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Using Ecological Sensitivity to guide Marine Renewable Energy Potentials in the Mediterranean region

LIST OF ACRONYMS

BAT: Best Available Techniques (or Technologies)
BEP: Best Environmental Practices
BE: Blue Energy
EBM: Ecosystem-based Management
MRE: Marine Renewable Energy
MPAs: Marine Protected Areas
MSP: Marine Spatial Planning
OWE: Offshore Wind Energy
OWF: Offshore Wind Farm
OWT: Offshore Wind Turbines
SDG: Sustainable Development Goals
EIA: Environmental Impact Assessment

The exploitation of Marine Renewable Energy (MRE) potential in the Mediterranean is crucial to contributing to global and European decarbonisation efforts in the framework of the UN Sustainable Development Goals (i.e. SDG7 Affordable and Clean Energy and SDG13 Climate Action) and the European Green Deal[1]. If their low impacts on biodiversity are ensured, MREs also represent an opportunity for sustainable economic growth in the region. Indeed, the continuous development of MRE technologies will increase the efficiency of energy production. Nonetheless, MRE in the Mediterranean must be achieved without posing any additional threats to biodiversity and ecosystem conservation. Ecosystem-based Management (EBM) principles should therefore be applied in planning and throughout the implementation of MRE technologies.

Best Available Techniques (or Technologies) are the most effective and advanced available methods of operation ensuring emission limit values and other conditions in order to prevent and, where that is not practicable, to reduce impacts on the environment as a whole [1]; [2]; [3]; [4].

Best Environmental Practices refer to the application of the most appropriate combination of environmental control measures and strategies, such as resource efficiency (including energy); avoiding the use of hazardous substances or products and the generation of hazardous waste; the development and application of codes of good environmental practice that cover all aspects of an activity throughout its life cycle (Ospar Convention, Appendix).

[1]For more information, consult the European Commission's "Guidance document on wind energy developments and EU nature legislation", available here.

Marine Renewable Energy in the Mediterranean: State of Play, Potential Development, and Limitations

The Mediterranean Sea presents specific natural conditions with lower wind, tide and current as well as greater depths. Due to these factors, it contains less sites that are suitable for MRE compared to other maritime areas such as the Atlantic Ocean or the North Sea, but nonetheless has the potential to host different types of MRE (wind energy, wave energy, tidal energy, energy from salinity gradient). In terms of adoption and development, the two most advanced MRE in the Mediterranean are Offshore Wind Energy (OWE) and Tidal Energy.

Regarding OWE, practically no large installations of wind turbines with fixed foundations are possible in the Mediterranean due to its intrinsic features: the steep bathymetry resulting in the narrow continental shelf makes it difficult to anchor devices in locations far removed from the coastline. Floating offshore wind turbines (OWT) appear to be a better solution, since they are feasible at much greater depths, thus allowing for the distancing of installations from the shore and the preservation of valuable marine biodiversity and ecosystems.

Estimations of offshore wind power potential [5] suggest that the most suitable areas for OWE development are the Gulf of Lion and the central Aegean Sea. However, the latter presents considerable spatial planning limitations, since the large number of islands and islets in the area makes it difficult to place OWE far away from the coastline. High offshore wind resource is also found in the offshore areas east and west of Crete, east of the Strait of Gibraltar, in the western Ligurian Sea, in the Strait of Sicily and in the Strait of Otranto. Several protection measures are in place in these areas due to the presence of important habitats for Vulnerable Mediterranean species. Conducting a very thorough Environmental Impact Assessment (EIA) is therefore a prerequisite of any potential MRE implementation.

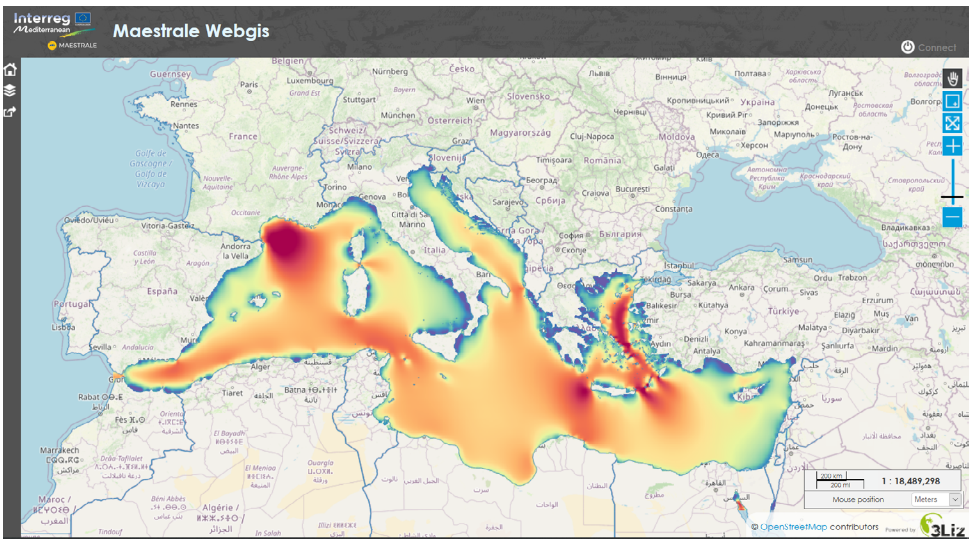

Figure 1: Mean annual wind energy potential (Source: MAESTRALE WebGIS, maestrale-webgis.unisi.it)

Offshore Wind Energy Plants in the Mediterranean

Gulf of Taranto (Italy): Renaxia is building a fixed foundation, near-shore wind plant, with a total capacity of 30 MW and expected production of 80 GWh – corresponding to the electricity consumption of about 30,000 households. It is situated at depths ranging from 3 to 14 m, has a hub height of 100 m, and is located 2.9 km from the shore (Soukissian et al., 2017) [6]. The plant was due to be completed in early 2020 but works are still ongoing.

