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Floating offshore wind farms in Mediterranean marine protected areas: a cautionary tale

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As offshore wind energy expands in Europe, maritime planners increasingly need to consider the potential effects of these activities on the different types of marine protected areas (MPAs), including Natura 2000 sites. The aim of this article is to critically review the initial development of offshore wind energy inside and/or in the vicinity of Mediterranean Natura 2000 sites and other types of MPAs. The western Mediterranean Sea is taken as an example as this is where most of the offshore wind developments have been proposed. In order to open up discussion of offshore wind energy policy and guide ecological research that supports holistic decisions regarding offshore wind farm (OWF) installation in the region, we (i) outline the context of Natura 2000 and other MPA policy in the Mediterranean for OWF development, (ii) summarize the potential impacts of OWF on EU-protected habitats and species, (iii) assess the interactions of OWFs, the Natura 2000 sites, and other MPAs, and (iv) propose recommendations to approach OWF development in the Mediterranean in order to safeguard the Natura 2000 sites and other MPAs. After documenting the potential overlaps between OWFs and MPAs in the western Mediterranean, we recommend OWFs be placed outside Natura 2000 and other MPA sites, including their buffer zones. We also advocate for rigorous and independent Appropriate Assessments to be carried out for OWF proposals that could affect protected areas.

Keywords: appropriate assessment, floating offshore wind farms, marine habitats, MPA, Natura 2000 sites, protected species.

Introduction

With the goal of Europe becoming climate neutral by 2050, the European Union (EU) estimates that offshore wind energy must meet 30% of the electricity demand of Member States by 2050, increasing from the current 12 GW capacity to a target of >300 GW (European Parliament, 2019). This means multiplying the current marine space allocated to wind energy by 15, with the exact space needed being dependent on the number and size of the turbines installed. In this regard, EU member states are planning new large-scale developments of offshore wind farms (OWFs) in European Seas, including the Baltic, the North Sea, the North Atlantic, and the Mediterranean (EEA, 2009; ICES, 2021). No OWFs have so far been proposed in the Black Sea.

At the same time, the European Commission (2020a) highlights that the designated spaces for marine offshore energy exploitation should be compatible with biodiversity conservation and should not compromise the good environmental status of its marine waters, while taking into consideration the socioeconomic consequences for sectors that rely on the good health of marine ecosystems and also integrating other uses of the sea as far as possible. In this context, EU Member States have obligations towards achieving the Natura 2000 objectives, the implementation of the Marine Strategy Framework Directive (MSFD), and the objectives set by the EU biodiversity strategy for 2030.

Natura 2000 is the name of the ecological network of protected sites for selected habitats and species within the EU, which includes Sites of Community Importance (SCI) and Special Areas of Conservation (SAC), designated under the Habitats Directive (Habitats 92/43/EEC Directive), and Special Protection Areas (SPA), designated under the Birds Directive (Birds 2009/147/EC Directive). The Natura 2000 network constitutes the most effective way to safeguard marine and coastal ecosystems in the EU (O'Leary *et al*., 2016), with the Habitats and Birds Directives being the cornerstones of the EU's nature and biodiversity policy. The purpose of the Natura 2000 network is to ensure that the species and habitat types listed in Annexes I and II of the Habitats Directive, as well as those bird species listed in Annex I of the Birds Directive, are protected or restored to a favourable conservation status throughout their range within EU territory, as well as bird species listed in Annex I of the Birds Directive. In addition to other marine protected area (MPA) designations, Natura

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2000 sites will play an important role in the EU's Biodiversity Strategy for 2030, which aims to effectively protect 30% of European seas by 2030, with one-third (10%) strictly protected (European Commission, 2020b). In the Mediterranean Sea, 9.7% of EU waters are covered by Natura 2000 sites, compared to 27.6% in the Greater North Sea (including the Kattegat and the English Channel) and 15.5% in the Baltic Sea (EEA, 2023).

However, climate change is already affecting the Mediterranean Sea, which ranks among the fastest-warming ocean regions worldwide (MedECC, 2020; Ali *et al*., 2022). Many studies conducted in recent years have already identified the impacts that climate change may have in marine populations, assemblages, and ecosystem structure (Moullec *et al*., 2019). In this regard, seawater warming is contributing to the expansion of warm-water species from southernmost areas, the decline of cold-water species, and the arrival of exotic species from an Atlantic or Indo-Pacific origin (Sabatés *et al*., 2006; Lejeusne *et al*., 2009; Calvo *et al*., 2011; Lloret *et al*., 2015). Sea warming is also a plausible cause for the increase of opportunistic species, such as several species of common jellyfish (Gravili, 2020) and for changes in the composition of plankton communities (Pallack *et al*., 2021). Furthermore, marine heatwaves in the Mediterranean are associated with increasing events of mass mortalities of foundation benthic species, such as habitat-forming, sessile gorgonians and seaweeds in benthic communities localized above the thermocline (Garrabou *et al*., 2009, 2022; Verdura *et al*., 2021). Despite the nature-based solutions offered by MPAs to support conservation efforts towards climate change adaptation and mitigation, they are not safeguarded from the consequences produced by climate change (Otero *et al*., 2013).

