been investigated yet. In general there are still substantial knowledge gaps in the quantification of environmental impacts of OWFs. Occurrence of impacts depend on the life cycle phases of an OWF and strength of impacts vary in terms of duration and spatial extend.

6 MITIGATION MEASURES AND TECHNIQUES

In this chapter we present the potential to mitigate the negative effects of the impacts on marine wildlife as presented in chapter 5 (abiotic environment, benthic communities and habitats, invertebrates, fish, reptiles, marine mammals, birds, socio-economic impacts).

6.1 Site selection

From all mitigation measures, site selection is one of the most important tools. Ideally, conflicts between offshore windfarms and nature conservation can be avoided or largely mitigated by selecting sites of low value for nature conservation. However, as a complete separation of offshore wind farming and nature conservation interests is not possible, a balanced approach is required. To achieve this, several instruments are available.

6.1.1 Marine spatial planning (MSP)

Especially in coastal areas the maritime space is limited and several ecological and economic interests may compete for space (Figure 6.1). Long term and strategic planning is needed to manage the use and the protection of the marine realm. Marine spatial planning (MSP) was developed as a tool to manage the different human activities on a long-term and spatial scale and balance those with environmental protection. There is no official definition of MSP, but several have been suggested, e.g. by the UNESCO Intergovernmental Oceanographic Commission (IOC): “MSP is 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 are usually specified through a political process.” There are already designated zones in many countries, which specify the areas’ usage for certain activities. Usually this is accomplished on a case-by-case basis rather than being an integrated approach considering the different sectors and their (long-term) interactions, either between two economic sectors or between human uses and the environment. An important task of MSP is to minimize spatial conflicts between human activities and environmental issues.

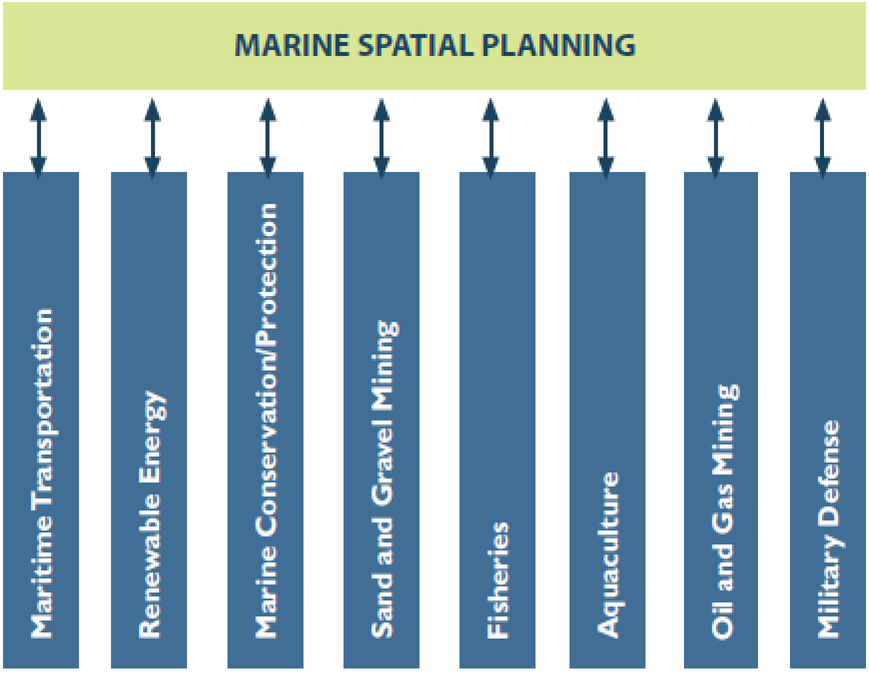


Figure 6.1 *Main sectors involved in Marine Spatial Planning.* (UNESCO & INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION 2009)

According to the definition of the UNESCO, MSP include ecosystem-based, area-based, integrated, adaptive, strategic and participatory characteristics. In recent years the view has been established that a marine spatial plan should always be based on an ecosystem approach in the first place, meaning that the approach to management takes the entire ecosystem, including humans, into account (UNESCO & INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION 2009). In a first step, the heterogeneity of an area has to be considered to discover important ecological (e.g. areas of high biodiversity), economic (e.g. areas of sustained winds) and cultural areas (e.g. underwater archeological sites) to set priorities for this area. A MSP management plan is thought to have a 10-20 year horizon. MSP is supposed to meet the requirements and needs of the different stakeholders, support *Blue Growth* and at the same time meet environmental criteria, e.g. the EU targets for Good Environmental Status (GES) or Favourable Conservation Status (FCS) for species and habitats. MSP is not thought to be a static one-time decision, but rather a process adapting and being developed over time, which also includes monitoring. A compilation and detailed step-by-step guideline for successful MSP was published by the UNESCO in 2009 (UNESCO & INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION 2009).

Since the construction of the first OWFs and the expansion of turbines in the sea, MSP has raised increasing attention to make this use of the sea compatible with other economic interests and environmental protection. In North Sea countries the need of an efficient spatial planning became obvious as the first potential conflicts of offshore wind energy with shipping lanes occurred. Additionally concerns were expressed how the presence of the turbines impact on bird migration and the status of the UNESCO world heritage ‘Wadden Sea’ (MARIBUS et al. 2015).

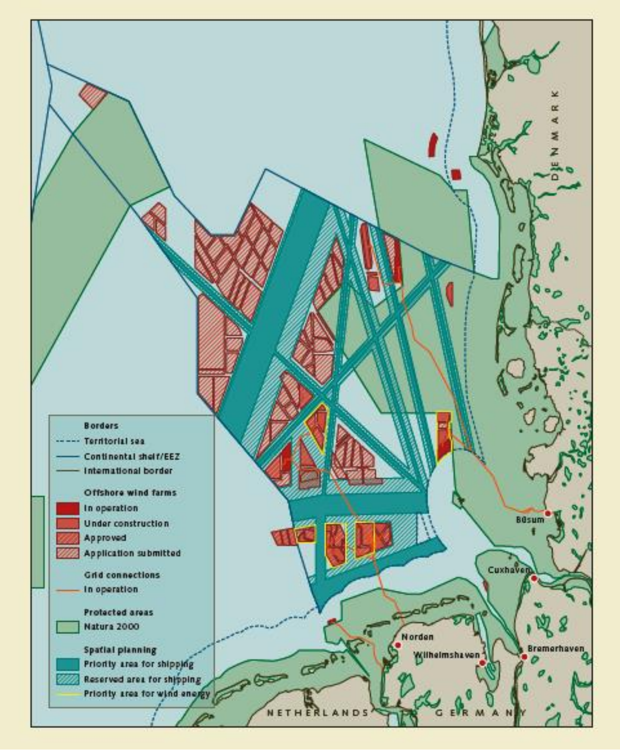


Figure 6.2 *Marine spatial plans for the German EEZ, developed since 2009. OWFs (operating, constructed, approved or submitted for approval) are displayed in red. (MARIBUS et al. 2015)*

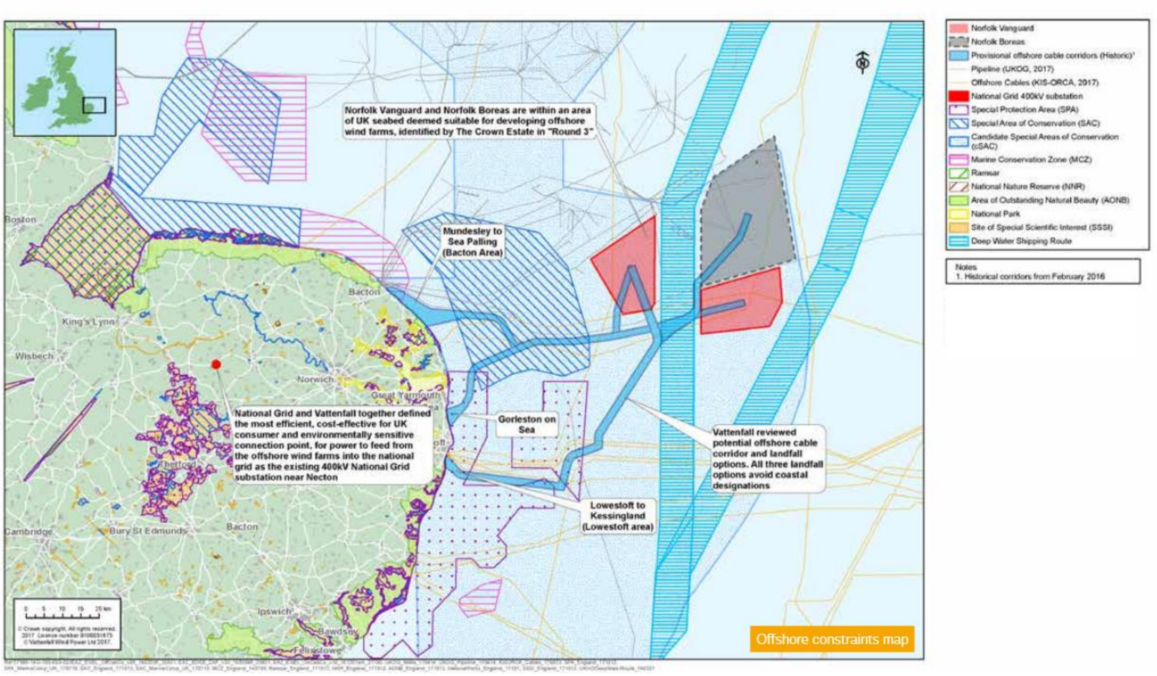


Figure 6.3 *Examples for marine spatial planning in the southwest of Great Britain (lower panel) taking spatial requirements for OWFs (build, planned and/or approved), OWF related grid connections, marine protected areas and shipping routes into account. (VATTENFALL 2015)*

Nowadays the potential areas for OWFs in the EEZ of countries in Europe, where MSP is now mandatory (2018a), have implemented the planning of OWF in MSP (Figure 6.2 and Figure 6.3) in order to avoid/minimize conflicts with other human activities or nature conservation issues, such as shipping lanes or marine protected areas. This does not mean that these uses can be strictly divided (e.g. grid connection of OWF may lead through Natura 2000 sites), but as seen on Figure 6.2 the construction of turbines within the borders of a MPA is not planned for future OWFs. In a number of countries, MSP is now implemented in regulations and under national law (e.g. Belgium, China, Germany, the United Kingdom and the US) (MARIBUS et al. 2015). In Germany the areas in the German EEZ were designated for a specific use, and risk analyses (e.g. for ship collisions) were conducted for planned OWFs due to their long-term immense space occupation. These analyses led to areas, where the construction of turbines was prohibited. In Great Britain the Marine Management Organization (MMO) responsible for marine spatial planning split England's waters in 11 marine plan areas. In 2015 planning was still ongoing and involved a variety of stakeholders, such as representatives from aquaculture, defense, marine conservation, energy production, local authorities etc. (MARIBUS et al. 2015). MSP can thus not only find solutions how to split space equally between sources of use, but also identify potential co-uses of activities. Since many fishing techniques are forbidden or simply not feasible within an OWF, these areas can potentially contribute to nature conservation by serving as reserves for fish and other marine fauna, presenting an option to partially integrate OWF in conservation needs for certain species. But the potential effects of the turbines and associated structures on the integrity of the environment have to be investigated thoroughly beforehand in order to avoid adverse effects instead of the targeted conservation issues. Other suggested co-uses are OWF as tourist attraction points or as aquaculture areas. Recently there has been growing criticism of the implementation of MSP as scientists suggest that the planning favours *Blue Growth* in most cases instead of following the eco-system approach, which prioritizes the good environmental status (JONES et al. 2016).

In contrast to e.g. the Baltic and the North Sea in the Mediterranean Sea there is a large portion of high seas, making planning under national jurisdiction and regulations limited. Integrated approaches can be conducted within the national territorial waters (12 NM, in some cases only 6 NM) while an eco-system approach would include protection and sustainable use of the sea beyond these territorial waters. Nevertheless, the planning of the first (floating) OWFs in the French Mediterranean already included many features of MSP to investigate the most suitable areas to establish an OWF (DIRECTION INTERRÉGIONALE DE LA MER MÉDITERRANÉE 2018). An example of cross-border implications of MSP is the framework developed by the HELCOM (Helsinki-Paris-Commission) in the Baltic Sea, which is currently developing a MSP in the Baltic Sea with EU- and non-EU countries (HELCOM BALTIC MARINE ENVIRONMENT PROTECTION COMMISSION 2018).

Most of the regulatory systems in the Mediterranean (e.g. Barcelona Convention) are based on single-use or sectoral recommendations or frameworks. Under the umbrella of the UNEP a report was published in 2017 focussing explicitly on this problem "Marine Spatial Planning and the protection of biodiversity Beyond national jurisdiction (BBNJ) in the Mediterranean Sea (UNITED NATIONS ENVIRONMENT PROGRAMME / MEDITERRANEAN ACTION PLAN (UNEP/MAP) 2017). The authors conclude that developing MSP beyond areas of national jurisdiction would be a future-based way to establish an integrated approach, especially before activities further offshore become more extensive and need reasonable regulations. Also on behalf of the European Union, studies have been conducted to investigate potentials for MSP in the Mediterranean Sea (DEPARTMENT OF ENERGY AND CLIMATE CHANGE & ENERGY PLANNING REFORM 2010) and areas identified where applying MSP would be most useful taking stakeholders, institutional frameworks and international cooperation into account. According to this study, development of MSP is most needed in areas, where economic activities and environmental needs face conflicts, and in general, where new activities are expected. The latter would be the case for areas planning OWFs. The Adriatic Sea, the Alboran Sea, waters around Malta and the Western Mediterranean Sea were identified to have the greatest potential to successfully apply MSP across-borders and beyond areas of national jurisdiction based on three major aspects formulated by (DEPARTMENT OF ENERGY AND CLIMATE CHANGE & ENERGY PLANNING REFORM (2010):

- Purpose of MSP in the area: type and intensity of uses as well as the ecological value of the marine area;
- Feasibility of MSP in the area: scientific data/knowledge base, institutional capacity, legal and administrative supportive framework and stakeholders involvement;
- Conditions for cross-border/international cooperation: in case the marine area falls beyond national jurisdiction – which is mostly the case for marine areas in the Mediterranean Sea basin.

The European Union is aware of the urgent need to develop appropriate thorough MSP in the Mediterranean. Thus several projects were funded in recent years or are currently funded for developing and bringing MSP approaches forward, some of which take OWF into account (EUROPEAN COMMISSION 2018a), e.g.:

ADRIPLAN - ADRiatic Ionian maritime spatial PLANning (2013-15).

SIMWESTMED – The project will support Maritime Spatial Planning, launch and carry out concrete and cross-border MSP initiatives between Member States in the in the Western Mediterranean (2017-18)

SUPREME – The project will support the implementation of Maritime Spatial Planning in EU Member States within their marine waters in the Eastern Mediterranean, including the Adriatic, Ionian, Aegean and Levantine Seas, launch and carry out concrete and cross-border MSP initiative between Member States in the Eastern Mediterranean (2017-18)

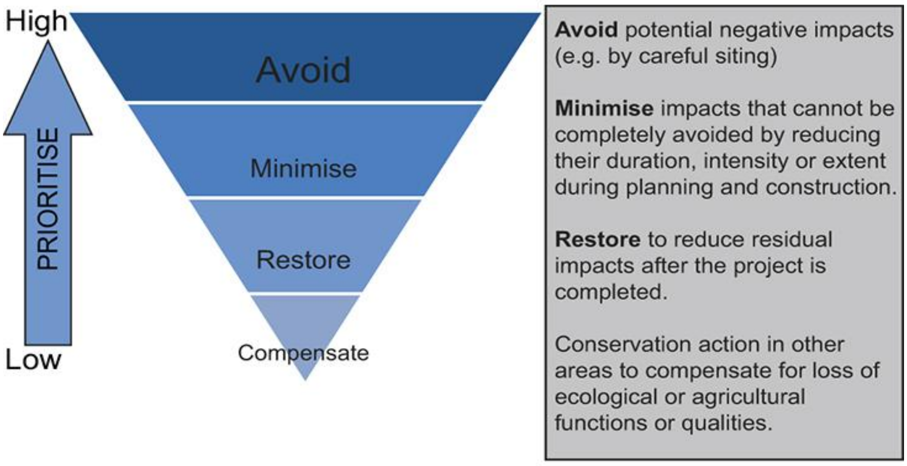
6.1.2 Strategic planning

Strategic planning and Strategic Environmental Assessments (SEA) are very important tools in order to avoid and mitigate adverse environmental impacts of projects already in the planning phase. Strategic Environmental Assessments (SEA) are mandatory in the EU for certain projects and plans (see chapter 8.1.2) but in practice there are substantial differences how states implement SEAs in marine planning. While the UK has established quite extensive SEA procedure for various offshore activities (https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process) other countries give more focus to project specific EIAs.

With respect to offshore wind farming SEA can be very useful if sufficient information is available or generated by dedicated investigations. For example in the UK large scale aerial surveys have been performed in order to prepare site selection for offshore windfarms. This information are then used to map seabird sensitivity to offshore windfarms (Bradbury et al. 2016) and provide highly relevant information for decision-making at the strategic level such as marine spatial planning.

A Strategic Environmental Assessment of plans to designate sites for offshore windfarm development will at the next stage be followed by project specific environmental impact assessments which are conducted to assess the (positive and negative) effects an OWF might have on the environment (LÜDEKE 2017). BOEHLERT & GILL 2010 described contents of the EIA when planning OWFs: "environmental stressors (e.g. acoustic issues), receptors (e.g. marine mammals), effects (e.g. multiple/short term) impacts (e.g. biotic process alteration), and cumulative impacts (e.g. spatial, temporal and other human activity impacts)" (LÜDEKE 2017). Nevertheless, for most species, the causal relation between OWFs and alterations in species population processes and abundances have are not fully understood yet (MASDEN et al. 2010a, 2015). The impacts on species considered within EIA varies between the European countries, e.g. the Netherlands include the threat to fish as a crucial factor in the decision-making process, whereas Germany does not (LÜDEKE 2017). Also the monitoring and assessment systems differ between the countries which in turn make it difficult to do cumulative assessments of different OWFs as required by the EIA Directive (LÜDEKE 2017). Therefore, for assessing the OWF environmental impacts objectively and to make it internationally comparable, an international standardization of the assessment system is preferable, which is not the case yet (LÜDEKE 2017).

The processes of SEA for plans and EIA for projects are complementary and there are different approaches how detailed assessments on the strategic (planning) level (SEA) and the project level (EIA) shall be. According to the Avoid-mitigate-compensate approach the first stage is the avoidance of negative environmental impacts through spatial planning (Figure 6.4). This implies a strong emphasis on the strategic planning and strategic environmental assessments. It is important to note that decisions on the planning level are often the only way to avoid negative impacts on the environment through spatial segregation of an industry such as offshore wind farming and areas of high value for nature conservation. At the project level, impacts may still be mitigated but usually cannot be completely avoided as the site selection has already been done. Large scale SEA offer the opportunity to designate priority areas for an industry and priority areas for conservation and it appears as justified putting much emphasis on the strategic level when planning to develop offshore windfarm areas.



Avoid potential negative impacts (e.g. by careful siting)

Minimise impacts that cannot be completely avoided by reducing their duration, intensity or extent during planning and construction.

Restore to reduce residual impacts after the project is completed.

Conservation action in other areas to compensate for loss of ecological or agricultural functions or qualities.

Figure 6.4 Avoid - Mitigate - Compensate approach. The most effective way of reducing negative impacts is always to avoid damage, and the preferred sequence of steps is to avoid damage, followed by minimization of impacts, restoration, with compensation as the last resort (NORWEGIAN MINISTRY OF CLIMATE AND ENVIRONMENT 2015)

This before it comes to project-specific EIA, effective marine spatial planning (MSP) (see chapter 6.1.1) is another basic approach to mitigate impacts by evaluating the considered region including the environment, marine protected areas, and human activities with standardised principles, to involve every interest group by defining assigned areas for each interest group and therefore by identifying possible alternative locations for OWFs (LÜDEKE 2017).

6.1.3 Restrictions in terms of space and time

Presence and vulnerability of species in an area may show substantial seasonal variation and impacts may be mitigated by restricting certain activities to periods of low abundance or low vulnerability. For example in Germany restrictions for pile driving are stricter in the summer period in areas of importance as nursing areas of harbour porpoises. Limiting restrictions to certain periods will also make it easier for the industry to accept restrictions. Difficulties occur when considering more than a single or only a few species, since times of restricted activities may otherwise be spread over a great part of the year, making e.g. planning of construction works challenging.

6.1.4 Overview of spatial mitigation approaches

Future thorough site selection is crucial to avoid or minimize negative effects of OWFs on the marine environment. According to the possible impacts following criteria regarding site selection should be considered:

Habitats

- Marine priority habitats, such as *Posidonia oceanica* seabeds and on coastal priority habitats like 1150* Coastal lagoons. Bundling of cables to reduce the area that is affected by cable laying.

Fish

- Important spawning grounds of fish.

Birds

- Corridors of bird migration
- Resting/wintering/breeding sites and bird foraging areas.
- Plan offshore windfarms in clusters to avoid bird population scattering and patchy displacement

Sea turtles

- Sea turtle reproductive sites in order to avoid impacts due to light and general disturbance.

Monk seals

- Monk seal reproductive sites and caves in order to avoid impacts due to light and general human disturbance.

Cetaceans

- Nursing areas of cetaceans
- Main migration routes
- Feeding grounds

Socio-economic sector

Investigate alternative sites if siting of an OWF or cables is planned

- in main shipping lanes
- in main fishing grounds
- in areas of enhanced military use
- in areas with known mineral resources
- across sites of cultural importance.
- Investigate the potentials for co-use, e.g. aquaculture
- Investigate the potentials to integrate OWFs in touristic activities or public information

6.1.5 Compensation

Also proposed by LÜDEKE 2017 within the marine mitigation hierarchy is the establishment of marine compensation measures to become mandatory for OWFs - but up to date, compensation measures do not exists for every species or all biotops, even international agreements, pieces of legislation (such as HELCOM, OSPAR, Habitat and Bird Directive), and the German MSP document request that approach.

In the marine environment, construction of artificial reefs or rebuilding of former reefs is a common practice which might compensate impacts on benthic habitats and fish but can also be beneficial for marine mammals. Further options to compensate for impacts associated with offshore wind energy might be the reduction of other impacts such as from fishing, shipping, sand mining or hunting. In such cases, specific stakeholders (e.g. fisheries, shipping companies) might receive a compensation payment when not using specific sensitive areas (LÜDEKE 2017).

The turbines of the OWF itself can act as artificial reefs and provide the opportunity to reintroduce individual target species to an area. In Germany and the U.S. European target species, e.g. European Lobster (*Homarus gammarus*) were reintroduced in OWF areas (LÜDEKE 2017). Nevertheless, regarding the entire ecosystem, using newly established artificial reefs on the turbines to generally compensate for destructed native habitats is not seen as an appropriate compensation measure.

6.2 Mitigation of underwater noise during construction

Regulations on underwater noise differ between countries. The most detailed and far-reaching requirements have so far been defined in Germany where pile driving is not permitted without applying noise mitigation measures (BSH & BMU 2014). The German government and the German Authorities have launched a number of R&D projects to develop noise mitigation during offshore pile driving and developed guidelines for noise prognosis, noise mitigation and noise recording during construction and operation (see MÜLLER & ZERBS 2013). Noise mitigation measures must meet certain criteria (VERFUß & PROJEKTTRÄGER JÜLICH 2012): they need to be effective (e.g. defined threshold levels must not be exceeded), reliable, non-obstructing the installation process, safe and easy to handle, cost-effective and sustainable (e.g. reusable, eco-friendly). The appropriate mitigation measures themselves and the implementation during construction work need to be described in detail within a noise mitigation concept, as well as the background noise measurements before construction and expected noise emitted during construction work are obliged to be constituted within a forecast reporting, each created by the windfarm operators (BSH & BMU 2014). The BSH is responsible for the validation and assessment of the potential environmental impacts for both schemes, when submitted by the operators to the BSH 12 months before OWF construction work starts (BSH & BMU 2014). Additionally, the efficiency of methods to reduce underwater noise, needs to be measured while in process from various distances, especially during noise-intensive construction work (impact pile driving), but also in tests before offshore works start (e.g, in a harbour test, hoses and compressors must be tested and a documentation has to be handed in) (BSH & BMU 2014). 'Soft starts' (start of pile driving with low energy) and use of deterrence is mandatory before offshore piling starts. Loud seal scarers (with effects ranging two kilometers and further) are now replaced by purpose-build devices, emitting lower, adjustable, and species specific noises schemes. The construction work and applied mitigation measures are controlled by the BSH for infringements of the guidelines or potential improvements, and results in noise emission values and the effectiveness of mitigation measures must be documented and reported to the BSH within 24 hours (BSH & BMU 2014). BSH reserves the right to give permission for pilings in batches, meaning that the permission to pile a certain number of piles is hold back until results of noise measurements of the preceding batch are checked and accepted.

6.2.1 Noise threshold values

In Germany a value for marine mammals' noise protection has been implemented in 2011: 160 dB (SEL) or 190 dB (L_{peak}) in a distance of 750 m from the noise source (BELLMANN 2018). This threshold is specific for harbour porpoise hearing sensitivity and adapted to the conditions and construction types of OWFs in the North Sea. This is a precausios value derived from early discussions in an expert group, assuming a potential onset of TTS at 164 dB_{SEL}. The 750 m range is regared as sufficient as it is thought that this area might be kept clear from such animals by using deterrents. The rationale of the threshold is thus to (1) define a maximum you allow animals to be exposed to and (2) a radius where you believe you can control the presence of these animals. Additionally, the duration of piling is limited to 180 min., including the deterrence time (BELLMANN 2018). Since 2013, the noise control concept for the North Sea of the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety), allows not more than 10% of the EEZ area and max. 1% of MPAs being exposed to noise levels above threshold preventing cetaceans of cumulative noise impacts (BELLMANN 2018). This hampers parallel construction of neighbouring turbines or parallel construction of turbines located close to Natura 2000 areas. However, there are no regulations national or international to restrict the continuous sound yet or to regulate crossborder effects of piling (BMU 2013). For the Mediterranean different threshold levels and exposure areas will have to be defined depending on the species resident in or migrating through that area. When applying floating technology the construction noise will be considerably lower compared to fixed foundations. This aswell has to be taken into account and further investigated to define appropriate threshold values and exposure areas in the Mediterranean Sea.

6.2.2 Deterrence devices

For this mitigation measure, several names exist: Acoustic Mitigation Devices (AMD), Acoustic Deterrent Devices (ADD) and Acoustic Harassment Devices (AHD). All terms aiming the same, but can be separated by their understandings, as for ADD the pinger (Figure 6.5) is known, for AHD a sealscarer (Figure 6.6), and both (pinger and sealscarer) are used for AMD. The aim of these acoustic harassment devices is the displacement of marine species from the area of risk. For sealscares themselves can elicit TTS, a combination of pingers (deployed ten minutes prior to the sealscarer to clear the area where the transducer of the sealscarer is lowered into the water) and a sealscarer (to clear the radius of 750 m) is often used. The devices are not adjusted to a single species but rather to a hearing range of seals (and also roughly e.g., harbour porpoises), specific devices for mysticetes/ baleen whales are not existent yet (but for high-frequency marine mammals, see below). Irregular sound profiles reduced the chance of habituation when application is prolonged. AHDs have initially been used for the protection of aquaculture against seals (underwater hearing range 50 Hz to 86 kHz) (FINDLAY et al. 2018). The variety of ADD types differ in their acoustic characteristics, but most of them produce sounds in the range of 2 to 40 kHz and source levels ≥ 185 dB re 1 µPa at 1 m (FINDLAY et al. 2018), and are able to be detected in distances up to 20 km to 50 km from the noise source (JACOBS & TERHUNE 2002; OLESIUK et al. 2002). Therefore, AHDs are critical as the soundslevel emitted to scare the marine species reach within levels which harm (physical and behavioural effects) the target and non-target species instead of protect them from piling induced injuries (FINDLAY et al. 2018). For fish no specific studies exist investigating the potential effectiveness of ADDs, but it was suggested that they may also be affective for fish with a good hearing capability. Care has to be taken when using ADDs as mitigation method in spawning areas during spawning season/spawning events as they could potentially displace the spawning fish from their spawning ground (BOYLE & NEW 2018). These issues even intensify, when several AHDs simultaneously are used within adjacent sites, over large areas or over longer periods of time (FINDLAY et al. 2018). Nevertheless, the deployment of ADDs is still widespread and partially increasing (FINDLAY et al. 2018). ADDs are included as potential beneficial measures in the Marine Framework Directive (MSFD) and in the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) (FINDLAY et al. 2018).

Figure 6.5 Pinger (© BioConsult SH 2018).

Figure 6.6 Seal scarer (© BioConsult SH 2018).

Within the last years, research continued so that a new type of pinger could be released which is low in costs, longer lasting (battery), optimized in pings, prevent habituation, and meet the criteria of EU and US regulations (FISHTEK MARINE 2018). The so-called Banana Pinger reaches randomized ping source levels of 145 dB with included harmonics (FISHTEK MARINE 2018) and therefore lies below the critical level of 160 dB. Since no large and widespread long-term studies have been released yet (only e.g. one from CROSBY et al. 2013), which used these Banana Pingers, it remains to be seen in future how effective and reliable it is.

Another most recently released AHD is the Fauna Guard (Figure 6.7), developed by Van Oord, to specifically scare off different kind of marine mammal species, and has been successfully implemented within the Dutch OWF projects 'Luchterduinen' and 'Gemini', and several German OWF in 2017 and 2018 (BIOCONSULT SH 2018). This mitigation device produce irregular noise patterns using similar frequencies to that of e.g., harbour porpoises and using "porpoise like" signals to warn and scare of the target species.

Figure 6.7 *Fauna Guard (FAUNAGUARD 2013)*

6.2.3 Primary mitigation measures

The mitigation measures of noise during construction work can be distinguished between primary and secondary approaches. The primary measures relate to adjustments of the piling materials and processes (e.g. time, hammer energy), the secondary refer to the concept to reduce noise due to extra devices.

The applicable noise mitigation during pile-driving depends on the foundation type of the turbines, which is in turn dependent of the ocean conditions (e.g. water depth, soil properties) (BSH & BMU 2014) and thus differs between projects.

Modification of piling (hydraulic) hammer

This approach is to reduce the noise from pile-driving by integrating a dynamic layer between hammer and pile (lengthen the contact time between hammer and pile), a so-called 'piling cushion' (BSH & BMU 2014). The 'cushion' is made of aramid fibres (BSH & BMU 2014). Alternatively, a spring or a pile head structure acting like a spring can be used (NEHLS et al. 2007). Also a drop hammer accelerated by gravity, or a double-acting pile driver working below its maximum power, can generate similar noise mitigation effects (NEHLS et al. 2007). These measure approaches prolongs the impacts time (NEHLS et al. 2007) and modifies the shape of the sound impulse (BSH & BMU 2014).

This 'cushion'-approach was applied during the installation for the foundation of the FINO2 research platform at Kriegers Flak in the Baltic Sea, where a monopile (3.3 m diameter) was rammed (BSH & BMU 2014). The 'cushion'-modification is able to reduce the noise by 11 dB (SEL) or 13 dB (L_{peak}) (BSH & BMU 2014) by prolonging the force impulse by a factor of two (NEHLS et al. 2007). However, as it proves to be difficult to find materials which can stand the high energy of large hydraulic hammers, the approach appears to be not feasible.

Adjustment of piling energy (soft start)

The adjustment of piling energy, the so-called "soft-start" of piling, is the pile-driving-process with reduced piling energy in the beginning (e.g. for 15 min) and a subsequent gradual increase of the piling energy. The advantage of a *soft-start* for pile-driving is that noise-sensitive, mobile animals (e.g. marine mammals, some fish species) are able to leave areas exposed to critical noise levels (BSH & BMU 2014). This noise mitigation measure decreases the risk of hearing damages to marine mammals present in the area, and is advised by an expert group to several Danish offshore windfarm operators already (PERROW 2019). Soft-start is mandatory in German windfarms, starting with around 10% of the hammer capacity (200-300kJ) and ramping up to full power after ten minutes (reaching usually around 1800-2400kJ). The soft-start often includes several single blows after the self-penetration (in between the inclination of the pile is controlled and corrected). These single blows also serve as a pre-warning for marine mammals. The *soft-start* is suggested to be used in combination with other mitigation measures simultaneously, such as pingers and seal scarers.

6.2.4 Secondary mitigations measures

Bubble curtain (Small BC/ Big BC)

There are different types of 'bubble curtains' (BC), but all are following the same principles: compressed air escapes from a perforated structure (like a hose laid on the sea ground) and generates air bubbles when ascending to the surface creating a curtain of bubbles, ideally all the way from the seabed to the water surface (BSH & BMU 2014). The air supply is produced by oil-free compressors located on a vessel. This measure is only applicable for certain depths (up to 42 m) (BAILEY et al. 2010), because if the water is too deep, the bubbles are too small at the bottom (due to high pressure in higher depth) and the effect is reduced (at least near the ground). A reduction of the affected area by up to 79% has been reached by a double 'big bubble curtain' and scientifically documented at measurement campaigns in two windfarms founded by the German authorities (all results available at www.hydroschall.de, NEHLS & BELLMANN 2016). The bubble curtain was first developed for harbour works and bridge building, e.g. in 2000 during the installation of the bridge pillars for the Bay Bridge (San Francisco-Oakland, USA) and has since than reached industrial standards (BSH & BMU 2014).

The 'small bubble curtain' (SBC) is set up in the vicinity of the corresponding pile which is planned to be drilled or piled coats the pile with bubbles (BSH & BMU 2014); whereas the 'big bubble curtain' (BBC) surrounds the whole pile-construction-site by placing it in a distance of 70 to 150 m from the pile (BSH & BMU 2014), thus reaching length of up to 600 m per hose.

'Big bubble curtain' (BBC)

The BBC (Figure 6.8) was initially used for an offshore wind turbine in a full-scale test in June 2008 during the foundation installation of the FINO3 research platform, erecting a 4.5 m diameter monopole (GRIEßMANN et al. 2009). As this first prototype *BBC* was non-optimised, an improved prototype *BBC* was used at the Trianel Windpark Borkum in 2011/2012 (BIOCONSULT SH et al. 2014). Overall, the *BBC* was improved multiple times, whereby the hose design (nozzle size), quantity of supplied air, and the system layout (linear or circular) varied and were tested successfully on 31 out of 40 tripod foundations (BSH & BMU 2014). Measurements of the most effective single and circular layout, used in 12 cases, resulted in an average noise reduction of 11 dB (SEL) and 14 dB (L_{peak}), whereas the double and linear *BBC* delivered greater decreases of up to 18 dB (SEL) and 22 dB (L_{peak}) (BSH & BMU 2014).

The very first serial test of a BBC during the construction period of an OWF was the R&D project, followed by several more applications with similar layouts of different OWF projects in the German Bight (NEHLS & BELLMANN 2016).

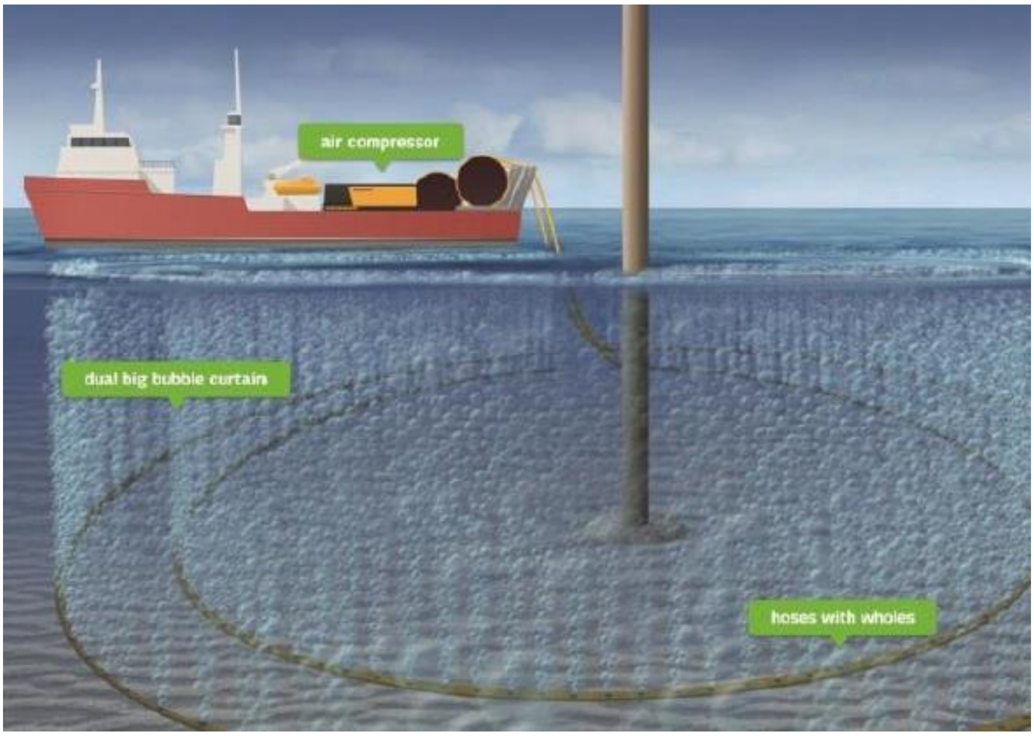


Figure 6.8 Schematic of a double ‚big bubble curtain' (RUMES et al. 2016)

the achieved noise reduction varies substantially between projects, depending on the *BBC* configuration itself, but also on ocean conditions (e.g. seabed, currents) and the project-specific installation logistics (e.g. *BBC* set up procedure, distance to pile) (BSH & BMU 2014).

Until now (state 12.08.2016) more than 1000 *BBC* have been installed for several projects, starting with the above mentioned FINO3, followed by 'Alpha Ventus' and Borkum West II (HYDROTECHNIK LÜBECK SPEZIALWASSERBAU 2016) (Figure 6.9).