Gulf of Lion (France): Three floating offshore farms pilot projects are under construction: the EOLMED project in Gruissan, led by QUADRAN, with 4 wind turbines of 6.15 MW; the "Provence Grand Large" project in Faramans, led by EDF EN with 3 wind turbines of 8.4 MW; the "Les Eoliennes Flottantes du Golfe du Lion" project in Leucate, led by Engie, with 4 wind turbines of 6 MW. Completion of works is expected by 2022 (Plan Bleu, 2020) [7].

Strait of Sicily (Italy): A floating wind farm at 300 m depth is planned about 35 km from Marsala and will not be visible from the shore. The so-called 7Seas Med project will involve 25 floating wind turbines producing up to 10MW each. The project is still awaiting an EIA and the necessary permits from local governments, following which it should be installed in 2023 and begin producing energy by 2024.

Over the last decade, progress has also been made regarding wave energy development in the Mediterranean, especially in Italy. A full-scale demonstration project has been developed in Pantelleria, where an Inertial Sea Wave Energy Converter (ISWEC) prototype was tested at 800 m from the coast at a water depth of 35 m and its environmental impacts assessed. This technology was also recently tested in a smart grid hybrid system under development in the Adriatic Sea [8].
Another device for wave and tide energy harvesting is the H24-50KW machine. This small device operates nearshore, is completely submerged, and works seamlessly as a wave and tidal unit. It was acquired by Enel GP and the energy produced at the Marina di Pisa test site was recently delivered into the Italian electricity grid. Moreover, onshore devices for wave energy harvesting are also noteworthy (Overtopping Breakwater for Wave Energy Conversion – OBREC1, Resonant Wave Energy Converter – REWEC, WaveSAX) although they are at a less mature state of development [8].

• 1 GWh of MRE (equivalent to 1,000,000 kWh) of energy produced can serve about 250 households and save up to 296 tonnes of CO_2 emissions per year (CO_2 emission intensity for electricity generation in Europe in 2016, Source: European Environment Agency). In 2017, the estimated average European electricity consumption per household in 2017 was 4,000 kWh (Source: Odissee-Mure project).

[2] The principle of operation of ISWEC consists in the interaction of sea waves with the hull of the device and the gyroscopic system.

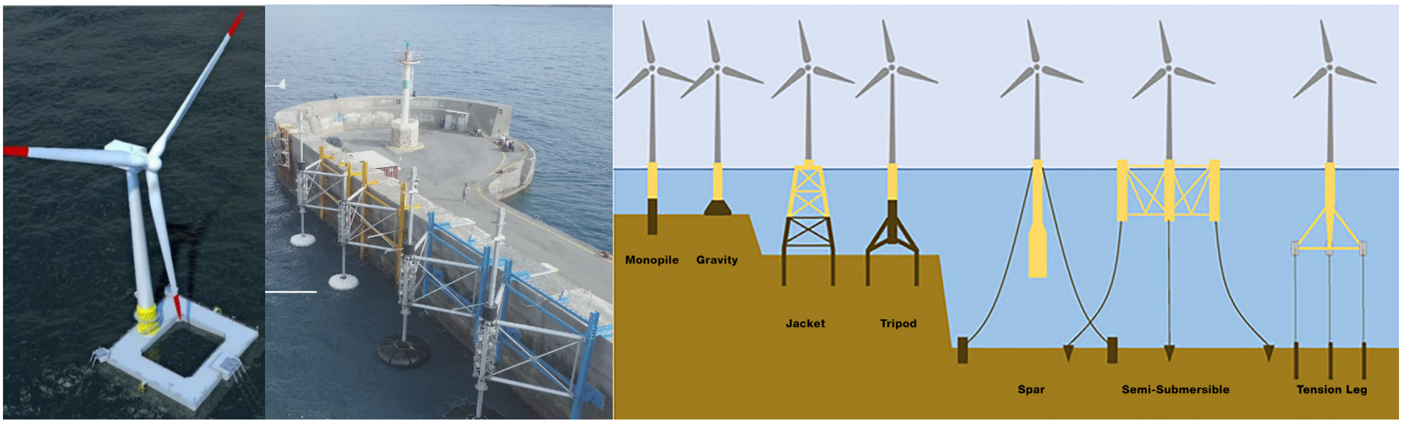

Figure 2: LEFT: Floating wind turbine used in EOLMED project @IDEOL; CENTER: R&D wave energy facility at the breakwater wall in Greece (Iraklion) @ SINNPOWER; RIGHT: Support structures for offshore wind turbines (monopile, gravity-based foundation, jacket, tripod, ballast stabilised spar buoy, tension leg platform) [6]

Impacts of Marine Renewable Energy on the Marine Environment

Various pressures associated with Offshore Wind Farms (OWF) can impact the marine environment. These risks either apply to the entire life cycle of an OWF or only during a specific phase. While the effects of a single wind farm on a particular wildlife population may be negligible, the cumulative spatiotemporal effects of multiple OWFs will cause wildlife population decline. The preeminent pressures from operating turbines are potential bird collisions and continuous noise disturbance or injuring marine mammals over hundreds of kilometres away from OWFs. Observed responses to noise in cetaceans are behavioural disturbance, the avoidance or abandoning of portions of habitats, damage to hearing and other tissues causing decreased foraging success, higher energetic demands and decreased reproduction rates [9].