In this context, as the number of wind farm developments across the EU will rapidly increase, some of the new projects are (and will be) proposed in or near areas of high biodiversity and climatic value, such as Natura 2000 sites. In the Mediterranean Sea, the development of offshore wind energy is still in its infancy. However, this situation will soon change as there are currently plans in place for the development of ∼30 projects in Mediterranean countries (mostly using floating turbines; Defingou *et al*., 2019), raising concerns about their potential effects on the ecological integrity of the 1087 officially designated MPAs, of which 257 have a national statute and 829 are Natura 2000 sites (MedPAN/SPA/RAC, 2016).

The spatial planning and management implementation of offshore wind developments varies from country to country. The construction of infrastructures such as OWFs in many regional and national designed MPAs is legally possible depending on the designation type, which varies greatly between countries (Defingou *et al*., 2019). For example, in France, OWF developments are forbidden in marine National Natural Reserves and in the core area of marine National Parks (but consent is required in the marine area adjacent to the National Park), whereas OWFs are allowed in Marine Natural Parks with a simple or compulsory consent depending on the predicted impact on the marine environment (Defingou *et al*., 2019). In Spain and France, national authorities have defined offshore wind development areas (OWDAs) where OWFs can be developed. In Italy, however, developers apply to the public authorities for OWDAs and restrictions in relation to Natura 2000 sites are not considered as an impediment. Besides the specific legislation affecting Natura 2000 sites, the MSFD requires that EU member states ensure that their marine waters achieve the good environmental status (GES), such that marine resources are used sustainably in order to ensure their continuity for future generations. The MSFD provides an overall legal framework for the development and implementation of marine management strategies, including OWFs (EEA, 2009).

The goal of this study is to critically review the initial development of offshore wind energy in relation to the Mediterranean Natura 2000 sites and other types of MPA, taking the western Mediterranean basin as an example, given that this is where most of the offshore wind developments, principally floating turbines, have been proposed (Defingou *et al*., 2019; Lloret *et al*., 2022). In order to focus the debate regarding offshore wind energy policy in Mediterranean Natura 2000 sites and guide ecological research that supports holistic decision-making regarding OWF installation in the region, we (i) outline the context of MPA policy in the Mediterranean for OWF development, (ii) summarize the potential impact of OWFs on Natura 2000 sites, (iii) assess the interaction of OWFs and Natura 2000 sites in the western Mediterranean, and (iv) propose recommendations for the approach to OWF developments in the Mediterranean, taking into account Natura 2000 sites and other types of MPA. In this study, we particularly focus on the Natura 2000 sites since these have the strictest requirements for environmental conservation among all MPA types and are legally binding under EU legislation. Although this study is focused on the western Mediterranean, lessons learned can be useful for other areas in the Mediterranean and other seas.

Methodology

We first analysed the key literature regarding legislation on the development of OWFs in Natura 2000 sites, as well as the potential impacts of OWF developments on habitats and species protected under the Habitats and Birds Directives (hereinafter referred to as EU-protected habitats and species), which determine the ecological value of the Natura 2000 sites. Second, the Natura 2000 sites found in the western Mediterranean were identified and mapped using the European Environmental Agency Natura 2000 database (https://www.eea.europa.eu/). The Spanish OWDAs were identified through "Royal Decree 150/2023, of 28 February, which approves the maritime spatial planning of the five Spanish marine demarcations" (https://www.boe.es/diario_boe/txt.php?id=BOE-A-2023-5704) and the metadata provided by the Spanish Ministry for the Ecological Transition and the Demographic Challenge (https://www.mapama.gob.es/ide/metadatos/srv/spa/catalog.search#/home). The French OWDAs were obtained from the "Decision of 17 March, 2022 following the public debate on the floating wind turbine project in the Mediterranean and their connection" (https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000045381641). The Italian OWDAs were obtained from the documentation on the projects provided on the environmental assessments and permits website of the Italian Ministry of the Environment and Energy Security (https://va.mite.gov.it/it-IT) and from the coastguard territorial commands notice (https://www.guardiacostiera.gov.it/).