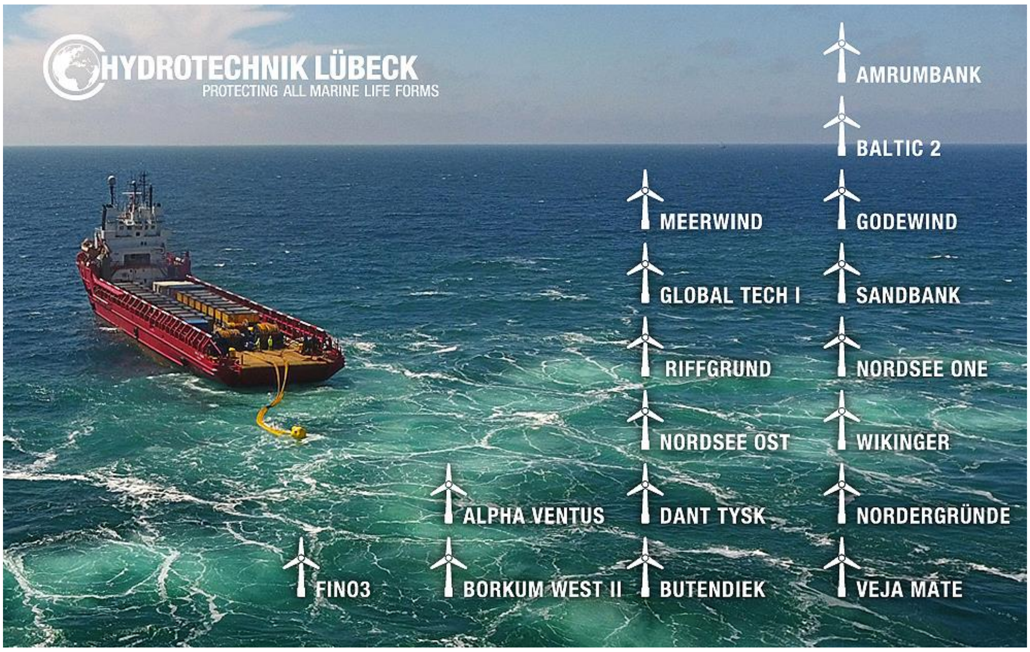


Figure 6.9 *Projects, in which 'big bubble curtains' have been used (state 08.2016)*(HYDROTECHNIK LÜBECK SPEZIALWASSERBAU 2016)

'Small bubble curtain' (SBC)

Likewise, as with the BBC, the first prototype of the SBC was non-optimised (used at 'Alpha Ventus' in 2009), as due to the current and weather conditions one part of the *SBC* failed, leading to an uneven bubble curtain formation as well as 'acoustic windows' (BSH & BMU 2014). After this failure, the SBC was redesigned entirely and has been tested at first in 2012 during the tripile foundation installation at the 'BARD Offshore 1' windfarm (BSH & BMU 2014). This redesigned *SBC* comprised three hose arrays, where "each array consisted of eleven elastic polyethylene hoses with a length of 60 m, with one unperforated hose supplying the ten perforated hoses with air" (BSH & BMU 2014). The three hose arrays "reeled out from drums at the top of the pile guidance frame" (BSH & BMU 2014). During the implementation, different configurations were tested which revealed the most effective having all three hose arrays active, resulting in maximum air supply (BSH & BMU 2014) and a noise reduction in direction of current of 13 dB (SEL) and 14 dB (L_{peak}) (BELLMANN et al. 2014). This noise reduction was not possible to achieve when measuring the noise reduction values against the current direction; it resulted in a noise reduction of only 2 dB (SEL) and 0 dB (L_{peak}). This means, 'small bubble curtains' become inefficient, when currents drift the bubbles and the noise emitting source is not surrounded by the curtain. The redesigned SBC is commercially available, even though still in serial testing. However, the drift of the bubbles and the resulting problems with only unidirectional attenuation has not been solved (BSH & BMU 2014).

Casings (Pile sleeve & telescopic tube)

Casings act as noise barrier as they surround the pile (NEHLS et al. 2007). Casings are well applicable for monopiles - they are bigger than the pile diameter itself – as well as implementable for other foundation types (jackets and tripods), too (BSH & BMU 2014, KOSCHINSKI & LÜDEMANN 2013). The casings differ between pile sleeves of different materials, or hollow steel tubes (BSH & BMU 2014).

The *IHC Noise Mitigation System (NMS)* is one example for the umbrella term 'casings'. It is made of a double steel wall, the interspace between inner and outer wall is filled with air, and inside the cylinder (between inner wall and pile) it is possible to add a bubble curtain, so that the noise emission is reduced twofold (BSH & BMU 2014). In 2012, the first IHC NMS was applied at the Riffgat windfarm (BSH & BMU 2014). The noise reduction at Riffgat was approx. 16 to 18 dB (SEL) and 13 to 21 dB (L_{peak}) for the IHC NMS, using a 5.7 to 6.5 pile diameter (BSH & BMU 2014). The maximum damping efficiency is between 500 Hz and 10 kHz (VERFUß & PROJEKTTRÄGER JÜLICH 2012). Although this mitigation measure is very efficient, it is limited on the other hand, as "the weight of a casing increases with water depth" and therefore the deployment depends on the jack-up vessels' storage and crane capacity (BSH & BMU 2014). However, the IHC-System has been fully developed as an installation tool (the "integrated monopile installer"), including a guiding system, to hold the pile and correct the pile alignment and instruments to measure inclination and rotation.

Cofferdams

A cofferdam was primarily tested in 14 – 25 m water depth in 2011 at 'Aarhus', using a pile diameter of 2.1 m, a diaphragm seal at the bottom, and 4 ejector pumps to evacuate the water (VERFUß & PROJEKTTRÄGER JÜLICH 2012; BSH & BMU 2014). The cofferdam was placed to the seabed, followed by the insertion of the pile, after which the water is pumped out of the space between the pile and the cofferdam (BSH & BMU 2014). This noise mitigation measure resulted in noise reduction within 16 to 20 kHz and 22 dB (SEL) and 18 dB (L_{peak}), being thus quiet effective (VERFUß & PROJEKTTRÄGER JÜLICH 2012; BSH & BMU 2014). However, as a cofferdam is more difficult to handle as compared to casings like the NMS, it has not been used apart from the demonstration project.

HSD (Hydro Sound Dampers)

Likewise 'small bubble curtains', hydro sound dampers (HSD) are placed in the vicinity of the pile but differ in construction (BSH & BMU 2014). Unlike the 'small bubble curtains', the HSD consist of a fixed net or frame at which small elastic balloons filled with gas and robust PE-foam elements are fixed (KOSCHINSKI & LÜDEMANN 2013). This whole construction is released by winches to be laid around the pile during pile-driving (Figure 6.10) and is hold to the seabed by weights (ELMER et al. 2011). The weight of that measure is low (VERFUß & PROJEKTTRÄGER JÜLICH 2012).

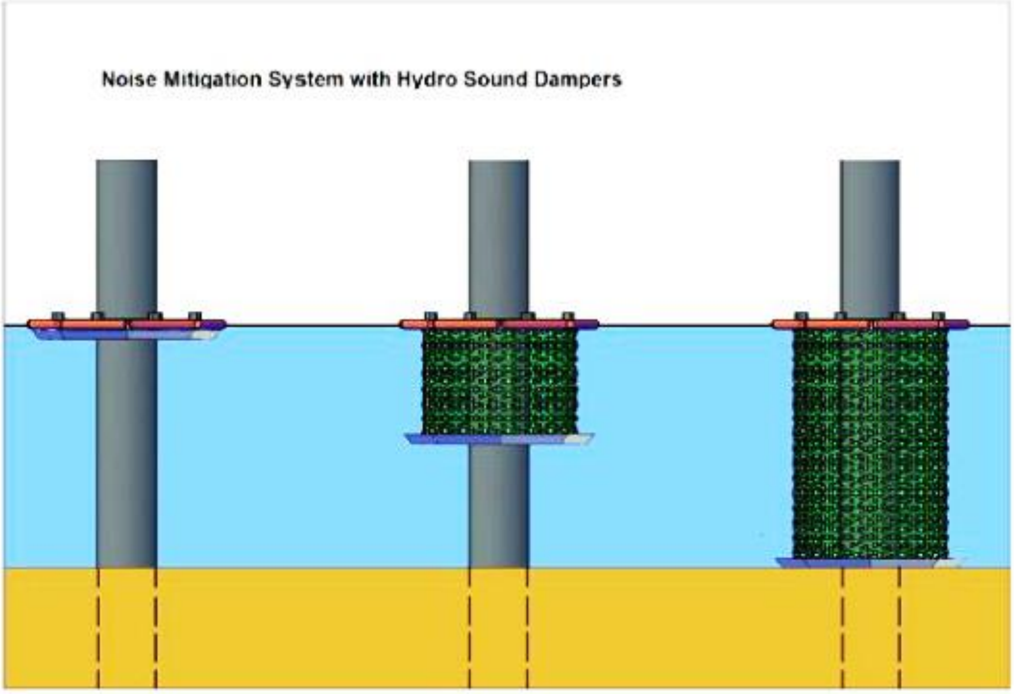


Figure 6.10 Schematic of the HSD single-net system (KOSCHINSKI & LÜDEMANN 2013)

The main advantage of the HSD system compared to the 'small bubble curtain' is, that the number and composition of the HSD elements can be varied, as well as the balloon size is adaptable to the necessary noise emission reduction, depending on the varying ramming noise during pile-driving (Koschinski & Lüdemann 2013), and that the "bubbles" cannot drift to one side of the pile. On the contrary, regarding the bubble curtains the air bubbles are difficult to adjust to a specific range of sound (Elmer et al. 2011). Another advantage of the HSD net is that it is permeable for the ocean currents, effective for the whole frequency range, as well as independent of continuous compressed air supply (BSH & BMU 2014, Elmer et al. 2011). Also an essential benefit of HSD is the very variable system to apply it to several different pile-designs, e.g. it can either be attached at the pile or float around it (Koschinski & Lüdemann 2013).

The first HSD-system test was conducted with the non-optimised prototype during the ESRa project (BSH & BMU 2014), followed by a full-scale test with the optimised prototype in 2012 during the installation of one monopile for the London Array windfarm (BSH & BMU 2014). Measurements at different positions resulted in broadband noise reductions of 7 to 13 dB (SEL) and 7 to 15 dB (L_{peak}), and a "maximum damping efficiency of approx. 15 dB (SEL) between 200 and 500 Hz, while above 4 kHz no insertion loss could be recorded" (BSH & BMU 2014). Measurements within a large wave flume revealed much larger sound reduction by HSD elements than bubble curtains in offshore waters yet (Elmer et al. 2011). "A defined maximum reduction within the frequency range of 100 to 300 Hz was reached by tuning the HSD elements to 120 Hz. It is unclear if these results can be transferred to piling noise under offshore conditions" (Koschinski & Lüdemann 2013).

This optimized HSD system is commercially available and has been used in several windfarm construction periods between 2014 and 2018 (www.offnoise-solutions.com).

BLUE Piling Technology

Blue piling is a new technology to reduce the piling noise made of the steel ram by using accelerated water mass created due to gas combustion (Figure 6.11) (Fistuca 2018). According to Fistuca 2018, this approach reduces the noise normally produced by a conventional hydraulic hammer while piling by approx. 20 dB (Fistuca 2018). Moreover, fewer blows are needed for the installation and the low stress amplitudes will descend the installation fatigue (Fistuca 2018). Also the loads on components and the number of offshore operations for installation of secondary equipment (e.g. boat landing, anodes) can be reduced as pile pre-assembling previous of piling is possible (Fistuca 2018). In accordance to Fistuca 2018, this noise mitigation measure is appropriate for all conventional piling types and foundation works.

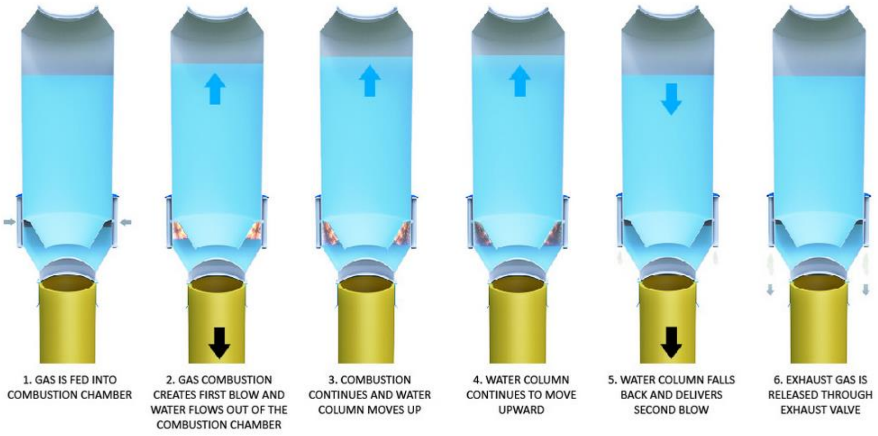


Figure 6.11 Illustration of the blue piling technology (Fistuca 2018)

Vibratory piling/ 'vibrodriving'

For this noise mitigation measure, the hydraulic hammer is replaced by a vibratory plate (BSH & BMU 2014). Using *vibratory piling*, the pile can have a diameter of up to 6.5 m and be installed in medium to dense bedded soils (BSH & BMU 2014). For construction works apart from OWFs, shorter piles with diameters up to 30m have been vibrated into the ground. With this approach, a noise level reduction of 15 to 20 dB below the SEL (Sound Exposure Level) associated with undamped impact pile driving can be achieved (BSH & BMU 2014). Vibratory piling was used at the offshore windfarms 'Alpha Ventus', 'Riffgat' and 'Anholt' with different results in noise level reductions depending on the piling depth, pile diameter and soil properties (BSH & BMU 2014). In many OWF construction processes, vibratory piling has been used to bring the pile to an initial depth before continuing piling with a hydraulic hammer. For other on- and offshore projects, vibro-piling is commonly used, therefore this installation method is expected to become more common within the next years.

Drilled foundations/ Offshore foundation drilling (OFD)

The offshore foundation drilling was implemented in a project funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Nukleare Sicherheit, BMU), called "Further Development of VSM" (VERFUß & PROJEKTTRÄGER JÜLICH 2012). This measure is suitable for e.g. rocky seabed, suitable for pile diameters up to 8-10 m, and reaches noise levels expected to begin at 117 dB (SEL) and 122 dB (L_{peak}) respectively (VERFUß & PROJEKTTRÄGER JÜLICH 2012), reaching up to 155 dB in 750 m for larger diameters. Basically, this approach is possible to use for depths up to 80 m (BSH & BMU 2014). The disadvantage of OFD are high costs (BSH & BMU 2014). OFD has been applied at three monopiles with each 4.75 m at the UK 'Barrow' windfarm – but without any noise measurements (BSH & BMU 2014). However, in Italy (Naples) at a water-saturated onshore environment a 5 m wide shaft was drilled into the soil for 39 m and estimated noise values resulted in SPL of 117 dB and a peak SPL of 122 dB at a distance of 750 m (BSH & BMU 2014). Much higher values are expected for bigger diameters and rocky grounds. As the costs for drilling technology are still high, the cutting speeds, capacity for bigger monopile diameters (up to 10) and compatibility for offshore conditions are attempted to improve (BSH & BMU 2014).

Suction buckets/ suction cans

Instead of using piling and drilling approaches, quite some offshore structures can be installed in the seabed with suction buckets or suction cans (BSH & BMU 2014). The only noise source for suction buckets/ cans is the suction pump to remove the water and loose sediment out of the inner part of the suction bucket (BSH & BMU 2014). For the installation of this substructure, the suction bucket/can is set to the seabed and subsequently sinks into the soil by its tare weight (BSH & BMU 2014). In addition, the suction pumps generate a depression to the inner part of the bucket/can and both, the weight of the foundation and negative pressure difference, lead to lower the bucket/can into the seabed (BSH & BMU 2014). Suction foundations comprise 'monopods', the suction buckets with diameters of 9 to 30 m, and 'multipods', the suction cans having diameters of 3 to 6 m for the use of tripods or jackets (BSH & BMU 2014). The mono- and multipods can be levelled to the seabed conditions (BSH & BMU 2014).

The suction bucket/can foundation appears like "a hybrid of a gravity-based structure and a monopile" and are deployable in deep and shallow waters, but limited to homogenous water-saturated sediments (e.g. sandy soils and clay) (BSH & BMU 2014).

Gravity-based and floating foundations

Both foundation types, the gravity-based and floating foundation, are both suitable to assembly without great noise emissions, as they do not have to be drilled into the seabed. Measurements for noise emitted by installation or during the operational phase (e.g. for the chains the floating foundation is attached to the anchoring element) have not been taken yet.

Both foundation types have their specific advantages. Gravity-based foundations have been tested successfully for OWFs especially in flatter waters, but not within very deep waters yet (> 40 m) (LÜDEKE 2017). Whereas floating foundations are especially suitable for deep water depths, when drilling is not applicable anymore (more information see chapter 2).

6.2.5 Surveillance of construction sites

In many countries, active or passive surveillance is mandatory before, during or after constructions works. Methods to monitor the direct vicinity of a piling location include Marine Mammal Observers (MMOs), specially trained biologists, scanning 360° around the construction site. In a method statement, the scanning area and range of the MMOs is defined and what actions have to be taken when marine mammals enter so called pre-warning or warning zones too close to the site. Identification of marine mammals by the MMOs can lead to additional deterrence cycles, reduction of hammer energy or a temporary stop of piling. If piling after sunset is allowed, MMO or the vessel often must be equipped with thermal imaging cameras.

An alternative to MMOs (or in combination with MMOs) is a wireless detection system, laid in a dense circle around the construction site (Figure 6.12). To monitor marine mammal intruders a grid of buoys is spread around the windfarm, all of which transfer marine mammal signals to monitors onboard a vessel. The monitors are under permanent surveillance and marine mammals can be detected in real time, and mitigation or deterrence actions can be started immediately.

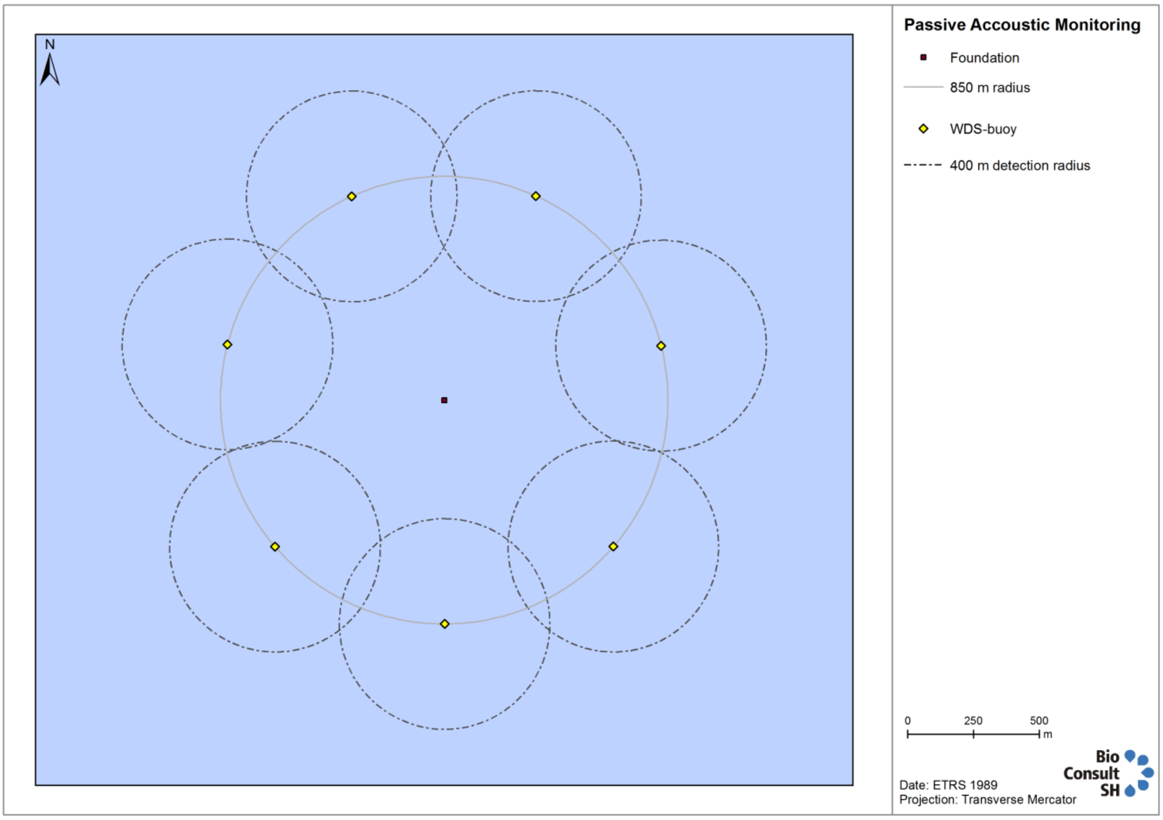


Figure 6.12 Exemplary distribution of wireless marine mammal monitoring buoys with a detection range of 400m (BIOCONSULT SH 2018)

This system has been tested and used successfully throughout the construction phase at the German windfarm 'NSO' (BIOCONSULT SH 2014).

6.2.6 Compensation

Impacts on the environment and species will remain, even though avoidance and mitigation measures have been considered and implemented before and during the OWF construction work, as well as during operational phase (LÜDEKE 2017). Compensation measures are a requirement within the German Federal Nature Conservation Act when interfering with nature (LÜDEKE 2017). However, German offshore wind has been excluded from the otherwise mandatory compensation measures to support this renewable energy technique for many years. Nevertheless, compensation measures should focus on the affected species and mitigate the impacts on those - thus, compensation measures should lead to the establishment or stabilization of habitats (e.g. reefs) or to improvements of a populations´status. In Germany for example, a lobster population (*Homarus gammarus*) was reintegrated to the OWF Riffgate for it new rocky scour protection formed a suitable habitat. In the US compensation measures were implemented as well, e.g. for oyster reefs (LÜDEKE 2017).

Compensations for OWFs implemented on land are possible, but only for species inhabiting both areas, on- and offshore, e.g. specific bird species (LÜDEKE 2017). This onshore compensation for offshore impacts might be difficult for the legal status, at least in Germany, as "the German federal law requires compensation to be made in the same natural area" (LÜDEKE 2017).

Another form of compensation measure is the minimization of the intensive marine use of e.g. fisheries or shipping companies by paying stakeholders to leave specific sensitive areas out of their catchment area (LÜDEKE 2017).

An international marine compensation regulation might be helpful to take appropriate measures and pay regards to the fact, that most waters are cross-border linked and thus international measures are urgently needed (Figure 6.13).

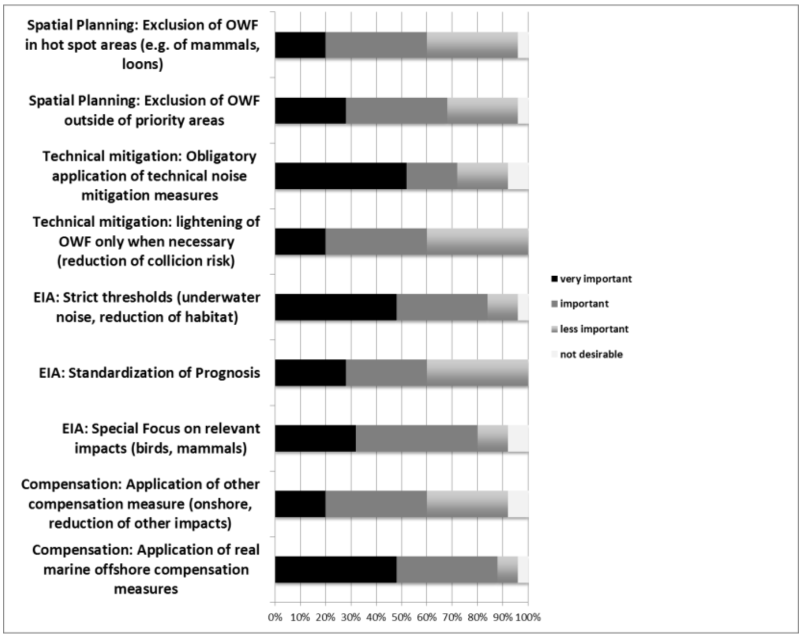


Figure 6.13 Overview of assessed „relevance of suggestions for good practice in the environmentally sound development of OWFs" (Delphi method by LÜDEKE 2017, expert interviews via questionnaire)

6.2.7 Conclusion

The mitigation measures for noise during OWF installations presented in this chapter are based on the knowledge of studies and experiences from OWF-projects especially in the North and Baltic Sea. The conditions in the North and Baltic Sea differ from those in the Mediterranean Sea severely, e.g. the soil properties (North and Baltic Sea mainly sandy, Mediterranean several different types of soils) and depths (the Mediterranean Sea is in part considerably deeper than North Sea and Baltic Sea). However, as there are less tidal currents in the Mediterranean most mitigation methods will likely be applicable for projects using non-floating foundation in shallow waters.

For marine mammals it has been shown that noise mitigation reduces the disturbance response greatly (BIOCONSULT SH et al. 2016). Little known is about the effects of noise mitigation on fish sea turtles, however, it is a fair assumption that the species groups will also benefit from lowered noise.

6.3 Mitigation of light

As for all emissions, light pollution from offshore windfarms should be reduced to what is needed and what is required legally. Specific mitigation strategies are recommended with respect to the collision risk of birds.

For birds, there is overwhelming evidence that night lighting of offshore structures attracts especially migrating land birds under poor weather conditions and may thus increase the collision risk. While it is plausible, that lighting also increases the visibility of turbines and thereby might enhance avoidance, there is little indication that this could result in a successful mitigation strategy and a reduction of lighting must be given first priority to mitigate the attraction of birds and other wildlife to offshore windfarms.

Light might further attract other marine wildlife such as fish and turtles to offshore windfarms, however, at this stage there is no information available whether this might lead to negative impacts and no specific mitigation has been demanded so far.

Offshore turbines and substations in the windfarms are equipped with two types of lights: on the top aviation lights and ship navigation lights on the lower parts.

Recently, the Bureau of Ocean Energy Management drafted the following recommendations (ORR et al. 2013):

1) Fewer lights are preferable to more lights.

2) Lower intensity lights are preferable to higher intensity lights.

3) White lights are the least favorable choice for lighting structures.

4) Strobing lights are preferable to steady lights.

Light on demand

The airspace in the height of the turbines is not regularly used for aviation and aviation lights are in practice only needed for the case that rescue helicopters or service helicopters have to operate in the windfarms. If aviation lights of the windfarms are only turned on when such air traffic occurs, lighting can be reduced by more than 99%.

In Germany, light on demand will be mandatory for the aviation lights on top of the onshore wind turbines. In general, there will be no red or white lights turned on for aviation safety; a sensor (either radar or transponder system) will detect approaching air traffic and turn the lights on.

Concepts for light on demand are so far restricted to aviation light, however, as navigation of ships is today primarily based on GPS and radar, the demand of navigation lights of offshore windfarms should be evaluated and mitigation concepts should be developed.

Light color

Several studies have aimed to mitigate attraction of birds by light colour selection, but haven’t so far reached conclusive results, although the tendency is to avoid the colour white or luminaires which have a broad wavelength spectrum. Also red and white light should be avoided and instead green and blue light should be preferred (SSC WIND 2014). An additional complication is added by the fact that the colour red of a certain wavelength does affect the orientation abilities of birds at night (e.g. BISCHOF et al. 2011).

Two studies from the North Sea and the Netherlands found that fewer birds were attracted to low-frequency-red lights (including green and blue lights), compared with the number expected, or the number attracted to white or red lights. A study at a gas production platform in the southern North Sea on three nights in October 2007 (VAN DE LAAR 2007) found that the number of migrating birds circling the rig was 10-50% of the number expected when the majority of external lights were replaced with 'low frequency red' bulbs (150-2,500 birds observed circling vs. 750-5,000 birds expected). Low red bulbs emit lower levels of red light than standard bulbs. A replicated, controlled study from Friesland, the Netherlands (POOT et al. 2008), in September-November 2003, found that on clear nights, significantly more migrating birds were attracted to two 1,000 W lamps when they were covered with opaque white or red filters (61% of 38 birds and 54% of 13 birds reacting to each), compared with green (13% of eight) or blue (3% of 37) filters. The same pattern, but with higher overall levels of disorientation and attraction were detected on overcast nights (white: 81% of 156 birds reacting; red: 54% of 24; green: 27% of 77; blue: 5% of 38). Thus, recommendations to use lights with short wavelength radiation are thought to decrease collision risk.

The same pattern in light avoidance was confirmed by the results of HILL et al. (2014) which show that the light colour plays a role in the effect of phototaxis on nocturnal migrating birds. With regard to the coloured lamps a colour effect could be determined. With the light colour red, the highest number of bird-positive images was detected compared to the light colours yellow, green and blue. So all analyses presented in the study lead to the colour green as the least phototactic. At this point it should be remembered that the sample size was not very large. For the practical application of emergency lighting this circumstance is less favourable, since colour green is not used. Nevertheless, care can be taken with white lighting not to use the long-wave red portions as possible and rather resort to cold white bluish lamps. Red lamps could be replaced with other coloured lamps.

Flashing frequency

Past recommendations suggest removing non-flashing or steady burning (red) lights on communication towers or rejecting the use of strobe lights. It is recommended to keep the luminescent phases as short as possible, the dark phases as long as possible (SSC WIND 2014).

For migrant birds, Kerlinger et al. (2010) as well as Gehring et al. (2009) investigated that steady-burning red lights attract migrants but flashing ones do not, as they did not find evidence to suggest that flashing red lights cause large numbers of fatalities. Solid red or pulsating red incandescent lights should be avoided as they appear to attract night-migrating birds (e.g. passerines) (GARTMAN et al. 2016a and references therein)). HÖTKER (2006) states that flashing red safety lights should be reduced to a minimum and intervals between each flash should be made as large as possible.

On the contrary, less bird attraction or less frequent behavioural reactions caused by flashing light when compared to continuous light (e.g. RICH & LONGCORE 2006a; EVANS et al. 2007; GEHRING et al. 2009) were not confirmed by HILL et al. (2014) results.

Light intensity

It is still unknown how lighting intensity offshore can affect migrant and seabird species movement, whether it be viewing the facility as an obstacle and flying around it, becoming disoriented i.e. have a 'trapping effect', or becoming attracted to them to rest or forage (HÜPPOP et al. 2006; BAND et al. 2007; BLEW et al. 2013; SSC WIND 2014). However, it is clear that light intensity and thus the range where the light might be visible or attractive do play a role.

Various opinions in lighting are given but all conclude to avoiding lighting turbines when and where possible. BALLASUS et al. (2009), from an evaluation of 400 studies, view artificial lighting as a threat to birds and bats and recommend reduced lighting.

A before-and-after study on St Kilda, Scotland, between 2005 and 2008 (MILES et al. 2010) found that fewer seabirds were attracted to artificial lighting and downed when lighting was reduced at night, compared to when normal lighting was in place (27 birds found when lighting was reduced for the whole of autumn 2007 and most of 2008 vs. 54 birds downed and two dead when lighting was not reduced in 2005-6 and 24 downed in 20 days when lighting was not reduced in 2008).

However one should consider that lighting of turbines is not standardized and it must fall within the country’s aviation transport regulations which vary. Similar to land-based lighting requirements, offshore wind facilities are obliged to be equipped with lighting for general aviation and shipping safety. So for safety reasons and in case they cannot be avoided, they should be set within the minimum number, minimum intensity, and minimum number of flashes based on the country’s regulation (MANVILLE 2005).

BLEW et al. (2013) presented that for offshore wind facilities and specific turbines ‘the less the lights, the better’. It was recommended to rather install ship safety lights only on corners of the facility and some peripheral wind turbines per windfarm.

Light emission

Also the general minimization of lighting intensity of facilities is a suggestion for example by not illuminating large areas or by using inverse LED plates/letters/numbers and other distinctive recognition elements. It is recommended to keep the radiation angle as small as possible, the radiation upwards should be avoided and indirect radiation should be preferred against direct radiation (SSC WIND 2014).

Additional radar systems for ships and aircrafts / Deflectors

Also considering that birds may become attracted to the light during adverse weather (BSH & BMU 2014) the possible use of need-based lighting when aircrafts or ship vessels approach (using appropriate detection technology) is also recommended. So in this sense airplanes could be equipped with secondary radars (Transporter), passive radars or other systems (‘FLARM’) used for traffic and collision warning in general aviation. In this way security lights could be automatically switched on but only while ships or aircrafts are in the vicinity of the offshore windfarm. Deflectors are also recommended offshore, so markings that were traditionally lit elements could potentially be replaced by self-reflective imprints (BLEW et al. 2013).

Further research

Current research has mainly focused on migratory birds and little for bats or any other species groups in or around wind facilities. This is most likely be due to minimal direct impacts, but the species are still nevertheless impacted through light intensities and land management measures that may alter, displace, or disorient them. It must be noted that some effects of lighting are very difficult to study as for now there is no method to register bird collisions offshore (DIRKSEN 2017). There has been significant research on such issues like artificial lighting (RICH & LONGCORE 2006b), where mitigation measures can be applicable but none directly involving wind energy (GARTMAN et al. 2016 and references therein).

Due to inconclusive results, more recent studies need to be conducted to verify previous studies (GARTMAN et al. 2016a) and due to unavoidable subjectivity, it seems appropriate to make the interpretation of changes in flight direction as cautious as possible (HILL et al. 2014).

There is also a need for further research into the effects of light combined with the influence of weather. This would require a data collection over a long period of time with as different weather conditions as possible. Especially the performance of light tests in nights with strong bird migration and at the same time adverse weather conditions with fog or other conditions restricting the visibility would presumably be promising, since under such conditions the response of birds to artificial light sources is particularly pronounced.

A number of studies around the Canary islands focus on fatal light attractions (street lights on the islands) for night-active species of the groups *Calonectris, Oceanodroma, Hydrobates* and *Puffinus*; some of those species come only at night to their breeding places on land and can be confused by street lighting (RODRIGUES et al. 2009, 2012, 2015; RODRIGUES & UNEP 2016). It should be considered to assess the presence of these species in the Mediterranean Sea and potential effects of lighting regimes offshore.

6.4 Mitigation of impacts on habitats and benthic communities

As mentioned in chapter 6.1.1 marine spatial planning is the initial step to mitigate impacts to habitats and benthic communities by selecting appropriate marine sites for offshore windfarm installation as well as the most appropriate route for cable laying. Important targets are to minimize impacts on ecological important areas such as Marine Protected Areas and other areas hosting protected habitat types included in Annex I and protected species included in Annexes II and IV of the EU Habitats Directive 92/43/EEC.

In cases where protected habitats are present, detailed delineation of their distribution and of the seabed in general should be undertaken. Sensitive or protected habitats should be avoided by selection of suitable locations for individual wind turbines. Through detailed delineation the most appropriate cable routing can also be identified and as well as necessary planning adjustments in micro scale to avoid sensitive or protected habitats.

Choosing methods with the smallest possible footprint: To reduce the impacts on benthic organisms and communities near windfarms, preference should be given to foundation designs with the smallest possible impermeable footprint. Also construction zones should allocate just the minimum areas necessary and construction activities should not deviate outside the specified zones. OSPAR commission guidelines (OSPAR COMMISSION 2012), also suggest shortest possible length for laying cables, bundling with existing cables and to select the minimum number of crossings with other cables to minimize number of crossing structures. These mitigation measures can contribute to minimize areas needed for the operation of offshore windfarms either from individual project or from clusters of projects because of cumulative impacts.

Methods minimising turbitity and sediment suspension: Effort should be made during construction to avoid or minimise the re-suspension of sediment and the generation of turbidity plumes. In cable laying as in the construction of wind turbines, the techniques used should be selected so as to keep sediment relocation and turbidity plumes to a minimum. Burial technique and depth are of major importance during construction (burial technique) and operation (burial technique and depth) of an OWF. When planning the cable route, it is recommended to use a technique that causes few sediment displacement as well as few (morphological) changes of the sediment. Morphological changes of the sediment may occur in soft substrates. Burial techniques should be applied dependent on the type of substrate and in general should re-suspend as little sediment as possible. In case the cable trench does not fill naturally with surrounding sediment, it should be filled with on-site material.

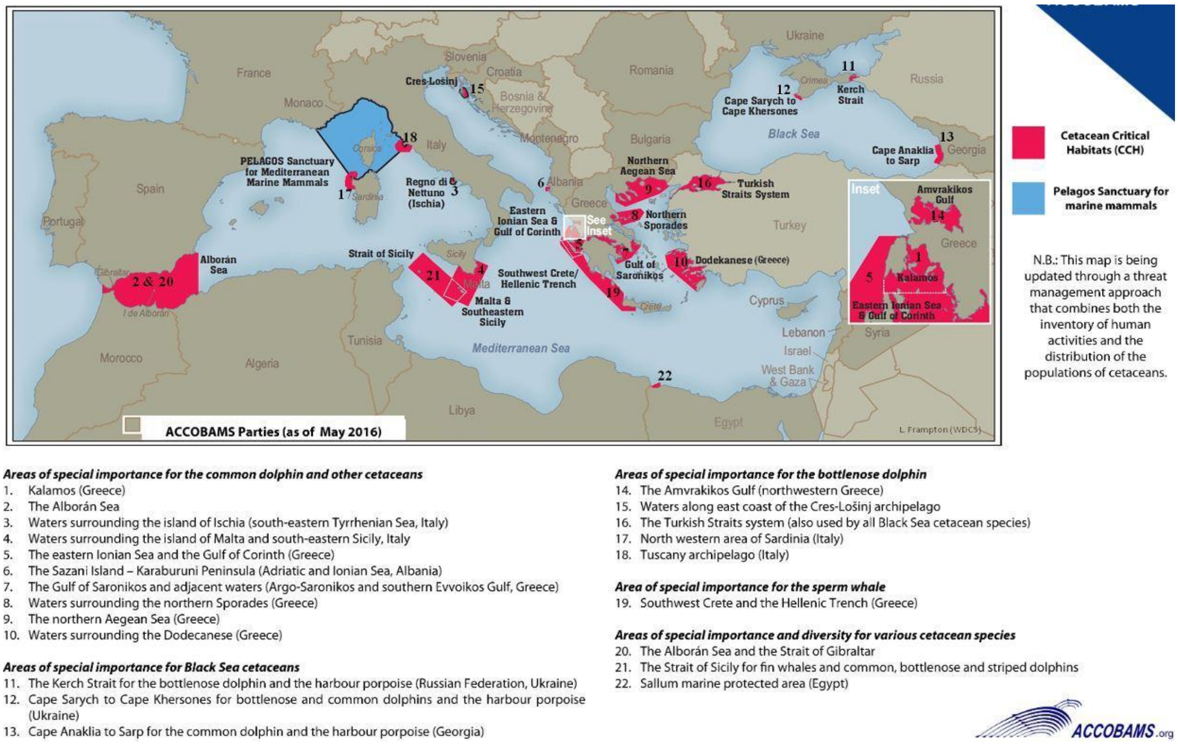
As burial techniques the OSPAR guidelines recommend jetting or ploughing. In case of sensitive habitats (e.g. salt marshes), horizontal drilling could be a method with the least environmental impacts. During horizontal drilling the timing of drilling has to be considered, as performed on the island of Norderney, Germany (located in a Natura 2000 area), where horizontal drilling was performed considering tides in order to minimize environmental disturbance. Nevertheless, in areas with hard substrates and of great water depth burial of the cables is not always possible. BERR et al. (BERR DEPARTMENT FOR BUSINESS ENTERPRISE & REGULATORY REFORM 2008) describe alternative cable protections for cases where cables either cannot be buried or at cable crossings. These techniques impact different on the marine environment and require different mitigation techniques. Rock dumping for instance is an established technique for covering and protecting cables along the entire cable route or at cable/pipeline crossings. It is recommended to favour on-site rocky materials over non-local rocks or concrete as every substrate foreign to the area provides an additional habitat that might favour the colonization of invasive species (BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE 2017). Protection by frond mattresses have the advantage that they force the suspended material to settle and this way cover the cable with natural on-site material. According to (BERR DEPARTMENT FOR BUSINESS ENTERPRISE & REGULATORY REFORM (2008) storm events can remove the deposited material from the cables and the fronds.