Multiple OWFs can also add to the pressures generated by other maritime sectors. Cumulative effects (cf. Figure 3) are an important concern in terms of marine habitat fragmentation and degradation. For instance, although cable laying only requires relatively narrow trenches, multiple OWFs may result in numerous trenches in the seabed, causing a significant overall footprint.

An understanding of the cumulative effects of all impacts is needed at all potential development sites. Until then, all Marine Spatial Planning for OWFs in the Mediterranean should take a precautionary approach [29].

Abiotic environment	• Modified wind characteristics: wind-wake effect causing upwelling and downwelling patterns, • Changes in local hydrodynamics (fixed foundations), • Increase of suspended sediments (plumes extending for several kilometres), • Water pollution: release of metals (mostly Al and Zn) and heavy metals (mostly In) from sacrificial anodes that can accumulate in sediments and porewaters.
Benthic habitats and species	• Permanent habitat loss due to foundations and related infrastructure. Coastal habitats ('1140, 1130, 1150*and 1160) potentially impacted from cable laying in areas where they reach the mainland. • Physical disturbance, damage, displacement and removal of flora and fauna, clogging of feeding and respiration organs in filter-feeders due to installation activities, anchoring and resuspension. • Reef effect: positive/neutral effect if the colonisation comes from autochthonous species and serves as a biodiversity niche and refuge for affected species; negative effect if invasive species benefit from the new colonisation opportunities. • Electro-magnetic fields and temperature rise due to cables can affect benthic invertebrates. • Particularly impacted habitats: biogenic structures like mussel beds, sea grass beds, *Sabellaria* reefs or maerl beds.
Fish	• Impact from noise. Inhibited predator-avoidance behaviour, abnormal swimming behaviour, damage to swim bladder and impaired communication. • Impact from electromagnetic fields generated by cables. Alteration in moving directions, delay of migrations. • Possible impacts from polluted waters and sediments (heavy metals). • Attraction effect of artificial reefs and/or a positive effect due to fishery exclusion within the OWFs.
Marine mammals	• Impact from noise. During OWF construction, temporary or permanent hearing loss. During operation, possible chronic and potential masking effects. Observed responses to noise in cetaceans are behavioural disturbance, avoidance or abandoning of portions of habitats, injuries and damages to hearing and other tissues. Such responses could result in impacts such as decreased foraging success, higher energetic demands and decreased reproduction. • Higher risk of collision due to increased vessel traffic.
Birds	• Impact from collision. Migrating raptors and passerines at sea might be attracted to windfarms. Collision risk may further increase if structures are illuminated. • Barrier effect impacting migrating birds (extension of migration distances) and resident birds (deviations of the path between roosting/nesting and feeding sites). • Displacement and avoidance: impact on nesting and foraging with some species (divers, northern gannets, grebes and northern fulmars) completely avoiding the area, and others (long-tailed ducks, common scoters, common guillemots, razorbills, little gulls and sandwich terns) still present but less frequently and in smaller numbers. • Loss of foraging habitats may lead to reduced foraging success, increased competition, reduced body condition with effects on reproduction and survival.
Marine turtles	• Impact from noise. Interruption of feeding, breeding and other normal behaviours, avoidance leading to displacement from the area and exclusion from critical habitats, depressed immune function, increased swim speeds and altered dive durations, extreme cases of physical damage and mortality. • Impact from vessel collision. Injury and mortality due to increased vessel traffic. • Impact of electromagnetic fields. Possible effects on orientation, navigation, and migration capacity. • Impact of light pollution. Possible disorientation of hatchlings.

Table 1: Impacts of OWF on marine ecosystems and biodiversity. The references included in the table can be found in [18].