We also analysed the interaction of OWF developments with other protected areas beyond Natura 2000 sites, focusing on the northern Catalan Sea and the Gulf of Lion (NW Mediterranean), where various protected areas coexist (Figure 1). We identified those protected areas existing in the

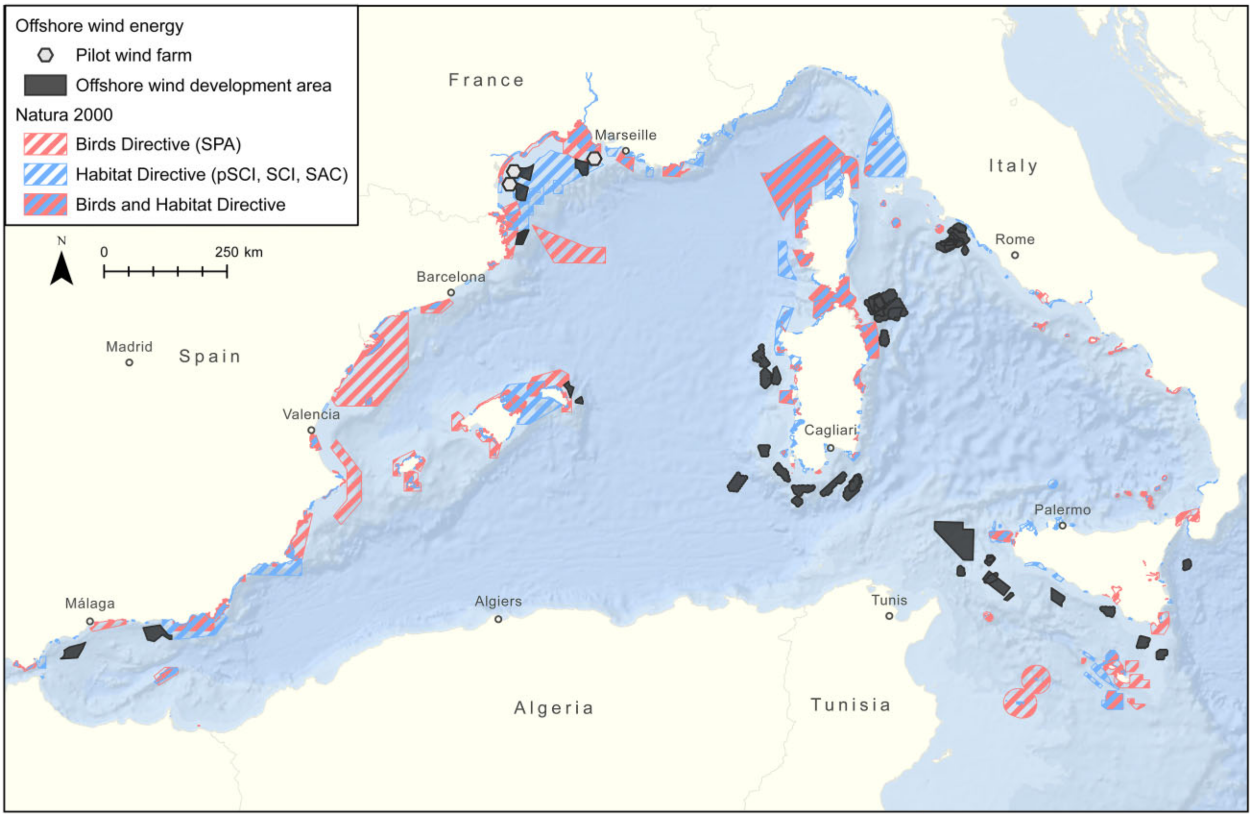

Figure 1. Map displaying the location of Natura 2000 sites (SPA, SCI, and pSCI), offshore wind farm development areas, and pilot OWF in the western Mediterranean. SPA: special protection area; SCI: site of community importance; pSCI: proposed sites of community importance.

study area: (i) MPAs designated under the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution (the so-called Specially Protected Areas of Mediterranean Importance, SPAMI), (ii) MPAs designated by intergovernmental treaties and international institutions, such as RAMSAR sites, UNESCO Man and Biosphere reserves, IMO Particularly Sensitive Sea Areas (PSSA), permanent and seasonal fisheries restricted areas (FRA), (iii) other protected areas recommended by different institutions, such as Important Bird Areas (IBA), Important Marine Mammal Areas (IMMA), Cetacean Critical Habitats (CCH), Key Biodiversity Areas (KBA), Important Shark and Ray Areas (ISRA) and (iv) natural protected areas established by national or regional governments. All these MPA categories have been proposed by different organizations and, depending on the country and MPA, their protection goals and enforcement measures vary greatly, with relatively few (mostly SPAMIs, FRAs, and those established by governments) having been established in legislation (MedPAN/SPA/RAC, 2021) (Table 1). It should be emphasized that these categories often have levels of protection that overlap with Natura 2000 sites.

All these protected areas were mapped using shape files found in public repositories, or provided by the organizations responsible for the designation of these areas, as was the case with IMMA and KBA (IUCN MMPAFT, 2022; BirdLife International, 2022). We did not consider areas that are governed and managed in ways that do not necessarily have a primary conservation objective, such as other effective area-based conservation measures (OECM). Maps compiling the Natura 2000 sites and other MPA, OWDA and windfarm pilot projects (as of February 2023) were created using the ArcGIS Pro software.