In cases of solid rock at the landing of cable route and avoidance of this area is not possible, horizontal directional drilling has been proposed as the most suitable protection method as blasting through the rock would lead to significant environmental impacts. Further offshore, either a rock ripping plough, rock wheel cutter or a vibratory share plough have been suggested to be most suitable (BERR DEPARTMENT FOR BUSINESS ENTERPRISE & REGULATORY REFORM 2008).

6.5 Mitigation of collision

6.5.1 Ship strikes

Among the five international ship strike hotspots, two Mediterranean Sea regions are determined: the northern Mediterranean Sea, and the Strait of Gibraltar (CARRILLO & RITTER 2010). As critical cetacean habitats (Figure 6.14) and main shipping routes often overlap, mitigation measures are already receiving increased attention by scientists and politicians, but without demanding measures so far (CAMPANA et al. 2015).



Areas of special importance for the common dolphin and other cetaceans
1. Kalamos (Greece)
2. The Alborán Sea
3. Waters surrounding the island of Ischia (south-eastern Tyrrhenian Sea, Italy)
4. Waters surrounding the island of Malta and south-eastern Sicily, Italy
5. The eastern Ionian Sea and the Gulf of Corinth (Greece)
6. The Sazani Island – Karaburuni Peninsula (Adriatic and Ionian Sea, Albania)
7. The Gulf of Saronikos and adjacent waters (Argo-Saronikos and southern Evvoikos Gulf, Greece)
8. Waters surrounding the northern Sporades (Greece)
9. The northern Aegean Sea (Greece)
10. Waters surrounding the Dodecanese (Greece)

Areas of special importance for Black Sea cetaceans
11. The Kerch Strait for the bottlenose dolphin and the harbour porpoise (Russian Federation, Ukraine)
12. Cape Sarych to Cape Khersones for bottlenose and common dolphins and the harbour porpoise (Ukraine)
13. Cape Anaklia to Sarp for the common dolphin and the harbour porpoise (Georgia)

Areas of special importance for the bottlenose dolphin
14. The Amvrakikos Gulf (northwestern Greece)
15. Waters along east coast of the Cres-Lošinj archipelago
16. The Turkish Straits system (also used by all Black Sea cetacean species)
17. North western area of Sardinia (Italy)
18. Tuscany archipelago (Italy)

Area of special importance for the sperm whale
19. Southwest Crete and the Hellenic Trench (Greece)

Areas of special importance and diversity for various cetacean species
20. The Alborán Sea and the Strait of Gibraltar
21. The Strait of Sicily for fin whales and common, bottlenose and striped dolphins
22. Sallum marine protected area (Egypt)

Figure 6.14 Map of the Cetacean Critical Habitats (CCH) and areas important for particular species (ACCOBAMS 2016)

Collisions with ships are a risk to marine mammals and sea turtles mainly. Especially large, heavy and slow swimming whale species are affected by ship collisions as they are not as manoeuvrable as smaller species. Studies revealed that cetaceans do not move away from ship noise which results in more than the overall whale deaths caused by ship strikes (ORAL & SIMARD 2008). But also dolphins and small cetaceans, as well as the small and agile sea turtles collide with ships and suffer from severe wounds.

The appropriate site selection for OWFs and their concurrent ship traffic is also of concerns for other marine species. Since 2004, all passenger vessels and vessels over 299 gross tonnages are obliged to install an AIS (Automatic Identification System) transponder, which is a ship-to-ship and ship-to-shore system to track the vessel movements as a surveillance tool to increase the protection of the oceans environment (COOMBER et al. 2016). Based on AIS data, ship speed and routes can be assessed and for the windfarm relevant traffic adjusted. The main measures are usually to reduce the speed (especially crew vessel and service vessel reach high speeds and should be regulated) and to define ship lanes/corridors which all vessels have to use as far as possible.

Maps – derived from AIS data and monitoring data as conservation planning tool - can help to detect critical areas in revealing marine mammal hotspots (Figure 6.15) and subsequently consider those areas in more detail to precise the development of measures to mitigate the collision risk.

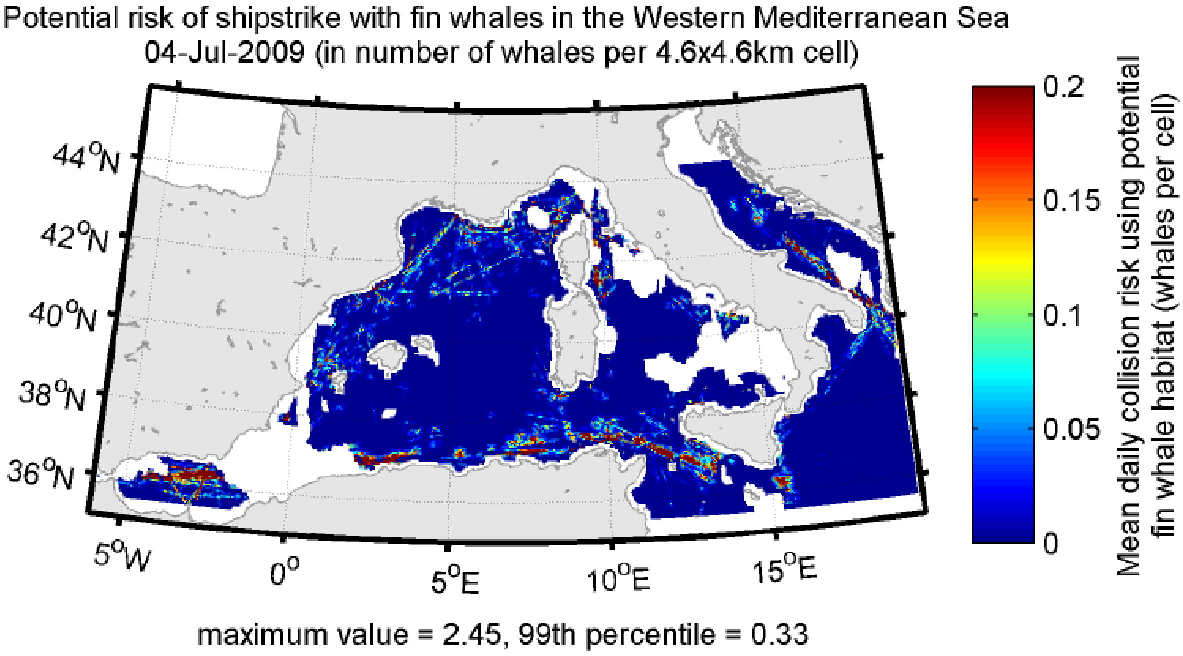


*Figure 6.15 An example map of the western Mediterranean Sea, for potentially ship-fin-whale collision risk areas (*Vaes et al. 2013).

A speed limitation to maximum 10 knots is suggested by Vaes et al. (2013) for Mediterranean areas where marine mammal abundance is high, because ship strikes would be decreased drastically. Also for turtles, the speed limit or speed reduction when discovering an individual is suggested (Euro Turtle 2018) and can reduce the extent of injuries and number of ship strike victims rapidly (Work et al. 2010). Ship speeds higher than 4 km h^{-1} will lead to ship strikes with turtles, as Hazel et al. (Hazel et al. 2007) found out in studies outside the Mediterranean Sea. This results in speed being once again a crucial factor, not only in noise emission but also for collision risks. Speed reductions are one of the cheapest and the most feasible mitigation measures, while other measures are extremely expensive to install, or have already failed in their effectiveness (Carrillo & Ritter 2010).

The IWC developed a “Strategic Plan to Mitigate the Impacts of Ship Strikes” to develop concepts and solution approaches to accomplish a sustained and permanent ship strike decrease by 2020 (IWC 2018).

Summarising, the risk of ship strikes is applying to several marine mammal species and turtles. As mentioned above, the hazard for the monk seal is unknown, but potentially existing and therefore should be investigated in long-term studies for various periods of the year.

6.5.2 Collision with turbines

Avoidance through spatial planning

Reducing the impacts of OWFs on migrating birds can within limits be done by selecting sites outside of areas of special importance to bird and bat migration. As in the offshore environment migration corridors are mostly observed to narrow straits and specific sites where birds depart for migration over sea this poses little restriction to offshore windfarm planning. Further mitigation of the collision risk of birds can be achieved by considering the distance to breeding colonies of seabirds in the process of spatial planning. Many countries have developed sensitivity maps (Mc Guinness et al. 2015), especially within European Commisions Statements (European Commission 2010): '*Developing wildlife sensitivity maps at the strategic planning stage enables areas to be identified where windfarm development might be considered a low, medium or high risk in terms of nature and wildlife...* ' and '*Such wildlife sensitivity maps will also help to avoid potential conflicts with the provisions of article 5 of the Birds Directive and 12&13 of the Habitats Directive as regards the need to protect species of EU importance throughout their entire natural range within the EU (ie also outside N2000 sites)*'. Sensitivity maps can highlight the species-specific sensitivities that need to be considered when siting such infrastructure and can be considered as important guidance tool within the frame of strategic planning processes.

Turbine shutdown on demand

Temporary shutdown during mass migration events to reduce collision risk (especially in bad weather and visibility conditions) has been recommended as mitigation measure. Whenever a dangerous situation occurs, e.g. birds flying in a high collision risk area or within a safety perimeter, the wind turbines presenting greatest risk should stop spinning. This strategy may be applied in windfarms with high levels of risk, and can operate year-round or be limited to a specific period (Marques et al. 2014).

De Lucas et al. (2012) demonstrate that wind turbine shutdown on demand halved Griffon vulture fatalities in Andalusia, Spain, with only a marginal (0.07%) reduction in energy production. In this region, windfarm surveillance programs use human observers, takes place year-round, with the main objective being to detect hazardous situations that might prompt turbine shutdown, such as the presence of endangered species flying in the windfarm or the appearance of carcasses that might attract vultures.

Depending on the species and the number of birds, there are different criteria for stopping the wind turbines. However, this approach requires a real-time surveillance program, which requires significant resources to detect birds at risk.

There are emerging new independent - operating systems that detect flying birds in real-time and take automated actions, for example radar, cameras or other technologies. These systems may be particularly useful in remote areas, such as marine areas, where logistic issues may constrain the implementation of surveillance protocols based on human observers or during night periods, where human visual acuity is limited in detecting birds. These new systems are based on video recording images such as 'DTbird' (Collier et al. 2011; May et al. 2012), (BSH & BMU 2014), or radar technology such as 'Merlin SCADA™ Mortality Risk Mitigation System' (Collier et al. 2011).

For example, an experimental design at 'Smøla' windfarm WF showed that the 'DTbird' system recognized between 76% and 96% of all bird flights in the vicinity of the wind turbines (May et al. 2012).

Analyzing the characteristics of these technologies and taking into account factors influencing the risk of collision, cameras can be particularly useful in small WF, for specific high risk wind turbines or when it is necessary to identify local bird movements. Radar systems appear to be a more powerful tool for identifying large-scale movements like pronounced migration periods and are also particularly useful during night periods.

Currently, several other systems are under development or being implemented to detect bird-wind turbine collisions or to monitor bird activity close to wind turbines (using acoustic sensors, imaging and radar). Hence, it is likely that new automated tools will be available in the future (Marques et al. 2014 and references therein).

Restrict turbine operation

The use of curtailment, i.e. establishing operational stopping periods can be most effective during periods when at-risk species are within the facility or nearby, enabling a shut-down period to reduce the collision risk and avoid going over previously identified activity thresholds for particular species (GARTMAN et al. 2016b).

This curtailment strategy is distinct from that described above (turbine shutdown on demand) in that it is supported by collision risk models and not necessarily by the occurrence of actual high risk scenarios. This approach may imply a larger inoperable period and, consequently, greater losses in terms of energy production. As a result, it has not been well-received by wind energy companies.

These time periods can be identified based on variables such as seasonality, weather movements, and species. Turbine operation may be restricted to certain times of the day, seasons (such as migratory periods) or specific weather conditions (GARTMAN et al. 2016b and references therein).

Additionally, curtailment can be used for specific turbines within high mortality 'hot spots' (PIORKOWSKI et al. 2012) where wind facilities can shut down these hot spot turbines based on times, seasons, or year based on monitoring to lower collision mortality without compromising the energy generation of the rest of the turbines not impacting mortality rates (PIORKOWSKI et al. 2012). Powering down topographically specific turbines during certain weather conditions, but does not empirically evaluate the effectiveness of this measure (GARTMAN et al. 2016b and references therein). LIECHTI et al. (2013) discusses the essential application of a shut-down regime via thresholds based on bird migration intensity. They state that the effect of expected mortality based on population demographics of involved species defines these thresholds and establish a 'rule of thumb' for developers that 'an acceptable number of additional fatalities by wind turbine(s) should be about two orders of magnitudes below casualties caused by tall man-made structures' (LIECHTI et al. 2013).

Such requirement for shut down of wind turbines in future windfarms in Netherlands is explicitly written in the license for a specific windfarm area (in Dutch: Kavelbesluiten). For example in the case study of 'Kavelbesluit of Borssele I' the current cut-off point is 500 birds/km/hr above which turbines need to be shut down. At the moment the government is developing the precise measure in terms of duration from operation to shut down, duration of the shutdown itself, and the type of measuring system to detect these 500 birds/km/hr (Finj R., personal communication 2018; see also https://www.rvo.nl/sites/default/files/2016/04/definitieve%20versie%20Kavebesluit-%20I.pdf).

Curtailment offshore has particularly focused on seabirds and migratory birds offshore, recommending shutdowns during mass migration (BSH & BMU 2014), bad weather, at night (HÜPPOP et al. 2006), and those close to breeding colonies during high flight occurrences (as observed by EVERAERT & STIENEN (2007). There have also been site-species specific investigations such as for the offshore 'Cape Wind Project' in the U.S. for the common loon (*Gavia immer*) in developing a model giving specific recommendations when to operate curtailment. Another offshore investigation for Franklin's gull (*Leucophaeus pipixcan*) in Tehuantepec Isthmus Mexico, recommends establishing curtailment to occur in April when winds come down from the north. However, effective curtailment strategies offshore have yet to be realized through empirical research (GARTMAN et al. 2016b and references therein).

Based on collision risk models, if all wind turbines in the 'Altamont Pass Wind Resource Area' could be shutdown with fixed blades during the winter, Burrowing owl (*Athene cunicularia*) fatalities would be reduced by 35% with an associated 14% reduction in annual electricity generation research (GARTMAN et al. 2016b and references therein).

Restricting turbine operation could be implemented when particularly high risk factors overlap. For example, wind turbines on migratory routes could be shut down on nights of poor weather conditions for nocturnal bird migration (MARQUES et al. 2014).

Recent technological advances can help input several variables (e.g. weather, migration behaviours) and determine curtailment periods, as well as even shutting down the turbines on command to reduce collision mortality with the blades. Using field observers can be beneficial, but the use of SCADA, control and surveillance radar systems or the use of thermal cameras can detect birds and bats in real time and can even program the turbine(s) to shut down. These have been beneficial in not only reducing collision risk but have also in monitoring and better understanding at-risk species for further research. However, those visual systems primarily detect large birds such as raptors whereas detection of other smaller species (e.g. passerines) is not possible. Moreover, other large objects such as aircrafts are detected as well and can lead to high amounts of false positives possibly resulting in false stop events. Consequently, this promising technology needs further research and testing (GARTMAN et al. 2016b and references therein).

Increasing turbine visibility

Although the efficiency of increasing turbine visibility has not yet been demonstrated in the field, laboratory experiments show encouraging results for such techniques. Various attempts to increase blade visibility and consequently reduce avian collision have been made by using patterns and colors that are more conspicuous to birds. Based on laboratory research, McIsaac (2000) proposes patterns with square-wave black-and-white bands across the blade to increase their visibility, and proposes a single black blade paired with two white blades as the best option (MINIMIZING OF MOTION SMEAR REPORT NREL 2003).

As some birds have the ability to see in the ultraviolet spectrum, ultraviolet-reflective paint has been suggested for increasing blade visibility. Although this method has proved to be effective in avoiding bird strikes against windows, its applicability in windfarms remains to be proven (MARQUES et al. 2014 and references therein).

Also as migratory birds have been observed to be attracted by lighted offshore structures during adverse weather, bird-friendly marking or lighting of wind turbines and converter platforms has also been suggested (see chapters 5.6 and6.3) for more information on impacts and mitigation measures for artificial light).

Deterrents

Deterrent devices that scare or frighten birds and make them move away from a specific area. However, there is no empirical proof as to how effective deterrents are with wind turbines, as much of this research looks at power lines, buildings, airports, and towers and research is fairly old (GARTMAN et al. 2016b).

Deterrents can be activated by automated real-time surveillance systems as an initial mitigation step and prior to blade curtailment (COOK et al. 2011; MAY et al. 2012). Systems such as ‘TD Bird’ or ‘Merlin ARS™’ incorporate this option in their possible configurations. While they state they are effective, further field studies into these surveillance systems is needed (GARTMAN et al. 2016b).

Although results are preliminary, this type of methodology may have an unpredictable effect on the flight path of a bird, so caution is needed if it is applied at a short distance from a wind turbine or within a windfarm. Nevertheless, it may be used as a potential measure to divert birds from flying straight at a wind turbine (MARQUES et al. 2014).

6.6 Mitigation of waste

To avoid any pollution with micro- and macroscopic waste as well as any contamination with pollutants, for any offshore windfarm a waste management concept must be developed to guarantee zero emission at the site. Waste, if not possible to avoid, must be taken back to shore and properly recycled or disposed.

To avoid the use of sacrificial anodes for corrosion protection and the release of (heavy) metals in the water, alternative methods for corrosion control have been suggested or are already in use (e.g. 'Trianel Windpark Borkum' in the German part of the North Sea). For instance 'Impressed Current Cathodic Protection' (ICCP) system can be used. It consists of titan-anodes with a 'Mixed Metal Oxide' coating with estimated life duration of more than 25 years. The release of metals is relatively low compared to the use of sacrificial anodes. However, this system is another source of electromagnetic fields and thus has potential impact on marine biota. Further studies have to be conducted to investigate the strength of EMFs of ICCP systems and their potential disturbance of marine animals.

6.7 Mitigation of electromagnetic fields and temperature

Electromagnetic fields and elevated temperature of the surrounding seabed or water column are generated by the cables transporting the electricity from the turbines to shore.

6.7.1 Electromagnetic fields

Directly generated electric fields in the surrounding of the power cable can be avoided by the choice of the cable type and adequate shielding, e.g. sheaths within the cable insulating the conductor (OSPAR COMMISSION 2012). However, an induced electric field generated by the magnetic field may occur. In case of high current flows or passing organisms an induced electric field can be generated by the magnetic field during power transmission. These electric fields may exceed values typical under natural conditions (OSPAR COMMISSION 2012).

Cable type and cable laying

Electric fields can be avoided by suitable shielding. Since unshielded cables will generate electric fields, the British Department of Energy and Climate Change recommends the usage of armored power cables (DEPARTMENT OF ENERGY AND CLIMATE CHANGE & ENERGY PLANNING REFORM 2010). In case of using two separate single-conductor DC (Direct electric currents) cables for energy transport, cables should be placed parallel and as close to each other as possible. This way the magnetic fields from each of the cables would neutralize each other, in the optimum case there would be a complete ease of the magnetic fields (OSPAR COMMISSION 2012). According to the same guideline document, the best technique to minimize the magnetic field in case of AC (altering electric currents) cables (three-phase system) is by bundling them in tripolar cable or lay them as close as possible and parallel to each other to achieve a cancelation of the magnetic fields. Nevertheless, this will not prevent the induction of an electric field in surrounding conductive materials such as salt water.

Burial depth

Burial of the cables in the sea floor will lead to a significant decrease of electromagnetic fields above the seabed (Figure 6.16). According to German regulations within offshore windfarms, cable burial depth is at least 0.6 m. In tidal channels of the Wadden Sea cables are buried at least 2 m below the seabed (TRICAS & GILL 2011) and for offshore wind projects in UK waters a burial depth of at least 1.5 m is required (DEPARTMENT OF ENERGY AND CLIMATE CHANGE & ENERGY PLANNING REFORM 2010). In North America and Southeast Asia burial depths for all sorts of cable are between 0.9 and 3.5 m (OSPAR COMMISSION 2012). One has to keep in mind that deeper burial depth might in turn lead to an increase in other potential pressures on marine organisms and habitats.

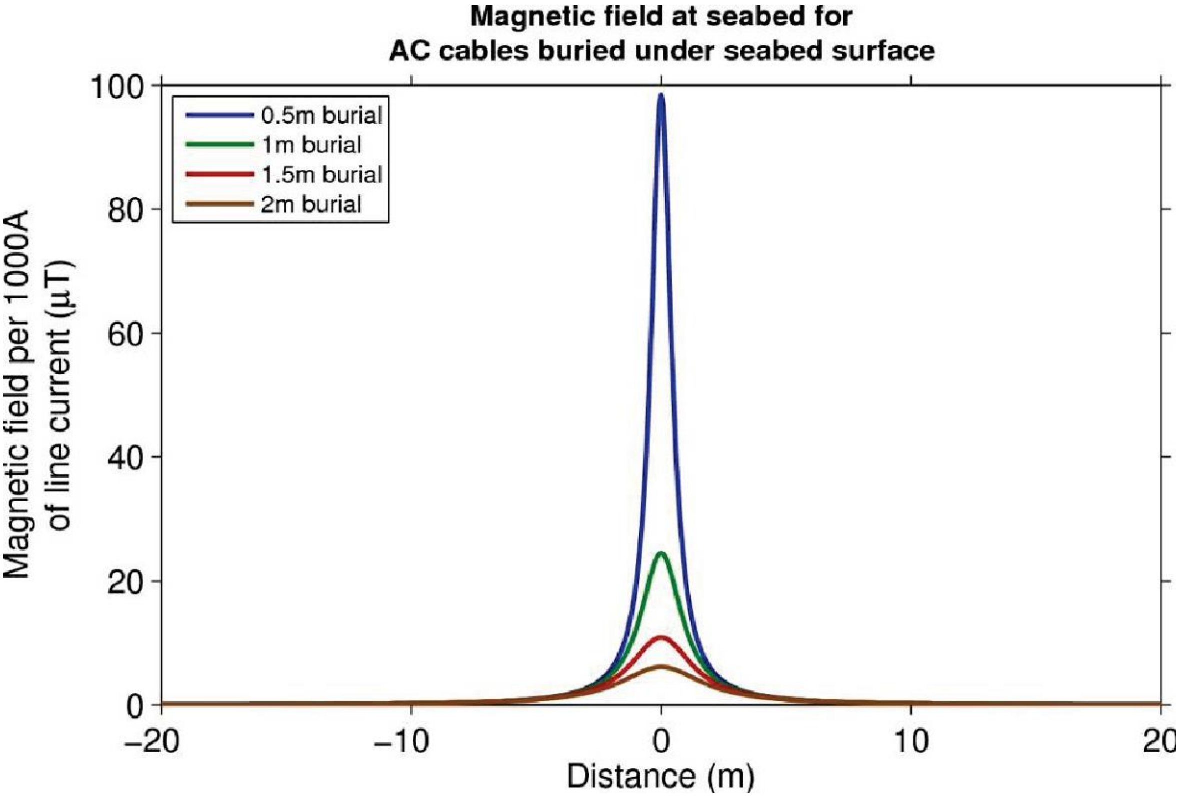


Figure 6.16 Magnetic field profiles at seabed level for an AC cable buried 0.5 m, 1 m, 1.5 m, or 2 m. X-axis displays the distance from the cable to the seabed. (TRICAS & GILL 2011)

In some cases, the substrate conditions might not be sufficient to bury under the seafloor. The alternative suggested by TRICAS & GILL (2011) is to place the cable directly on the seafloor and cover it with rocky materials or concrete mattresses, which protects the cable and reduces the EMF levels in the surrounding water column. If applying this method, it is recommended to favour on-site rocky materials over non-local rocks or concrete as every substrate foreign to the area provides an additional habitat that might favour the colonization of invasive species (BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE 2017) (see also chapter 6.4). TRICAS & GILL (2011) suggest that the effectiveness of mitigation measures can be determined beforehand by appropriate modelling of the magnetic fields of the planned cable design with varying the design factors based on the specific information of the cables:

- Cable design
- Burial depth and layout
- Magnetic permeability of the sheathing
- Loading (amperes)

- Modeling of DC cables must take local geomagnetic field into account to accurately predict field strength

As secondary effects of any mitigation measure can occur it is crucial to evaluate environmental effects of the considered mitigation technique, e.g. investigate if any burial or covering of the cable might lead to an increase in temperature or an alternation in habitat structure, which can potentially impact on benthic organisms.

6.7.2 Temperature

Cable type and cable laying

The choice of the cable type can already have an impact on the temperature emission. The OSPAR commission (2012) suggests the use of HVDC cables instead of AC cables to reduce heat emissions. At equal transmission rates AC cables have a higher heat dissipation than DC cables (IFAÖ 2006).

If transmission cables can be bundled this will reduce the number of individual power cables, which reduces the space occupied and the total area affected by temperature rise (OSPAR COMMISSION 2012).

Burial depth

To mitigate negative impacts of the heat emitted by the cable it is recommended to bury or cover the cable. Up to now it is not known which temperature increase in the sediments will lead to significant (negative) impacts on the marine environment (BFS 2005). In Germany the so called ‘2K-criterion’ has been established developed by the German Federal Institute for Nature Conservation (BfN), stating that the increase in temperature must not increase by more than 2K in the upper 20 cm of the seabed to prevent benthic organisms and habitats from harm or changes due to a local increase in seafloor temperature (OSPAR COMMISSION 2012). This threshold will eventually be included in the German ‘Bundesfachplan Offshore’ (BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE 2017), which includes standards for techniques to be used in offshore wind projects. This threshold can be accomplished by an adequate burial depth, in accordance with depths appropriate to mitigate electromagnetic fields. These burial depths have been defined, e.g. for German and UK waters (see above), but may vary depending on the structure of the present seafloor, which can differ in their thermal properties.

Thus, a thorough planning of the cable properties and the methods for cable laying and systems of grid connections is inevitable to achieve appropriate mitigation of pressures associated with cables from OWFs.

6.8 Mitigation of socio-economic impacts

The most favorable mitigation measure will always be the avoidance of any potential conflict of OWFs and stakeholders of the socio-economic sector by appropriate site selection, which in an optimal case is achieved via appropriate MSP. To increase the social acceptance of the establishment of OWFs in general SOUKISSIAN et al. (2017) suggest several actions:

- Co-use of OWF with other economic sectors (e.g. aquaculture or tourist attractions) in order to minimize prejudices by compensation measures to the local communities impacted by the OWF.

- Informing the local communities and raising environmental awareness for the project, including realistic projections of potential advantages/benefits and disadvantages of the OWF. Local information campaigns could be one of the actions taken.
- Thorough socio-economic valuation surveys during the planning phase of the OWF are needed, including consultation processes of stakeholders and other OWF associated issues, concerns and interests.

For single potentially impacted economic and cultural fields suggested and approved mitigation measures are described in the following.

6.8.1 Fisheries and aquaculture

One of the major conflicts between the fishery sector and an OWF is competition for space. To find solutions which suit both sides, MSP shall balance the interests and avoid any long-term conflicts. Consultation, information and involvement of stakeholders, i.e. the fishermen, are a prerequisite to make mitigation plans successful. Collaboration with the fishing industry during the site selection phase has resulted in the construction of the OWF 'Princess Amalia' in the Netherlands in an area that was already closed for fisheries (PERRY et al. 2012 and references therein). To avoid any damage of fishing gear by OWF associated components (e.g. cables), cables should be buried deep enough or appropriately covered and cable route planning potentially adapted in order to avoid main fishing grounds (MOURA et al. 2015). The developers of the Danish OWF 'Horns Rev' decided to bury the cables at a certain depth to prevent damages of the cables by fishing gear and anchor. This way fishing in the area around and within the windfarm could be maintained (PERRY et al. 2012 and references therein). Regular and post-storm inspection will help to detect and repair any potential cable exposure. Consultation of local fishermen by the offshore wind industry for the most appropriate sediment and cable route has already been fruitful for both sides as fishermen have a detailed knowledge about seabed structures in and around their fishing grounds. Also test-fishing on newly constructed cable routes seem to be a beneficial method for both sides to avoid cable related damages on fishing gear and vice versa (MOURA et al. 2015).

In terms of construction phase of an OWF fishing seasons can be taken into account to avoid any disturbance or temporal displacements of the fish stocks during main fishing seasons.

Safety for fishermen can be enhanced by e.g. better communication and information, e.g. radio broadcasts with developments in construction and operation and associated safety guidelines and information can help to reduce risk for injuries (MOURA et al. 2015).

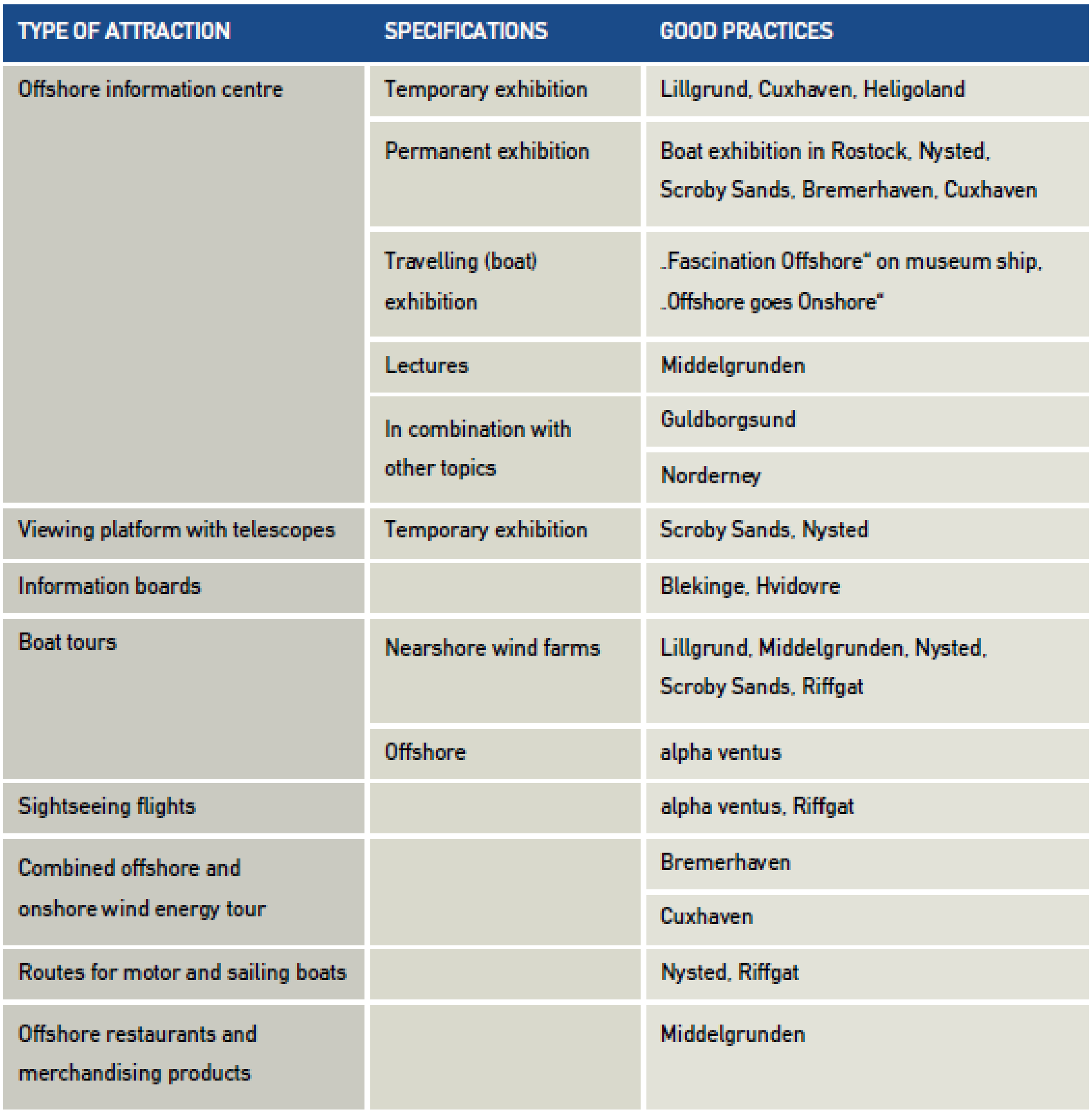
As described earlier, the risk of aquaculture facilities competing for space with OWF is relatively low since these facilities are often located in calmer water, protected from rough winds and waves. Though it has been intensively discussed whether and how OWF could form a possible area for aquaculture (MICHLER-CIELUCH et al. 2009; WEVER et al. 2015). This could have the advantage of shared services (such as maintenance vessels). The type of cultured organisms would depend widely on the area and the conditions where the OWF is located and if the used turbine foundation is adequate for anchoring any aquaculture associated gear. The concerns for the North Sea are the harsh weather conditions and that aquaculture facilities and equipment is needed to withstand severe weather and sea state condition (MICHLER-CIELUCH et al. 2009).

Further research is needed on developing foundation designs which could fulfil the requirements needed for aquaculture and on nutrient availability and abiotic factors in areas with a potential of co-use (MICHLER-CIELUCH et al. 2009 and references therein). Economic and ecologic feasibility has to be tested depending on the type of OWF, the habitat and the desired aquaculture organism.

6.8.2 Tourism

There are some potential measures suggested to mitigate conflicts of the tourism sector and OWFs. One suggestion is the total avoidance of potential conflicts by placing the OWF as far offshore that it is not visible from the shore (Westerberg et al. 2013). Alternatively if a windfarm is constructed closer to the shore it can be associated with recreational and touristic activities accompanied by reasonable environmental policies. If newly formed artificial reefs benefit the marine environment, environmental education e.g. via boating could take place. The technical fascination has led to the invention of boat trips to the OWF 'Meerwind Süd/Ost' in the North Sea located 23 km away from the island of Helgoland. In the year 2012 a study showed that about 32% of the people participating in a survey at the North and Baltic Sea coast were interested in an information centre of the OWF in the particular area and 15% showed interest in organized boat tours (STIFTUNG OFFSHORE-WINDENERGIE 2013 and references therein). Other types of tourist attractions and OWF, where these touristic activities were combined with the presence of an OWF are listed in Table 6.1. However, according to findings summarized in Westerberg et al. (2013) only half of the tourists did consider paying more in order to support sustainability initiatives at their holiday destination.

Table 6.1 Examples of OWFs as tourist attractions and specifications of the type of tourist activity. (STIFTUNG OFFSHORE-WINDENERGIE, 2013)



TYPE OF ATTRACTION	SPECIFICATIONS	GOOD PRACTICES
Offshore information centre	Temporary exhibition	Lillgrund, Cuxhaven, Heligoland
	Permanent exhibition	Boat exhibition in Rostock, Nysted, Scroby Sands, Bremerhaven, Cuxhaven
	Travelling (boat) exhibition	„Fascination Offshore“ on museum ship, „Offshore goes Onshore“
	Lectures	Middelgrunden
	In combination with other topics	Guldborgsund
		Norderney
Viewing platform with telescopes	Temporary exhibition	Scroby Sands, Nysted
Information boards		Blekinge, Hvidovre
Boat tours	Nearshore wind farms	Lillgrund, Middelgrunden, Nysted, Scroby Sands, Riffgat
	Offshore	alpha ventus
Sightseeing flights		alpha ventus, Riffgat
Combined offshore and onshore wind energy tour		Bremerhaven
		Cuxhaven
Routes for motor and sailing boats		Nysted, Riffgat
Offshore restaurants and merchandising products		Middelgrunden

6.8.3 Transport

To ensure as little conflicts between maritime transport and the operation of OWF as well as ensure safety for mariners, several recommendations have been suggested in Dutch waters by a consultancy (Arcadis 2018). According to their findings they suggest that entering, passing through and fishing within the windfarms should be allowed under certain conditions:

> “1. For ships up to 24 meters length;
> 2. At daytime;
> 3. With a functioning and active VHF and AIS installation;
> 4. During transit, professional fishers have to carry bottom disturbing gear above the waterline, where it is visible;
> 5. Seabed disturbing activities are forbidden;
> 6. Third party diving activities are forbidden;
> 7. Professional fishery is allowed with gear approved by the Dutch government;
> 8. Within the windfarms, a safety zone of 50 meters is established around the turbines. The 500 meters safety zones around offshore transformer stations will remain in place.”

Safety for mariners can be enhanced by e.g. better communication and information, e.g. radio broadcasts with developments in construction and operation and associated safety guidelines and information can help to reduce risk for injuries (Moura et al. 2015). Lighting on the turbines could increase visibility of the windfarm.

6.8.4 Cultural heritage

Physical impacts on e.g. submerged archaeological sites can be avoided by avoiding this area for constructing the turbines or for cable laying. As these sites are static and are located in a defined area, mitigation measures are thought to be comparatively simple to implement. At the OWF ‘Neart na Gaoithe’ in the UK a minimum Temporary Exclusion Zone (TEZ) of 50-100 m was suggested around archaeological sites (EDF Renewables & Neart na Gaoithe Offshore Wind 2012). A written guideline ensures proper mitigation and monitoring and gives recommendations how to handle sites or other targets for cultural importance discovered during construction. This protocol includes also the education of the staff and personal involved in the construction of the OWF. In Greece there are legally binding restrictions regarding the distance of OWF from archaeological and cultural sites up to 3000 m in cases of world heritage monuments, in other cases the minimum distance is a function of the rotor size (Κυβέρνηση της Ελληνικής Δημοκρατίας 2008).

6.9 General conclusion on mitigation measures

Mitigation includes avoidance of impacts through siting, mitigating the impacts when they cannot be avoided through management, and compensating for impacts by replacing losses or reducing other anthropogenic stressors.

Avoidance

Avoidance entails siting OWFs away from ecologically sensitive marine areas that are critical habitat for wildlife as well as away from significant migratory routes and high productivity coastal sites. From all mitigation measures, proper site selection is considered the most effective proactive mitigation measure and marine spatial planning (MSP) and Strategic planning and Strategic Environmental Assessments (SEA) are very important tools in this context. Since the construction of the first OWFs and the expansion of turbines in the sea, MSP has raised increasing attention to make this use of the sea compatible with other economic interests and environmental protection. Ideally, conflicts between offshore windfarms and nature conservation can be avoided or largely mitigated by selecting sites of low value for nature conservation.

Mitigation

Mitigating pressures of a project level includes consideration of OWF design (e.g., layout and turbine spacing), changes to turbine design (e.g., size, paint schemes, blade technology, lighting, support structure), use of different operational methodologies (e.g., timing of construction, bubble nets, support vessel travel speed, blade cut-in speed, curtailment during migration), and implementation of adaptive management (e.g., curtailing turbines that are causing the greatest adverse effects).