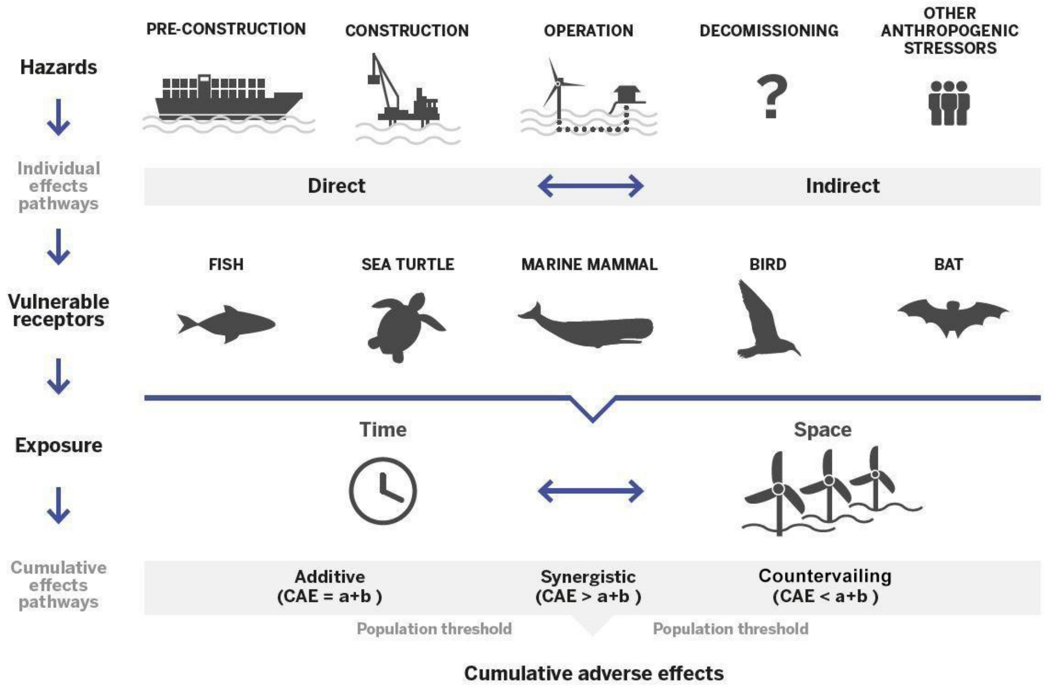

Figure 3: Cumulative adverse effects of offshore wind energy development on wildlife [10].

Collision of Birds with Offshore Wind Turbines

Specific sources in this paragraph can be found in [18]

Although collisions with Offshore Wind Turbines (OWT) appear to kill fewer birds compared to other man-made structures such as power lines, buildings or traffic [11], bird mortality is one of the major ecological concerns associated with OWE. For onshore windfarms, the number of bird collisions has been estimated from 0 to almost 40 fatalities per wind turbine per year [12]; [13].

In the Atlantic Ocean and North Sea, the species most at risk of collision with OWT are gulls (primarily Herring gull, Great and Lesser black-backed gull), the Northern gannet and the White-tailed eagle, while alcids and procellariforms are at lower risk. Migrating raptors at sea might be attracted to windfarms [14]. Raptors have also been observed using OWT and associated structures as roosting sites.

A higher collision risk of nocturnal migrants with offshore structures is also reported, possibly due to poorer visibility of obstacles at night [15]. Collision risk may further increase if structures are illuminated and, hence, attract birds [16]; [17]. Although most available data concerns species of the North Sea and northern Atlantic, indications about the collision risk of Mediterranean species can be inferred, since flight behaviour within species groups is likely to be similar [18].

However, such considerations cannot substitute direct observations of focal species in a Mediterranean setting. Potential population effects of collision depend on various factors, such as population sizes, longevity, reproductive rates, age at first breeding, etc. Seabird populations may be more vulnerable to collision mortality as these are long-lived species with slow maturation and low reproductive rates, and hence adult mortality has a potentially high impact on population dynamics. Migrating raptors (e.g. Egyptian vulture, Short-toed eagle, Black kite etc.) are quite vulnerable. Passerines, on the other hand, are mostly short-lived with high annual reproductive output and thus may be more resilient to impacts. Nevertheless, because migrating birds cross two ecological barriers during the pre-nuptial season (the Sahara and the Mediterranean), they are potentially highly exposed to collisions when migrating overnight because lights attract them before reaching land.