Interaction between OWDAs and Natura 2000 sites in the western Mediterranean

Figure 1 shows the location of OWDAs and Natura 2000 sites in the western Mediterranean. The area contains five OWDAs proposed by the Spanish Government and three OWDAs proposed by the French Government, as well as 39 OWDAs in Italy that energy companies have proposed to develop their OWFs. Furthermore, there are three pilot OWFs in France that will have three turbines each. Overall, all three OWDAs in France fully overlap with SCIs of the Natura 2000 network, and one area in the southeast of Spain (of the five OWDAs in this country) partially overlaps with an SCI. In Italy, there are no OWDAs overlapping Natura 2000 sites. Among the three pilot OWFs in France, the one closest to Marseille overlaps with an SPA. Furthermore, most (90%) of the OWDAs and pilot OWFs placed outside the Natura 2000 sites in the western Mediterranean are located at a distance of <30–40 km from a protected site (calculated as the shortest distance between Natura 2000 boundaries and OWDA or pilot OWF boundaries; Figure 2). Overall, while some are found inside Natura 2000 sites, five OWDAs are adjacent to Natura 2000 sites (i.e. their borders are in contact).

Potential impacts of OWF on Mediterranean Natura 2000 sites

The Mediterranean Sea is biologically highly diverse (Coll *et al.*, 2010), hosting between 4 and 18% of the world's marine

Table 1. Categories of marine protected areas (MPAs) other than Natura 2000 sites in the Mediterranean.

MPA category	Definition
Specially Protected Areas of Mediterranean Importance (SPAMIs)	SPAMIs are defined by the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean as areas of importance for conserving the components of biological diversity in the Mediterranean. Legal obligations are attached to the SPAMI status and are formulated in the binding terms of the Protocol.
RAMSAR sites	RAMSAR sites are defined by the Convention on Wetlands as wetlands of international importance that must be preserved.
UNESCO man and Biosphere Reserves	Biosphere reserves are defined by UNESCO as sites for testing interdisciplinary approaches to understanding and managing changes and interactions between social and ecological systems, including conflict prevention and management of biodiversity.
IMO Particularly Sensitive Sea Areas (PSSAs)	PSSA are defined by the International Maritime Organization as areas that needs special protection because of their significance for recognized ecological or socio-economic or scientific reasons and which may be vulnerable to damage by international maritime activities.
Fisheries Restricted Areas (FRAs)	FRAs are defined by national governments or the General Fisheries Commission for the Mediterranean and Black Sea as geographically defined areas in which all or certain fishing activities are temporarily or permanently banned or restricted, in order to improve the conservation and sustainable exploitation of living aquatic resources and the protection of marine ecosystems. FRAs are incorporated into governmental legislation.
Important Bird Areas (IBAs)	IBAs are defined by BirdLife International as areas being globally important for the conservation of bird populations.
Important Marine Mammal Areas (IMMAs)	IMMAs are defined by the Marine Mammal Protected Areas Task Force as discrete portions of habitat, important to marine mammal species, that have the potential to be delineated and managed for conservation.
Cetacean Critical Habitats (CCHs)	CCHs are defined by the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area as sites in need of protection due to the occurrence of significant interactions between cetaceans and human activities.
Key Biodiversity Areas (KBAs)	KBAs are defined by a partnership of global conservation organizations as the most important places in the world for species and their habitats.
Important Shark and Ray Areas (ISRAs)	ISRAs are discrete, three-dimensional portions of habitat, important for one or more shark species, that are delineated and have the potential to be managed for conservation.

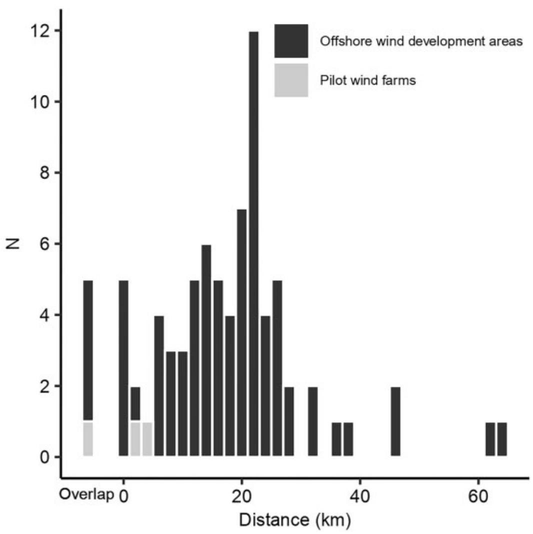

Figure 2. Distance (in km) between the boundaries of OWFDA (black) or pilot OWF (grey) in the western Mediterranean and the boundaries of the closest Natura 2000 site.