An important mitigation measure during construction is the mitigation of underwater noise. Several methods are available which efficiently reduce noise from pile driving. For marine mammals it has been shown that noise mitigation reduces the disturbance response greatly. Little known is about the effects of noise mitigation on fish sea turtles; however, it is a fair assumption that the species groups will also benefit from lowered noise.

During operational phase mitigation of light is suggested. For birds, there is overwhelming evidence that night lighting of offshore structures attracts especially migrating land birds under poor weather conditions and may thus increase the collision risk. No light at all seems to be optimum option but aviation and ship safety protocols are do not foresee absolute light absence. For this alternative mitigation measures have been suggested that include radar systems for ships and aircrafts for on demand lighting and deflectors on offshore structures recognisable when ship lights are projected on them.

Temporary shutdown during mass migration events to reduce collision risk (especially in bad weather and visibility conditions) has been recommended as mitigation measure. There are emerging new independent - operating systems that detect flying birds in real-time and take automated actions, for example radar, cameras or other technologies.

Choosing methods with the smallest possible footprint can contribute to the reduction of impacts on benthic organisms and communities near windfarms. Construction zones should allocate just the minimum areas necessary and construction activities should not deviate outside the specified zones. In addition methods minimising turbidity and sediment suspension should be used.

Mitigation of electromagnetic fields and heat emission from operating cables include shielding and burying the cables at an adequate depth. One has to keep in mind that deeper burial depth might in turn lead to an increase in other potential pressures on marine organisms and habitats.

Throughout all phases mitigation from ship collisions should be considered. As ship strikes are mostly caused by fast boats, a speed limit will reduce the collision risk.

To avoid any pollution with micro- and macroscopic waste as well as any contamination with pollutants, for any offshore windfarm a waste management concept must be developed to guarantee zero emission at the site. Waste, if not possible to avoid, must be taken back to shore and properly recycled or disposed. To avoid the use of sacrificial anodes for corrosion protection and the release of (heavy) metals in the water, alternative methods for corrosion control have been suggested or are already in use such as „Impressed Current Cathodic Protection (ICCP) system".

A synoptical figure showing mitigation categories is presented below (GARTMAN et al. 2016a) (Figure 6.17).

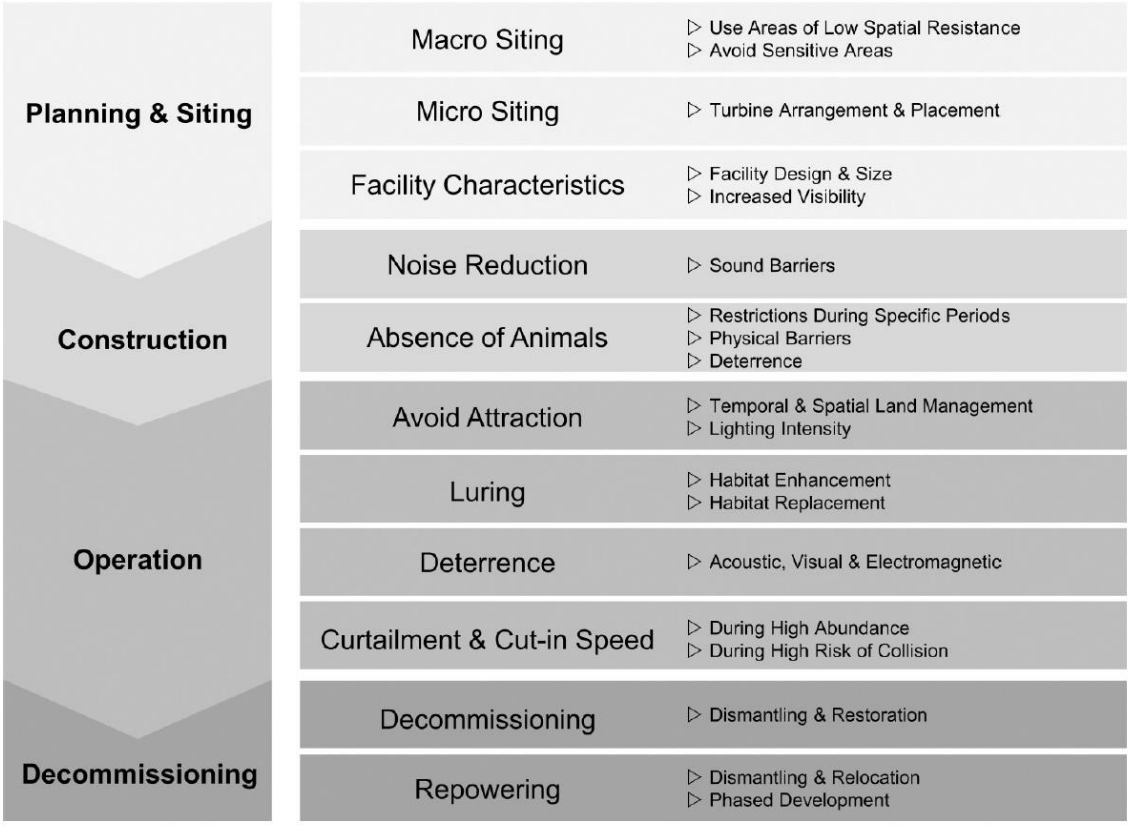


Figure 6.17 Mitigation measure classification (GARTMAN et al. 2016a)

Compensation

When adverse effects due to OWF cannot be avoided or sufficiently minimized, mitigation can include compensation. Examples of compensation include protecting or expanding existing breeding habitat, such as seabird nesting islands; reducing mortality of adults of long-lived species, such as in marine mammal boat collisions or fisheries by-catch (birds, sea turtle, non-target vulnerable fish species) etc.

The following table summarizes mitigation measure applicable for different taxonomic groups and habitats (Table 6.2). Highlighted are the mitigation measures with proved efficacy while the rest either contribute additively or need to be further investigated.

Table 6.2 Taxonomic groups / habitats, pressures, resulting impacts, ranking of impacts and suggested mitigation measure is presented below; Mitigation measures with proved efficacy are highlighted by bold letters while the rest either contribute additively or need to be further investigated.

	Pressure	Impact	Siting phase	Construction	Operation	Decommissioning	Mitigation
Habitats/ benthic communities	Cable laying	Habitat loss	-	medium/high	low	low/unknown	Selection of most appropriate route for cable laying
	Cable laying	Habitat loss	-	medium/high	low	low/unknown	Shortest possible length for laying cables / Bundling with existing cables / Minimize number of cable crossing structures
	Cable laying	Habitat loss	-	medium/high	low	low/unknown	Allocation of just the minimum areas necessary for construction activities
	Cable laying	Physical damage, disturbance	-	medium/high	low	unknown	Prefer methods minimising turbidity and sediment suspension (jetting / ploughing /horizontal drilling, seabed laying, rock dumping with on-site material, frond mattresses)
	Foundations occupation	Habitat loss	-	medium/high	low	-	**Appropriate site selection through marine spatial planning**
	Foundations occupation	Habitat loss	-	medium/high	low	-	Selection of suitable locations through detailed delineation habitat/ sensitive species distribution
	Foundations occupation	Physical damage, disturbance	-	medium/high	low	-	Allocation of just the minimum areas necessary for construction activities
	Submerged structures	Reef effect	-	-	unknown	unknown	Monitoring
	Underwater operating cables	Electromagnetic fields	-	-	unknown	-	Cable burying in appropriate sites / shielding
Fish	Piling noise	Physical damage, disturbance	-	high	-	-	Noise mitigation techniques (modification of piling -hydraulic) hammer, bubble curtain types, soft start, casings, cofferdams)
	Underwater operating cables	Electromagnetic fields	-	-	unknown	unknown	Cable burying / shielding
	Submerged structures	Reef effect	-	-	unknown	unknown	Monitoring
	Foundations occupation	Habitat loss	-	medium/high	low	-	Appropriate site selection through marine spatial planning

	Pressure	Impact	Siting phase	Construction	Operation	Decommissioning	Mitigation
	Foundations occupation	Habitat loss	-	medium/high	low	-	Allocation of just the minimum areas necessary for construction activities
Marine mammals	Piling noise	Physical damage, disturbance	-	high	-	-	**Noise mitigation techniques** (modification of piling -hydraulic) hammer, bubble curtain types, HSD, soft start, casings, cofferdams) / **Threshold values** / **Deterrence devices** / **Low-noise foundation installation**
	Ship traffic	Collision	unknown	unknown	unknown	unknown	Speed regulations
	Ship traffic - noise	Displacement	low/medium	medium/high	medium/high	medium/high	Routing regulations
	Ship traffic - presence	Displacement	unknown	unknown	unknown	unknown	Routing regulations
Birds	Ship traffic	Displacement	low/medium	low/medium/high depending on species			Routing regulations
	Light	Collision	low	low/medium/high depending on species			Avoid lighting / Lighting on demand with radars / Use of deflectors
	Operating wind turbines	Collision	-	-	low/ medium/ high depending on species	-	**Temporary shut down** /curtailment
	Operating wind turbines	Collision	-	-		-	Appropriate site selection through marine spatial planning (also development of sensitivity maps)
	Operating wind turbines	Collision	-	-		-	Increase turbine visibility / Use of deterrents
	Operating wind turbines	Barrier effect	-	-		-	Appropriate site selection through marine spatial planning
Bats	Operating wind turbines	Collision	-	-	unknown	-	Monitoring
Sea turtles	Ship traffic	Collision	low/medium	medium/high	low/medium	low/medium	Speed regulations
	Ship traffic	Collision	low/medium	medium/high	low/medium	low/medium	Routing regulations
	Piling noise	Physical damage, disturbance	-	high	-	-	Noise mitigation techniques (modification of piling -hydraulic) hammer, bubble curtain types, soft start, casings, cofferdams)

	Pressure	**Impact**	**Siting phase**	**Construction**	**Operation**	**Decommissioning**	**Mitigation**
	Light	Disorientation	unknown	unknown	unknown	unknown	Avoid lighting / Lighting on demand with radars / Use of deflectors
	Underwater operating cables	Disorientation due to EMFs	-	-	unknown	-	Cable burying in appropriate sites / shielding
All groups	Waste and pollution	Habitat degradation, disturbance, physical damage	low	low	low	low	Alternative corrosion protection and alternative (anti-fouling) paints, appropriate disposal
	Sacrificial anodes	Habitat degradation, disturbance, physical damage	-	unknown	unknown	unknown	Alternative corrosion protection, appropriate disposal

7 MONITORING METHODS AND PROJECTS AND CONCLUSIONS FOR THE MEDITERRANEAN

7.1 Introduction and overview

Installation and operation of offshore windfarms bring new anthropogenic activities to the marine environment. Because of the anticipated large scale the new industry requires considerable attention in terms of the planning process and impact assessment. With technological advances in the future there is likely to be a continued increase in the size of offshore wind projects but there are still uncertainties about the effects on the environment as shown in chapter 5. The novelty of the technology and construction processes make it difficult to identify all of the stressors on marine wildlife and to estimate the effect of these activities in advance, thus posing limitations to Environmental Impact Assessments (Bailey et al. 2014 and references therein).

In this sense dedicated monitoring is essential for recording the environmental conditions before, during and after the construction of offshore windfarms in order to assess environmental impacts and to inform future planning.

Monitoring programs should consider the ‘Before After Control Impact’ (BACI) approach. BACI is a schematic method used to trace environmental effects from man-made changes to the environment. The aim of the method is to estimate the state of the environment before and after any change and in particular to compare changes at reference sites (or control sites) with the actual area of impact.

In Denmark, extensive monitoring programs were implemented at the two first large offshore windfarms (Horns Rev and Nysted). These projects have been the subject of extensive research and monitoring on potential environmental impacts. Horns Rev, constructed during the summer of 2002, is sited 8.7 to 12.4 miles (14 to 20 km) off the coast of Denmark in the North Sea, and consists of 80 turbines totaling 160 MW. Nysted was constructed between 2002 and 2003 approximately 6.2 miles (10 km) offshore in the Baltic Sea, and incorporates 72 wind turbines placed in 8 rows of 9 turbines each, with a total installed capacity of 165.5 MW.

The monitoring data at both sites consisted of three years of baseline monitoring, monitoring during construction, and three years of monitoring during operation phase. The studies and analyses in the environmental monitoring program have dealt with:

- Benthic fauna and vegetation with, with particular focus on the consequences of the introduction of a hard bottom habitat e.g. the turbine foundation and scour protection
- Distribution of fish around the wind turbines and the scour protection and the impact of electromagnetic fields on fish.
- Marine mammals: Studies of the behaviour of harbour porpoises and seals in and near the windfarm areas.
- Birds: Studies of resting, foraging and moulting birds, including modeling of collision risks and monitoring of bird collisions with wind turbines.
- Attitudes: Sociological and environmental economic studies of people’s attitudes towards the windfarms (NIELSEN 2006).

In Germany, extensive environmental research and monitoring programs have been conducted along the first offshore windfarm 'Alpha Ventus', which has been built as a test windfarm to investigate various aspects of offshore wind technologies (2018b). The main ecological research topics aimed to provide answers to the following questions:

- How do habitats change for benthic organisms and fish close to the foundations? How are these organisms affected by the artificial reef structures? How do habitats change as a result of fisheries being excluded from the windfarm area?
- How do birds react to the rotating, illuminated wind turbines? Is there a risk of migratory birds colliding with the turbines at sea? Will resting birds avoid the windfarm area?
- What impacts will noise-intensive construction work have on marine mammals? Will they continue to use the windfarm area as habitat and how can they be protected from noise? How do they react to operating noise?

The results of the projects have been published in reports (DIEDERICHS et al. 2002; BEIERSDORF et al. 2014) and scientific papers and have been presented at various conferences to the industry, the scientific community and the public. They form an important base for decision making on further offshore windfarm planning. The aim of the project was also to evaluate the monitoring techniques which are mandatory for all German offshore windfarm projects which are described in the Standard Investigation of the impacts of offshore wind turbines on the Marine Environment (StUK). During extensive field research, novel observation methods and technologies such as aerial digital survey techniques and new migration radars were applied for the first time in German waters.

In October 2013 the 4th update of existing monitoring frameworks for offshore windfarms in Germany (StUK4) was published. More details regarding the German Standard 'StUK4' is presented in chapter 8.2.1.

In order to obtain a solid basis for decision making on future offshore windfarm development each project in Germany has to fulfill extensive monitoring obligations including five year post-construction monitoring. The StUK provides the methodological standard for this. Today, most monitoring activities in German offshore windfarms are organized in clusters, each covering several windfarms. In large clusters, the survey area for aerial seabird and marine mammal surveys may cover up to 4,000 km^2. The mandatory activities cover

- benthic communities in the windfarms and reference areas and on the turbine foundations
- fish fauna in the windfarms and reference areas
- bird migration studied by radar, visual observations and acoustic recordings, usually conducted from transformer platforms in the windfarms
- abundance and distribution of waterbirds from ship and digital aerial surveys covering 20 km around the windfarms (aerials)
- abundance and distribution of marine mammals waterbirds from ship and digital aerial surveys as well as passive acoustic monitoring of harbour porpoise
- measurements of underwater noise during construction and operation

For benthos/fish the size of the assessment area corresponds to the current size and location of the windfarm. For avifauna/marine mammals aerial surveys of the area must cover at least 2.000 km^2. The windfarm shall be at the center of the assessment area. The distance between the sides of the windfarm and the margins of the assessment area shall principally be at least 20 km. For ship based surveys the assessment area must cover at least 200 km^2. The distance between the sides of the windfarm and the margins of the assessment area shall principally be at least 4 km.

The results of the monitoring programs have to be reported annually to the relevant authority BSH. The monitoring programs of the offshore windfarms are accompanied by large-scale surveys on birds and marine mammals using digital aerial surveys on behalf of the Federal Agency for Nature Conservation and dedicated research projects. The results of all activities are regularly presented at conferences and published in scientific reports and papers.

7.2 Monitoring methods & projects for abiotic environment

Monitoring concepts have been established for the North Sea (OSPAR) and Baltic Sea (HELCOM) and the Mediterranean Sea (MAP) to fulfil European legislation, e.g., the Marine Strategy Framework Directive (MSFD), Habitats Directive or the Water Framework Directive (WFD). In the MSFD the abiotic environment is assigned to descriptor D7 'Hydrographical changes' and D8 'Contaminants'. HELCOM provides guidelines for monitoring of turbidity and for the determination of heavy metals and other chemical pollutants in the water column and in sediments. Monitoring concepts for D7 'Hydrographical changes' have been established for current velocity, sea temperature, wave exposure, turbidity, salinity, topography and bathymetry, upwelling, transparency, oxygen levels, pH, mixing characteristics, tidal characteristics, climatology, and habitats in most of the Mediterranean countries (DUPONT et al. 2015). HELCOM's monitoring guideline includes methods for Al and Zn and heavy metals are monitored by all Mediterranean countries in general within the framework of the MSFD (DUPONT et al. 2015). All these monitoring concepts have been developed for a large scale long-term monitoring in contrast to an effective impact monitoring of OWFs. In Germany, sediment properties (e.g. grain size distribution and loss on ignition) and measurements of salinity, temperature and oxygen levels are monitored as part of the standard investigation combined with monitoring benthic communities and fish monitoring (BSH 2013a). In addition a side scan sonar survey is conducted to gain information on sediment and habitat structure and its dynamics before construction and during operation (BSH 2013a). In Belgium, like in Germany, environmental data such as grain size distribution is sampled parallel with benthos samples (DEGRAER et al. 2017). However, an emphasis is placed on benthic communities and not on the abiotic environment. Current knowledge on potential impacts of OWFs on the abiotic environment is scarce and results primarily from scientific studies. There seems to be no standard procedure for monitoring potential impacts of OWFs. FLOETER ET AL. (2017; and references therein) and VANHELLEMONT & RUDDICK (2014; and references within) give a good overview about monitoring local hydrodynamics and sediment plumes, respectively. However, KIRCHGEORG ET AL. (2018) identify the need to develop environmental monitoring strategies for chemical emissions in OWFs. In 2017 the German Federal Maritime and Hydrographic Agency (BSH) started a R&D (research and development) project analysing all emissions of OWF into the marine environment. This project focusses on anticorrosive coatings and the emission of cathodic corrosion protection systems and aims to provide tools to identify, analyse, and evaluate the effects of organic and anorganic emmissions on abiotic (but also biotic) environmental parameters until 2020 (see OffChEm project: HZG n.d.).

7.3 Monitoring methods & projects for benthic communities and habitats

The monitoring programs should be planned according to the 'Before After Control Impact' (BACI) approach to assess the potential impacts of offshore windfarms on marine habitats and benthic communities within a spatio-temporal frame.

The individual features of conservation interest require different assessment areas in terms of size and location. Considering the experience gained from the research project ''Alpha Ventus'' and the resulting monitoring standard 'StUK4' (BSH 2013b), it is suggested that for benthos (and fish) the size of the assessment area should correspond to the current size and location of the windfarm.

Reference areas outside of the project areas should be used for comparison to document the development of habitats and benthic communities without the impact of the windfarm. The natural ambient conditions in the reference area (location, current conditions, water depth, sediment properties, size, species spectrum, number of individuals) should be largely comparable to those in the project area concerned. As far as possible, the anthropogenic influences in the reference area should be likewise comparable to those in the construction area, with the exemption of fishing, wind turbine construction activities and their operation. If the reference area is part of another project area, it must be made sure that the reference area remains free of construction activity during the assessment period.

The location of the reference areas for benthos and fish must largely correspond. The size of the reference area must correspond to that of the project area. If the abiotic environment of a project area very heterogeneous (e. g. different sediment properties, hydrography or water depth), a reference area should be chosen which has very similar properties. If such conditions do not exist in a single reference area, the reference area may also be composed of several smaller areas whose habitat patterns, in combination, correspond to that in the construction area. The individual areas should be located as close together as possible. The reference area should be located in the vicinity of the project area but should be largely free of any impacts from the project area (construction/operation noise, turbidity plumes) and precautionary the minimum buffer zone should be 1 km wide.

If possible, the benthos investigations should be carried out at the same time as the fish -investigations, but mutual disturbance should be avoided.

As for the monitoring periods, 'StUK4' (BSH 2013b) suggests that, within the context of the baseline study, monitoring should be performed over two successive, complete seasonal cycles (24 months) without any interruption to determine the status quo as a basis for construction and operation phase monitoring. The results shall be the input of an EIA. The baseline study must be updated by inclusion of a third survey year, if the time between end of baseline study and construction start exceeds two years. If more than five years pass between end of baseline study and construction start, a new, complete two-year baseline study must be carried out. It is possible to apply after six months for a reduction of the monitoring program to one year if the results of the investigations show that no significant changes in the conditions regarding location have occurred.

Construction-phase monitoring has to be performed from the start of construction work until completion of the construction project. If essential components are put into operation prior to completion of the construction project, operation monitoring in the project section concerned may be started.

Operation-phase monitoring has to be performed for a period of three to five years, depending on specific conditions regarding the site/project and the features of conservation interest, in order to verify the assumptions made in the approval (EIA). Any additional marine environmental protection measures which are later found to be necessary on the basis of latest findings and/or the results of operation-phase monitoring shall be included in a suitable way in the monitoring schedule.

The monitoring requirements during decommissioning phase correspond to those in the construction phase. Possible environmental impacts depend mainly on the dismantling techniques used, which are expected to undergo major technical improvement in the future when numerous oil and gas platforms are due for decommissioning.

In Germany the benthos investigations and monitoring comprise:

- Investigation of the sediment and habitat structure and their dynamics
- Video survey of epifauna, macrophytes and habitat structure
- Grab sampling survey of infauna
- Beam trawl survey of epifauna
- Installation based grab sampling survey of infauna
- Investigation of growth and demersal megafauna on the underwater construction structure
- Investigation of benthos and habitat structures in the context of installation of cable routes for connecting offshore windfarms

Also a demarcation for areas of sensitive and ecologically important habitats should be realised.

Monitoring during cable installation and removal could be concentrated on disturbance effects for habitats and benthic communities general. In areas with elevated contaminant load the effects of contamination should be documented (recording of contamination levels in substrats and biota, specific effect monitoring). In environmentally sensitive areas additional aspects have to be addressed. For the operational phase a monitoring of seabed temperature in the vicinity of the cable and of generated electromagnetic fields should become a standard. Monitoring during cable operation also has to include investigation of the ecology of seabed (biogeochemical flow, composition and structure of benthic communities) (IFAÖ 2006).

The above mentioned monitoring methods have been formulated based on OWFs in the North Sea and the Baltic Sea. Hence, they cannot directly be applied to future projects in the Mediterranean Sea. Projects and monitoring programs have to be modified according to the local conditions. The various protected marine habitats in Mediterranean as described in chapter 0 need habitat specific methodologies in order to monitor the potential impacts from the construction and operation of offshore windfarms.

Emphasis should be given to priority habitats such as 1120* *Posidonion oceanica* beds where the monitoring methods should include detailed delineation during the baseline study in order to avoid overlapping with cable route design, foundations locations and anchoring. In general, non-invasive methods should be used in order to monitor distribution and status of the habitat at all phases. It is suggested for these methods to operate in three scales: (i) system scale (aerial photographs, measurement of bottom cover, permanent transects), (ii) meadow scale (e.g. photographs of Posidonia around cement markers positioned along meadow limits, shoot-density, permanent quadrats) and (iii) shoot scale (e.g. plagiotopic to orthotropic rhizome ratio, laying bare of the rhizomes, lepidochronology, leaf epiphytes, leaf biometry) (BOUDOURESQUE et al. 2007).

As mentioned in chapter 0 direct impacts on habitat types within the Mediterranean basin that are situated along the coast (1140, 1130, 1150* and 1160) can potentially result from the cable laying activities through their areas and at connection points to feed the electricity grids in the mainland. Appropriate spatial planning based on careful delineation during the baseline surveys should take under consideration the distribution of these habitats.

Regarding habitat type ‘1170 - Reefs’ monitoring methods include diver surveys for evaluation of predetermined areas (in shallow areas for fixed wind farms). Remote operated vehicule has to be favoured as much as possible in deeper areas. Precise quadrat surveys for accurate estimation of species percentage cover, species composition and population status are recommended. The grid size, the quadrants locations and temporal use can be adjusted to serve better the research scope and objectives. Monitoring surveys should be coupled with photographic techniques. Another commonly used monitoring method is the use of line transects. The line/measuring tape can be laid out randomly, or can be laid in the same place each time using permanent marking points. Surveyors may use multiple short lines, or a single long transect line, depending on their survey design.

As mentioned before some of the basic key environmental issues that deemed research in North and Baltic sea were the consequences of the introduction of a hard bottom habitat e.g. the turbine foundation and scour protection on benthic fauna and vegetation, how do habitats change for benthic organisms and fish close to the foundations and how these organisms are affected by the artificial reef structures. Same questions are expected to rise in cases of offshore windfarms in Mediterranean which will in turn lead to need for specialised research adjusted to the Mediterranean species, habitats and environmental conditions.

7.4 Monitoring methods & projects for fish/elasmobranchs

To monitor the potential impacts of an OWF on fish, the BACI approach (Before-After/Control-Impact) is often regarded as suitable to investigate changes between pre- and post-construction. For this approach it is needed to sample the project/impact area (the area within and in the direct vicinity of an OWF) as well as a reference area, which is close enough to the windfarm area to be comparable in terms of habitat and community, but far away to not be impacted by the OWF. This approach was tested for instance at the Danish OWFs Horns Rev and Nysted (NIELSEN 2006), in a long-term program at Belgian OWFs (DEGRAER et al. 2017) and at the German OWF 'Alpha Ventus' (BSH & BMU 2014).

In Germany monitoring of fish in the North and the Baltic Sea is part of the StUK4 (BSH 2013a), thus there is clear guideline to follow in order to make the monitoring conclusive and comparable, which follow the BACI approach by including investigations during the pre-construction phase (baseline study), during construction and during the post-construction phase (operation phase). The guidelines are developed for North Sea and Baltic Sea conditions. The objectives of the recommended trawl surveys are the description of the local fish fauna and possible changes in abundance, distribution and community composition before and after the construction of an OWF. For this purpose at least two consecutive complete seasonal cycles prior to the start of construction should be sampled (minimum one survey per year) with standardized gear (which differs between North Sea and Baltic Sea due to the different seabed conditions), standardized sampling design (including recording of hydrographic data) with defined towing speeds and haul durations. More surveys per year are needed if seasonal conditions are a target objective. The number of required hauls per survey depends on the size of the project area. During the operational phase surveys should be conducted every two years (first, third and fifth year post-construction) according to the StUK4 regulations. Furthermore regulations for analysing the results are given, e.g.

- Total number of individuals per area/number of individuals per species and area.
- Total biomass per area/biomass per species and area.
- Dominance structure.
- Diversity and evenness.

- Average number of species per haul.
- Length frequency distribution of dominant species.
- Analytical statistics (univariate analyses, community analysis).

Besides fish trawls, hydroacoustic methods can be a useful non-invasive method to monitor fish and e.g. detect areas of aggregation. This method was for instance applied at the long-term research projects 'Alpha Ventus' (BSH & BMU 2014) and 'Nysted' (NIELSEN 2006). At the turbine foundations in the Danish OWF 'Nysted' a hydroacoustic survey was performed to monitor fish communities. The survey was conducted along transects inside (impact area) and outside (reference area) of the windfarm area. In this project the fish community around one turbine was additionally observed by SCUBA divers.

It has to be noted that demersal and pelagic fish might require different monitoring methods. Demersal fish are largely associated with the sea bottom and might therefore be most impacted by habitat loss and destruction during construction and operation of an OWF. Pelagic fish might not be directly impacted by the construction or operation of an OWF, but they might use the sea beds as spawning grounds or nursery areas. Besides monitoring of the adult fish stocks, monitoring methods for other life stages should be applied.

BOJĀRS et al. (2016) suggest for the Baltic Sea for instance:

- Video surveys to investigate spawning migration routes.
- Diving surveys to investigate benthic spawning grounds.
- Plankton net sampling to investigate fish larvae in nursery areas.

To detect and investigate fish spawning migration routes and spawning grounds and seasons, data of already existing surveys or sampling programs (e.g. from the International Council for the Exploration of the Seas, ICES) can be used, as it was performed during the ORJIP project in the UK (BOYLE & NEW 2018) to improve knowledge on e.g. commercially important species in order to advance the EIA for a project.

These projects and monitoring concepts around OWFs are solely based on experiences and knowledge of OWFs in the North Sea and the Baltic Sea. Hence, they cannot directly be applied to future projects in the Mediterranean Sea. Projects and monitoring programs have to be modified according to the local conditions in the Mediterranean Sea. The most important pressures need to be defined depending on the foundation type of the turbines, on the habitat conditions and on the local fish community and the target species within. If certain elasmobranch species or cephalopods are among the target species, monitoring concepts might have to be planned from scratch including thorough research programs as knowledge on these animal groups is rather limited compared to many teleost fish species.

As seabed structures in the North Sea in the areas of OWF sites is mostly sand or fine grained gravel ground suitable for example for bottom trawling, sampling gear and methods have to be modified according to the conditions at the future construction sites. In the Mediterranean data from monitoring programs on Bluefin Tuna from the ICCAT (International Commission for the Conservation of Atlantic Tunas) can be used (e.g. CARRUTHERS et al. 2018) to investigate and monitor migration routes and potential spawning grounds.

7.5 Monitoring methods & projects for sea turtles

Traditionally, marine megafauna is monitored by trained observers onboard ships or airplanes. Systematic monitoring especially for sea turtles has not been implemented in northern countries which is attributed mainly to the absence of sea turtles in North and Baltic Sea.

Monitoring methods that are already used for other marine wildlife with similar mobility characteristics may be useful for monitoring sea turtles as well. These include high resolution digital aerial surveys, on birds and marine mammals which according to Pacific Northwest National Laboratory (OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY 2012) shows promise for monitoring sea turtles near the sea surface.

Also the rapidly advancing field of unmanned aerial vehicle (UAV also known as drone) technology is currently being used to address a wide variety of subjects regarding wildlife biology and conservation. This technology seems highly applicable platform for identifying and monitoring sea turtles. It must be noted that literature on UAV so far only covers identification and monitoring of sea turtles in nearshore habitats, and represent a limited range of the potential scope of UAVs as ecological tools (REES et al. 2018).

Tracking of tagged animals swimming near wind turbines by satellite also shows considerable promise as is it a more accurate way to determine the movement of animals and possible interactions with offshore windfarms also at night. Acoustic methods include active acoustics in water (sonar) which Pacific Northwest National Laboratory Laboratory (OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY 2012) can locate sea turtles. The acoustic technologies provide additional information adding to information collected by aerial videography, and augment aerial video data capture for sea turtles.

A recent UNEP guideline document (2017) describes and suggests improvement on the methodology for the long term standardized collection and assimilation of data on adult and juvenile loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles at nesting, foraging and wintering areas throughout the Mediterranean. In particular, it suggests (i) standardized monitoring techniques for establishing the current distribution of nesting, wintering and feeding areas in parallel to detecting shifts in distribution over time and (ii) standardized monitoring techniques for establishing the population size of selected nesting, wintering and feeding areas. These monitoring methods are based on an international cooperative network for documenting and recording distribution and status of the species throughout the Mediterranean. It remains still unclear in what degree these monitoring methods could be used to assess the impacts of offshore windfarms on sea turtle populations within the Mediterranean Basin. They could serve as initial guidelines for monitoring programs; however site specific surveys are necessary to derive an adjusted and standardized monitoring technique before, during and after construction of the windfarms and for sufficient periods.

7.6 Monitoring methods & projects for birds

Monitoring of avifauna concerns all bird species present and considers especially those species listed under Annex I to the EU Birds Directive and all regularly occurring migratory bird species according to Art. 4, § 2, of Birds Directive, which are not listed under Annex 1. However, a generally applicable and binding list of such vulnerable migratory bird species does not exist but information could be extracted from the reports delivered from EU member states following the reporting obligations coming from Article 11 of Birds Directive.

Resting birds

Prior to construction, and for at least two consecutive complete seasonal cycles, the status quo of distribution and abundance of birds and observation of bird behaviour should be surveyed in order to assess the assessment area's importance as a resting, feeding and/or moulting area. Monitoring should continue throughout the entire construction phase and at least three years, up to five years if required, after commissioning (operation phase) according to StUK4 Standard (BSH 2013b). Distribution, abundance of birds and bird behaviour in the assessment area will be reported in order to assess potential impacts during these phases.

Two methods are commonly used for surveying birds at sea: ship-based and digital aircraft-based surveys (video/photo) along transects performed throughout the year (Perrow 2019).

Standards for ship transect surveys (such as transect spacing, transect width, transect direction, cruising speed, counting intervals, bird records types, observer position guidelines, survey conditions etc.) are based on Garthe et al. (2002) and have been adopted in StUK4 Standard (BSH 2013b). Aerial surveys are conducted as observer surveys flying at low altitudes (250 ft, Diederichs et al. 2002) (Figure 7.1). In recent years, observer surveys are replaced by digital aerial surveys flying at higher altitudes (1500 – 1800 ft). Apart from higher safety especially during post-construction monitoring, high-resolution digital aerial surveys provide substantial advantages against observer surveys with respect to recording and identification especially of smaller and less suspicious species (Weiß et al. 2016; Perrow 2019). The results of a comparison study between digital video survey technique and visual aerial survey during simultaneous survey flights support the above mentioned statement. The digital survey covered a larger area through direct registrations, provided higher numbers of bird sightings and identified species, and higher spatial accuracy than the visual survey. However visual survey remains a valuable monitoring method for marine birds and one should keep in mind that the chosen survey method should match the objectives of the study in question (Žydelis et al. 2019).

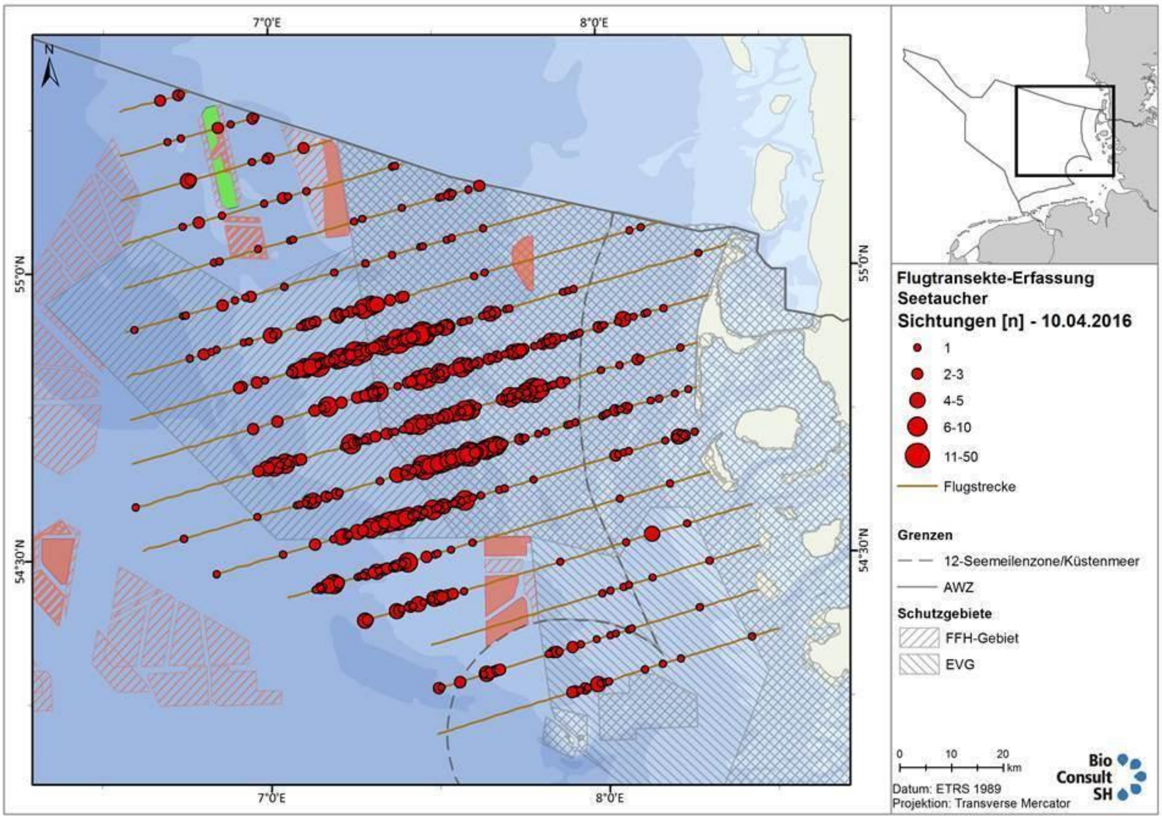


Figure 7.1 Observations of divers from HiDef digital flight monitoring surveys

More details about the suggested presentation of monitoring results for the occurrence and distribution for relevant species (maps, species list, documented information etc.) can be found in StUK4 Standard (BSH 2013b).

Migratory birds

To monitor bird migration around offshore windfarms, the use of radars is the most common method. Radar is an indispensable tool for obtaining long-term monitoring data on seabird behaviour at windfarms and used to monitor migration intensity, flight direction and flight altitude. Video recording of bird activity within offshore windfarms has also been considered, although to date only small samples of bird behaviours around turbines offshore have been available (Skov et al. 2018 and references therein).

Prior to construction, and for at least two consecutive complete seasonal cycles, recording of bird movements (migration, foraging, flights between feeding and resting grounds etc.) should be carried out. Monitoring should continue throughout the entire construction phase and at least three years, up to five years if required, after commissioning (operation phase) according to StUK4 Standard (BSH 2013b) in order to record potential impacts due to construction and operation (evasive behaviour, attraction etc.).

A series or remote sense devices were tested within the frame of StUKplus programe funded by the German government. The devices were installed at FINO1 research platform, at the offshore transformer station and at one wind turbine (Figure 7.2) the automated and camera techniques enabled continuous monitoring of birds at the 'Alpha Ventus' windfarm (BSH & BMU 2014).