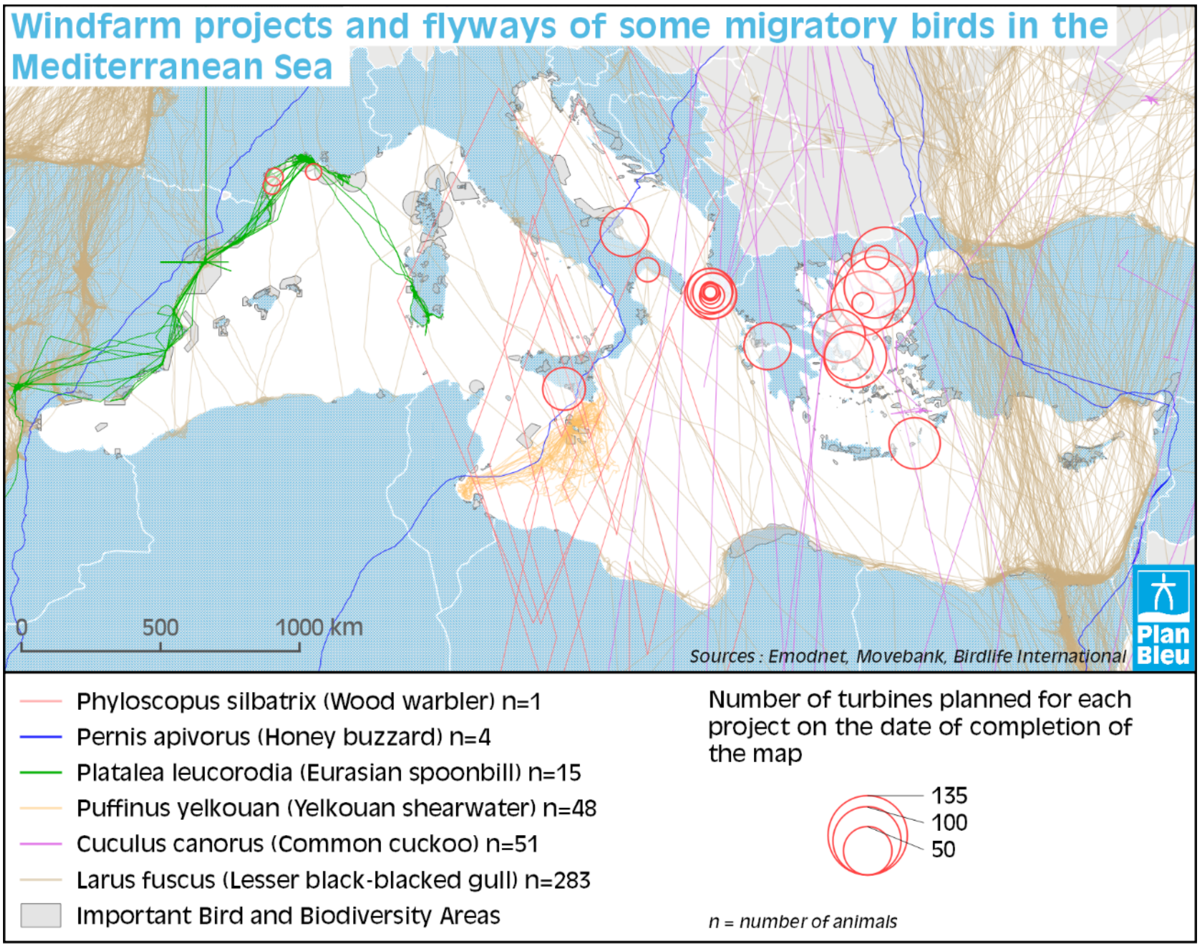

Figure 5: Windfarm projects and flyways of several Mediterranean migratory bird species[3] (Plan Bleu, 2021)

[3] Mapping method: Raw migration data (GPS loggers fixed to animals) was directly added to the map. Concerning windfarms, only those projects for which the number of turbines is known are represented (to date, for some projects the total power is known whereas the number of turbines has not been decided yet). Proportional circles for the number of turbines of windfarms have been traced using the Flannery method. This method compensates for the fact that individuals are usually poor judges of relative areas by applying the apparent magnitude scaling technique, which increases the circle by applying an exponent on the scaling factor. The GIS layer cannot be representative of birds that are potentially impacted by wind farms, because it is partial in terms of number of individuals for a given population, in terms of populations monitored and in terms of species (6 species are represented here, whereas it is estimated that at least 300 terrestrial species cross the Mediterranean).

All current Mediterranean OWF projects are located in the northern part of the basin, mainly in France, Italy, Albania and Greece. They are located close to or directly on some birds' corridors of migration. *Larus fuscus* (Lesser Black-backed Gull) seems to be the most threatened species by OWF installations in the sample set of birds selected.

In addition, local threats exist: *Platalea leucorodia* (Eurasian spoonbill) in southern France, *Cuculus canorus* (Common cuckoo) in Albania but the type of tags used on this species (geolocators) does not allow a precise visualisation of the tracks; *Pernis apivorus* (Honey buzzard) and *Phylloscopus silbatrix* (Woodwarbler) on the western coast of Italy; *Pernis apivorus* (Honey buzzard) and *Puffinus yelkouan* (Yelkouan shearwater) in southern Italy; and *Cuculus canorus* (Common cuckoo) in the Aegean Sea.

Bird trajectories represented here are only a partial and biased sample of the hundreds of species crossing the Mediterranean Sea twice a year. Hence, the cartographic representation of interspecific variation deserves tagging many more species to document their main migratory routes. Furthermore, trajectories depend on only a few numbers of birds tagged with GPS, meaning that intra-specific variation is also poorly documented here. Despite these limitations, Figure 5 illustrates the conflicts between OWFs and migratory birds that would deserve further attention, including more research to avoid, reduce and mitigate future OWF development. More data acquisition and research programmes could therefore contribute to filling this gap, especially because migratory birds decline more than non-migratory birds. Moreover, some OWFs are located close to important bird and biodiversity areas.

To make biodiversity conservation compatible with MRE infrastructure, spatial planning must avoid conflicts of interest and negative impacts on the environment as much as possible. A study conducted by the University of Thessaloniki and AEGEA [40] analysed different scenarios considering the exclusion of vulnerable areas from several impacts such as shipping, bird paths, and strategic distances from protected areas, identifying key sites in which to avoid OWF installations in the Greek Islands. The study was based on a GIS approach analysis, and presents an integrated proposal for the siting of OWFs which comprises planning stages and criteria that can be adopted and used in various settings and at different planning scales.

Figure 6: LEFT: The Red-throated diver (*Gavia stellata*) has been shown to be at substantial risk of habitat displacement impact due to OWF [18]. RIGHT: The Black-legged kittiwake (*Rissa tridactyla*) – IUCN endangered species, EU-27 Red List, is at substantial risk from collisions [18]. (Source: medwaterbirds.net)

Impacts of Offshore Wind Farms on Marine Mammals

Specific sources in this paragraph can be found in [18]

Since vast areas of the ocean receive little or no light, marine mammals rely primarily on their acoustic sense for foraging, communication, social interaction and navigation. Anthropogenic noise may cause behavioural reactions and communication alterations and can even cause hearing damage at high levels.