species, of which 30% are considered endemic (Bianchi and Morri, 2000). It contains fragile habitats in littoral, pelagic, and deep-sea environments, including coastal wetlands, estuaries, seagrass meadows, maërl beds, coralligenous assemblages, sponge grounds, and cold-water coral reefs, among many others (Ballesteros, 2006; Barberá *et al.*, 2003; Orejas and Jimenez, 2019; Telesca *et al.*, 2015). Of all basins, the western Mediterranean displays the highest diversity of sea turtles, marine mammals, and seabirds. However, recent data show that a large number of EU-protected habitats and species are currently in a poor conservation status in all EU regions, especially in the Mediterranean, where ~60% of marine species are in a bad or poor state of conservation (EEA, 2020). Furthermore, the map of the integrated classification of biodiversity conditions in the European seas (EEA, 2021) shows a higher coverage of "problem areas" (i.e., areas with poor, moderate, and bad biodiversity status) in the Mediterranean Sea than in the North Sea and the North Atlantic. Given this, we can say that there is an urgent need to protect Mediterranean biodiversity.

The potential impacts of OWFs on Mediterranean EU-protected habitats and species are diverse and may arise in one (or more) of the five main phases of wind energy development: pre-construction, construction, operation (including maintenance), "repowering" (changing the number, type, and/or configuration of turbines in an existing OWF), and decommissioning (removing the OWF or individual turbines). The extent of the effects produced by OWFs will not only depend on their location and related power evacuation infrastructure (e.g. cable routes and substations), but also the structure, functionality, and vulnerability of the ecosystems found on site and in vicinity. Although some positive effects have been reported in northern European Seas (e.g. Degraer *et al.*, 2020), changes to the characteristic habitats or communities produced by the installation of turbines may adversely affect the conservation objectives set by the Natura 2000 sites, regardless of the net biodiversity gain (European Commission, 2020b), and such effects must be carefully analysed. EU-protected species, which include marine mammals, sea turtles, fish, invertebrates, and bats, listed in either Annex II or Annex IV of the Habitats Directive, and birds protected by the Birds Directive, could be affected by entanglement risks, collision danger, barrier effects, disturbance, displacement, noise, and electromagnetic field effects, among others (see e.g. Benjamins *et al.*, 2014; Bergström *et al.*, 2014; Clark *et al.*, 2014; Perrow, 2019; Gill *et al.*, 2020; Lloret *et al.*, 2022).

Several Mediterranean habitats listed in Annex I of the Habitats Directive are potentially vulnerable to the installation of such infrastructures, including *Posidonia* beds [Habitat 1120], sandbanks [Habitat 1110], large shallow inlets and bays including seagrass beds (*Zostera* sp., *Cymodocea nodosa*) and maërl beds (*Lithothamnion corallioides*, *Phymatoliton calcareum*) [Habitat 1160], "reefs" including coralligenous assemblages, cold-water coral reefs (*Madrepora oculata*, *Lophelia pertusa*, and *Dendrophyllia cornigera*), deep-sea sponge grounds and other biogenic concretions [Habitat 1170], and estuaries [Habitat 1130] (European Commission, 2013). The long-term conservation of these habitats could be at risk if OWFs are located in the area of their distribution or even in close proximity (see Lloret *et al.*, 2022). In the case of floating OWFs, impacts directly relate to the direct physical contact produced by moorings and anchoring systems consisting of heavy chains and cables used to keep their substructures stationary, and also to changes in the dominant hydrodynamic regime or sedimentation rates (Defingou *et al.*, 2019; Van Berkel *et al.*, 2020; Farr *et al.*, 2021). These changes have been assessed in a recent modelling study (Akhtar *et al.*, 2021), which showed that the impacts of an accelerated deployment of OWFs, added to the effects of climate change, could represent significant perturbations to marine ecosystems in and near the area of deployment. The model included, in particular, climate-related consequences, such as changes in the sea surface climate, in wind patterns, and in atmospheric conditions (Akhtar *et al.*, 2021). However, it should be noted that there may be areas where micrositing of turbines could potentially help mitigate the impact on specific marine habitats. As turbines get bigger and the required space between them gets larger, the overall area of benthic footprint could shrink.