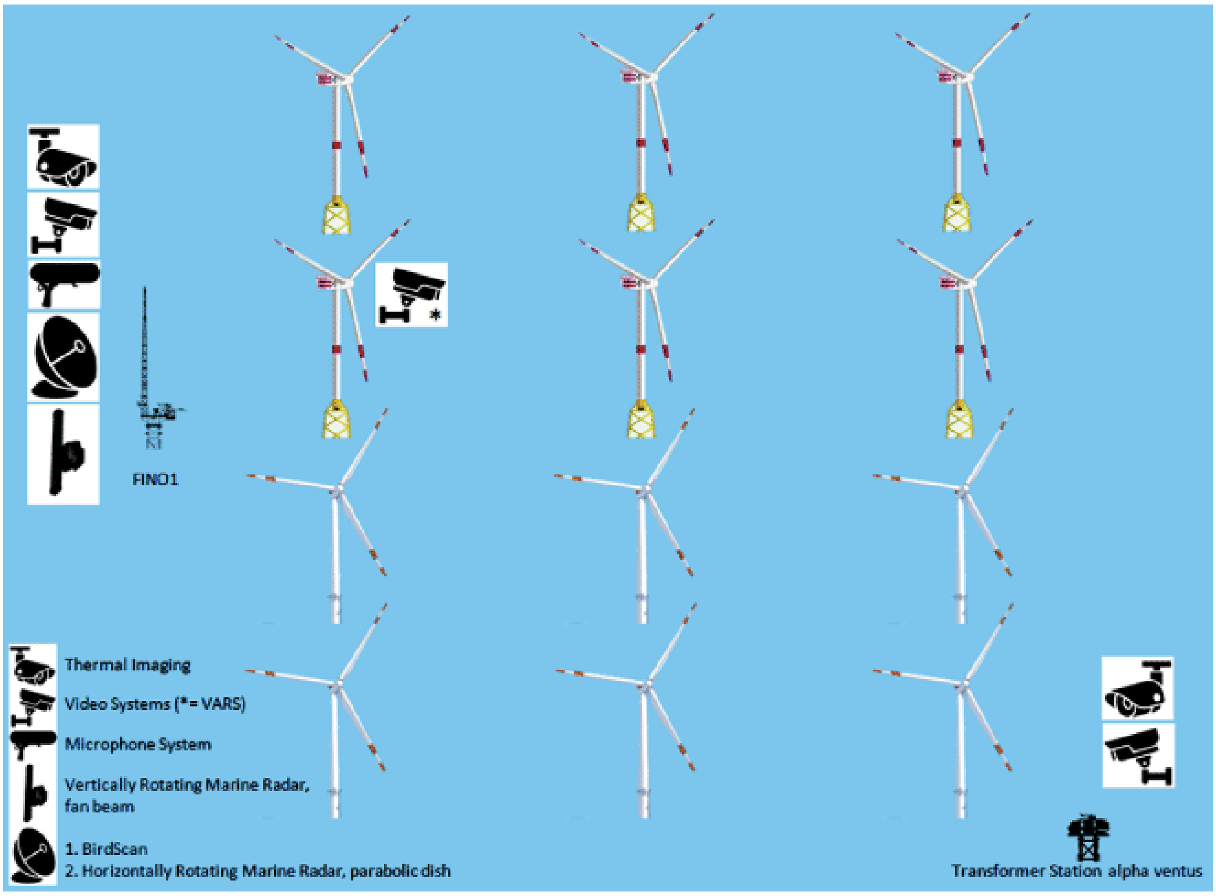


Figure 7.2 Overview of remote sensing techniques operating in the vicinity of 'Alpha Ventus'

The methods mentioned in StUK4 (BSH 2013b) instruct that radar devices can either be fixed on platforms or, in the absence thereof, on ships exclusively at fixed positions (e.g. anchoring buoy) at locations relative to the windfarm in the direction from where most of the birds come to ensure optimal detection of the evasive movements of flying birds. During all phases vertical radar is used to measure seasonal phenology of bird migration. Recording of flight calls is also used for monitoring migrating birds as many species utter calls during migration (FARNSWORTH 2005). Such a system was used on research platform FINO1 that autonomously recognized bird calls by their characteristic narrow sound spectrum filtering out most of wind, rain and wave sound. The calls were registered by a sensitive microphone and processed by a specially developed software (Automatic Recording of Migrating Aves – AROMA). Similar to the afore mentioned monitor strategies prior to construction, and for at least two consecutive complete seasonal cycles, recording of bird movements (migration, foraging, flights between feeding and resting grounds etc.) should be carried out. To determine the species spectrum, parallel day-time visual observations and recording of flight calls at night have to be carried out (day/night according to civil twilight).

While monitoring bird migration is mandatory in Germany, no other country has chosen this approach. It needs to be considered that the standard monitoring provides valuable insights of bird migration but it does provide data on the most important which is how many birds collide with the turbines. This needs to be studied by other methods such as cameras on top of the turbines as conducted at 'Alpha Ventus' (Schulz et al. 2014), but requires a higher effort due to the limited range a single camera can cover.

Future research in Mediterranean needs to address the factors influencing the probability of detecting migrating birds at sea and to understand the sensitivity of resting birds to offshore windfarms. Differences between localities such as these related to species composition and abundance, species distribution and habitat use, migration intensity variations, circumstances leading to night accumulation of night-migrating birds etc. make the assessment of impacts highly site dependent. The monitoring methods already described derived from valuable research efforts in German North Sea and other pioneer counties in the development of offshore windfarms. They could serve as initial guidelines for monitoring programs in the Mediterranean; however site specific surveys are necessary integrating high standard and Mediterranean-adjusted monitoring techniques before, during and after construction of the windfarms and for sufficient periods.

7.7 Monitoring methods & projects for marine mammals

Many marine mammal species are widely dispersed over a large sea area while others may form aggregations or occur in groups and shoals. Marine mammals are generally highly mobile and respond to changes in the location of their prey with consequent impacts on their distribution patterns at sea. Monitoring of marine mammals in relation to offshore windfarms is mainly conducted by two methods, though a variety of different approaches are available (DIEDERICHS et al. 2008):

1- Aerial surveys (today preferably digital video or stills)

2- Passive acoustic monitoring.

Monitoring should be conducted accordingly in appropriately large areas. Especially when several OWFs are located nearby, assessing cumulative effects by combining surveys is an important approach. Monitoring surveys can be applied within the project area, and additionally within a reference area, but due to the above mentioned mobility of species, reference areas and project areas show a very high inter-spatial and inter-annual variability anyway. It is thus recommended to sample large areas and then conduct gradient analysis to assess displacement effects rather than comparing reference and project areas.

To assess possible changes of marine mammals due to construction or operation of OWFs, and informing SEAs/EIAs (Secretariat of the Convention on Migratory Species of Wild Animals 2017), it is important to conduct a baseline study, and later dedicated surveys during and after (operation phase) the ramming procedures and during the operation of the windfarm. Monitoring of marine mammals should in all phases of windfarm construction, operation and decommissioning be accompanied by noise measurements.

Monitoring methods described below have been applied in some OWF projects in Germany (e.g. 'Alpha Ventus', BSH & BMU 2014), in Denmark (e.g. Horns Rev and Nysted, Nielsen 2006), in Belgium (Degraer et al. 2017), and in England (e.g. ORJIP, McGarry et al. 2017) so far.

As Germany has comprehensive guidelines for OWF installation, the monitoring methods within this chapter are presented on the basis of the "Standard Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment (StUK4)" which is published by the BSH (Bundesamt für Seeschifffahrt und Hydrographie, Federal Maritime and Hydrographic Agency) to standardise and control the surveys (technical and planning-related) and the approval process of OWFs and to consider the consequences for the marine environment (chapter 8.2.1).

The BACI approach is the basis for theses monitoring methods, though for some species such as marine mammals no reference areas are needed anymore. Instead a large-scaled monitoring program with survey areas of at least 2,000 km^2 in case of aerial surveys has been chosen. The monitoring procedures as well as the collected data are controlled, coordinated and checked from the BSH in Germany, even though the raw data belongs to the contracting companies had been classified as company secrets and was not available to NGOs. For the OWF Horns Rev and Nysted in Denmark, several panels/ groups took on these tasks (e.g. the International Advisory Panel of Experts on Marine Ecology, IAPEME, for evaluating results; Nielsen 2006) instead of having one federal office being in charge of it.

Abundance and distribution

The objectives for the suggested abundance and distribution survey of marine mammals are the assessment of the ecological importance of the project area (baseline study) regarding the potential impacts during construction and operation phase of an OWF (BSH 2013a). Aerial surveys (digital video/ photo) are combined with the aerial surveys of resting birds. For marine mammals aerial surveys shall cover at least 10% of the assessment area and be implemented at least 8 times through the year, whereby the number of surveys is dependent on the project area and seasonal occurrence of the marine mammal species. Furthermore regulations for analysing the results, differentiated between the investigated abundance and distribution, are given so that monitoring data and reports obtained from different survey groups are comparable.

Line-transect sampling

Line transect sampling is feasible from ships (ship surveys) or from air (observer based aerial surveys, and digital aerial surveys (Figure 7.3) in standardized conventional transect design (for single OWFs), or in standardized cluster design to monitor several OWFs located in vicinity. Ship surveys, though still widely used, are of limited value for monitoring of marine mammals in relation to offshore windfarms because of low siting rates and strong limitations with respect to weather conditions. Aerial digital surveys are today the by far most efficient method. The transect length, distance to the next transect line, and overall transect area depend on the area and its protection status. Digital aerial surveys can cover vast areas and allow identification of birds and mammals on species level. Flight altitudes vary, but should be chosen well above hub-height. Today's digital techniques allow the sampling of several hundred kilometers per flight applying four digital cameras at a time with analysis and identification of species in onshore offices. The resolution at water level reaches 2 cm per pixel.

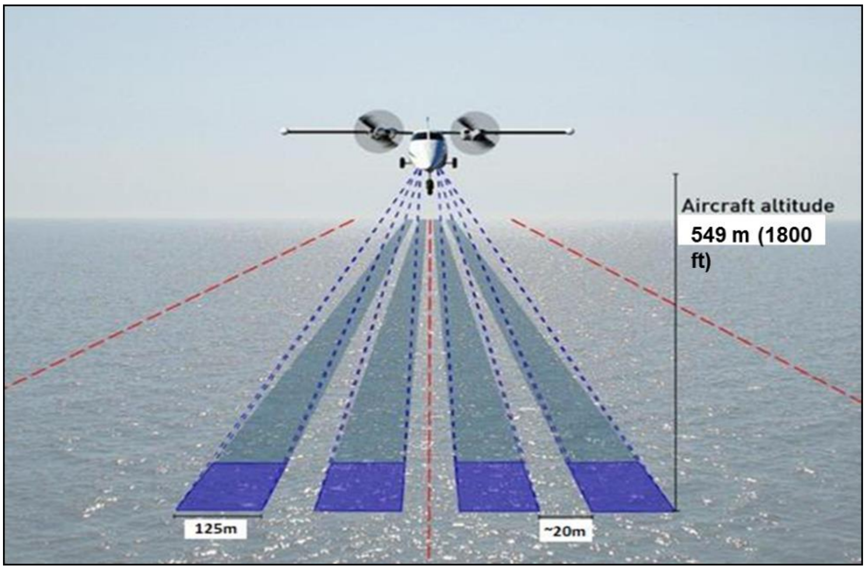


Figure 7.3 Schematic drawing camera orientation and set-up of HiDef digital aerial video surveys.

Passive acoustic monitoring

As most cetaceans vocalize continuously for orientation the recording of their clicks or calls offers a method to study their presence by passive acoustic recorders. Data on cetacean presence can be recorded by standardized, calibrated and continuously measuring acoustic equipment (hydrophones e.g. C-PODs; (DEGRAER et al. 2017)) and standardized sampling design throughout the entire period of investigation (BSH 2013a). Passive acoustic monitoring provide qualitative data which cannot easily be transferred into abundance data, but are able to measure cetacean presence independent of light and weather condition throughout the year and thus provide highly useful data on diurnal, seasonal and interannual changes of the relative abundance of target species. In the German North Sea a measuring grid of up to 15 C-POD Stations has been distributed in consultation with the BSH and stations haven been chosen and allocated by the wind industry to respective windfarm sites. In addition, 4-5 stationary individual PODs are deployed in suitable distances (dependent on the noise emission) to the wind turbines during the construction phase. During the operation phase, at least 3 PODS need to be installed in the windfarm.

Telemetry of individual animals

To determine the abundance and distribution of marine mammals, the telemetry from individual animals is an option. Though this method is limited to a few individuals of a focus species, telemetry gives the highest resolution on spatial temporal scales. Telemetry on seals has been used to analyse behaviour in windfarms, e.g., the repeated visiting of foundations by grey seals and on harbour porpoises to study their reaction on piling or vessels (WISNIEWSKA et al. 2018).

Seals' behaviour close to the OWF Horns Rev and Nysted were surveyed by tagging them with satellite transmitters during all BACI stages. Additionally, visual observations during the baseline study, and the usage of remotely controlled cameras during construction and post-construction phases were implemented. Furthermore, monthly aerial surveys supplemented the data acquisition.

Mediterranean Sea

The main target species of marine mammal monitoring conducted in Germany, Denmark and Belgium is the harbour porpoise which is not present in the Mediterranean Sea. Most other studies have also been conducted on species not present in the Mediterranean Sea. Thus, the most sensitive species must be identified, but the monitoring methods (transects by ships/ aircraft; acoustic and visual monitoring; telemetry) are suitable for virtually all species present.

Since 2009, TETHYS RESEARCH INSTITUTE (2016) in collaboration with the Italian Ministry of the Environment, the International Whaling Commission (IWC) and the Institute for Environmental Protection and Research (ISPRA), executed several aerial surveys for abundance, density and distribution surveys of cetaceans and other marine mega-vertebrates such as the giant devil rays, *Mobula mobular*, and loggerhead turtles, *Caretta caretta*. The aerial surveys were conducted in larger areas than the boat-based surveys before, as they include the Ligurian Sea, the Central and Southern Tyrrhenian Sea, parts of the Seas of Corsica and Sardinia, as well as the Ionian Sea and the Gulf of Taranto. Aerial surveys were also conducted by PANIGADA et al. (2011) in summer and winter 2009 for abundance monitoring of cetaceans in the Pelagos Sanctuary by transect sampling. AZZELLINO et al. (2012) investigated the spatial and temporal distribution of 7 different marine mammal species (striped dolphins, fin whales, Risso's dolphins, sperm whales, common bottlenose dolphins, long-finned pilot whales, and Cuvier's beaked whales) within the Pelagos Sanctuary over 18 years of ship-based surveys. In the Marine Park of the Gulf of Lion, France, the abundance and distribution of marine mammals and other megafauna was monitored in 2018 in the entire Park. Cetaceans were counted via boat transects and photo-identification of bottlenose dolphins did take place. For the same area, where the first OWF in the Mediterranean with floating turbines is being developed, the following recommendations regarding marine mammals in general and bottlenose dolphins in specific are suggested (AGENCE FRANÇAISE POUR LA BIODIVERSITÉ 2018):

- Photo-collecting and visual and acoustic behavioral survey campaigns at all seasons for one year
- regular and comparable monitoring of the use of the area, throughout the entire life cycle of the projects, including baseline investigations.
- research projects on the ecological impact of the development of floating wind turbines in the Gulf of Lion of Bottlenose Dolphin on a population level

Within the 1980', CIBRA (Centro Interdisciplinare di Bioacustica e Ricerche Ambientali) began to organize passive acoustic monitoring surveys for cetaceans, using towed hydrophones, continuing in 1995 with a cooperative project with the Italian Navy with the aim to protect marine mammals and the marine environment (COZZI 2005). As a result, a long-term study project of the sperm whales' ecology and behaviour started.

Special case: Monk seals

As the Mediterranean monk seal is an endangered species within the Mediterranean Sea, special focus should set on that threatened species, in case offshore windfarms are constructed in areas where this species occurs.

Besides monitoring at open sea, monk seal nesting and resting sites which are present in the vicinity of an offshore windfarm and its associate infrastructure should be in advance investigated in order to assess the suitability of a shelter as a potential habitat for the Mediterranean monk seal as well as potential impacts to the species population -dynamics. The methodology for recording the resting/nesting habitat of the Mediterranean monk seal is based on the experience gained by fieldwork by 'MOm / Hellenic Society for the Study and Protection of the Monk Seal' (MOM/HELLENIC SOCIETY FOR

THE STUDY AND PROTECTION OF THE MONK SEAL 2017) a Greek NGO with the legal status of a Non–profit association.

7.8 Monitoring socio-economic sector

Tourism/social acceptance

To investigate changes in touristic activities or social acceptance by the coastal population in general, follow up studies to surveys before and during the construction should be conducted to investigate changes in people's perception of the OWFs. Such a survey was conducted within the framework of Belgian OWFs (DEGRAER et al. 2013), showing the most important issues people would like to be informed of: Effects on nature and environment; costs, benefit, return; Location of OWF; Capacity of OWF. Similar to general social acceptance the way how other stakeholders see the OWF during the operational phase should be monitored by e.g. performance of workshops, as suggested by Wever et al. (2015).

Fisheries

In the fishery sector besides continuous questionnaires to monitor changes in acceptance or attitude towards OWFs, dynamics of fishing activity in the vicinity of an newly constructed OWF should be monitored as performed for instance by Degraer et al. (2013) around OWFs in the Belgian part of the North Sea. Large fishing vessels are equipped with a Vessel Monitoring System (VWS). This way the movements and spatial distribution and changes due to the OWF can be detected. It has to be noted, that only the presence of fishing vessels, but not the fishing effort of each vessel is monitored this way. However, this method is mostly limited to national vessels and Degraer et al. (2013) suggest an international exchange of data to improve outcomes of VMS based studies.

7.9 Research and Development projects

Various aspects of offshore windfarms and resulting environmental impacts can hardly be investigated by standardized monitoring programs but require dedicated research projects often relying on newly developed methods. Extensive research programs have been conducted in the UK, Denmark and Germany covering – amongst others – the following projects:

- Research at 'Alpha Ventus' (RAVE) – investigating impacts of offshore wind turbines on almost all faunal species in the windfarm: http://www.rave-offshore.de/en/ecology.html
- Development of bubble curtains for noise mitigation during offshore pile driving: www.hydroschall.de
- Investigations into the impacts of offshore windfarms north of Helgoland on seabirds (Helbird): http://www.ftz.uni-kiel.de/de/forschungsabteilungen/ecolab-oekologie-mariner-tiere/abgeschlossene-projekte/helbird
- Studying the response of red-throated diver to offshore windfarms by means of satellite tracking and digital area video surveys (DIVER): www.divertracking.com
- Impacts of offshore windfarms on bird migration in the German Bight (BIRDMOVE): http://ifv-vogelwarte.de/das-institut/forschung/vogelzug/ag-hueppop/birdmove.html

- Efficacy of acoustic deterrents: https://www.carbontrust.com/offshore-wind/orjip/acoustic-detterents/

- Monitoring program for underwater soundscapes (anthoropogenic and biological noise levels) in the Western Mediterranean (https://chorusacoustics.com/monitoring/)

- Bird collision avoidance study: https://www.carbontrust.com/offshore-wind/orjip/birds/

- Impacts on fish from piling at offshore wind sites: https://www.carbontrust.com/offshore-wind/orjip/fish/

- Modelling population consequences of disturbance on harbour porpoise: http://bios.au.dk/om-instituttet/organisation/havpattedyrforskning/projekter/depons/currently/

- Currently several research projects have been initiated at the European Offshore Wind Deployment Centre (EOWDC): https://corporate.vattenfall.co.uk/projects/operational-wind-farms/european-offshore-wind-deployment-centre/scientific-research/

These and other research projects continuously improve the scientific basis for the assessment of environmental impacts from offshore windfarms and form an important basis for decision making in all stages of the planning processes.

7.10 General conclusion on monitoring methods

Monitoring of species and habitats which may be affected from offshore wind developments is crucial to inform future planning processes and provide a scientific basis for decision making in this prospering industry.

Many of the monitoring methods already applied for developments of OWFs derive from three extensive monitoring and research studies (and the associated regulations) in Northern European countries: Germany, Denmark and Belgium (NIELSEN 2006; BSH 2013a; DEGRAER et al. 2017). For a successful monitoring of the impacts of OWFs on the marine (and anthropogenic) environment thorough planning is necessary to ensure that all relevant aspects will be covered. Planning and developing monitoring programs has to be included in the planning phase of the OWF itself as effective monitoring covers time frames prior to, during and post-construction. Baseline studies (pre-construction) as well as post-construction monitoring of environmental factors are most useful if conducted at a multi-annual basis. This way it can be ensured that seasonal dynamics and migration patterns (e.g. of migratory birds or migrating marine mammals) are detected and considered. Furthermore a broad spatial scale should be chosen as monitoring area to cover the impacted area inside and in the direct vicinity of an OWF as well as reference areas, far away from the OWF, so a direct impact can be largely excluded (e.g. BSH 2013a). In the case that OWFs are in close vicinity to each other, a joint monitoring program (cluster analysis) can be taken into account to cover a broader area and make it more cost-effective (BSH 2013a).

For the monitoring of the environmental parameter various guidelines are published, specifically for one or a few target factors (DIEDERICHS et al. 2002, 2008; GARTHE et al. 2002) or generally for a major part of factors potentially impacted by an OWF and to be applied at every OWF development project (e.g. BSH 2013a). It is evident, that according to the guidelines and the various impacts and impacted factors within the marine environment, a variety of monitoring methods can be applied. These depend widely on the target and local species/habitats and range from invasive methods, such as trawling (fish and benthos), grab sampling (benthos) or water sampling (abiotic factors) to non-invasive methods, such as camera observations (birds), hydroacoustics (fish, marine mammals), ship-based surveys (birds and marine mammals), aerial surveys (birds and marine mammals) and questionnaires (stakeholders). Besides these three major monitoring programs described in this chapter, there is an increasing number of research projects to gain further knowledge, minimize impacts on the environment and socio-economic aspects, also in order to create (or improve) holistic monitoring approaches. While most methods used for OWF monitoring are well established and proven in many projects, there is still a lack of suitable methods to monitor bird migration and the collision risk of migrating birds.

Generally many of the planning approaches in the aforementioned paragraphs can form a basis for the monitoring programs in future projects in the Mediterranean Sea in the light of the development of the offshore windfarm sector, since they imply general theoretical guidance how to plan and perform effective monitoring in an OWF project, such as the general concept of the BACI approach ("Before After Control Impact") (e.g. DEGRAER et al. 2013). However detailed monitoring methods and techniques will have to be standardized through initial research for the oligotrophic marine environment of the Mediterranean. Existing monitoring methods need to be carefully revised in order to test their applicability to Mediterranean conditions. In many cases monitoring methods will be modified or newly established to meet criteria important in the Mediterranean, for example in relation to fish which are more diverse and more difficult to monitor in area with extensive reefs or seagrass meadows.

Broad-scale research programs are crucial to investigate the environmental components possibly impacted by an OWF and to determine the most appropriate monitoring methods either following existing guidelines or develop additional ones. Animals, not present in northern marine waters, such as sea turtles or monk seals, are not covered in existing monitoring programs for OWFs and effort has to be made to include those hitherto unmonitored (in relation to OWFs) aspects into future programs in the Mediterranean Sea.

Another aspect to consider is the construction techniques of the OWFs developed so far. The described monitoring programs are developed for turbines with fixed foundations. Since the development of turbines with floating foundations has gained increased attention recently, monitoring programs with associated research programs should be established in order to generate monitoring methods adjusted to the applied construction technique as well as to the impacted environment.

In the following table (Table 7.1) we present the main monitoring concepts already applied to OWFs and the applicability of the monitoring methods to the Mediterranean marine environment.

Table 7.1 Monitoring concepts already applied to OWFs and the applicability to the Mediterranean marine environment

	Monitoring concepts applied to OWFs	**Applicability to the Mediterranean**
Abiotic environment	• Monitoring of several abiotic factors (e.g. grain size distribution, temperature, oxygen levels) • Monitoring of heavy metals / other chemical pollutants in the water column and in sediments • Side scan sonar survey for information on sediment and habitat structure	• Monitoring concepts within the framework of the MSFD "D7" can be used to establish monitoring programs • Monitoring of abiotic factors combined with monitoring of benthic and fish investigations. • Use of side scan sonar
Habitats /benthic communities	• Investigation of the sediment and habitat structure and their dynamics • Video survey of epifauna, macrophytes and habitat structure • Grab sampling survey of infauna, beam trawl survey of epifauna • Investigation of growth and demersal megafauna on the underwater construction structure, of benthos and habitat structures in the context of installation of cable routes	• Video, grab sampling, ROV investigations of habitats, benthos and species settled on new artificial substrate • Special emphasis needed on priority habitats such as 1120* *Posidonia oceanica* beds ○ system scale (aerial photographs, measurement of bottom cover, permanent transects) ○ meadow scale (e.g. photographs of Posidonia around cement markers positioned along meadow limits, shoot-density, permanent quadrats) ○ shoot scale (e.g. plagiotopic to orthotropic rhizome ratio, laying bare of the rhizomes, lepidochronology, leaf epiphytes, leaf biometry) (BOUDOURESQUE et al. 2007) • Apply reef effect monitoring techniques with divers or remote operated vehicule
Fish	• Trawl surveys • Use of data of existing surveys & sampling programs • non-invasive methods such as hydroacoustic methods and SCUBA diving surveys	• Use of data of existing surveys & sampling programs (e.g. ICCAT) • ROV investigations of community composition at new artificial substrate (reef effect) • Trawl surveys; non-invasive survey methods • Longer-term: Use of catch data
Sea turtles	• No monitoring of sea turtles at OWFs applied so far	• Monitoring by ship surveys or (digital) aircraft-based surveys • Tracking of tagged animals swimming by satellite; acoustic methods
Birds	• Ship-based and (digital) aircraft-based surveys (video/photo) along transects • Use of radars/cameras for long-term monitoring data on seabird behaviour around OWFs and to monitor migration intensity, flight direction and flight altitude	• Ship-based and (digital) aircraft-based surveys (video/photo) along transects • Use of radars/cameras for long-term monitoring data on seabird behaviour around OWFs and to monitor migration intensity, flight direction and flight altitude • Special focus to Mediterranean endemic species (such as puffins) and bird species whose main reproductive polulations breed in Mediterranean (such as Eleonora's falcon).

	Monitoring concepts applied to OWFs	Applicability to the Mediterranean
Marine mammals	• Passive acoustic monitoring (PAM) methods on temporary and permanent monitoring-stations • (Digital) aircraft-based surveys • No monitoring of Mediterranean monk seals at OWFs applied so far	• PAM and (digital), ship-based and aircraft-based surveys • Tagging of individual animals for investigating habitat use and migration patterns • Year-round surveys to cover migrating as well as resident species • As the Mediterranean monk seal is an endangered species within the Mediterranean Sea, special focus should set on that threatened species, in case OWFs are constructed in areas where this species occurs. Besides monitoring at open sea, monk seal nesting and resting sites which are present in the vicinity of an OWF and its associate infrastructure should be in advance investigated in order to assess the suitability of a shelter as a potential habitat for the Mediterranean monk seal as well as potential impacts to the species population -dynamics. The methodology for recording the resting/nesting habitat of the Mediterranean monk seal can be based on the experience gained by fieldwork by 'MOm / Hellenic Society for the Study and Protection of the Monk Seal' (MOm/Hellenic Society for the Study and Protection of the Monk Seal 2017) a Greek NGO with the legal status of a Non–profit association.

8 REGULATORY FRAMEWORKS

Offshore wind farming creates new activities and structures in the marine environment. At the start, offshore wind farming has been initiated with limited knowledge about the environmental impacts and regulatory frameworks were not specifically designed for this new activity. Different approaches have been taken to match the demands of a new and rapidly expanding industry and the requirement to balance this with the demands of maintaining or restoring marine biodiversity. Several countries have put various restrictions and used pilot projects to test the technology of offshore turbines and to investigate their impact on the marine environment, especially marine wildlife. In establishing regulatory frameworks for offshore wind farming and marine conservation the following topics are of special relevance:

1. Marine spatial planning: restriction/designation of planning areas for offshore windfarms
2. Designation of marine protected areas, in Europe mostly within the network Natura 2000 (EUROPEAN COMMISSION 2018b)
3. Development of SEA and EIA procedures and methods
4. Development of investigation methods for baseline and monitoring
5. Development of standards for construction and operation of offshore windfarms including mandatory mitigation measures

In the following sections a brief overview is given on applicable regulatory frameworks and how they have been adapted to offshore wind farming.

8.1 EU frameworks

8.1.1 Environmental Impact Assessment (EIA) Directive 85/337/EEC

An EIA is a systematic process that identifies, predicts and evaluates environmental effects of proposed projects, and identifies any required mitigation measures, informing the project’s design. In Europe, the Environmental Impact Assessment (EIA) Directive (85/337/EEC) (as amended[16]) provides a legal framework for the assessment of environmental effects of projects that are likely to have significant effects on the environment, which is often applicable to new offshore wind projects. Before any decision is taken to allow a project to proceed, the possible impacts it may have on the environment (either from its construction or operation) are to be identified and assessed. The Directive also ensures the participation of environmental authorities and the public in environmental decision-making procedures.

The Directive include Annexes where mandatory EIAs are needed for projects considered as having significant effects on the environment (Annex I) as well as projects for which the national authorities have to decide whether an EIA is needed by the "screening procedure" (Annex II). According to the

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[16] The initial Directive of 1985 and its three amendments have been codified by DIRECTIVE 2011/92/EU of 13 December 2011. Directive 2011/92/EU has been amended in 2014 by DIRECTIVE 2014/52/EU by 2014/52/EU.

Directive offshore windfarms are included in Annex II, Subcategory 3(i): 'Installations for harnessing of wind power for energy production (windfarms)'.

Additional information and reference and EU Commission guidance documents can be found in the EU internet site: http://ec.europa.eu/environment/eia/eia-support.htm

8.1.2 **SEA directive** 2001/42/EC – Strategic Environmental Assessment

The SEA Directive applies to a wide range of public plans and programs (e.g. on land use, transport, energy, waste, agriculture, etc) which need to be assessed with respect to their impacts on the environment before brought into practice. The SEA procedure can be summarized as follows: an environmental report is prepared in which the likely significant effects on the environment and the reasonable alternatives of the proposed plan or program are identified. The public and the environmental authorities are informed and consulted on the draft plan or program and the environmental report prepared. As regards plans and programs which are likely to have significant effects on the environment in another Member State, the Member State in whose territory the plan or program is being prepared must consult the other Member State(s). On this issue the SEA Directive follows the general approach taken by the SEA Protocol to the UN ECE Convention on Environmental Impact Assessment in a Transboundary Context.

The environmental report and the results of the consultations are taken into account before adoption. Once the plan or program is adopted, the environmental authorities and the public are informed and relevant information is made available to them. In order to identify unforeseen adverse effects at an early stage, significant environmental effects of the plan or program are to be monitored.

Strategic Environmental Assessments are considered as an important tool for planning offshore wind energy utilization in order to avoid rather than mitigate detrimental impacts (see chapter 6.1.2). Due to its scope of covering larger areas and identifying planning areas for projects, the SEA process is usually less detailed as the following project specific assessments. Because site selection and consideration of cumulative effects (chapter 5.9) are essential to facilitate offshore wind developments at a large scale, more emphasis should be given on the strategic level which is most appropriate to avoid impacts.

8.1.3 Habitats 92/43/EEC and Birds 2009/147/EC Directives & Guideline documents

Cornerstones to EU's biodiversity policy, the Habitats 92/43/EEC (EU 1992) and Birds 2009/147/EC Directives include strict legal provisions relating to the assessment of planned developments that have the potential to affect nature conservation interests, including Special Areas for Conservation (SAC) and Special Protection Areas (SPA), belonging to the Natura 2000 network.

The European Commission has released a document, 'Wind energy developments and Natura 2000' (EUROPEAN COMMISSION 2010), which provides guidance to national and regional authorities on how to ensure that the development of windfarms in Natura 2000 areas is compatible with the EU's Birds and Habitats Directives. It is also stated that 'The Habitats Directive does not, a priori, exclude windfarm developments in or adjacent to Natura 2000 sites. These need to be judged on a case by case basis'.

The European Commission's guidance document, although focused in onshore windfarm sector, outlines the benefits of strategic and proactive planning as a means of avoiding potential impacts of windfarm developments on nature and wildlife at an early stage in the planning process, for instance through the appropriate siting of windfarm developments away from areas of potential conflict with wildlife and nature. Furthermore it describes a step-by step procedure for windfarm developments affecting Natura 2000 sites. If it cannot be excluded that there will be a significant effect upon a Natura 2000 site then an Appropriate Assessment must be undertaken.

The purpose of the 'Appropriate Assessment' is to assess the implications of the plan or project in respect of the site's conservation objectives, individually or in combination with other plans or projects. The conclusions should enable the competent authorities to ascertain whether or not the plan or project would adversely affect the integrity of the site concerned.

The 'Appropriate Assessment' should focus on the species and habitats that are defined as conservation targets of a Natura 2000 site and should also consider all the elements that are essential to the functioning and the structure of that site. The appraisal of effects must be based on objective information.

The outcome of the 'Appropriate Assessment' is legally binding. If it cannot be ascertained that there will be no adverse effects on the integrity of the Natura 2000 sites, even after the introduction of mitigation measures or conditions in the development permit, then the plan or project cannot be approved unless overriding public interest can be proven.

The requirements of the habitats directive and the bird's directive are not, however, restricted to protected areas under the Natura 2000 network, but are highly relevant for planning outside these areas from their regulations on protected species and habitats. With respect to windfarms especially article 12 on the strict protection of species has been proven to be highly relevant, because it restricts incidental killing and disturbance of protected species. With respect to offshore windfarms article 12 forms the legal base to demand noise mitigation if noise immission might cause hearing impairment in whales and to demand a shutdown of turbines if the collision risk of birds is assessed as significant.

In conclusion, the regulations arising from the habitats directive which also cover the bird's directive are considered as the most effective legal framework to assess and avoid significant impacts on protected areas, protected species and protected habitats in European marine waters.

For further information see:

- Managing Natura 2000 sites: the provision of Article 6 of the 'Habitats' Directive 92/43/EEC (EUROPEAN COMMISSION 2018c)

- Assessment of plans and projects significantly affecting Natura 2000 sites: methodological guidance on the provisions of Article 6(3) and (4) of the Habitats Directive 92/43/EEC (EUROPEAN COMMISSION DG ENVIRONMENT 2001)

- Guidance document on Article 6(4) of the Habitats Directive 92/43/EEC: clarification of the concepts of alternative solutions, imperative reasons of overriding public interest, compensatory measures, overall coherence, Opinion of the Commission (EUROPEAN COMMISSION DG ENVIRONMENT 2001)

- Guidance document on the strict protection of animal species of Community interest under the Habitats Directive 92/43/EEC

8.1.4 Marine Strategy Framework Directive (MSFD)

The Marine Strategy Framework Directive (MSFD) was established by the European Union in 2008 with the objective to increase the efficiency of protection of the European marine environment. With help of a catalogue of detailed criteria and standards the member states of the European Union must apply the Marine directive within their national borders and also in waters beyond national jurisdiction. The overall aim is to achieve Good Environmental status (GES), where criteria are included in the MSFD. The MSFD represents a legislative framework to manage human activities interacting with or impacting on the marine environment, also by integrating the ecosystem approach. Each member state is called upon developing a so called “Marine Strategy” for its marine waters and report on progress and short-comings. The Marine Strategies include the initial definition of Good Environmental Status in their national marine waters. Furthermore targets and respective environmental monitoring have to be developed to achieve or maintain GES by 2020. The GES can be defined upon 11 descriptors:

D1	Biodiversity
D2	Non-indigenous species
D3	Condition of the populations of commercial fish and shellfish species
D4	Food webs
D5	Eutrophication
D6	Sea floor integrity
D7	Hydrographical conditions
D8	Contaminants
D9	Contaminants in seafood
D10	Marine litter
D11	Introduction of energy (including underwater noise)

Descriptor 11 for instance focuses on the introduction of energy, including underwater noise, and according to the MSFD the anthropogenic induced underwater sound is supposed to not exceed levels that “adversely affect populations of marine animals. Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities” (European Commission 2017). The development of the procedure relies on the member states, which has been criticized as the member states are flexible in interpreting the criteria given in the MSFD (Boyes et al. 2015).

According to the MSFD the European Seas are divided into marine regions and subregions depending on geographic and environmental criteria: The Baltic Sea, the North-East Atlantic Ocean, the Mediterranean Sea and the Black Sea. The MSFD 2014 report from the Mediterranean region summarizes the efforts and achievements made by the Mediterranean member states to achieve or maintain GES in the Mediterranean (Dupont et al. 2015). Only one country, France, has listed offshore renewable energy as one of the ongoing activities. In the light of future development of OWFs in the Mediterranean, also in areas beyond national jurisdiction, effort is needed to obtain a better coverage of non-national waters as these areas were covered to less than 10% in the monitoring programs within the MSFD across the Mediterranean countries (Dupont et al. 2015).

8.2 Examples from European countries on existing guidelines, regulations and standards

8.2.1 Germany

In Germany, the first windfarms in the EEZ were consented under the Maritime Facilities Ordinance (Seeanlagenverordnung) which was not designed for the development of offshore windfarms and allowed an almost free application for windfarm sites outside the main shipping routes. After a first pilot windfarm, 'Alpha Ventus', was consented in 2001, a high number of planning companies applied for offshore windfarm sites in the German EEZ of the North Sea and the German Baltic Sea in several occasions in competition for the same site. A high number of these applications were finally consented; however, two applications were rejected for causing significant impacts on wintering waterbirds.

In parallel to the development of offshore windfarms marine protected areas were established under the European network Natura 2000, now covering about 30% of German marine areas. The marine protected areas were partly arranged around offshore windfarm areas and included one project which got consent before the MPAs were finally established.

In order to steer the developing industry the Federal Maritime and Shipping Authority (BSH) developed consenting procedures and published a series of standards defining effort and methodology of investigations required to get consent for a project. BSH has further implemented a number of conditions into each permit demanding that windfarm operators

- Apply state of the art noise mitigation measure to reduce pile-driving underwater noise below 160 dB_{SEL} at a distance of 750 m
- monitor bird migration (BSH reserves the right to demand shut-down of windfarms in nights of mass migration)
- bury cables at sufficient depth so that heating of the sediment does not exceed 2 K at 30 cm depth.
- Conduct dedicated environmental construction monitoring and 5 years post-construction monitoring according to StUK4" Standard: "Investigation of the impacts of offshore wind turbines on the marine environment"

'StUK4' constitutes a framework of minimum requirements for marine environmental surveys and monitoring during the planning, construction and operation phase of an offshore windfarm regarding features of conservation interest, (i. e. fish, benthos, birds, and -marine mammals). The main objectives are the determination of their spatial distribution and temporal variability in the pre-construction phase (baseline survey), the monitoring of the effects of construction, operation and decommissioning and the establishment of a basis for evaluating the monitoring results. The aim is to identify environmental impacts at the earliest stage possible and minimise potential effects on marine organisms.

A central component of the approval process for offshore windfarms is an environmental impact assessment (EIA) and its requirements are described in 'StUK4 Standard'. Therein information is provided to applicants on investigations required by the planning approval/approval authority.

The procedure for evaluating the impacts of an offshore windfarm includes the initial literature documentation regarding the planning area as well as a proposal of an investigation program in accordance to the StUK4. The Environmental impact assessment requires a baseline study, monitoring in the construction phase and in the operation phase as well.