Cetaceans are the most impacted marine mammal species. Bottlenose dolphins and minke whales (and other mid- and low-frequency hearing cetaceans) may exhibit behavioural disturbances up to 50 km away from the construction site of an OWF [19]. Auditory injury zones have been estimated to occur within a range of 100 m of pile-driving operations. Avoidance as a reaction to noise may lead to temporary habitat loss. For instance, the first OWFs in Denmark and Germany caused rather large-ranged effects on harbour porpoises (*Phocoena phocoena*): reduced porpoise activity was recorded up to 20 km during and shortly after piling [20]; [21]; [22]; [23]. Compared to cetaceans and phocids, seals are far less sensitive to hearing impairments caused by underwater noise. The increase in vessel traffic during the lifecycle of an OWF also increases the potential for marine mammals to be struck by vessels. Along with noise resulting from OWF construction and operation, other pressures occur such as electromagnetic fields from cables, scour protection, active and passive corrosion protection of the foundations and turbine lights. In some areas, turbines are equipped with sonar transponders as navigation aids for submarines. So far, all of these factors have not been considered as causing more than subtle effects on marine mammals, if any, but contribute to a changing environment in areas where OWFs are built.

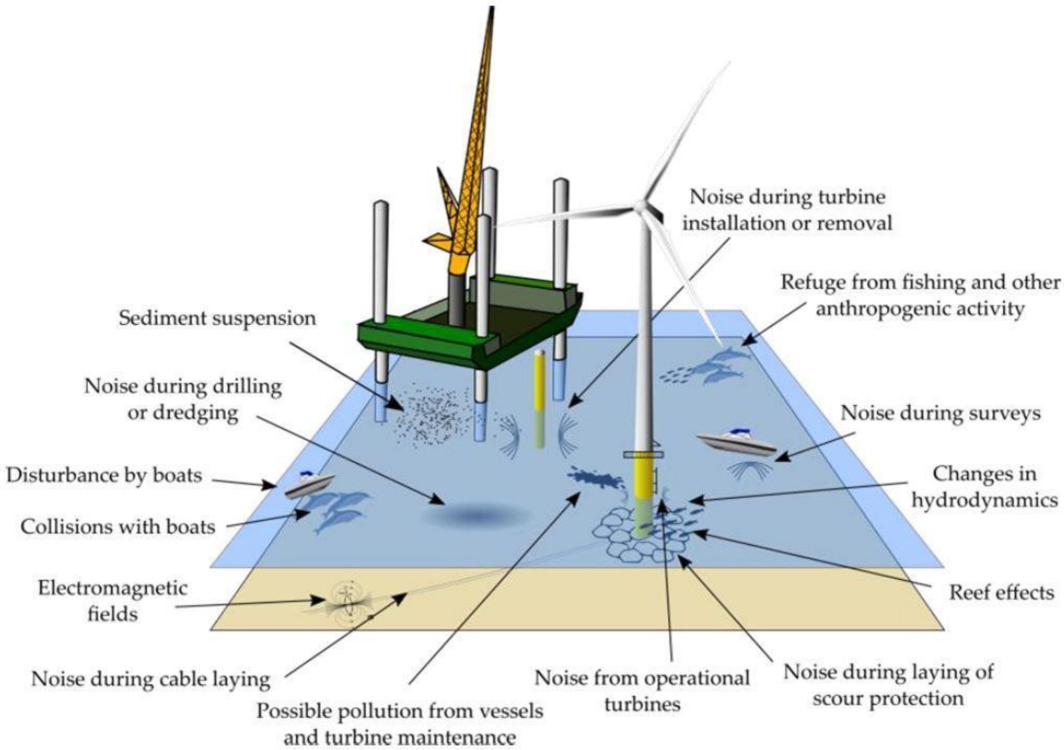

Figure 7: Effects that may influence marine mammals during the lifecycle of an OWF [25]

Impacts of OWF on marine turtles

Specific sources in this paragraph can be found in [18]

Little is known about the impacts of OWF on sea turtles. Noise impacts during their construction phase is expected to be an issue. Like with cetaceans, noise can interrupt normal behaviours (such as feeding or breeding) and avoidance, leading to displacement and exclusion from critical habitats [26]. Observed responses of sea turtles to low-frequency signals include agitated behaviour, abrupt body movements, startle responses, changes in swimming patterns and orientation. Increased vessel traffic in OWF areas (before and after construction and for surveying, installation and maintenance activities) poses threats to sea turtles.

Collisions with vessels and propellers may also cause injury and increased mortality. Studies on loggerheads suggest that sea turtles also use geomagnetic sensitivity for orientation, navigation, and migration [27]. These systems may be impacted by the electromagnetic fields generated by cables during the operation phase.

Artificial light associated with OWF during the construction and operational phases may impact sea turtles, and is known to have detrimental effects on hatchlings when they emerge from nests on natal beaches and head towards the sea. Light is an important navigational cue once hatchlings enter the water [28]. Artificial light is also likely to increase the chances of mortality by predation, with detrimental effects on the survival and resilience of turtles [28].

Best Available Technologies and Practices

Legend: C = construction, **O** = operation, **D** = decommissioning, **Red** = High Impact/Risk, **Orange** = Medium Impact/Risk, **Yellow** = Low Impact/Risk, **White** = No Impact/Risk, **Grey** = Unknown. The attribution of impact/risk levels is indicative and varies significantly depending on species, habitats and local conditions.