It should be recognized that the potential impacts of floating OWFs on deep continental shelf habitats in the Mediterranean could lead to biodiversity loss. For example, in the north-western Mediterranean, and especially in the southern part of the Gulf of Lion, rocky outcrops of the outer shelf (considered "reefs" in the Habitats Directive) are biodiversity hotspots that host a large number of sessile invertebrate species (Dominguez-Carrió *et al.*, 2022). The emergence of these rocks is related to erosion processes on the continental shelf governed by the prevailing bottom currents, which are influenced by the cold, northerly winds recurrent in the area (Ulses *et al.*, 2008; Estournel *et al.*, 2023). Furthermore, these shelf habitats, between 70 and 150 m deep, could play an important role in the resilience of marine biota to climate change impacts, as they are likely to be less affected by sea warming than shallow assemblages since they are located below the thermocline. It is worth noting that some species colonizing these deep shelf habitats are the same as those found on rocky habitats in coastal areas (Ballesteros, 2006), and therefore could be considered biodiversity refuges (Bongaerts and Smith, 2019). Besides the impact on the marine biota, OWFs could also have large-scale effects on the primary productivity of pelagic environments within Natura 2000 sites due to changes in the atmospheric and oceanic dynamics associated with the activity of the turbines, as has already been reported in the North Sea (e.g. Miles *et al.*, 2020).

However, in the absence of trawling (usually forbidden within OWFs), the abundance of benthopelagic and benthic species could increase due to using the OWF for shelter and as feeding grounds, with potential spillover effects to adjacent areas (Hammar *et al.*, 2016; Gill *et al.*, 2020). Despite the positive effects produced by OWFs on seabeds degraded due to bottom trawling, this does not apply to the Natura 2000 sites where bottom trawling is already prohibited. It should also be noted that the EU has already proposed new regulations to prohibit trawling in all Natura 2000 sites under the EU Action Plan for protecting and restoring marine ecosystems for sustainable and resilient fisheries (European Commission, COM(2023)102 final). In addition, some OWFs in the Mediterranean Sea are planned to be built in areas already closed to trawl fisheries, where the benefits arising from this prohibition have already been observed in comparison to analogous areas open to fishing (Sala-Coromina *et al.*, 2021; Vigo *et al.*, 2023). Furthermore, it is highly probable that banning trawling and vessel navigation in OWFs situated in the vicinities of MPAs that currently do not have management plans could potentially hamper their conservation goals due to a displacement of these activities towards the MPAs.

Apart from the impact on habitats and associated diversity, the effects produced by OWFs on the cultural heritage of Natura 2000 sites must not be neglected. There is an increasing awareness of the strong connections that exist between the natural and the built cultural heritage, which ultimately call for an integrated management approach to ensure their long-term sustainability, especially if found in the context of the Natura 2000 sites (European Commission, 2019). In this regard, the Habitats Directive itself states in Article 2 that the measures to be taken shall consider economic, social, and cultural requirements, as well as regional and local characteristics. Thus, not only does the Habitats Directive set the standard for nature conservation across EU countries, but it also offers great potential for safeguarding the cultural heritage (European Commission, 2019) and the associated cultural ecosystem services, among which the seascape emerges as a key concept (Pungetti, 2022). Seascape, in line with the definition of landscape in the European Landscape Convention (2000), is a product of the interaction of the natural and cultural components of our environment, and how they are understood and experienced by people (Natural England, 2012). It is known that some OWDAs in the Mediterranean Sea can potentially disrupt the seascape and/or landscape of Natura 2000 sites (see Lloret *et al.*, 2022).

Protection and management of western Mediterranean Natura 2000 sites faced with offshore wind energy developments

Under current EU recommendations, new wind energy installations in or near Natura 2000 sites are possible as long as they do not adversely affect the integrity of those sites (European Commission, 2020b). Although the Natura 2000 sites were initially excluded from the potential wind energy calculations, acknowledging that these are sensitive areas that require careful stewardship (EEA, 2009), recent global developments related to energy security and the urgency to tackle climate change have prompted a shift in strategy. In this regard, the EU has recently proposed a Council regulation laying down a temporary framework to accelerate the permit granting process and the development of renewable energy projects within

EU territory [COM (2022) 591 final 2022/0367]. There is, however, a strong environmental legislative framework at the EU level to protect Natura 2000 sites from any human activities that may have a negative impact on the integrity of the sites, including offshore wind developments. In this sense, Article 6 of the EU Habitats Directive lays down the procedure to be followed for authorizing plans and projects that are likely to have a "significant effect" on a Natura 2000 site (European Commission, 2001, 2020b) ("Member States shall take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive"). A "significant effect" is an undefined legal concept introduced by Article 6.2 of the Habitats Directive. An undefined legal concept must be defined either by the respective administrative authority implementing legislation, or by a court ruling. The Guidance Document on Wind Energy Development and EU Nature Legislation (European Commission, 2021) states that it is a concept that requires interpretation by the respective administrative authority, which must be objective. It also establishes certain criteria for the effects to be considered significant: direct loss of habitat, habitat degradation, habitat fragmentation, disturbance of species, and indirect effects such as an indirect change to the quality of the environment. In addition, some Member States, such as Germany, have developed methodological guidelines for determining significant effects (Lambrecht and Trautner, 2007).