A baseline study over two successive, complete seasonal cycles has to be performed without any interruption to determine the status quo as a basis for construction and operation phase monitoring as well as for compilation of the EIA. One seasonal cycle comprises twelve calendar months including the month in which the survey begins. After completion of the baseline study, an EIA must be submitted to the planning approval/ approval authority. If an EIA has already been compiled on the basis of one seasonal cycle, it must be extended by inclusion of the results of the second seasonal cycle. The baseline study must be updated by inclusion of a third survey year, if the time between end of baseline study and construction start exceeds two years. If more than five years pass between end of baseline study and construction start, a new, complete two-year baseline study must be carried out. It is possible to apply after six months for a reduction of the monitoring program to one year (together with the submission of a detailed preliminary report), if the results of the investigations show that no significant changes in the conditions regarding location have occurred.

Today, planning of offshore windfarms are more regulated in Germany: offshore windfarm sites are designated as part of marine spatial planning procedures and a full EIA is conducted on behalf of BSH before sites are auctioned. BSH has kept the obligations for noise mitigation, cable heating and monitoring and still reserves the right to demand the shutdown of windfarms in case of increased risks of bird collisions in nights of mass migration.

8.2.2 United Kingdom (UK)

The UK is made up of several nations with separate laws and regulators in each. Licenses to operate offshore windfarms are provided by different Government Agencies in each nation within the UK. In England and Wales the regulator is the Marine Management Organisation (MMO), in Scotland it is Marine Scotland and in Northern Ireland it is the Department of the Environment Northern Ireland.

The regulatory framework in the UK is provided by the translation of EU Directives in to separate laws in England and Wales, Scotland and Northern Ireland. While these laws are different between each country in the UK, their content is much the same. So, for any of the regulations mentioned below, a very similar law exists in Scotland and Northern Ireland. In England and Wales the Environmental Impact Assessment (EIA) Directive (2014/52/EU) was enacted as The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (usually referred to as the “2017 EIA Regulations”). This requires any development that has a “likely significant effect” on the environment to undertake an assessment of those likely significant effects. There is not overall fixed framework which a development must follow. However, most environmental impact assessment for offshore windfarms in the last 5 – 10 years follow a very similar overall approach.

In addition to completing a EIA, it is also necessary for a developer to complete a Habitats Regulations Assessment (HRA). The HRA is a requirement of The Conservation of Habitats and Species Regulations 2010 (as amended), which enacts Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (usually referred to as “the Habitats Directive”).

EIA Reports (until 2017 termed “Environmental Statements”) for OWFs typically contain multiple chapters on a wide variety of subjects. The wildlife chapters include separate chapter on Ornithology, Marine Mammals (including other marine megafauna, such as sharks, turtles), benthos, natural fish populations, and fisheries. Other chapters include socio-economic aspects.

EIA Reports on wildlife subject typically present assessment of the baseline environment, potential impacts from the windfarm alone, the effects of these impacts on populations and a cumulative impact assessment from all other reasonably foreseeable impacts on the populations being assessed, including the project itself.

HRA Reports are more prescriptive where there is an initial screening report (an assessment of no likely significant effect on Natura 2000 sites) followed by a Report to Inform the Appropriate Assessment (RIAA). Both of these reports must assess the potential for the project alone, and in-combination with any other reasonably foreseeable plans and projects, on a site by site basis.

There is a variety of guidance available on undertaking impact assessment, at either an EIA or HRA scale. Scottish Natural Heritage is the source of the most comprehensive guidance:

"General advice on marine renewables development" (SCOTTISH NATURAL HERITAGE 2017)

Advice on the production of EIA Reports (or Environmental Statements) has been provided for offshore developments by the Chartered Institute of Ecology and Environmental Management:

https://www.cieem.net/data/files/Resource_Library/Technical_Guidance_Series/EcIA_Guidelines/Final_EcIA_Marine_01_Dec_2010.pdf

Marine Scotland have a comprehensive guide on the planning and licensing process for development in Scottish waters:

https://www.gov.scot/binaries/content/documents/govscot/publications/consultation-paper/2018/10/marine-scotland-consenting-licensing-manual-offshore-wind-wave-tidal-energy-applications/documents/00542001-pdf/00542001-pdf/govscot%3Adocument

Detailed guidance for nationally important infrastructure projects, including offshore windfarms, is provided in England and Wales by the Department for Environment, Food and Rural Affairs (DEFRA), The Environment Agency and Natural England (THE ENVIRONMENT AGENCY AND NATURAL ENGLAND & DEPARTMENT FOR ENVIRONMENT, FOOD & RURAL AFFAIRS 2018).

8.2.3 Denmark

According to EU legislation, two assessment processes are mandatory: Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA).

In Denmark Energistyrelsen or the Danish Energy Agency (DEA) is responsible for Danish OWF projects. Denmark has the longest experience in the construction of OWFs as it established the world's first OWF ('Vindeby') in 1991. No standard environmental impact assessment (EIA) framework exists so far. The requirements and needs for an EIA are decided case by case depending on the environmental priorities at the respective site. The description of the potential impacts on the environment covers fauna and flora, seabed conditions, abiotic features, such as water, air and climate, archaeological sites, landscape and coastal safety. The EIA report must also include possible mitigation and compensation measures. Furthermore, alternative locations for the project must be included (NIELSEN 2006). The EIA report is part of the application, which requires a phase public consultation and where the authority's decision on the project application will depend on. In general OWFs in Natura 2000 sites are not prohibited a priori (MOCKLER et al. 2015). At two Danish OWFs, 'Nysted' and 'Horns Rev', extensive EIA, mitigation and monitoring programs were performed (BACI approach). Due to the great differences and sensitive areas at the two sites, the environmental regulatory requirements differed greatly between the sites.

At both sites the following general points were addressed in the EIA during the construction phase in varying orders of priority (MOCKLER et al. 2015):

- Sediment spill monitoring
- Incidents, accidents and oil spill
- Waste handling
- Precautions regarding pile driving/vibration of sheet piles/monopiles
- Sediment depositing
- Marine archaeology
- Registration of navigation in the area

Also, regarding noise mitigation there are no standardized mitigation measures required during construction:

- Mitigation measures depend on the EIA and on the experiences on former turbine constructions.
- Soft-start is required, but depends on the permit.
- No marine mammal observers are required.
- No seasonal restrictions on piling.
- Seal scarers are not obligatory.

The objective of these two extensive programs was to thoroughly investigate and monitor economic, technical and environmental factors to benefit from this experience in order to speed up future OWF projects. After termination of the projects, the experiences made at the two sites during planning, site selection, construction and operation, were summarized in a book (DONG ENERGY et al. 2006) and an associated report (NIELSEN 2006). The main findings and lessons learned were summarized for the two sites.

Recommendations for the pre-construction phase were described as follows:

- “Carry out a thorough screening and planning before designating areas for offshore wind turbines.
- Take wind conditions, sea depths, grid connection options, seabed conditions, marine life etc. into consideration when screening for suitable sites for offshore windfarms.
- Consult all relevant authorities with interests at sea, in order to avoid future conflicting interests. Often compromises can be found.
- Consider also as a minimum competing interests such as shipping routes, environmentally sensitive sites, fishing areas, resources and extraction up front in the planning.
- Involve all affected parties with interests at sea at government level already at the beginning of the planning procedure. This will create interest in a commitment to the process as well as to the sites chosen.

- Consult with evidence from effect studies on environmental impacts already assessed and accessible in the public domain before requiring expensive and time consuming analysis as part of the EIA requirements.
- If not in place, consider setting up a general framework for environmental impact assessments (EIAs)."

8.2.4 France

Experiences with offshore wind power in the Mediterranean are still lacking, nevertheless in the French Mediterranean there are guidelines for the OWF in the Marine Natural Park of Gulf of Lion, being currently under development. This is of major importance as the windfarm is going to operate within an MPA.

The Environmental Impact Assessment includes a baseline assessment of the occurring habitats, organisms, archaeological sites as well as socio-economic aspects and a project's impact assessment including appropriate mitigation measures for each of the potential impacts. A strong focus is put in the EIA on the "Avoidance Mitigation and Compensation-approach". The OWF developer needs first to avoid all negative effects (Avoidance). If this is not possible, the reasons have to be explained and appropriate mitigation measures proposed to reduce negative impacts (Mitigation). In the case of absence of appropriate mitigation measures the OWF developer needs to compensate the negative impacts through actions for equivalent habitats restoration (Compensation).

The EIA is then evaluated by the Environmental Authority followed by public consultation and administrative validation.

The basis of the recommendation is the formation of a working group, which works in close collaboration with the windfarm developer to merge the interests of the OWF project with the MPA management plan. The working group acts as a subcommittee of the management council and consist of around 20 persons with different backgrounds: Management council, MPA project manager, representatives from federal institutions, from tourism industry, from recreational and commercial fisheries, NGOs and scientists.

These first recommendations/guidelines of a Mediterranean country together with the guidelines from countries with a longer offshore energy experience can act as useful tools to formulate guidelines and standards appropriate for habitats, species and socio-economic conditions in the Mediterranean Sea.

9 DISCUSSION ON MPAS AND OWFS

Based on the information of potential impacts, proven and developing mitigation measures and monitoring techniques, this chapter discusses these issues in the light of the possible interaction of OWFs and marine protected areas. The role and different types of MPAs in the Mediterranean Sea are described and the question is raised, if OWFs in MPAs are at all compatible. With case studies from France, Germany, Greece, Belgium and the UK, legislative frameworks and (decision) processes of the co-location are presented. Lessons learned from previous projects and planned projects in the

Mediterranean Sea as well as general recommendations to different stakeholders are given to highlight the most important issues that need to be considered in the development of the OWF sector in the Mediterranean.

9.1 MPAs in the Mediterranean Sea

The Mediterranean Sea is a sensitive marine basin with high levels of biodiversity and many ecologically important areas. Within it, anthropogenic activities such as transport, tourism and fisheries have potential negative impacts on marine wildlife and ecosystems. Nature protection in the region needs to be considerably strengthened. For this purpose, designating marine protected areas is an important tool to protect marine habitats and biodiversity in the Mediterranean and there are several types of MPAs in the Mediterranean Sea. The term "Marine protected area" is not a standardized definition. It includes nearshore and marine areas, which are designated as protected areas for various conservation targets (e.g. specific animals or habitat types) under national, regional or international frameworks and legislations. Thus, there is no generic protection status or management plans for the areas designated as MPAs in the Mediterranean Sea. In total there are almost 50 different names for MPAs or Other Effective area based Conservation Measures (OECMs), characterized by different and variable strength of protection status. Approximately 15% of the MPAs in the Mediterranean Sea are larger than 100 km^2, but almost 50% smaller than 5 km^2 (EUROPEAN ENVIRONMENT AGENCY 2018b).In the entire Mediterranean Sea (EU and non-EU countries) about 7% of the marine area is protected under different legislative frameworks:

National designated areas

Countries can designate MPAs in their territorial waters under national frameworks, legislation and management plans. For example Albania has nine MPAs designated under national legislation and Italy 32 of different categories/designations (e.g. MPA, National Park, Protected landscape) (MEDPAN et al. 2016). In 2016 186 sites, covering 1.6% of the Mediterranean Sea were designated at national levels (MEDPAN et al. 2016).

Regional designated areas

In total 898 sites and areas are designated as protected areas under the framework of the Natura 2000 network of the European Union. These can either be designated as Special Protected Areas (SPAs), established under the EU Birds Directive (Directive 2009/147/EC) or sites under the Habitats directive (Council Directive 92/43/EEC): Sites of Community Importance (SCI) and Special Areas of Conservation (SAC). The legislation in the Natura 2000 network provides a strong protection tool for the marine protected areas, since it includes strict requirements for appropriate assessments, which are legally binding under EU legislation. The locations, dimensions and designations of Natura 2000 areas in the Mediterranean Sea are displayed in the Natura 2000 viewer (EUROPEAN ENVIRONMENT AGENCY 2018a) (Figure 9.1).

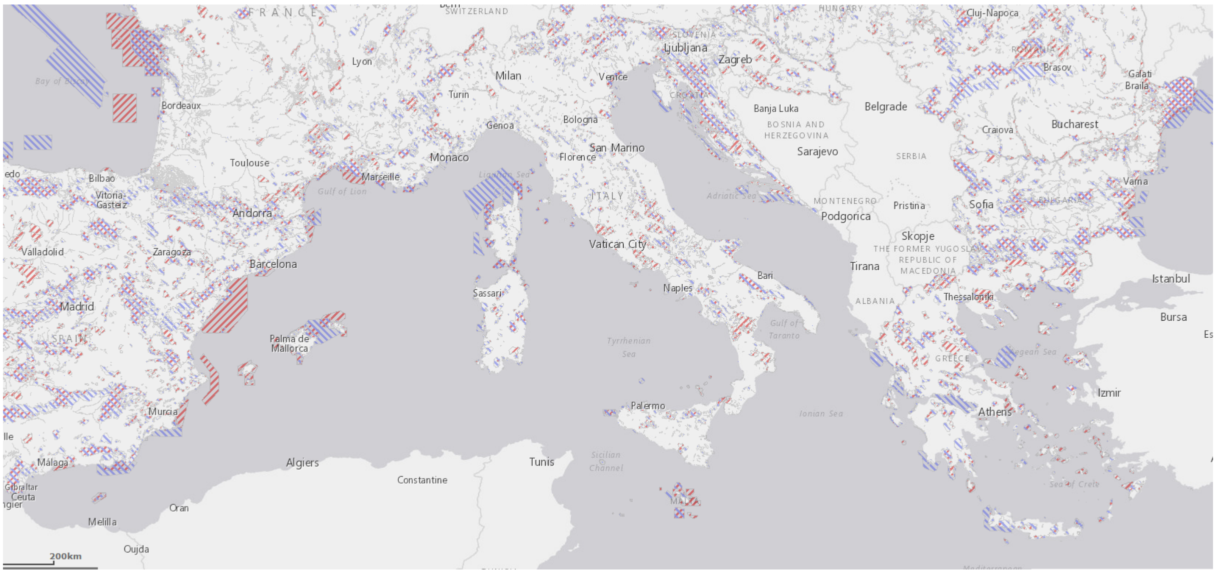


Figure 9.1 MPAs under the Natura 2000 network in the Mediterranean Sea. SPAs are displayed in red, areas protected under the EU Habitats directive in blue. (EUROPEAN ENVIRONMENT AGENCY, 2018b)

Specially Protected Areas of Mediterranean Importance (SPAMIs) are areas designated by the Mediterranean Action Plan (MAP) under the Barcelona Convention and the UNEP (Figure 9.2). Areas can be declared as SPAMI, e.g. if they are of importance for Mediterranean biodiversity, contain endangered species or specific ecosystems. One example for a SPAMI is the Pelagos sanctuary designated for the protection of marine mammals involving authorities of Monaco, Italy and France.

International designated areas

International designated MPAs include regions such as Ramsar sites, UNESCO Man And Biosphere reserves and UNESCO World Heritage Sites. The afore mentioned areas contain coastal lagoons permanently linked to the sea and marine waters and cover respectively 0.13 %, 0.06 %, and 0.01 % of the Mediterranean Sea. In addition, 1 Particularly Sensitive Sea Area (PSSA) was created by the International Maritime Organisation in the Strait of Bonifacio and covers an area of 10,956 km^2 (0.44 % of the Mediterranean) (MEDPAN et al. 2016) .

Recommended MPAs

Furthermore there are recommendations of different conservation institutions for geographical areas, which are of special importance to certain animals, for instance “Important Bird Areas” (IBAs) by Bird Life International (https://www.birdlife.org/worldwide/programme-additional-info/important-bird-and-biodiversity-areas-ibas) and “Important Marine Mammal Areas” (IMMAs) described by the IUCN (https://www.marinemammalhabitat.org/) (Table 9.1).

In general most of the MPAs in the Mediterranean are located nearshore (EUROPEAN ENVIRONMENT AGENCY 2018a) which leaves a great part of the deeper and areas located further offshore unprotected and thus unmanaged on the environmental level. This and other factors, such as the diversity of MPAs and hence the legal frameworks or underdeveloped management plans for some MPAs (MEDPAN et al. 2016), make managing of MPAs challenging.

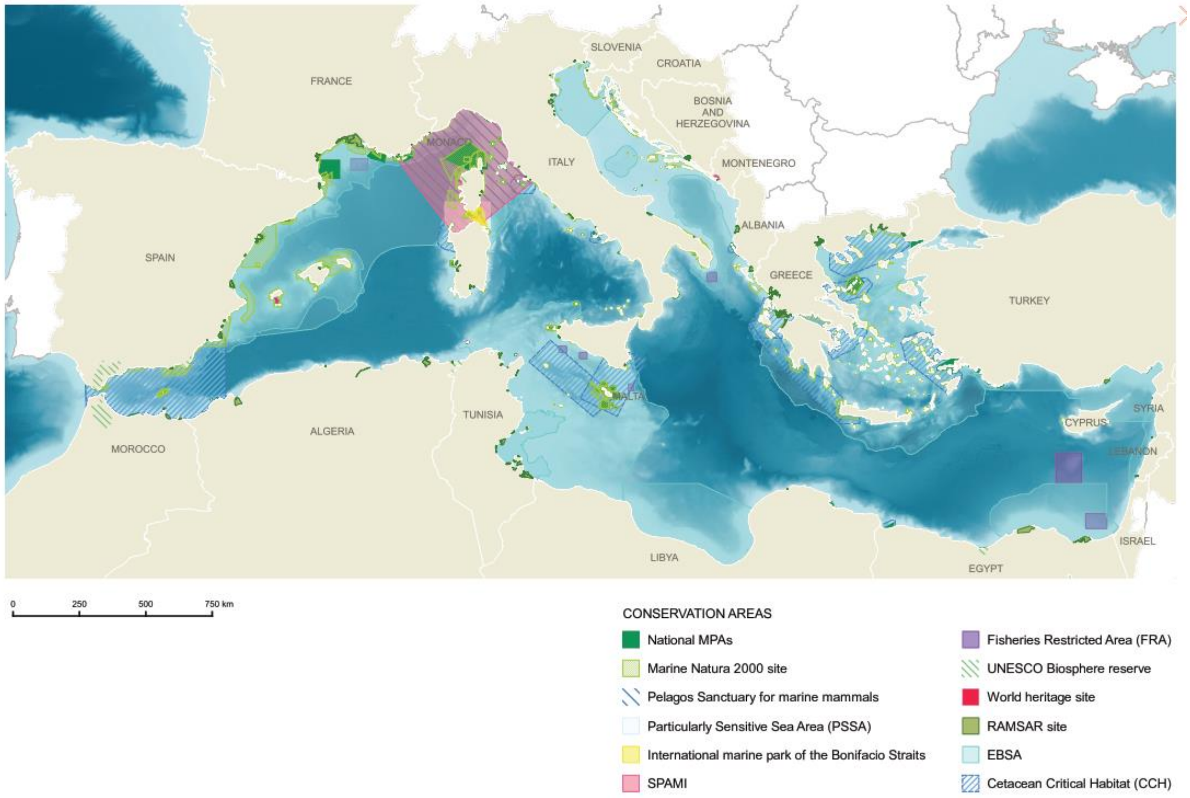


Figure 9.2 MPAs in the Mediterranean. The different designation types are colour coded. (MedPAN, UNEP/MAP/SPA-RAC, 2017)

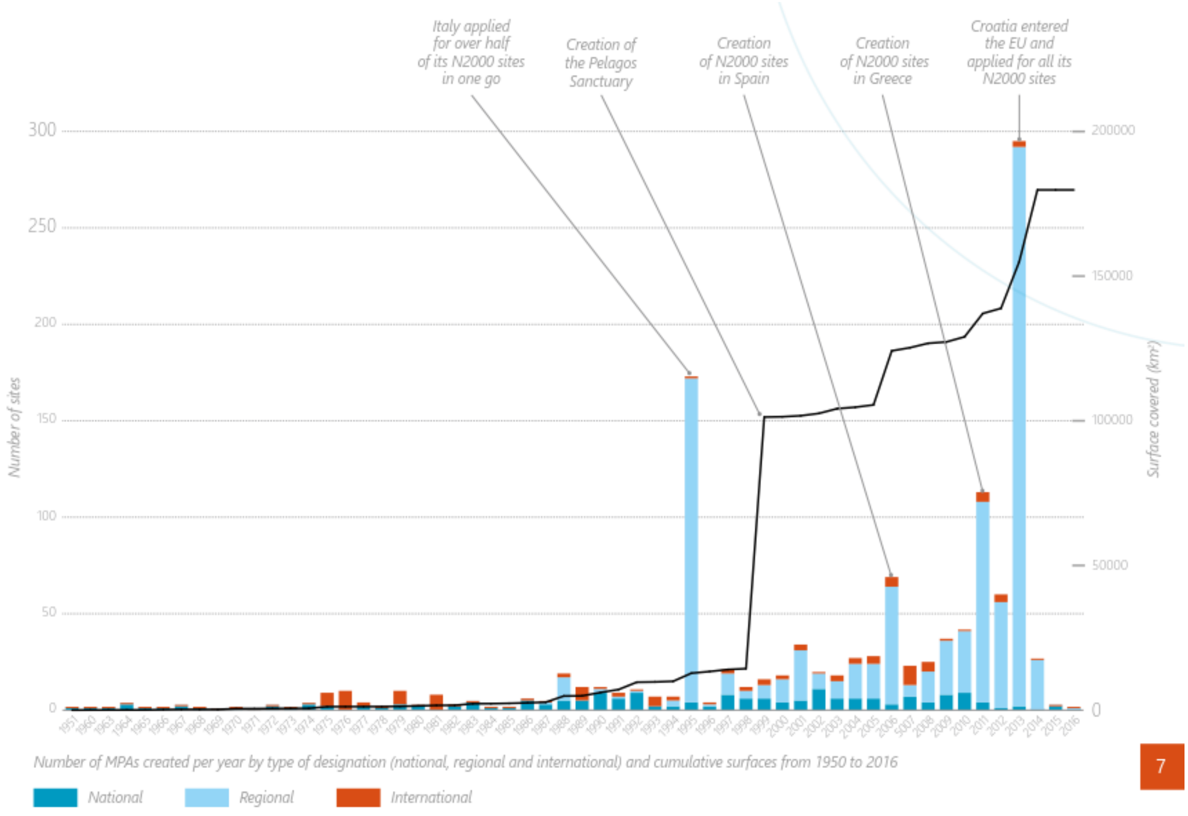
Table 9.1 Types of MPAs in the Mediterranean Sea. Types of legislation and examples for designations are given. Sources: (MedPAN et al. 2016)

Type of MPA	Description	Examples
National designated MPA	National legislation, No common definition. Restricted to territorial waters 1.6% of Mediterranean Sea	Albania: 9 national MPAs of 4 different designation types (Managed Nature Reserve, National Marine Park, National Park and Protected Landscape) Italy: 32 MPAs of 4 different designation types (Marine Protected Area, National Park, Regional Nature Reserve and Underwater
Regional designated MPA	designated under the Natura 2000 network of the European Union Strict requirements Legally binding under EU legislation	Designated under EU Birds Directive*: Special Protected Areas (SPAs) Habitats directive **: Sites of Community Importance (SCI) and Special Areas of Conservation (SAC).
Regional designated MPA	designated by the Mediterranean Action Plan (MAP) under the Barcelona Convention and the UNEP	Specially Protected Areas of Mediterranean Importance (SPAMIs): e.g. Pelagos sanctuary

Type of MPA	Description	Examples
International designated MPA	Designated by intergovernmental treaties (RAMSAR Convention) and international institutions (UNESCO)	Ramsar sites, UNESCO Man And Biosphere reserves and UNESCO World Heritage Sites Particularly Sensitive Sea Area (PSSA) created by the International Maritime Organisation in the Strait of Bonifacio
Recommended MPA	recommendations of different conservation institutions for geographical areas, which are of special importance to certain animals not legally binding	Bird Life International : 'Important Bird Areas '(IBAs) IUCN: 'Important Marine Mammal Areas '(IMMAs) ACCOBAMS: 'Cetacean Critical Habitats (CCH)'

** Birds 2009/147/EC Directive*
*** Habitats 92/43/EEC Directive*

Figure 9.3 illustrates the development of MPAs in the Mediterranean Sea since 1950s. These sites are established under a wide variety of designations at national level, at regional level (European or Mediterranean scale) or at international level.



Number of MPAs created per year by type of designation (national, regional and international) and cumulative surfaces from 1950 to 2016

Figure 9.3: Development of MPAs in the Mediterranean Sea since 1950s. Bars show the number of newly designated MPAs per year. The black line indicates the cumulative surface of protected area. Source: MedPAN & UNEP-MAP-SPA/RAC (MEDPAN, UN ENVIRONMENT/MAP & SPA/RAC, 2016).

9.2 OWFs in MPAs?

All Mediterranean countries have committed themselves to fulfil the Aichi targets and establish MPAs covering least 10% of coastal and marine areas by 2020. In addition EU member states aim to achieve or restore, by 2020 as well, Good Environmental Status of EU marine waters and Favourable Conservation Status of protected habitats and species according to EU MSFD and Habitats Directive respectively. On the other hand they need to meet the EU Energy targets of 27% renewable energies by 2030, where energy generated from OWF is seen as a main contributor. Thus it is apparent that there is still concern on how to balance the development of OWFs with MPAs conservation objectives, and the general question remains if a co-location might be compatible.

The construction, operation and decommissioning of an OWF has impacts on the surrounding environment, which heavily depend on the location and the habitats and species present in the area.

Possible negative impacts:

- Changes in the hydrography through the presence of the turbines, which as a consequence may also impact on planktonic organisms, which depend on favourable water movements for nutrient/food supply and transport.
- Pollutants emitted from construction activities, corrosion protection or the use of sacrificial anodes may impact on the surrounding water column or lead to accumulations in the sea bottom.
- Land use of the turbines and associated facilities (e.g. cables) involves habitat destruction and thus a temporary or permanent habitat loss.
- In the Mediterranean special attention has to be given to protected habitats, such as *Posidonia oceanica* meadows.
- One of the main impacts on marine mammals, sea turtles and fish might be high noise levels from construction works leading to physical damages in severe cases as well as masking of communication signals and avoidance behaviour. The noise is generated by the installation (and to a lesser extent by the operation) of the turbines, especially when piling of the foundations is involved, and due to the increased ship traffic associated with construction and maintanance.
- Ship traffic increases the collision risk for cetaceans and sea turtles which is an important issue in the Mediterranean with several local and migrating cetacean species.
- The presence of ships and (operating) turbines as well as the lighting of the turbines cause pressure on birds, leading to collisions especially in conditions of poor visibility and/or displacement effects.
- For other animals, such as bats and sea turtles, the knowledge on the impacts of OWFs is rather limited.
- For bats it is assumed that the rotation of the turbines may cause barotrauma due to the pressure.
- Avoiding the OWF area can result in a habitat loss as the avoided area was formerly used as foraging habitat.
- The foundations of turbines might support the spatial expansion of invasive species by acting as stepping stones or providing beneficial feeding conditions.
- Other anthropogenic sectors, such as tourism and fisheries can be impacted by an OWF mostly due to spatial competition (e.g. fishery or traffic exclusion) which has to be considered when planning OWFs in the Mediterranean Sea.

Besides negative effects, potential positive impacts have been anticipated.

Potential positive effects:

- The surface of the turbines can act as artificial reef structure and provide additional habitat and increase the local species richness.
- Together with fishery restrictions in windfarm areas it may enhance fish biomass and contribute to fishing success in areas surrounding the OWF.
- The windfarm area can provide shelter for fish and other marine animals due to the limited additional anthropogenic activities taking place inside the area.

In general as the habitats and species composition in the Mediterranean differs from the one in the North and Baltic Sea, from where the majority of studies related to OWFs is available, broad-scale research programs are crucial to investigate the environmental components possibly impacted by an OWF. It is important to increase specific knowledge on endangered and vulnerable species as well as the major impacts an OWF may have in the respective area. This is particularly important for floating OWFs which have gained increased attention recently since they are thought to be more appropriate to the Mediterranean marine environment with its steep bathymetry.

Decision making processes regarding future locations for OWFs should carefully consider aspects of nature conservation and aim to avoid ecologically valuable and protected areas, keeping also in mind that approaches may differ between countries on how to balance the demands for renewable energy with nature conservation.

9.2.1 **Avoidance – mitigation - compensation approach**

The most favoured approach when it comes to mitigation is the ‘Avoidance-mitigation-compensation approach’ (see also chapter 6.1), stating that assumed impacts should preferably be avoided by not placing OWFs in ecologically sensitive marine areas.

Avoidance

The most effective method to avoid impacts is spatial segregation, e.g. avoidance of areas of high value for nature conservation which would exclude MPAs as potential locations for OWFs. From an ecological point of view this would exclude MPAs as potential locations for OWFs, even though the designation as an MPA does not automatically exclude anthropogenic activities from that area. Effective MSP is seen as an effective tool to decide and plan beforehand possible locations for OWFs and MPAs, when including all stakeholders in the planning and decision process, and avoid or mitigate spatial conflicts on a longer time-scale.

From an industry perspective, avoidance of protected areas and more generally areas of importance for protected species and habitats will minimize legal risks to their investments because a permit might finally be denied if the impacts assessment leads to conclude that significant impairment of protected areas, habitats or species cannot be ruled out.

Thorough ecosystem-based MSP and SEA are seen as the most important tools to prevent installations of OWFs in areas that contain protected habitats, species and/or ecological processes that are particularly sensitive to its impacts, during construction and/or operation. Successful MSP, and thus SEAs, depend on thorough baseline investigations and research programs to assess the potentially affected animal groups and the expected impacts of OWFs.

Strategic environmental assessments (SEAs) are conducted on a larger spatial scale as a prerequisite for effective MSP. As many species (e.g. migratory species) - and also impacts on the marine environment - are not restricted to national borders, recent EU projects (e.g. SEANSE) focus on methods of SEAs to make MSP internationally comparable and facilitate international collaborations. Outcomes of these projects can enable countries in the Mediterranean to further develop MSP, including the development of OWFs, on an international basis from the start to account for cumulative impacts arising from large-scale development. Successful MSP, and thus SEAs depend on thorough baseline investigations and research programs to assess the potentially affected animal groups and the expected impacts of OWFs.

Mitigation

A full segregation of OWF and MPAs may not always be possible. For example in the case of cable connections to the mainland or for the service vessels it may sometimes be difficult to avoid protected areas.

If avoidance of MPAs is not possible, the most appropriate mitigation method for potential impacts should be applied. In those countries where OWFs already lie within MPAs or are at the stage of environmental impact and appropriate assessment, the environmental impacts of these developments should be robustly assessed on a case-by-case basis according to the relevant nature conservation legislation (EIAs, Appropriate Assessments etc.) taking a precautionary approach to ensure that site conservation objectives are met.

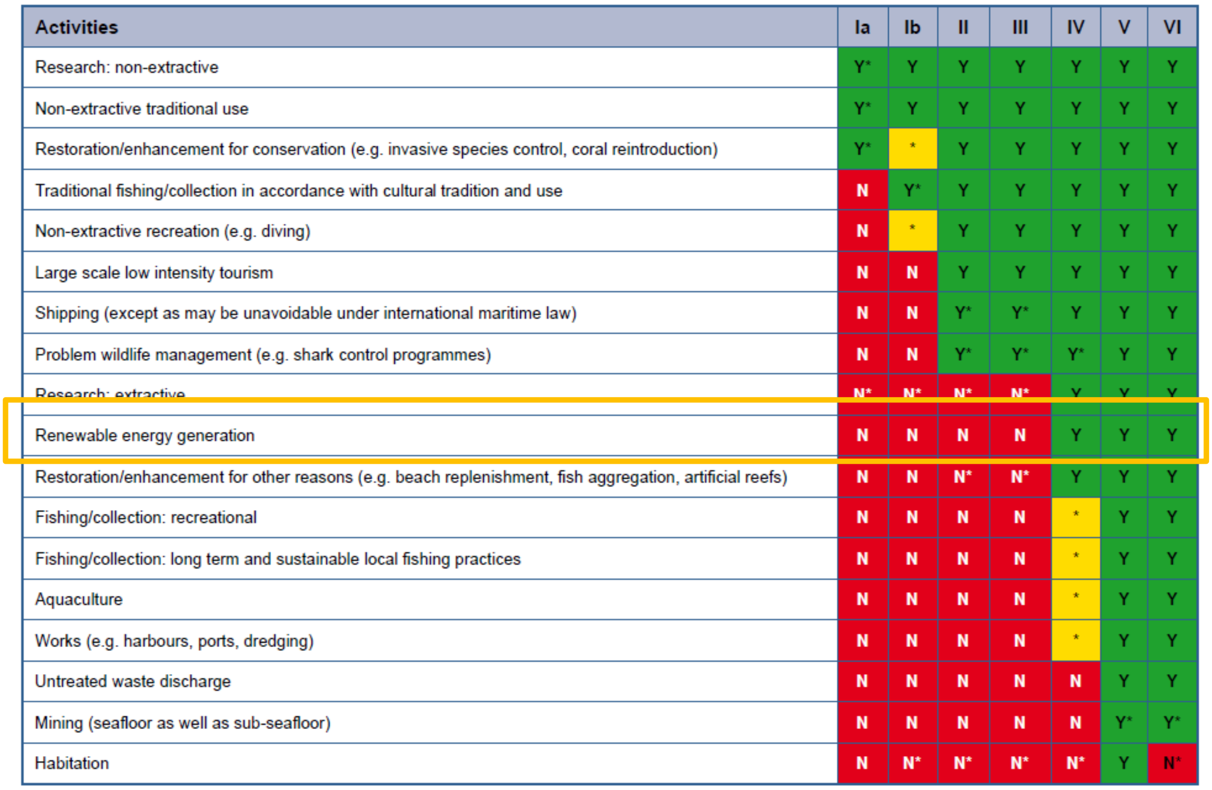
Compensation

Compensation is seen as a last option in case of potential impact remaining after the implementation of the mitigation measures. Such measures must be considered as a last resort, due to their uncertainties, complexity and costs (NORWEGIAN MINISTRY OF CLIMATE AND ENVIRONMENT 2015) and are not discussed in this document.

9.2.2 Compatibility options for the co-location of OWFs and MPAs

Marine protected areas usually do not exclude human activities but put them under the restriction that the conservation targets of an area may not be impaired significantly. The IUCN divides MPAs into six categories depending on their primary conservation objectives. In three types of MPAs renewable energy production is considered appropriate by IUCN under certain conditions (IUCN 2012).

- Category IV, aiming at protection of particular species or habitats (e.g. sanctuaries for marine mammals), often including active management to limit the impacts of human activities
- Category V, aiming at seascape protection, typically in coastal areas with a focus on the interaction of people and nature
- Category VI, aiming at sustainable use of natural resources, where social and economic benefits for local communities are included among secondary objectives.



Activities	Ia	Ib	II	III	IV	V	VI
Research: non-extractive	Y*	Y	Y	Y	Y	Y	Y
Non-extractive traditional use	Y*	Y	Y	Y	Y	Y	Y
Restoration/enhancement for conservation (e.g. invasive species control, coral reintroduction)	Y*	*	Y	Y	Y	Y	Y
Traditional fishing/collection in accordance with cultural tradition and use	N	Y*	Y	Y	Y	Y	Y
Non-extractive recreation (e.g. diving)	N	*	Y	Y	Y	Y	Y
Large scale low intensity tourism	N	N	Y	Y	Y	Y	Y
Shipping (except as may be unavoidable under international maritime law)	N	N	Y*	Y*	Y	Y	Y
Problem wildlife management (e.g. shark control programmes)	N	N	Y*	Y*	Y*	Y	Y
Research: extractive	N*	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons (e.g. beach replenishment, fish aggregation, artificial reefs)	N	N	N*	N*	Y	Y	Y
Fishing/collection: recreational	N	N	N	N	*	Y	Y
Fishing/collection: long term and sustainable local fishing practices	N	N	N	N	*	Y	Y
Aquaculture	N	N	N	N	*	Y	Y
Works (e.g. harbours, ports, dredging)	N	N	N	N	*	Y	Y
Untreated waste discharge	N	N	N	N	N	Y	Y
Mining (seafloor as well as sub-seafloor)	N	N	N	N	N	Y*	Y*
Habitation	N	N*	N*	N*	N*	Y	N*

Figure 9.4 *Matrix of marine activities that may be appropriate for each IUCN management category (IUCN 2012).*

On the other hand, however, the IUCN takes the view that an MPA effective management implies that the MPA does not have any environmentally damaging industrial activities or infrastructural developments located in or otherwise negatively affecting it, with the associated adverse ecological impacts and effects (IUCN WCPA 2018).

There are two conceivable scenarios of OWF inside MPAs:

1. The area of a newly established OWF is designated as a MPA.

The area of an OWF could be designated as a permanent no-take zone, protecting the present animals from any further harm of anthropogenic activities and attract other animals/predators to the new feeding ground. A prerequisite for this approach is an area-based EIA study to make sure that the potential benefits surpass the expected negative impacts during construction and operation. Habitats outside coastal areas are mostly not covered by the Habitats directive and developing MPAs associated to OWFs constructed in those areas provides a possibility to designate areas further offshore (BOERO et al. 2016).

2. The OWF is constructed or planned in an already existing MPA

The possibility of the second case largely depends on the conservation targets and status of the area and the expected dimensions of the OWF. The conservation targets of an MPA need to be carefully considered as these targets address not only single organisms, but the entire life cycle of the protected organisms/communities, e.g. migration patterns, spawning grounds, trophic relationships during the lifecycle, further impeding the decision of any designation as OWF development area. Some impacts of the OWF might be more difficultly mitigated or compensated than others and in many cases this will not allow to construct a windfarm in an MPA. A successful co-existence of MPAs and OWFs requires effective baseline studies and monitoring plans (pre- and post-construction) on a broad spatial scale including reference as well as impact areas. This is necessary to assure that the OWF does not hamper the conservation objectives of the MPA (CHRISTIE et al. 2014). In areas designated as generally suitable for OWFs, project-specific EIAs (commissioned by the developer) investigate the impacts on the environment in order to assess the impacts of specific projects.

9.2.3 Case studies regarding co-location of OWFs and MPAs

In the following three European case studies of legislation based on national law or conservation status of the sites are presented.

Germany: One OWF ("Butendiek", consented in 2002) is located inside a Natura 2000 site (designated in 2004). Two other projects in Natura 2000 areas were denied approval in 2002 and since then no further applications within Natura 2000 areas have been forwarded. Today, planning regulations do not allow OWFs to be planned in Natura 2000 areas, but cable connections and service vessels still need to cross some MPAs including the Wadden Sea National Parks. Various cable connections and service traffic cross marine Natura 2000 areas for OWFs in the North and Baltic Sea.

United Kingdom: In the UK OWFs inside MPAs are not prohibited according to national law. Certain fishing methods (bottom-trawling) are restricted in MPAs as well as inside OWFs. The co-location of OWFs and MPAs is regarded as beneficial for fisheries because it avoids closing areas outside MPAs for certain fishing gear. According to the Offshore Energy Strategic Environmental Assessment (SEA) 'The Government's strategy for contributing to the delivery of a UK network of marine protected areas' (DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS 2010) notes, that "*Where offshore wind developments are proposed and do not conflict with the conservation objectives of MCZs (*Marine conservation zones, note from the authors*) preference should be given to locating windfarms in such areas to mitigate spatial conflict with other users*". Some sites have different kinds of advisory groups, enabling stakeholders such as fishermen to participate in the development and management process. Advice on the MPA is for instance given by statuary advisors, such as JNCC (Joint Nature Conservation Committee).