IMPACT	CAUSE	TARGET	PHASE			BAT & BEP
Habitat loss	Foundations	Benthic communities, fish	C	O	D	Select appropriate sites using ecosystem-based MSP and EIA
						Allocate minimum areas for construction
	Cable laying					Select shortest possible/most appropriate routes
						Plan and share grid connections between several OWFs
						Bundle with existing cables
Physical damage & disturbance	Piling noise	Marine mammals, turtles, fish	C	O	D	Modified hydraulic piling hammers, bubble curtains, soft starts, casings, cofferdams
	Ship traffic (presence and noise)					Speed and routing regulations
Collision & displacement	Turbines	Birds	C	O	D	Develop ecological sensitivity maps and select appropriate sites through ecosystem-based MSP
						Increase turbine visibility
	Lights	Birds, turtles				Avoid lights where possible, install lights on demand, use deflectors
Disorientation	Electromagnetic fields from underwater operating cables	Benthic communities, fish, turtles	C	O	D	Bury and shield cables

Table 2: Main available BAT and BEP for the prevention and mitigation of impacts from MRE installations [29]

Ecosystem-based Marine Spatial Planning and Strategic Environmental Assessments as Tools for Impact Prevention

Ecosystem-based management (EBM) principles applied to the planning and adaptive management of a project are the most important components among mitigation measures that aim at limiting its environmental impacts. This entails considering ecosystem connectivity as a basis in which ecological sensitivity, biological diversity and ecosystem service provision and their abiotic components are to be considered for site selection [30]; [31]; [32]. Indeed, Marine Spatial Planning (MSP) represents a valuable instrument to achieve this.

This is also envisaged by the Common Regional Framework for Integrated Coastal Zone Management [35], which recommends the use of EBM to ensure the sustainable development and integrity of a coastal zone, its ecosystems and related services and landscapes. Amongst others, this consists in formulating appropriate land/sea use strategies, plans and programmes for activities in the coastal zone and applying appropriate tools, in particular MSP and Strategic Environmental Assessments.

EBM processes in MSPs should be used to select appropriate sites for OWF installation, as well as the most appropriate routes for cable laying in order to limit impacts on habitats and benthic communities. This requires sound data collection to reduce uncertainties (mapping of species distribution ranges, spatial and temporal use, etc.) and the mapping of species and habitat sensitivity to OWFs. Where sensitive or protected habitats are present, detailed delineation of their distribution and of the seabed in general is needed in order for individual wind turbines to be sited appropriately so as to avoid them. Due to their cumulative impacts, it is important to minimise areas needed for OWF construction and operation, either individually or within clusters of projects. For example, by using the shortest possible area for laying cables, bundling new cables with existing cables, and minimising the number of intersections with other cables to avoid the need for more infrastructure [39].

Figure 8: Big Bubble system to reduce underwater noise from pile-driving operations during the construction of an OWF [29]

Mitigation of Impacts from Light Emissions [29, 39]

According to current regulations, OWF turbines are equipped with red lights on top for aviation and white lights lower down for shipping. They should be set to flash with the minimum intensity and frequency permissible under relevant national regulations. OWF lighting usually follows recommendations drafted by the International Association of Lighthouse Authorities (IALA). So far, few national regulations which limit night lighting exist.

- "**Light on demand**": switching on lights only when necessary should be prioritised as a mitigation technique for all OWFs, both for aviation and possibly vessel navigation lighting.
- **Colour**: light with low frequency and short wavelength radiation is thought to decrease collision risks. Indeed, low-frequency red, green and blue lights seem to attract fewer birds than normal white or red lights. Red lamps could be replaced with other coloured lamps.
- **Intensity**: it is still unknown how offshore lighting intensity can affect migrant and seabird species' movements, that may view these facilities as an obstacle and fly around them, thereby becoming disoriented i.e., experiencing a 'trapping effect', or becoming attracted to them to rest or forage. However, light intensity and thus the range at which the light may be visible or attractive play a role. It is recommended to avoid lighting turbines whenever and wherever possible.
- **Frequency**: using flashing lights instead of steady lights and shortening luminescent phases and lengthening dark phases as possible.

Light emissions can be further minimised by not illuminating large areas, or by using inverse LED plates/letters/numbers and other distinctive recognition elements. The radiation angle should be kept as small as possible, upwards radiation should be avoided, and indirect radiation should be preferred over direct radiation. Deflectors are recommended: traditionally lit markings may potentially be replaced by self-reflective imprints.

From Compatibility to Synergy: Multi-Use of the Sea by combining Marine Renewable Energy Production and other Maritime Activities

The Multi-Use approach developed by the H2020 MUSES project aims to reduce spatial pressures on seas, create new opportunities for socio-economic development and yield potential environmental benefits [34]. Blue Energy (BE) production is suitable to be combined with other maritime activities such as tourism, aquaculture, fisheries as well as other BE typologies.

OWE and Marine Protected Areas (MPAs): the most effective environmental impacts of OWFs are diverse and require a wide range of mitigation strategies. The most effective method for limiting negative impacts is spatial segregation, i.e., careful initial site selection to avoid high conservation value areas: this would exclude MPAs as potential locations for OWFs [29]. However, full segregation of OWFs and MPAs may not always be possible. In countries where OWF deployment already lies within MPAs, or which are at the stage of environmental impact and appropriate assessment, developments should be robustly assessed on a case-by-case basis in line with relevant nature conservation legislation, adopting a precautionary approach

to ensure that site conservation objectives are met. Synergies can be strengthened: OWF areas could be designated as permanent no-take zones, protecting animals present from any further anthropogenic harm and attracting other animals/predators to the new feeding grounds. It is 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 [29]. When avoidance is impossible, mitigation measures must be implemented. Ultimately, ecological compensation may be needed if significant residual impacts remain. This could include the degraded habitat's restoration or the creation of new habitat areas.