According to Article 6.3 of the Habitats Directive, any plan or project, not directly connected with or necessary to the management of the site but likely to have a significant effect upon the site, either individually or in combination with other plans or projects, shall be subject to the Appropriate Assessment (AA) of its implications for the site in view of the site's conservation objectives. The AA is an assessment process, similar to the Environmental Impact Assessment (EIA) or Strategic Environmental Assessment (SEA), which determines whether or not a plan or project will cause damage to the integrity of a special area of conservation (Annex I of the Habitats Directive) or to animal and plant species of Community interest. The conservation of such species requires special areas of conservation to be designated (Annex II of the Habitats Directive). The EU's methodological guidance (European Commission, 2001) also notes that where plans or projects to be implemented in Natura 2000 sites are subject to EIA or SEA, the AA may form part of these assessments. In such cases, the AA required by Article 6 should be clearly distinguishable and identified within an environmental statement or reported separately (European Commission, 2001).

Therefore, offshore wind developments in Natura 2000 sites can only be authorized on a case-by-case basis after adopting an AA. This AA applies not only to plans or projects within a Natura 2000 site, but also to those planned in the vicinity if they affect the integrity of that special conservation area. This includes (i) Natura 2000 sites that geographically overlap (or are adjacent to) any of the actions or aspects included in the project during any phase of its development; (ii) any Natura 2000 sites within the likely zone of influence of the plan or project; (iii) any Natura 2000 sites in the surroundings of the project or plan (or at some distance) that host fauna that could move to the project area and suffer mortality or other negative impacts; and (iv) any Natura 2000 sites whose connectivity or ecological continuity can be negatively affected by the project (European Commission, 2020b). Furthermore, EU Member States are required to protect species of EU importance throughout their whole distribution range within the EU territory, which also relates to areas outside Natura 2000 sites (Article 5 of the Birds Directive and Articles 12 and 13 of the Habitats Directive).

The procedure to be followed by national and regional authorities for the AA, where offshore wind developments are likely to affect Natura 2000 sites, sets out different stages, which are specified in Article 6 (3) and (4) of the Habitats Directive (European Commission, 2020b). This procedure differs from plans or projects subject to the SEA or EIA Directives. In the first stage, the competent authorities conduct a screening process to assess whether the plan or project, alone or in combination with others, is likely to significantly affect a Natura 2000 site. If, during the screening process, significant effects cannot be excluded with certainty, an AA is required in a second stage, also under the responsibility of the competent authorities. The AA is particularly crucial: it should assess the likely effects on the Natura 2000 site in terms of its conservation objectives and also whether the implementation of the offshore wind plan/project may negatively affect—directly or indirectly, both immediately and in the long term—the integrity of the site, either individually or in combination with other plans or projects, i.e. also taking into consideration the cumulative impact (Damian and Merck, 2014; Goodale and Milman, 2016). In particular, AA should assess whether a particular plan or project compromises the favourable conservation status of the protected habitats and species within the specific MPA affected by an OWF, demonstrating any significant effects at the scale of the species/habitat. The AA should be based on the best available methods and knowledge, using reliable data, and taking the precautionary principle into account. The conclusions of the AA, which are legally binding, should enable the competent authorities to determine whether or not the plan or project will adversely affect the integrity of the Natura 2000 site (European Commission, 2020b). 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 offshore wind plan or project must not be approved unless "overriding public interest" (i.e. when a plan or project is essential for achieving the climate neutrality and energy security goals of an EU member state) or a demonstrated lack of alternative solutions can be proven in the third stage of the AA (European Commission, 2020b). "Overriding public interest" is an undefined legal concept introduced by Article 3 of the Council Regulation (EU) 2022/2577 laying down a framework to accelerate the deployment of renewable energy, which must be defined either by the respective administrative authority implementing legislation, or by a court ruling ("The planning, construction and operation of plants and installations for the production of energy from renewable sources, and their connection to the grid, the related grid itself and storage assets shall be presumed as being in the overriding public interest and serving public health and safety when balancing legal interests in the individual case…". "Member States shall ensure, at least for projects which are recognised as being of overriding public interest, that in the planning and permit-granting process, the construction and operation of plants and installations for the production of energy from renewable sources and the related grid infrastructure development are given priority when balancing legal interests in the individual case”). However, the requirement stated in Article 3 of Council Regulation (EU) 2022/2577, concerning the priority of renewable energy infrastructure when balancing legal interests in the individual case, only applies, according to this Article, if and to the extent that appropriate species conservation measures contributing to the maintenance or restoration of the populations of the species at a favourable conservation status are undertaken and sufficient financial resources, as well as areas, are made available for that purpose.

Interaction of OWF and other protected areas in the western Mediterranean

In the Gulf of Lion and northern Catalan Sea (NW Mediterranean), we found a complex interaction of four OWDA (1–4) and three pilot (A–C) windfarms located outside the OWDA, not only with Natura 2000 sites (Figure 1), but also with several other MPAs (Figure 3). Apart from these protected areas situated at sea, there are also protected areas along the coast that may be affected by the installation of export cables, electric substations, and port extensions that will be needed for the functioning of the OWF (WindEurope, 2020, 2021).