One example of the construction of an OWF within a MPA can be found in 'Inner Dowsing Race Bank and North Ridge Special Area of Conservation' (SAC, designated under Natura 2000) on the East coast of England, which contains three operating OWFs: Lincs, Lynn and Inner Dowsing, and Race Bank.

The protected features (specific habitat features) and the conservation objectives (recover to favourable conditions) were set into focus. The expected effects (loss of a certain amount of protected features) were set into relation to the potential benefits (reduced impact on protected habitats by limited bottom trawling within the site). Mitigation measures were applied with respect to sensitive habitats (adjustment of cable routing) and sensitive species (restrictions in timing of piling to avoid/mitigate impacts on specific fish and bird species). As bottom destructive fishing was performed in the MPA, the co-location was seen as an opportunity to reduce this impact on the protected features of the site.

Furthermore, reporting of the condition of the protected features is required every six years according to the Habitats Directive, which will provide long-term data on potential benefits and disadvantages of co-location as the long-term effects are uncertain so far. Impacts described as temporary (habitat occupation) might be longer than anticipated (min. 20 years) as it is currently unknown whether all components of the turbines will be removed at decommissioning. Nevertheless, the focus on specific impacts should be avoided and a broad-scale assessment of potential impacts is required instead, in order to thoroughly investigate the feasibility of a co-location. Ongoing monitoring at this site investigates if recovery to favourable conditions of the site (conservation objective) is achieved, also in the light of conservation targets with very long recovery times, in the presence of the OWF and how the fishery restrictions impact on the recovery of the site (YATES & BRADSHAW 2018).

France: In France the Marine Natural Park of Gulf of Lion (NMPGL) might face the development of the OWF "Les éoliennes flottantes du golfe du Lion" within its boundaries. In general the construction of an OWF in an MPA is possible on a legal basis depending on the designation type of the MPA (Table 9.2 and *Figure 9.5*). However, the management body of the MPA was not in favour of this development and the decision was made by MSP authorities.

Table 9.2 Compatibility with OWFs and the different MPA categories according to French legislation (Source: AGENCE FRANÇAISE pour la BIODIVERSITÉ, http://www.aires-marines.fr/Concilier/Energies-marines-renouvelables-et-AMP).

MPA category	OWF compatibility
National Natural Reserve	Incompatible
National Park	Incompatible in the Park core area /consent required in the marine adjacent area
Marine Natural Park	Simple or compulsory consent depending on the impacts on the marine environment
Marine Natura 2000 Site	One a case-by-case basis

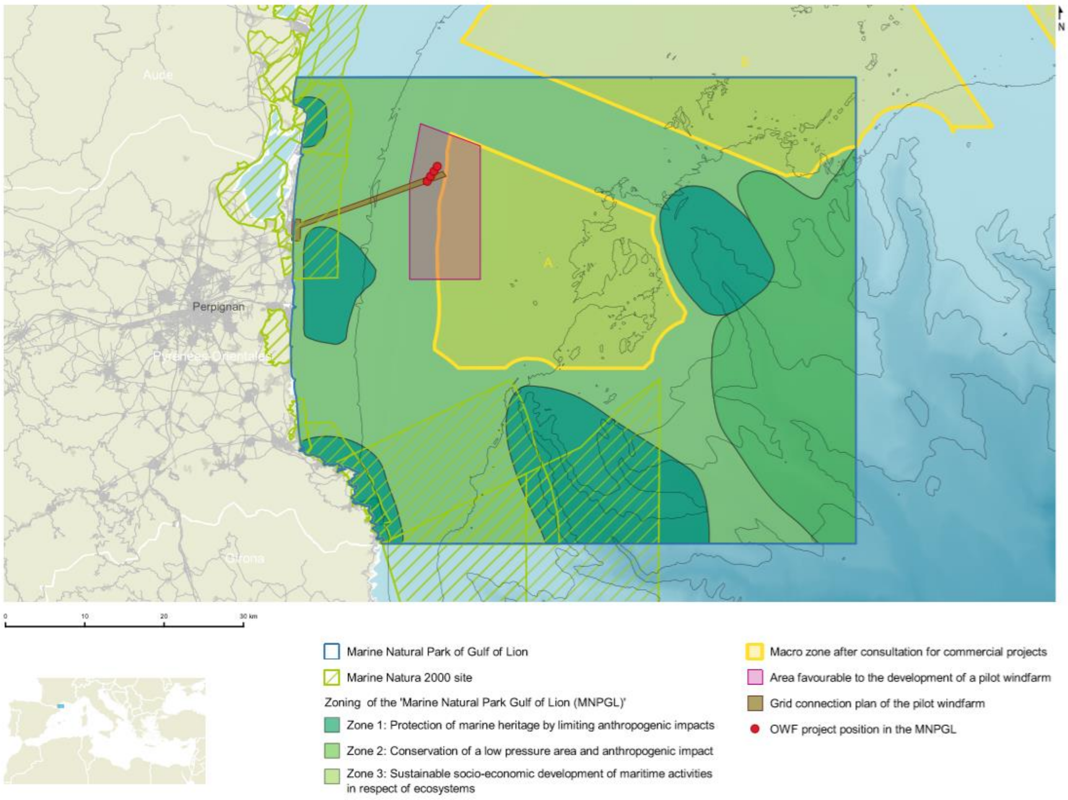


Figure 9.5 *Area identified as less impacting (in red) for the development of a pilot OWF project in the NMPGL. The different zones of the Park are shaded in green (AGENCE FRANCAISE POUR LA BIODIVERSITE, 2018).*

Greece: There are planned OWFs in areas overlapping with MPAs. After the update of Greek Natura 2000 Network in 2017 which included new marine areas, 24 proposed OWFs are currently situated in 14 different Natura sites and one is also situated in the outer limits of a National Park/Ramsar site (Figure 9.6). The permitting process includes appropriate assessment according to article 6 of the EU Habitats directive. Within the frame of the initial SEA conducted for a former proposed MSP regarding OWF development (currently inactive due to governmental decisions), the Natura 2000 sites and IBAs were exclusion criteria for siting OWFs.

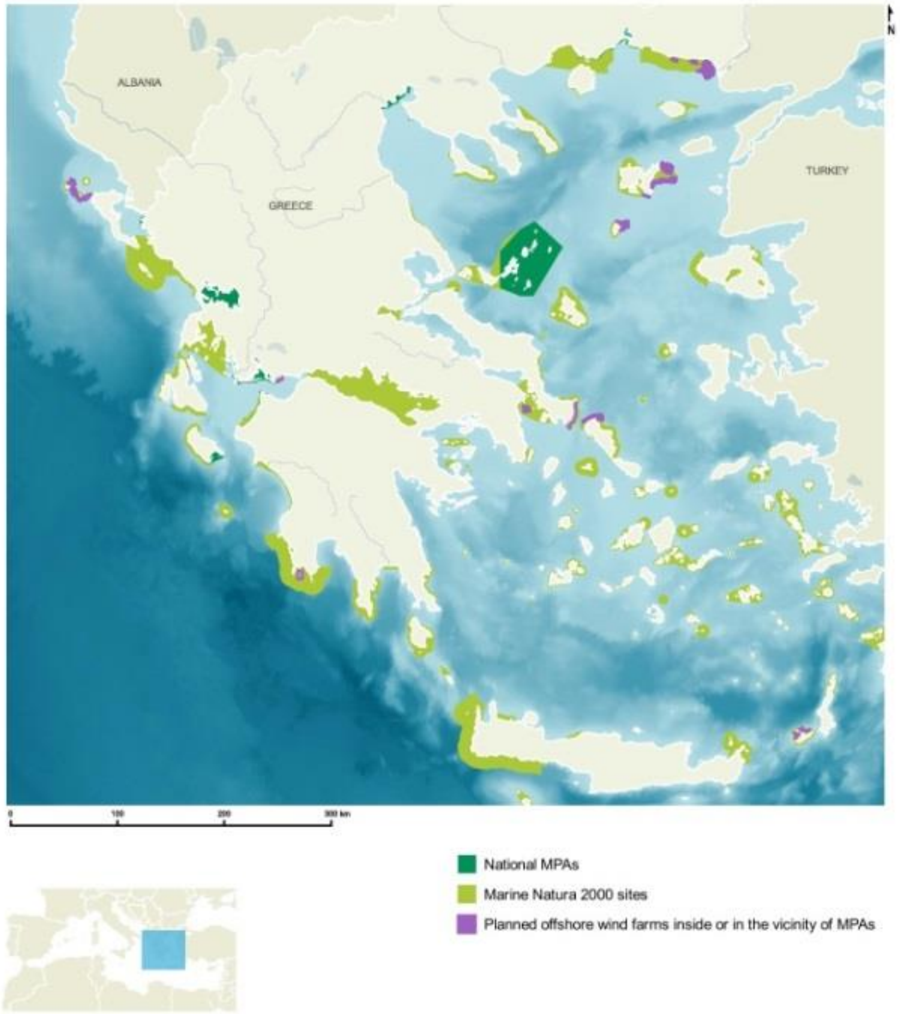


Figure 9.6 National MPAs (Natural parks), marine Natura 2000 sites and planned OWFs overlapping with MPAs in Greece (GREEK REGULATORY AUTHORITY FOR ENERGY & GREEK MINISTRY 2017).

Belgium: In this case study there is limited space for OWF due to small EEZ and MSP regulates the use of space in EEZ. At present no OWF is located within or in close vicinity of Natura 2000 sites. However the newly adopted MSP in 2018 includes planned concession zones in Natura 2000 areas.

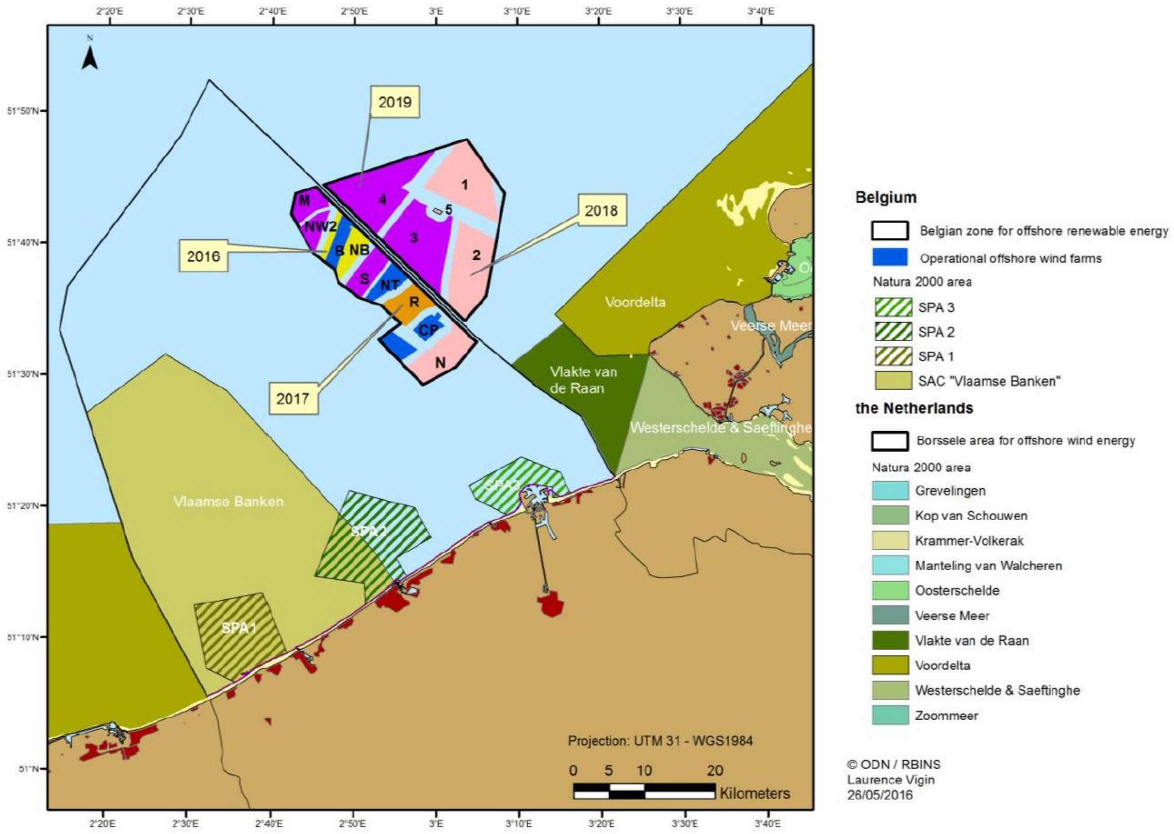


Figure 9.7 *Map of the Belgian zone for offshore renewable energy, the Dutch Borssele offshore wind area and Natura 2000 areas in the vicinity. Already constructed wind farms are indicated in blue (CP:C-Power, NT: Northwind and B: Belwind), wind farms under construction in 2016 in yellow (NB: Nobelwind), 2017 in orange (R: Rentel), 2018 pink (N: Norther, 1 and 2: Borssele 1 and 2) and 2019 in purple (S: Seastar, NW2: Northwester2, M: Mermaid, 3 and 4: Borssele 3 and 4) (DEGRAER et al. 2016)*

9.3 Recommendations

There is no doubt that OWF change the marine environment. In times of growing demands for renewable energy and increasing needs for marine conservation, various issues of the interactions between the offshore windfarm sector and marine protected areas need to be addressed.

In this sense we present recommendations to the following stakeholders involved in the decision process. These recommendations are based on case studies from OWF planned or constructed within the borders of an MPA and on lessons learnt from pioneer countries:

- Public authorities
- MPA managers
- OWF business sector

There are some general recommendations which need to be considered by all stakeholders:

- Collaboration or engagement of different stakeholders (e.g. conservation and industry) can generate the most appropriate solution (YATES & BRADSHAW 2018). When common ground can be found (e.g. environmental/operational risk) shared goals can be defined (e.g. reducing environmental and social risks), even if the motivation is contradictory (environmental vs. economical motivation).

- Effective cross-border co-ordination of plans and projects such as the development of OWF as well as the efficient development of MPA networks will be essential to develop more offshore wind farms while minimizing the environmental impact in times of growing need of renewable energy and increased ocean protection.

9.3.1 Recommendations to public authorities

It is recommended that MSP authorities follow the Avoid - Mitigate - Compensate approach, and prioritize the spatial segregation of protected areas and areas designated for OWFs. Decision making processes regarding future locations for renewable energy generation should carefully consider aspects of nature conservation and aim to avoid ecologically valuable and protected areas. When avoidance is impossible, mitigation measures must be implemented by the competent authority (for mitigation measures see chapter 3). Ultimately, ecological compensation may be needed if there are still significant residual impacts. These could include the adoption of measures to restore degraded habitat or create new habitat areas. However, such measures are generally considered as a last resort, due to their uncertainties, complexity and costs [80], and they are not discussed in this document.

It is recommended that MSP authorities follow the ecosystem approach to reach or maintain Good Environmental Status as well as Favourable Conservation Status. This needs strong strategic environmental assessment (SEA) to identify potential future locations for OWFs and guide renewable energy away from ecologically sensitive areas in general and MPAs in particular. MSP should also consider cumulative impacts and assess them more broadly.

The role of strategic environmental assessments
Strategic environmental assessments (SEAs) are conducted on a large spatial scale, and are a prerequisite for effective MSP. There are many species (e.g. migratory species) and marine environmental issues which are not restricted within national borders, so some recent EU projects (e.g. SEANSE) have focused on how SEAs can be improved to support international MSP protocols and facilitate cross-border collaborations. The outcomes of these projects will enable Mediterranean countries to develop MSP on an international basis, meaning they can account for the cumulative impacts of large-scale development, including of OWFs. Successful MSP – and thus the SEAs that support it – depends in this context on thorough baseline investigations and research to assess the potentially affected animal groups and the expected impacts of OWFs.

Specific recommendations apply to ecological assessments:

- Consider the entire lifecycle of the OWF and all its associated infrastructure (offshore infrastructure and cable installation)

- Create a national scientific expert group to advise OWF developers and MPA managers
- Conduct baseline studies prior to construction
- Start long-term monitoring programmes to investigate impacts on species, protected ecosystem features and general ecosystem development in order to assess future project proposals
- Share monitoring data with all stakeholders
- For multiple OWFs, consider cluster analysis to detect cumulative impacts. Develop shared monitoring protocols and methods across entire species distribution areas.
- Develop regulations and best practice standards for future OWF development
- Balance negative impacts against positive effects.

Finally, collaborations between countries and areas sharing sea space or transborder MPAs is essential for the exchange of information, and for setting unified conservation goals, monitoring concepts and action plans.

Case study on the identification of OWF development zones in the French Mediterranean (Hardy, WWF France, pers. Comm.)

According to the French regulatory framework on maritime spatial planning, the identification of OWF potential sites requires a consultation process with all the relevant stakeholders, including the business sector, the local public authorities, the representatives of national authorities, fishermen and other sea users, as well as NGOs and MPA managers. This consultation process takes place under the umbrella of the Coastal Maritime Council and its dedicated Offshore Windfarm Commission.

A first consultation process started in 2015 led to the designation in 2016 of several areas for pilot OWFs of 3 to 4 turbines each. A second consultation in 2018 resulted in the designation of potential maximum perimeters for OWF commercial deployment, so called macro-zones (Figure 9.8). The offshore location of these four macro-zones reflects the decision of the government to move the future parks at minimum of 16km from the shore to reduce the visual impacts of turbines on seascapes. It also reflects the results of the consultation about the potential impacts on marine mammals, trimming the macro zones 2 miles away from the heads of canyons of the Gulf of Lion, establishing a buffer zone protecting these areas of high conservation value.

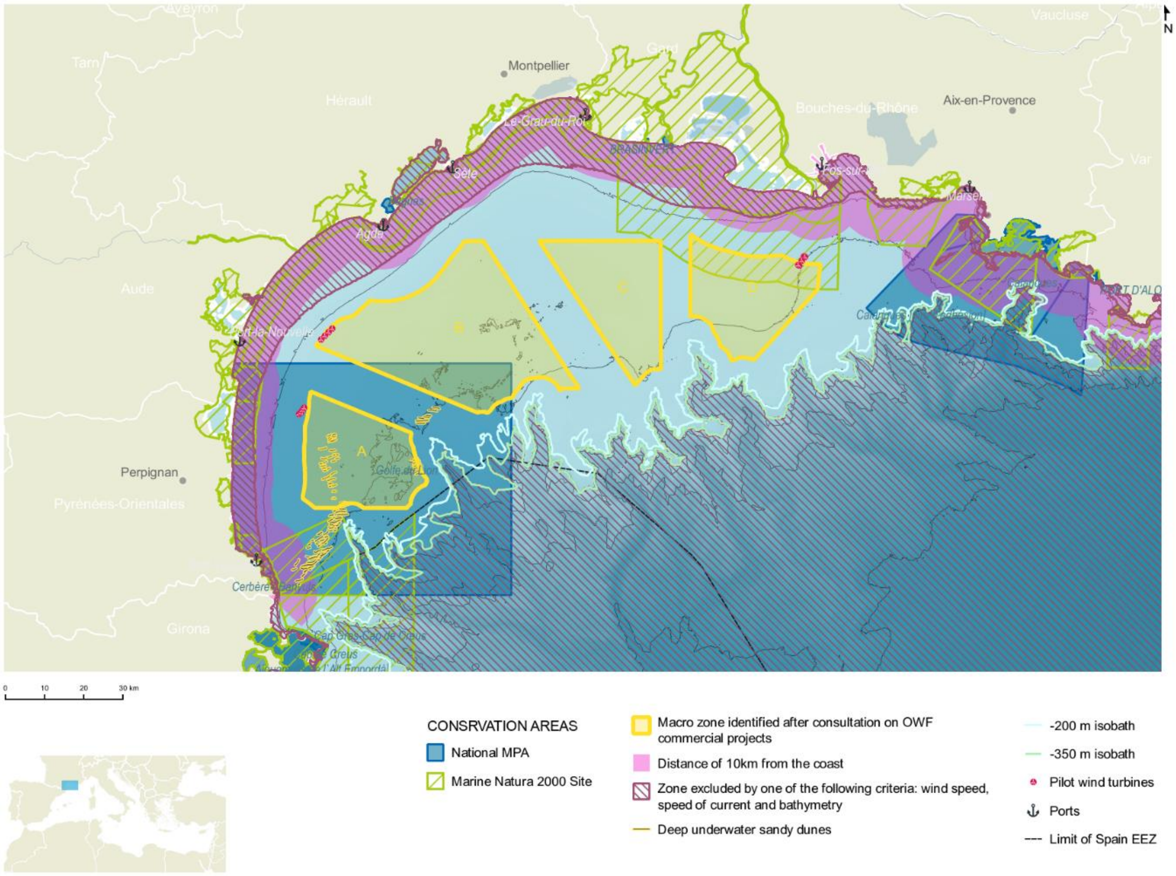


Figure 9.8 The localization of the four macro-zones identified to potentially host the development of commercial windfarms. The pilot OWF are depicted in red dots and give an idea of sites preferences. Natura 2000 sites and marine protected areas designated in the Gulf of Lion are depitected in green and blue (AGENCE FRANCAISE POUR LA BIODIVERSITE, 2018).

Looking at the Figure 9.8, the macro-zone D overlaps with the marine Special Area of Conservation of Camargue, being one of the most important wetlands on the northern Mediterranean shore and a key resting area for birds migrating on a north-south axis between Europe and Africa. For any industrial project in a Natura 2000 site, the French regulation framework imposes a Natura 2000 environmental impact study, equivalent to an Environment Impact Assessment with a special attention to the Natura 2000 objectives. The environmental impact study revealed an impact on the Scopoli’s shearwater and Yelkouan shearwater. Besides, the Environment Authority asked to revise the impact assessment, especially in terms of avifauna, explaining that a lack of information should not lead to bird populations’ under-estimation and under-sizing measures. However, a final administrative authorisation was given by the Prefect in 2018 to lauch the construction of the pilot farm (3 turbines). The scientific Advisory Group of the Camargue Regional Park wrote a statement saying that the Avoid - Reduce -Compensate approach was not applied in that case. In 2019, the consultation was still ongoing to site the commercial deployment off sensitive areas.

9.3.2 Recommendations to MPA managers

MPA managers play an essential role to setting up negotiations with the OWF developer and they have the possibility to gather all stakeholders to form working groups and provide concerted recommendations for OWF projects in or in close vicinity of MPAs. Key recommendations to MPA managers include the following:

- Support an ecosystem approach to MSP.
- Share MPA ecological monitoring data to make the EIA as comprehensive as possible.
- Create a working group with all relevant stakeholders as a constructive governance tool.
- Develop recommendations on micro-siting of the turbines.
- Recommend a thorough OWF monitoring programme for operators, including baseline studies prior to construction
- Make recommendations to authorities on how to mitigate OWF impacts
- Balance negative impacts against potential positive effects.

1. The area of a new OWF is designated as a new MPA

The area of an OWF could be designated as a permanent no-take zone, protecting animals present from any further anthropogenic harm and attracting other animals/predators to the new feeding ground. It's essential that appropriate assessments confirm that the potential benefits of this approach will outweigh the negative impacts of construction and operation. OWFs in remote areas offer opportunities for designating protected areas further offshore.

2. The OWF is constructed in an existing MPA

The presence of a management body in the MPA which speaks for all stakeholders will make it much easier to set up negotiations with the OWF developer. These bodies can form working groups and provide recommendations for how to make projects in or near the MPA a success.

Case study with existing management body: Natural Marine Park of Gulf of Lion (NMPGL) (Hardy, WWF France, pers. Comm.)

The decision process for the future development of an OWF with floating turbines in the *Natural Marine Park of Gulf of Lion (NMPGL)* is a good example how a specific governance mechanism (establishment of a dedicated working group) can help find the most suitable solutions for avoiding and mitigating OWF impacts.

Detailed recommendations and guidance on mitigation and monitoring was developed for the planned OWF involving a variety of stakeholders initiated by the management board of the MPA: Within the consultative MSP process started in 2015, the government decided to site a floating windfarm project inside the *Natural Marine Park of Gulf of Lion* (see*Figure 9.5*). The MPA management board composed of elected local representatives established an OWF working group consisting of 20 people representing all stakeholders, with the aim to implement the Avoid-Mitigate-Compensate approach and the monitoring framework of the project. From this working group specific recommendations (e.g. in terms of avoidance and mitigation) were presented to the management board and as a result of these and other efforts (e.g. workshops with the developers) the final project proposal did significantly differ from the initial proposal. It has to be noted that this approach is precautionary as the respective

OWF has not been constructed yet, so the effectiveness of the terms agreed has not been proved yet (Agence Française de Biodiversité 2015; Agence française pour la biodiversité 2018).

It is important to note that the presence of a management body in an MPA will make it much easier to set up negotiations with the OWF developer as these bodies have the possibility to gather all stakeholders to form working groups and provide concerted recommendations for OWF projects in or in close vicinity of MPAs.

National Marine Park of Gulf of Lion (NMPGL)

The NMPGL Management Board, composed of elected local representatives established an **OWF working group** consisting of 20 people representing all stakeholders, including the OWF industry, with the aim to realize the most appropriate project with least impact on the environment. As a result of the efforts and recommendations of the working group the final project proposal did significantly differ from the initial proposal.

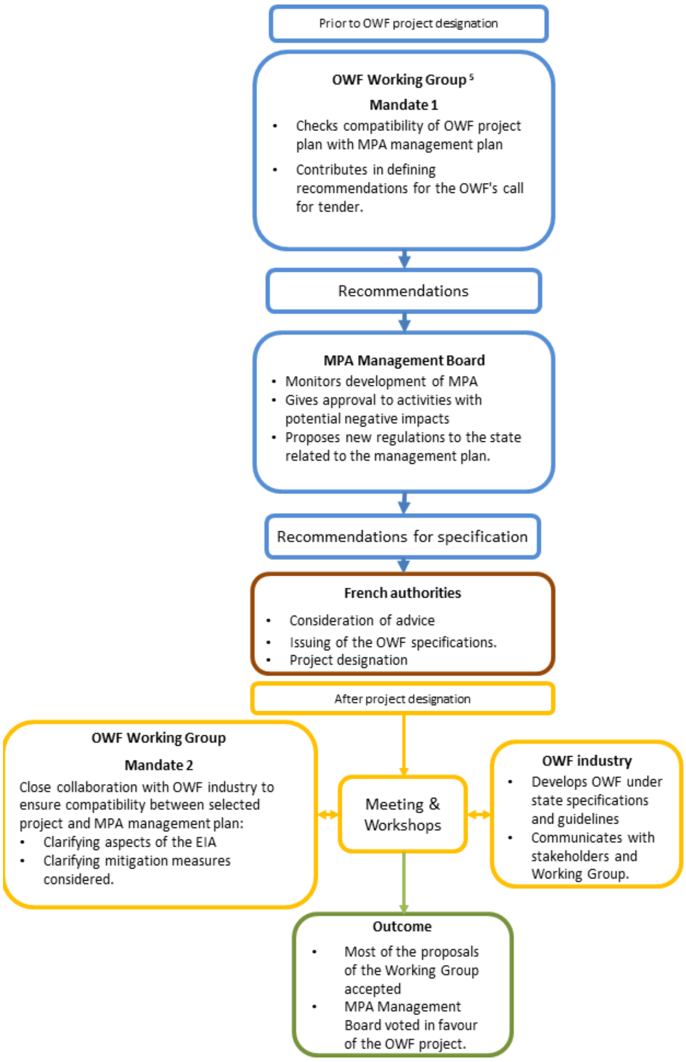


Figure 9.9 Overview of the decision process for the development of the OWF in the NMPGL. The process consisted of two mandates of the OWF working group prior to and after the designation of the OWF project and resulted in the acceptance of most of the working group's recommendations and an approval of the MPA management board.

9.3.3 Recommendations to the OWF business sector

The OWF business sector has a great responsibility to avoid and minimize impacts of OWFs on MPAs. The fast developing technology and existing expertise can contribute significantly to implementing best management practices. Furthermore, commitment to sustainability provides benefit in terms of return of their image from the adoption of environmental-friendly practices and eco-responsibility agreements.

As mentioned before avoidance of protected areas and more generally areas of importance for protected species and habitats will minimize legal risks to investments as a permit might finally be denied if the impacts assessment concludes that significant impairment of protected areas, habitats or species cannot be ruled out.

In areas designated as generally suitable for OWFs, project-specific EIAs commissioned by the developer investigate their likely impacts on the environment. The most appropriate solutions tend to be generated through engagement with different stakeholders (e.g. conservation and industry)(YATES & BRADSHAW 2018). When common ground can be found then shared goals can be defined (e.g. reducing environmental and social risk), even if stakeholders have different motivations (e.g. environmental vs. economic).

Key recommendations:

- Respect national legislations imposing restrictions on industrial development within MPAs.
- Consider alternative locations for OWFs outside the borders of MPAs.
- When performing the Environmental Impact Assessment (EIA) required by national authorities, the OWF developer should make sure to take into account all the available scientific knowledge and involve the MPA or marine Natura 2000 site management body in the review of the EIA.
- Make use of already existing data on the marine ecosystems from MPA monitoring programs.
- Share achieved data with authorities, MPA management boards and other stakeholders in order to develop best practices for future projects.
- Implement best mitigation practices linked to environmental and social issues specific to each MPA.
- Apply most recent construction techniques and use preferably environmental friendly alternatives for e.g. corrosion protection to minimize or avoid further impacts on the protected features and the entire ecosystem.

9.4 Apply lessons learned to the Mediterranean Sea

To apply lessons learned from former projects, research outcomes from countries with operating OWFs should be used in order to rapidly gain knowledge and to minimize ecological damage (NIELSEN 2006; BSH & BMU 2014; e.g. DEGRAER et al. 2017). This will help to apply an Adaptive Management (AM) approach (HANNA et al. 2016); a systematic process intended to improve policies and practices (e.g. standardize monitoring methods, if applicable, across borders) by learning from the outcome of management decisions and aiming to reduce scientific uncertainty and thus keeping MSP a dynamic rather than a static process.

Lessons learned about the impacts

The occurrence and importance of any impact depends on the OWF life cycle phase (siting, construction, operation or decommissioning), the type of the foundations and on the environmental characteristics at the OWF location.

Knowledge gained so far from OWF with fixed foundations in northern countries showed that the most relevant impacts on marine mammals result from underwater noise emitted during the construction process especially pile driving, which has received much attention over the previous years. Although this is the case in OWFs in the North Sea and the Baltic Sea, it may not be the case within the Mediterranean basin where floating technology is favoured at the rather narrow continental shelf and the steep bathymetry. Regarding floating OWFs the pilot projects so far have used methods where floating foundations and wind turbines were built on land then towed offshore to be anchored at the selected site, thus resulting in less noise levels due to the absence of piling. This is one of the main differences between fixed and floating foundations and it is necessary to gather more experience and information as the floating technology evolves.

Increase in vessel traffic during any stage of OWF caused by construction and maintenance ships increases the collision risk with marine mammals and this need to be considered especially when planning in areas of the Mediterranean Sea where larger whale species occur. Furthermore adding additional vessel traffic to the Mediterranean, , will increase the overall noise levels in areas which are already exposed to high vessel traffic (e.g. Gulf of Lions). This may lead to cumulative noise impacts on marine mammals, fish and sea turtles. Expected impacts regarding the planned floating and fixed OWFs in the Mediterranean also include the risk of bird collision with the wind turbines under conditions of bad weather and poor visibility, further disturbance leading to habitat loss because of displacement and potential shifts in distribution of sensitive species (such as red throat divers). While these types of impacts are expected in the Mediterranean, their quantified significance to the bird populations remains to be investigated (see below).

Potentially beneficial effects (artificial reefs, refuge for fish and benthic organisms) remain to be further investigated at the Mediterranean conditions taking under consideration the dynamics of the already invasive species populations.

In any case the Mediterranean species composition is also an undetermined factor in qualifying and quantifying the impacts of this new industry in the Mediterranean Sea. So far studies from the North and Baltic Sea, where harbour porpoises, harbour seals and grey seals are the most common and thus most investigated marine mammals, have not demonstrated that the abundance is reduced in operational windfarms, while some attraction has been shown especially for seals. If this will be the case for the Mediterranean, monk seal remains to be investigated in the future. Also it remains unclear if disturbance from introducing this new human activity in the marine environment (coastal cable landing, construction pressures, vessel traffic, etc) will have an impact on the behaviour of this sensitive species. Furthermore sea turtles were so far not considered in OWF related impacts studies. Thus the impacts of construction vessels, turbines and related infrastructure are poorly understood.

Marine habitats are negatively affected from sea bed occupation due to foundations of OWFs and related infrastructure and equipment used. The Mediterranean Sea is hosting, among others, the endemic *Posidonia oceanica* meadows, rare deep sea coralligenic reefs and undersea canyons which are high productivity habitats but also sensitive to impacts. Also changes in the abiotic conditions associated to construction activities (e.g. increased turbitity) may impact on the viability of sensitive habitats such as *Posidonia oceanica* meadows and they should be taken under consideration.

Lessons learned about mitigation

Mitigation includes avoidance of impacts through proper siting, mitigating the impacts when they cannot be avoided through initial management, and compensation as a last resort.

From all mitigation measures, the avoidance of ecologically sensitive areas by proper site selection is considered the most effective proactive mitigation measure. Marine spatial planning (MSP), Strategic planning and Strategic Environmental Assessments (SEA) are very important tools in this context. Ideally, using MSP, conflicts between OWFs and nature conservation goals can be avoided or largely mitigated by selecting sites of low value for nature conservation.

Mitigation measures implemented in the OWF sector so far include the mitigation of underwater noise. Several methods are available which efficiently reduce noise from pile driving. For marine mammals it has been shown that noise mitigation reduces the disturbance response greatly. Little known is about the effects of noise mitigation on fish sea turtles; however, it is a fair assumption that the species groups will also benefit from lowered noise. As mentioned before, this measure is considered in the frame of fixed OWFs which use pilling. Noise mitigation systems, such as the bubble curtain, need to be adapted to Mediterranean conditions as they are developed for shallow waters and will eventually be ineffective in greater water depth. Potential noise emitted from floating windfarms, e.g. by generated sound transmitted underwater by the floating platforms on the swell and the interlocking of the chains of the anchoring systems, may require specific mitigation methods in case negative impacts are expected.

Regarding artificial light the lesson learned implies that during operational phase no light at all seems to be optimum option. At present, aviation and ship safety protocols and laws in the northern seas do not foresee absolute light absence. Alternative mitigation measures have been suggested that include radar systems for ships and aircrafts for on demand lighting and deflectors on offshore structures recognisable when ship lights are projected on them, but so far they are not foreseen in the laws of the northern countries, pioneer in the development of OWFs. Exclusion in this direction comes from Germany, where light on demand will be mandatory for the aviation lights on top of wind turbines but for onshore windfarms. Projects in the Mediterranean should check the feasibility of this measure according to the respective national laws.

Temporary shutdown during mass migration events has been shown to reduce collision risk for birds (especially in bad weather and visibility conditions). This measure has been applied in the Netherlands already and since mass migration events can also occur in the Mediterranean, shutdown of windturbines should be undertaken under specific conditions.

A best practice that is used for all human activities and projects is choosing methods with the smallest possible footprint, avoiding sensitive areas (such as underwater canyons in the case study of the OWF in Gulf of Lion, or *Posidonia oceanica* meadows in shallower water depths). This can contribute to the reduction of impacts on benthic organisms and communities near windfarms. Also in the case of OWFs in the Mediterranean construction zones should allocate just the minimum areas necessary and construction activities should not deviate outside the specified zones.

Throughout all phases, mitigation against ship collisions should consider implementing speed limits and navigation routes that could reduce the collision risk. This is particularly true for the Mediterranean region where ship traffic is already dense.

It has become obvious in recent years that the use of sacrificial anodes for corrosion protection should be replaced by alternative methods to avoid or minimize the release of (heavy) metals in the water. Based on this knowledge „Impressed Current Cathodic Protection (ICCP) system" were proposed in the final project proposition of the first floating OWF planned in the Mediterranean "Eolienne flottante marine au Golfe du Lion": Furthermore in this project no antifouling against biomass accretion on floating structures will be used, rather a ballast system to cope for the extra weight expected by the biomass development on the submerged structures.

Compensation measures must be considered at this stage as a last resort only, due to their uncertainties, complexity and costs. However, it is recommended to further explore which measures may be implemented to enhance habitat quality or species protection in order to compensate for wind farm impacts.

Transferability of the above mentioned mitigation measures, which were applied or suggested in the context of OWFs in the northern seas to other marine areas is possible but not adequate to securely develop the OWF sector in the Mediterranean Sea. Further steps are necessary to ensure the marine wildlife conservation and the sustainable introduction and future development of the OWF sector in the Mediterranean Basin and mostly monitoring and research programs.

Lessons learned about monitoring and research

Monitoring of species and habitats which may be affected from OWF developments is crucial to provide a scientific basis for (future) decision making both on the strategic and on the project level. Planning and developing monitoring programs has to be included in the planning of the OWF or even as part of MSP. In comparison to other industries, offshore wind farming appears to be well studied, in order to respond to marine conservation concerns related to OWFs.

Generally many of the planning approaches which derive from three extensive monitoring and research studies (and the associated regulations) in Germany, Denmark and Belgium (NIELSEN 2006; BSH 2013a; DEGRAER et al. 2017) can form a basis for the monitoring programs in future projects in the Mediterranean Sea in the light of the development of the offshore windfarm sector. The 'Before After Control Impact' (BACI) approach is often considered as a useful method to assess impacts from offshore wind farms. Effective monitoring covers time frames before, during and after construction. Based on German experiences, it was found that a total of approximately 8 years of monitoring builds a strong database to show effects of the windfarm e.g., a potential change in distribution and numbers of species and individuals. More precisely 3 years of baseline studies during the pre-construction phase, approximately 2 years during the construction phase or as long as the construction is ongoing and 3 years during operational phase. Longer periods might have to be considered when the area contains organism and habitats with a prolonged recovery process. The monitoring requirements during the decommissioning phase correspond to those in the construction phase. Possible environmental impacts depend mainly on the dismantling techniques used. Proper definition of impact and reference areas e.g. for habitats, is a prerequisite for an effective monitoring. In cases of multiple closely located OWFs joint monitoring program (cluster analysis) can be recommendable to cover a broader area and make it more cost-effective (BSH 2013a).

It is evident, that according to the monitoring guidelines and the various impacts and impacted factors within the marine environment, a variety of monitoring methods can be applied. These methods will have to be standardized, modified or newly established through initial research for the marine environment of the Mediterranean to make sure that the most important aspects of the site and technique used can be considered beforehand.