OWE and aquaculture can be jointly developed through (i) the direct attachment of aquaculture installations (i.e. fish cages or mussel/ seaweed long-lines) to OWT foundations or the development of new infrastructural solutions (i.e. in the form of fully integrated multi-purpose platforms); (ii) the colocation of aquaculture installations within OWF security zones, such as seabed cultivation of mussels in the vicinity of the OWF [39]. In the Baltic Sea, theoretical concepts were developed in Kriegers Flak, southern Sweden within the scope of the MERMAID project [35] while on-site tests were conducted in the Rødsand 2 OWF off the south coast of Lolland, Denmark as part of the SUBMARINER project. In the Mediterranean, combining aquaculture with future OWE has been envisaged in France [36] and in Cyprus as a feed management system powered by a stand-alone renewable energy system [37]. For more details, see [33].

OWE and fishing are generally competing sectors. Fishing is usually prohibited in OWF, which reduces available fishing areas and represents barriers to navigation. OWF can jeopardise important fish habitats such as spawning and nursery grounds since their locations (shallow areas closer to the coast, on sandy banks) are often particularly suitable for OWF. On the other hand, preserving spawning and nursery areas is likely to be increasingly important in the context of climate change. At the same time, OWFs can contribute to preserving fish stocks by offering artificial reefs where fish can feed and cannot be captured. Despite these conflicts, there are examples of compatibility between OWF and fisheries where the latter is not excluded from either OWF development areas (which can include a maximum 500 m safety zone during OWF operation) or along the offshore export power cable corridor. It may also include access to the same staff pool, equipment (vessels) or infrastructure (port facilities) [39]. Monitoring may be conducted by fishermen as a service, and the same emergency system may be shared by the two activities. For more details, see [33].

Priorities for Sustainable Marine Renewable Energy Development in the Mediterranean

EU policy initiatives that aim to promote a rapid increase of MRE, such as the Offshore Renewable Energy Strategy COM (2020) 741 final and the Blue Growth Strategy COM (2012) 494 final, are raising concerns over the effects of MRE installation and operation on marine wildlife, especially in the Mediterranean. Scientific evidence developed in pioneering countries has shown infrastructure development and MRE platform operations have clear potential negative impacts on the surrounding environment. It is therefore essential to adopt the precautionary principle as a cornerstone of any MRE development plan in the Mediterranean [29].

Ensuring compatibility between MRE and marine biodiversity protection:

- Decision-making processes regarding future MRE locations should adopt coastal and marine ecosystems as the foundation of any decision. Moreover, they should transparently integrate conservation objectives and aim to incorporate ecological sensitivity to avoid ecologically sensitive and valuable habitats as well as areas under protection.
- EBM principles should be applied throughout the planning and implementation of MRE technologies.
- EBM processes in MSP should be used to select appropriate sites for OWF installation, as well as the most appropriate routes for cable laying to limit impacts on habitats and benthic communities.

Promoting environmentally friendly MRE devices and practices:

- Support the development of new technologies for floating wind turbines (floaters, anchors) capable of operating in deep waters and/or far away from shores and design them in order to minimise their impacts on marine ecosystems and biodiversity.
- Collocate MRE infrastructure (floating wind turbines, wave energy converters, solar panels) and support multi-use development to minimise the use of sea space while avoiding the concentration of cumulative impacts.
- Adopt innovative design for substructure technologies (materials, geometries) to support new schemes in deeper waters that simplify manufacturing and installation operations and make them more environmentally friendly.

Strengthening natural laboratories for testing MREs and measuring their effects on marine ecosystems and biodiversity:

- Reinforce the role of existing natural laboratories to test systems in operational environments, while collecting the data needed to assess impacts on environment and biodiversity.
- Collect long-term data on the effects of MRE infrastructure and operation on marine ecosystems and biodiversity.
- Promote the creation of a network of natural laboratories operating along the same standards to identify strategies for optimal resource use and share environmental best practices in planning, designing, installation and management.

This factsheet was developed in the framework of the Biodiversity Protection Horizontal Project of the Interreg MED Programme. It contributes to the capitalisation process of the results of the Mediterranean Biodiversity Protection Community's 15 modular projects and corresponds to the MBPC's Deliverable 5.4.3. This factsheet was developed in parallel with the "Towards a sustainable development of Marine Renewable Energies in the Mediterranean" capitalisation report, produced in the framework of the Interreg MED Blue Growth Community.

Authors:

Martina Bocci and Francesca Coccon (t-ELIKA, Italy)

Contributors:

Céline Dubreuil, Michael Karner, Antoine Lafitte and Gloria Lázaro (Plan Bleu, France)
Dania Abdul-Malak and Sonsoles San Román (ETC-UMA, Spain)
Christina Kassara (Amvrakikos Gulf-Lefkada Management Agency, Greece)
Jocelyn Champagnon and Arnaud Béchet (Tour du Valat, France)
Manos Kamilakis (Aegean Energy & Environment Agency, Greece)

WITH THE COLLABORATION OF:

References

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CONTACT US:

panacea-med@uma.es
glazaro@planbleu.org
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