The described monitoring programs were developed for turbines with fixed foundations in shallow waters. Since wind turbines with floating foundations have gained increased attention recently, new monitoring and associated research programs should be established in order to generate monitoring methods to fully understand the impacts and the appropriate mitigation/monitoring methods that need to be applied. This is also the case for areas, where the development of OWF has just started, such as the Mediterranean Sea. The transparent handling of the data is crucial to make sure that lessons learned (failures and successes) can be applied in any future project.

Broad-scale research programs are crucial in order to gain further knowledge on how minimize impacts on the environment and socio-economic aspects. Animals not present in northern marine waters, such as sea turtles, Yelkouan shearwaters or monk seals, are so far not studied in relation to offshore windfarms and thus it is of major importance to include these species into future research programs in the Mediterranean Sea for being able to properly assess potential impacts and establish effective mitigation and monitoring methods. Research projects, as already shown in the CoCoNet project (Boero et al. 2016) provide data and recommendations for the Mediterranean Sea in terms of most suitable sites for OWF in relation to wind conditions and with regard to MPAs.

In the Mediterranean Sea research on the offshore windfarms and the potential impacts and mitigation measures has been conducted in recent years (Boero et al. 2016; Bray et al. 2016; Soukissian et al. 2017). For instance Boero et al. (2016) show how an integrated approach for the development of OWF in the Mediterranean can be applied by establishing a framework which includes geotechnical, ecological and environmental features (Figure 9.10).

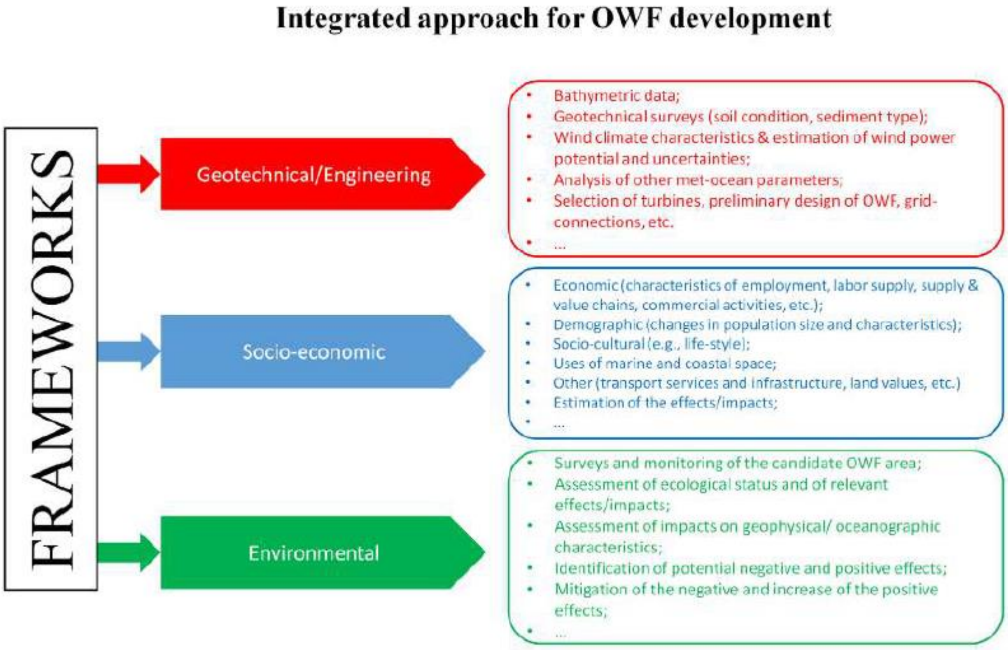


Figure 9.10 *Schematic view of an integrated approach for the development of OWF in the Mediterranean.* (BOERO et al. 2016)

Conclusively, decision making processes regarding future locations for renewable energy generation should carefully consider aspects of nature conservation and aim to avoid ecologically valuable and protected areas, keeping also in mind that approaches may differ between countries on how to balance the demands for renewable energy with nature conservation. Lessons can be learned and methods adapted from existing case studies, from extensive research and monitoring programs conducted in the past. As these measurements are based on measures in Northern European Seas, the findings and methods can solely act as guidelines for future projects in the Mediterranean Sea. Active cross-sectoral participation is essential for a successful marine spatial planning, which will be accepted by all stakeholders ensuring both, marine wildlife conservation and the sustainable development of OWFs in the Mediterranean.

10 LIST OF EU PROJECTS TO CAPITALISE UPON

In this chapter we provide a list of EU projects to capitalise upon.

These include the following:

- WHALESAFE - WHALE protection from Strike by Active cetaceans detection and alarm issue to ships and Ferries in Pelagos sanctuary
- DEVOTES - DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status
- 4 POWER - Policy and Public-Private Partnerships for Offshore Wind EneRgy
- BIAS - Baltic Sea Information on the Acoustic Soundscape
- COCONET - towards COast to COast NETworks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential
- SAMBAH - Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise
- SEANSE - Strategic Environmental Assessment North Sea Energy as an aid for Maritime Spatial Planning

PROJECT - Acronym	**WHALESAFE**
PROJECT - Title	WHALE protection from Strike by Active cetaceans detection and alarm issue to ships and Ferries in Pelagos sanctuary
Programme	LIFE
Period	2014-2018
Status	Ongoing
Short description	The WHALESAFE project promotes the conservation of the Sperm whales in the Pelagos Sanctuary, through the creation of a detection system to avoid collisions of cetaceans with ships. The project deployed an interference avoidance system capable to detect and track Sperm whale, to identify the threats and to prevent collisions by issuing warning messages in real time to ships in the area e.g., in front of the Savona harbor
Considered sectors	Maritime transport
Geographic area	Mediterranean - Pelagos Sanctuary
Categories of Impacts of maritime transport/ports on MPA	Reduction of risk of species of important conservation value (collisions with cetaceans)
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	The warning system developed by the project is based on two detection units each capable to reconstruct the sperm whale acoustic signal. From the joint analysis of the two directions it is possible to localize the animal and to track it during its underwater activity, and eventually predict the emersion point. Data entries from buoys system about the position and time of probable presence and emergence of cetaceans in the area are received by Savona Coast Guard that transmit the information by radio (VHF channels) only in case of presence of naval activity in traffic affected areas. A protocol of conduct for reducing disturbance and strike risks was developed and agreed by involved stakeholders, in cooperation with the local Coast Guard branch. Upon reception of the warning messages the ships present in the area are invited to follow the protocol of conduct and the Coast Guard supervises its application. System might pose an optional use to safeguard construction sites in real time
Key areas of recommendations	Ecosystem-1/Impact avoidance
Typology of recommendations	Technical solution
Relevant deliverables	Whalesafe Protocol of conduct
Project Website	http://www.whalesafe.eu/index.php/en/

PROJECT - Acronym	**DEVOTES**
PROJECT - Title	DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status
Programme	EU 7th Framework Programme
Period	2012-2016
Status	Completed
Short description	The overall goal of DEVOTES is to better understand the relationships between pressures from human activities and climatic influences and their effects on marine ecosystems, including biological diversity, in order to support the ecosystem based management and fully achieve the Good Environmental Status (GES) of marine waters.
Considered sectors	Collaborative project
Geographic area	Mediterranean, North-East Atlantic, North Sea, Baltic Sea
Categories of Impacts of OWFs on MPA	NA
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	1. The app **DevoMAP** developed in this project "is dedicated to researchers, technicians, stakeholders and policy makers directly involved in marine ecological monitoring programs, the MSFD and its implementation. With this app, the user can select a specific site and get information about it using the maps: such as what available data are there, how many and which type of habitats, lists of indicators and links to relevant publications and reports. The app also allows the user to overlay different maps to gain data and information. For each of the areas covered by the maps, the app can link to related web pages of the Regional Sea Conventions and the EU. Moreover, the app reports contact information for the relevant data managers, to encourage further and future scientific collaboration. Data entries from buoys system about the position and time of probable presence and emergence of cetaceans in the area are received by Savona Coast Guard that transmit the information by VHF channels only in case of presence of naval activity in traffic affected areas. " 2. The app **MY-GES** "has the main aim of increasing awareness about GEnS, environmental EU policies, environmental assessment and related scientific knowledge. The app allow the user to answer the following questions: what does the science know about the environment I am observing? what do I currently observe in this environment? how could I assess the environmental status today? 3. Release of a **European Seas Keystone Species Catalogue.** This database lists keystone species, among others in different habitats of the Mediterranean Sea. Both data bases are valuable tools for assessment of the status of areas of interest and available knowledge. Both can be used to estimate effects of additional pressures as construction sites or additional ship traffic
Key areas of recommendations	Knowledge improvement, Ecosystems 2/Impact mitigation
Typology of recommendations	Development of observational digital tools and models
Relevant deliverables	Deliverable 1.1. Conceptual models for the effects of marine pressures on biodiversity
Project Website	http://www.devotes-project.eu

PROJECT - Title	**4 POWER** Policy and Public-Private Partnerships for Offshore Wind EneRgy
Programme	EU INTERREG IVC
Period	2012-2014
Status	Completed
Short description	4POWER (Policy and Public Private Partnerships for Offshore Wind EneRgy) focuses on the role of regions in relation to Offshore wind energy (OSW).
Considered sectors	Energy and sustainable transport
Geographic area	Interregional
Categories of Impacts of OWFs on MPA	Sums up activities on onshore regions associated with economic business sectors of the maritime supplier industries and third-party service providers
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	Report on Best Practices in OSW, including guidelines how to implement them. Mini guidebook for onshore/industrial regions to prepare for OSW development as well as practical policy recommendations towards EU policymaking level on how to make regions more aware and better equipped to create an EU level playing field for OSW implementation.
Key areas of recommendations	Environment and risk prevention , connection of offshore industries and local providers
Typology of recommendations	Report and Guidelines
Relevant deliverables	https://www.offshore-stiftung.de/sites/offshorelink.de/files/documents/2014_4POWER_Regional%20Policies%20for%20Offshore%20Wind_A%20Guidebook_webversion.pdf
Project Website	https://www.offshore-stiftung.de/4POWER

PROJECT - Acronym	**BIAS**
PROJECT - Title	Baltic Sea Information on the Acoustic Soundscape
Programme	EU LIFE Programme
Period	2012-2016
Status	Completed
Short description	The overall goal of the BIAS project is to ensure that the introduction of underwater noise is at levels that do not adversely affect the marine environment of the Baltic Sea.
Considered sectors	Habitats - Marine Air & Noise - Noise pollution
Geographic area	Baltic Sea
Categories of Impacts of OWFs on MPA	Soundscape maps showing the underwater noise generated by commercial vessels
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	The BIAS implementation plan deals with the results in a greater detail as well as suggests a regional handling of continuous acoustic noise. Development of standards for noise measurements and the standards for signal processing. Affected areas can be derived and thus distances of noise effects can be calculated
Key areas of recommendations	Ecosystem-1/Impact avoidance
Typology of recommendations	Reports
Relevant deliverables	Deliverable B.1: “BIAS standards for noise measurements”
Project Website	https://biasproject.wordpress.com/

PROJECT - Acronym	**COCONET**
PROJECT - Title	towards COast to COast NETworks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential
Programme	EU 7th Framework Programme
Period	2012-2016
Status	Completed
Short description	COCONET identifies groups of putatively interconnected MPAs in the Mediterranean and the Black Seas, shifting from local (single MPA) to regional (Networks of MPAs) and basin (network of networks) scales. These activities will also individuate areas where Offshore Windfarms might become established, avoiding too sensitive habitats but acting as stepping stones through MPAs.
Considered sectors	MPAs and Offshore wind
Geographic area	Mediterranean and Black ´Sea
Categories of OWFs on MPA	NA
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	Four-step guideline for the selection of marine areas for conservation. The group also assessed Black Sea and Mediterranean coastlines for suitability for offshore wind farming, while assessing likely future wind speed changes. COCONET WebGIS publishes data stored in the Geodatabases with all information available for the Mediterranean and Black Seas, e.g. protected sites, offshore windfarms, habitats, oceanography, socioeconomics and threats (http://coconetgis.ismar.cnr.it/)
Key areas of recommendations	Marine protected areas
Typology of recommendations	Position paper and multilevel tool (Smart Wind Chart)
Relevant deliverables	Deliverable 6.1: Position paper on stakeholder perceptions of MPAs
Project Website	NA

PROJECT - Acronym	**SAMBAH**
PROJECT - Title	Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise
Programme	Life+ Nature and partners
Period	2010-2016
Status	Completed
Short description	Monitoring of harbour porpoises by a net of 300 C-POD stations in the mid and eastern baltic sea to assess the sub-population by estimating densities and distributions. An additional aim is to identify hotspots and potential areas of conflict with anthropogenic use. The intention of the project is also to increase the awareness of policymakers, stakeholders, managers and users of the marine environment.
Considered sectors	MPAs, Offshore wind, Marine traffic,
Geographic area	Baltic
Categories of Impacts of OWFs on MPA	Results showed low densities of this sub-population leading to the immediate installation of a large Swedish Natura 2000 area for harbour porpoises
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	Best practise and final report for monitoring of endangered marine mammal species including examples how to target the general public or “After-Life conservation plan” to put life-projects into a broader context
Key areas of recommendations	Marine protected areas / endangered species
Typology of recommendations	
Relevant deliverables	Reports (all included on the final report, including also relevant documents on e.g. a financial documentation
Project Website	http://sambah.org/index.html

PROJECT - Acronym	**SEANSE**
PROJECT - Title	Strategic Environmental Assessment North Sea Energy as an aid for Maritime Spatial Planning
Programme	European Maritime and Fisheries Fund
Period	2018-2020
Status	Ongoing
Short description	The general objective of the SEANSE project is: “to develop a coherent (logical and well-organised) approach to Strategic Environmental Assessments (SEAs) with a focus on renewable energy in support of the development and effective implementation of MSPs”
Considered sectors	Offshore windfarm sector
Geographic area	North-East Atlantic, North Sea, Baltic Sea
Categories of Impacts of OWFs on MPA	NA
Synergies among OWFs and MPA	NA
Relevant outputs for PHAROS4MPAs Recommendations/proposed solutions/Good practices to mitigate impacts	Report with an overview of the current practice and coherent parts in SEAs in the different North Sea countries; Baseline report describing a coherent approach of SEAs as a decision support tool to align and improve MSP Three case studies are formulated and the coherent approach to SEAs is tested on these and two further studies are performed into the potential use of SEAs in North Sea regions
Key areas of recommendations	Ecosystems 1&2/Impact avoidance & mitigation, Marine spatial planning (International)
Typology of recommendations	Development of a Common Environmental Assessment Framework (CEAF)-Emphasis on Cumulative effect assessment
Relevant deliverables	NA (project ongoing)
Project Website	https://northseaportal.eu/downloads/

11 LITERATURE

1. General introduction

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A ANNEX- DATA FROM 4COFFSHORE DATABASE ON WIND TURBINES

Table 1: List of offshore turbines available, Rated Power, Rotor Diameter, Manufacturer and Commercial availability. Source: Offshore Turbine Database (October 2018) by https://www.4coffshore.com/windfarms/turbines.aspx

Wind Turbine	Rated power	Rotor diameter	Manufacturer	Commercial availability
2B6	6	140.6	2-B Energy	Prototype
AD 8- 180	8	180	Adwen	Available
AD 5-116	5	116	Adwen	Available
AD 5-132	5	132	Adwen	Available
AD 5-135	5	135	Adwen	Available
aM 5.0/139	5	139	Aerodyn Engineering GmbH	Available
SCD 3MW	3	100	Aerodyn Engineering GmbH	Available
SCD 6MW	6	140	Aerodyn Engineering GmbH	Available
Sea Titan 10MW	10	190	AMSC	Concept
M500-116	5	116	Areva Wind	Discontinued
Bard 5.0	5	122	Bard	Discontinued
Bard 6.5	6.5	122	Bard	Discontinued
B35/450	0.45	35	Bonus	Discontinued
B76/2000	2	76	Bonus	Discontinued
B82/2300	2.3	82	Bonus	Discontinued
China Energine 2 MW	2	93	China Energine	Available
Britannia	10	150	Clipper	Cancelled
H 151 - 5MW	5	151	CSIC Haizhuang	Available
HZ 127-5MW	5	127	Windpower Equipment	Available
H102-2.0MW	2	102	CSIC Haizhuang	Available
DeWind D8.2 2000KW	2	80	DeWind	Available
WinDS3000/100	3	100	Doosan Heavy Industries	Available
WinDS3000/134	3	134	Doosan Heavy Industries	Available
WinDS 3000TM	3	91.6	Doosan Heavy Industries	Available
HQ5500/140	5.5	140	Doosan Heavy Industries	Available
E112/4500	4.5	114	Enercon	Discontinued
Enron Wind 70/1500	1.5	70	Enron Wind	Discontinued
EN-4.0-136	4	136	Envision Energy	Available
Envision 4.2-136	4.2	136	Envision Energy	Available
EOLINK 12MW FOWT 1/10 - scale prototype	NA	20	EOLINK	Not Available
WEMU (Wind Energy Marine Unit)	50	300	Far Eastern Federal University	Concept
Floating-VAWT	0.3	19.2	Floating Windfarms Corporation	Discontinued
Subaru 80/2.0	2	80	Fuji Heavy Industries	Discontinued
GAIA 0.011MW	0.011	13	GAIA-Wind	Available
Azimut Project	15	NA	Gamesa	Concept
Haliade 150-6MW	6	150	GE Energy	Available

Wind Turbine	Rated power	Rotor diameter	Manufacturer	Commercial availability
GE 4.1-113	4.1	113	GE Energy	Available
GE 1.6-82.5	1.6	82.5	GE Energy	Available
GE 3.6s Offshore	3.6	104	GE Energy	Decommissioned
Haliade-X 12 MW	12	220	GE Energy	Concept
GW 121/3000	3	NA	Goldwind	Available
GW154/6.7MW	6.7	NA	Goldwind	Prototype
GW3S	3.4	140	Goldwind	Available
GW164/6.45MW	NA	NA	Goldwind	NA
GW171/6.45MW	NA	NA	Goldwind	NA
GW 70/1500	1.5	70	Goldwind	Available
GW 109/2500	2.5	109	Goldwind	Available
UP3000-100	3	100.8	Guodian United Power	Available
UP6000-136	6	136	Guodian United Power	Available
UP1500-86	1.5	86.086	Guodian United Power	Available
Spinwind 2 10 kW	0.01	NA	Gwind	Prototype
Spinwind 1	0.001	NA	Gwind	Prototype in development
HTW5.0-126	5	126	Hitachi Ltd	Available
HTW2.0-80	2	80	Hitachi Ltd	Available
HTW5.2-136	5.2	136	Hitachi Ltd	Available
HTW5.2-127	5.2	127	Hitachi Ltd	Available
JSW J82 2MW	2	83.3	Japan Steel Works	Available
Keuka 30kW	0.03	7.6	Keuka Energy	Prototype
V112-3.45 MW Offshore	3.45	112	MHI Vestas Offshore Wind	Available
V126-3.45MW	3.45	126	MHI Vestas Offshore Wind	Available
V164-10 MW	10	164	MHI Vestas Offshore Wind	Available
V112-3.3 MW Offshore	3.3	112	MHI Vestas Offshore Wind	Available
V164-9.5 MW	9.5	164	MHI Vestas Offshore Wind	Available
V164-8.0 MW	8	164	MHI Vestas Offshore Wind	Available
V112-3.0 MW Offshore	3	112	MHI Vestas Offshore Wind	Available
MingYang SCD 3MW	3	100	MingYang	Available
MingYang SCD 6.0MW	6	140	MingYang	Available
MySE5.5-155	5.5	NA	MingYang	Available
MingYang SCD 6.5MW	6.5	140	MingYang	Available
MHI 2.4 MW	2.4	92	Mitsubishi Heavy Industries	Available
7MW Offshore Hydraulic Drive Turbine Formerly SeaAngel 7 MW	7	165	Mitsubishi Power Systems Europe	Discontinued
SKWID	0.5	15.2	MODEC Inc.	Prototype
Advanced Floating Turbine (AFT)	7	NA	Nautica Windpower	Concept
NedWind 40/500	0.5	40	NedWind	Discontinued
NM 72/2000	2	72	NEG Micon	Discontinued
N90/2300	2.3	90	Nordex	Available
N90/2500 HS Offshore	2.5	90	Nordex	Available
NTK 600/43	0.6	43	Nordtank	Discontinued
Wind Lens (test stage)	0.1	12.8	RIAMWIND Corp.	Prototype
Wind Lens	5	NA	RIAMWIND Corp.	Concept

Wind Turbine	Rated power	Rotor diameter	Manufacturer	Commercial availability
Wind Lens (test stage)	0.3	NA	RIAMWIND Corp.	Concept
Wind Lens (test stage)	0.003	2.5	RIAMWIND Corp.	Prototype
S7.0-171	7	171.2	Samsung Heavy Industries	Prototype
SeaTwirl 10MW	10	NA	SeaTwirl	Concept
SeaTwirl P3	0.0015	NA	SeaTwirl	Discontinued
SeaTwirl S1	0.03	NA	SeaTwirl	Prototype Installed
SeaTwirl 1MW	1	NA	SeaTwirl	Concept
SeaTwirl 3MW	3	NA	SeaTwirl	Concept
SeaTwirl S2	1	NA	SeaTwirl	Not Available
Seawind 10.4	10.4	210	Seawind	Not Available
6.2M152	6.15	152	Senvion	Available
3.0M122	3	122	Senvion	Available
5M	5.075	126	Senvion	Discontinued
6.2M126	6.15	126	Senvion	Available
CX Windtech 2MW	2	NA	Shandong Changxing Wind Power Technology Co., Ltd.	Available
W2000/93	2	93	Shanghai Electric - Aerodyn	Available
SE 2.0/93	2	93	Shanghai Electric Wind Power Equipment Co., Ltd. (Sewind)	Available
W3600-116	3.6	116	Shanghai Electric Wind Power Equipment Co., Ltd. (Sewind)	Available
W3600-122-90	3.6	122	Shanghai Electric Wind Power Equipment Co., Ltd. (Sewind)	Available
SWT-3.3-130	3.3	130	Siemens	Available
SWT-2.5-1085	2.5	NA	Siemens	Available
SWT-3.0-108	3	108	Siemens	Available
SWT-3.0-113	3	113	Siemens	Available
SWT-4.0-120	4	120	Siemens	Available
SWT-2.3-82 VS	2.3	82.4	Siemens	Available
SWT-2.3-82	2.3	82.4	Siemens	Available
SWT-2.3-93	2.3	93	Siemens	Available
SWT-2.3-101	2.3	101	Siemens	Available
SWT-3.0-101	3	101	Siemens	Available
SWT-3.6-107	3.6	107	Siemens	Available
SWT-3.6-120	3.6	120	Siemens	Available
SWT-6.0-120	6	120	Siemens	Discontinued
SWT-6.0-154	6	154	Siemens	Available
SWT-4.0-130	4	130	Siemens	Available
SG 8.0-167 DD	8	167	Siemens Gamesa	Available
G132-5.0MW	5	132	Siemens Gamesa	Available
SWT-DD-130	4.3	130	Siemens Gamesa	Available
SWT-8.0-154	8	154	Siemens Gamesa	Available
D1x	10	NA	Siemens Gamesa	Concept
SWT-7.0-154	7	154	Siemens Gamesa	Available
SL3000/113	3	113.3	Sinovel	Available
SL3000/90	3	90	Sinovel	Available

Wind Turbine	Rated power	Rotor diameter	Manufacturer	Commercial availability
SL3000/105	3	105	Sinovel	Available
SL6000/155	6	155	Sinovel	Available
SL5000/128	5	128	Sinovel	Available
SL6000/128	6	128	Sinovel	Available
SL5000/155	5	155	Sinovel	Available
Sterling Accelerator Turbine	20	NA	Sterling	Concept
STX 72 2MW	2	70.65	STX Windpower B.V.	Available
ST10	10	164	Sway Turbine AS	Prototype in development
TZ5000-153	5	153	Taiyuan Heavy Industry	Available
VertiWind	2.6	NA	Technip-Nénuphar	Prototype in development
SUPRAPOWER project	10	NA	Tecnalia Research & Innovation (TRI)	Concept
V112-3.3 MW Offshore	3.3	112	Vestas	Available
V80-2.0 MW	2	80	Vestas	Available
V90-3.0 MW Offshore	3	90	Vestas	Discontinued
V39-500kW	0.5	39	Vestas	Discontinued
V47-660kW	0.66	47	Vestas	Discontinued
V66-2MW	2	66	Vestas	Discontinued
WES18 mk1	0.08	18	WES	Available
Aerogenerator X	10	NA	Wind Power Limited	Prototype in development
Wind World 550kW	0.55	37	Wind World A/S	Discontinued
WWD-3-100	3	100	WinWinD	Discontinued
XEMC Z72-2000	2	70.65	XEMC	Available
XD115-5MW	5	115	XEMC - Darwind	Available
XE128-5MW	5	128	XEMC - Darwind	Available

Table 2: List of installed offshore wind turbines B = Belgium, D = Denmark, G = Germany, J = Japan, K = Korea, N = Netherlands, S = Sweden, UK = United Kingdom (Source: Offshore Turbine Database by https://www.4coffshore.com/windfarms/turbines.aspx; Oh et al. (2018))

Country	Offshore WP	Number of wind turbines	Foundation	Rated Power MW per Turbine	Total capacity (MW)	Turbine model	Diameter	Depth (m)	Distance to shore (km)
D	Avedøre Holme	3	Gravity	3.6	11	SWP-3.6-120	120	0-2	0,4
D	Middelgrunden	20	Gravity	2.0	40	Bonus B76	76	3-6	4,7
D	Nysted (Rødsand I)	72	Gravity	2.3	166	SWP-2.3-82	82	6-10	11
D	Rødsand II	90	Gravity	2.3	207	SWP-2.3-93	93	4-10	9
D	Sprogø	7	Gravity	3.0	21	Vestas V90	90	6-16	10,6
D	Tunø Knob	10	Gravity	0.5	5	Vestas V39	39	4-7	5,5
D	Vindeby	11	Gravity	0.45	5	Bonus 450 kW	35	2-4	1,8
G	Breitling	1	Gravity	2.5	2.5	Nordex N90	90	0,50	0,3
S	Karehamn	16	Gravity	3.0	48	Vestas V112	112	6-20	3,8

Country	Offshore WP	Number of wind turbines	Foundation	Rated Power MW per Turbine	Total capacity (MW)	Turbine model	Diameter	Depth (m)	Distance to shore (km)
S	Lillgrund	48	Gravity	2.3	110	SWT-2.3-93	93	4-13	11,3
B	Thornton Bank (Phase I)	6	Gravity	5.0	30	Repower 5M	126	18-28	28
D	Anholt	111	Monopile	3.6	400	SWP-3.6-120	120	15-19	15-23
D	Horns Rev I	80	Monopile	2.0	160	V80	80	6-14	18
D	Horns Rev II	91	Monopile	2.3	209	SWP-2.3-93	93	9-17	32
D	Samsø	10	Monopile	2.3	23	SWP-2.3-82	82	14-20	4
G	Amrumbank West	80	Monopile	3.6	288	SWP-3.6-120	120	20-25	44,8
G	DanTysk	80	Monopile	3.6	288	SWP-3.6-120	120	21-31	74,3
G	EnBW Baltic 1	21	Monopile	2.3	48	SWP-2.3-93	93	16-19	17,1
G	Meerwind Süd/Ost	80	Monopile	3.6	288	SWT-3.6-120	120	22-26	54,4
G	Riffgat	30	Monopile	3.6	108	SWT-3.6-120	120	18-23	15-42
N	Egmond aan Zee	36	Monopile	3.0	108	V90	90	15-18	10
N	Eneco Luchterduinen	43	Monopile	3.0	129	V112	112	18-24	24
N	Irene Vorrink	28	Monopile	0.6	17	NTK600-43	43	2-3	1
N	Lely	4	Monopile	0.5	2	Nedwind-41	41	3-4	0
N	Princess Amalia	60	Monopile	2.0	120	V80	80	19-24	26
S	Bockstigen	5	Monopile	0.55	3	WinWorld	NA	6	4
S	Utgrunden	7	Monopile	1.5	11	Enron 70	70	6-15	4,2
S	Yttre Stengrund	5	Monopile	2.0	10	NM 72	72	6-8	2
B	Belwind	55	Monopile	3.0	165	V90	90	12-20	44,7
B	Northwind	72	Monopile	3.0	216	V112	112	15-23	37
J	Kamisu – phase 1	7	Monopile	2.0	14	Subaru 80	80	5	0,2
J	Kamisu – phase 2	8	Monopile	2.0	16	HTW 2.0-80	80	5	0,1
UK	Barrow	30	Monopile	3.0	90	Vestas V90	90	12-20	7,5
UK	Blyth Offshore	2	Monopile	2.0	4	Vestas V66	66	6-11	1
UK	Burbo Bank	25	Monopile	3.6	90	SWT-3.6-107	107	0-8	6,4
UK	Greater Gabbard	140	Monopile	3.6	504	SWP-3.6-107	107	20-32	36
UK	Gunfleet Sands 1 & 2	48	Monopile	3.6	173	SWP-3.6-107	107	2-15	7
UK	Gunfleet Sands 3 (Demonstration)	2	Monopile	6.0	12	SWP-6.0-120	120	5-12	8
UK	Gwynt y Môr	160	Monopile	3.6	576	SWP-3.6-107	107	12-28	16
UK	Humber Gateway	73	Monopile	3.0	219	V112	112	10-18	10
UK	Kentish Flats	30	Monopile	3.0	90	V90	90	3-5	10
UK	Lincs	75	Monopile	3.6	270	SWP-3.6-120	120	10-15	8

Country	Offshore WP	Number of wind turbines	Foundation	Rated Power MW per Turbine	Total capacity (MW)	Turbine model	Diameter	Depth (m)	Distance to shore (km)
UK	London Array	175	Monopile	3.6	630	SWP-3.6-120	120	0-25	20
UK	Lynn and Inner Dowsing	54	Monopile	3.6	194	SWP-3.6-107	107	6-11	5
UK	North Hoyle	30	Monopile	2.0	60	Vestas V80	80	5-12	7
UK	Rhyl Flats	25	Monopile	3.6	90	SWP-3.6-107	107	4-11	8
UK	Robin Rigg	60	Monopile	3.0	180	V90	90	0-12	11
UK	Scroby Sands	30	Monopile	2.0	60	Vestas V80	80	0-8	2,5
UK	Sheringham Shoal	88	Monopile	3.6	317	SWP-3.6-107	107	14-23	23
UK	Teesside	27	Monopile	2.3	62	SWT-2.3-93	93	7-15	1,5
UK	Thanet	100	Monopile	3.0	300	V90	90	14-23	12
UK	Walney	102	Monopile	3.6	367	SWP-3.6-107	107	19-30	14
UK	West of Duddon Sands	108	Monopile	3.6	389	SWP-3.6-120	120	17-24	15
UK	Westermost Rough	35	Monopile	6.0	210	SWP-6.0-154	154	12-22	10
G	Alpha Ventus	12	Tripod	5.0	60	Areva M5000 REpower 5M	116	28-30	56
			Jacket						
G	BARD Offshore 1	80	Tripod	5.0	400	BARD 5.0	122	39-41	101
G	Global Tech I	80	Tripod	5.0	400	Areva M116	116	38-41	110
G	Hooksiel	1	Tripod	5.0	5	Bard 5.0	122	5	0,4
G	Nordsee Ost	48	Jacket	6.2	298	Senvion 126	126	22-26	51,4
G	Trianel Windpark Borkum (Phase 1)	40	Tripod	5.0	200	Areva M116	116	28-33	45-66
B	Thornton Bank phase II & III	48	Jacket	6.15	295	Senvion 126	126	12-26	28,2
K	Jeju Island (Demonstration)	2	Jacket	2.0	5	STX 72	70,65	15	2,8
				3.0		WinDS3000	100		
UK	Beatrice (Demonstration)	2	Jacket	5.0	10	Repower	NA	45	23
UK	Methil	1	Jacket	7.0	7	Samsung	171,2	5	0,05
UK	Ormonde	30	Jacket	5.0	150	Repower	NA	17-22	9,5

Table 3: Table Offshore windfarms constructed with gravity type foundations (B: Belgium, D: Denmark, G: Germany, S: Sweden (Source: Offshore Turbine Database by https://www.4coffshore.com/windfarms/turbines.aspx; Oh et al. (2018))

Windfarm	Turbine	Rating (MW)	# of WTs	Total capacity (MW)	Depth (m)	Distance to shore (km)	Loca-tion
Avedøre Holme	SWP-3.6-120	3.6	3	11	0–2	0.4	D
Middelgrunden	Bonus B76	2.0	20	40	3–6	4.7	D
Nysted (Rødsand I)	SWP-2.3-82	2.3	72	166	6–10	11	D

Windfarm	Turbine	Rating (MW)	# of WTs	Total capacity (MW)	Depth (m)	Distance to shore (km)	Loca-tion
Rødsand II	SWP-2.3-93	2.3	90	207	4–10	9	D
Sprogø	Vestas V90	3.0	7	21	6–16	10.6	D
Tunø Knob	Vestas V39	0.5	10	5	4–7	5.5	D
Vindeby	Bonus 450 kW	0.45	11	5	2–4	1.8	D
Breitling	Nordex N90	2.5	1	2.5	0.5	0.3	G
Karehamn	Vestas V112	3.0	16	48	6–20	3.8	S
Lillgrund	SWT-2.3-93	2.3	48	110	4–13	11.3	S
Thornton Bank (Phase I)	Repower 5M	5.0	6	30	18–28	28	B
Avedøre Holme	SWP-3.6-120	3.6	3	11	0–2	0.4	D

Table 4: Offshore windfarms constructed with monopile type foundations (B: Belgium, D: Denmark, G: Germany, J: Japan, N: Netherlands, S: Sweden, UK: United Kingdom (Source: Offshore Turbine Database by https://www.4coffshore.com/windfarms/turbines.aspx; Oh et al. (2018))

Windfarm	Turbine	Rating (MW)	# of WTs	Total capacity (MW)	Depth (m)	Distance to shore (km)	Loca-tion
Anholt	SWP-3.6-120	3.6	111	400	15–19	15–23	D
Horns Rev I	V80	2.0	80	160	6–14	18	D
Horns Rev II	SWP-2.3-93	2.3	91	209	9–17	32	D
Samsø	SWP-2.3-82	2.3	10	23	14–20	4	D
Amrumbank West	SWP-3.6-120	3.6	80	288	20–25	44.8	G
DanTysk	SWP-3.6-120	3.6	80	288	21–31	74.3	G
EnBW Baltic 1	SWP-2.3-93	2.3	21	48	16–19	17.1	G
Meerwind Süd/Ost	SWT-3.6-120	3.6	80	288	22–26	54.4	G
Riffgat	SWT-3.6-120	3.6	30	108	18–23	15–42	G
Egmond aan Zee	V90	3.0	36	108	15–18	10	N
Eneco Luchterduinen	V112	3.0	43	129	18–24	24	N
Irene Vorrink	NTK600-43	0.6	28	17	2–3	1	N
Lely	Nedwind-41	0.5	4	2	3–4	0	N
Princess Amalia	V80	2.0	60	120	19–24	26	N
Bockstigen	WinWorld	0.55	5	3	6	4	S
Utgrunden	Enron 70	1.5	7	11	6–15	4.2	S
Yttre Stengrund	NM 72	2.0	5	10	6–8	2	S
Belwind	V90	3.0	55	165	12–20	44.7	B
Northwind	V112	3.0	72	216	15–23	37	B
Kamisu – phase 1	Subaru 80	2.0	7	14	5	0.2	J
Kamisu – phase 2	HTW 2.0-80	2.0	8	16	5	0.1	J
Barrow	Vestas V90	3.0	30	90	12–20	7.5	UK
Blyth Offshore	Vestas V66	2.0	2	4	6–11	1	UK
Burbo Bank	SWT-3.6-107	3.6	25	90	0–8	6.4	UK
Greater Gabbard	SWP-3.6-107	3.6	140	504	20–32	36	UK
Gunfleet Sands 1 & 2	SWP-3.6-107	3.6	48	173	2–15	7	UK

Windfarm	Turbine	Rating (MW)	# of WTs	Total capacity (MW)	Depth (m)	Distance to shore (km)	Loca-tion
Gunfleet Sands 3 (Demonstration)	SWP-6.0-120	6.0	2	12	5–12	8	UK
Gwynt y Môr	SWP-3.6-107	3.6	160	576	12–28	16	UK
Humber Gateway	V112	3.0	73	219	10–18	10	UK
Kentish Flats	V90	3.0	30	90	3–5	10	UK
Lincs	SWP-3.6-120	3.6	75	270	10–15	8	UK
London Array	SWP-3.6-120	3.6	175	630	0–25	20	UK
Lynn and Inner Dowsing	SWP-3.6-107	3.6	54	194	6–11	5	UK
North Hoyle	Vestas V80	2.0	30	60	5–12	7	UK
Rhyl Flats	SWP-3.6-107	3.6	25	90	4–11	8	UK
Robin Rigg	V90	3.0	60	180	0–12	11	UK
Scroby Sands	Vestas V80	2.0	30	60	0–8	2.5	UK
Sheringham Shoal	SWP-3.6-107	3.6	88	317	14–23	23	UK
Teesside	SWT-2.3-93	2.3	27	62	7–15	1.5	UK
Thanet	V90	3.0	100	300	14–23	12	UK
Walney	SWP-3.6-107	3.6	102	367	19–30	14	UK
West of Duddon Sands	SWP-3.6-120	3.6	108	389	17–24	15	UK
Westermost Rough	SWP-6.0-154	6.0	35	210	12–22	10	UK

Table 5: Offshore windfarms constructed with tripod or jacket type foundations J: Jacket, T: Tripod, B: Belgium, G: Germany, K: Korea, UK: United Kingdom. (Source: Offshore Turbine Database by https://www.4coffshore.com/windfarms/turbines.aspx; Oh et al. (2018))

Windfarm	Turbine	Rating (MW)	# of WTs	Total capacity (MW)	Depth (m)	Distance to shore (km)	Type	Loca-tion
Alpha Ventus	Areva M5000 REpower 5M	5.0	12	60	28–30	56	T , J	G
BARD Offshore 1	BARD 5.0	5.0	80	400	39–41	101	T	G
Global Tech I	Areva M116	5.0	80	400	38–41	110	T	G
Hooksiel	Bard 5.0	5.0	1	5	5	0.4	T	G
Nordsee Ost	Senvion 126	6.2	48	298	22–26	51.4	J	G
Trianel Windpark Borkum (Phase 1)	Areva M116	5.0	40	200	28–33	45–66	T	G
Thornton Bank phase II & III	Senvion 126	6.15	48	295	12–26	28.2	J	B
Jeju Island (Demonstration)	STX 72 WinDS3000	2.0 3.0	2	5	15	2.8	J	K
Beatrice (Demonstration)	Repower	5.0	2	10	45	23	J	UK
Methil	Samsung	7.0	1	7	5	0.05	J	UK
Ormonde	Repower	5.0	30	150	17–22	9.5	J	UK

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