All four OWDAs and all three pilot windfarms overlap or border different MPAs (Figure 3). OWDA number 1 is on a permanent FRA, where specific fishing activities are banned or restricted in order to improve the exploitation and conservation status of specific fish stocks, as well as their habitats. Apart from being close to various Natura 2000 sites, OWDA number 1 also borders a KBA (one of the most important places in the world for species and their habitats) and an IBA (site of significant importance for birds and biodiversity), and is placed <30 km away from a SPAMI (site of importance for conserving components of biological diversity in the Mediterranean), various regional MPA and a RAMSAR site (a wetland designated to be of international importance under the RAMSAR Convention). Furthermore, this OWDA is situated in an area with a high potential for biodiversity conservation (not shown on the map) recommended by the Spanish Government through Royal Decree 150/2023, highlighting the ecological significance of this area due to the presence of EU-protected species and habitats.

OWDA numbers 2 and 3 and pilot windfarms A and C are completely or partially on a regional park and a KBA and within 50 km of RAMSAR sites and IBAs. OWDA number 4 borders a Biosphere Reserve (a site for testing interdisciplinary approaches to understanding and managing changes and interactions between social and ecological systems), and is <50 km from KBA, IBA, SPAMI, national and regional MPA and RAMSAR sites (Figure 3). OWDA numbers 2, 3, and 4 are partially on a seasonal FRA, where trawling activities are seasonally banned in order to preserve fish stocks and habitats (Figure 3). Furthermore, all OWDA and pilot wind farms are placed in an IMMA that covers nearly all of the Gulf of Lion and the northern Catalan Sea, comprising habitats important to marine mammal species.

This complex interaction is an example of the challenges that lie ahead for offshore wind developments in the Mediterranean Sea, where these MPA have been established during the last decades to conserve and restore the health of marine ecosystems with the view to protecting at least 30% of coastal and marine areas by 2030 (MedPAN/SPA/RAC, 2016) and/or to rebuild depleted fish stocks (Tuset *et al.*, 2021).

Considerations and recommendations for managers and policy makers regarding planning guidelines for OWFs

As offshore wind energy expands in the Mediterranean, marine managers increasingly need to consider the potential effects of these activities on the integrity of Natura 2000 sites and other MPA types. In order to promote the sustainable use of the sea, spatial planning that optimizes the location of OWFs should urgently address the challenging situation posed by wind farm developments proposed across the western Mediterranean inside or near Natura 2000 sites and other MPAs (Yates and Bradshaw, 2018). Spatial planning also needs to take into consideration the urgent need to protect and restore ocean functionality in the coming decades as a general and important objective by substantially reducing the pressures—protect species and spaces, harvest wisely, reduce pollution, and tackle climate change (Duarte *et al.*, 2020). In addition, we need to avoid increasing such pressures where ecological value is recognized.

As a general mandate, the Precautionary Principle should be respected and applied in the development of OWFs given the strong overlap between OWFs, Natura 2000 sites, and other MPA types in the Mediterranean Sea, and the limited existing information on the effects of floating OWFs on the marine environment, in alignment with the conservation goals of the Habitats and Birds Directives and the MSFD. Furthermore, the ecosystem approach should be applied, including all its associated principles (CBD, 1998). With regard to ecological related aspects, we must consider not only the diversity of species and habitats, but also their ecological functions (e.g. nursery, feeding grounds, spawning areas, and migration corridors) and their associated provision of ecosystem goods and services.

The following flowchart (Figure 4) summarizes the procedure we recommend for a step-by-step approach for wind farm projects potentially affecting Natura 2000 sites, considering Articles 6(3) and 6(4) of the Habitats Directive and based on the guidance by the EU (European Commission, 2020b) and our experience in the north-western Mediterranean.

As a first choice, OWF should not be placed within Mediterranean Natura 2000 sites, that is, not inside them nor in their surroundings or their peripheral zones (defined as “buffer zones”). Buffer zones and ecological corridors are an important part of conservation strategies for a wide variety of sites of biodiversity importance (UNDP, 2013), and are set with the objective of minimizing the impacts of externalities and constituting a possible solution to safeguarding the MPA, providing an extra layer of protection (Halpern *et al.*, 2010). Buffer zones should be defined for each MPA and for each human activity taking place nearby, whether this be offshore wind energy development, fisheries or maritime transport, among others. The size of the buffer zones to protect Natura 2000 sites against OWF developments should not be arbitrary, but defined case-by-case (i.e. by site), depending on the technical characteristics of the OWF and the ecological and biological characteristics of the site. The concept of “buffer zone” is already embedded in the Guidance document on wind energy developments and EU nature legislation (European Commis-

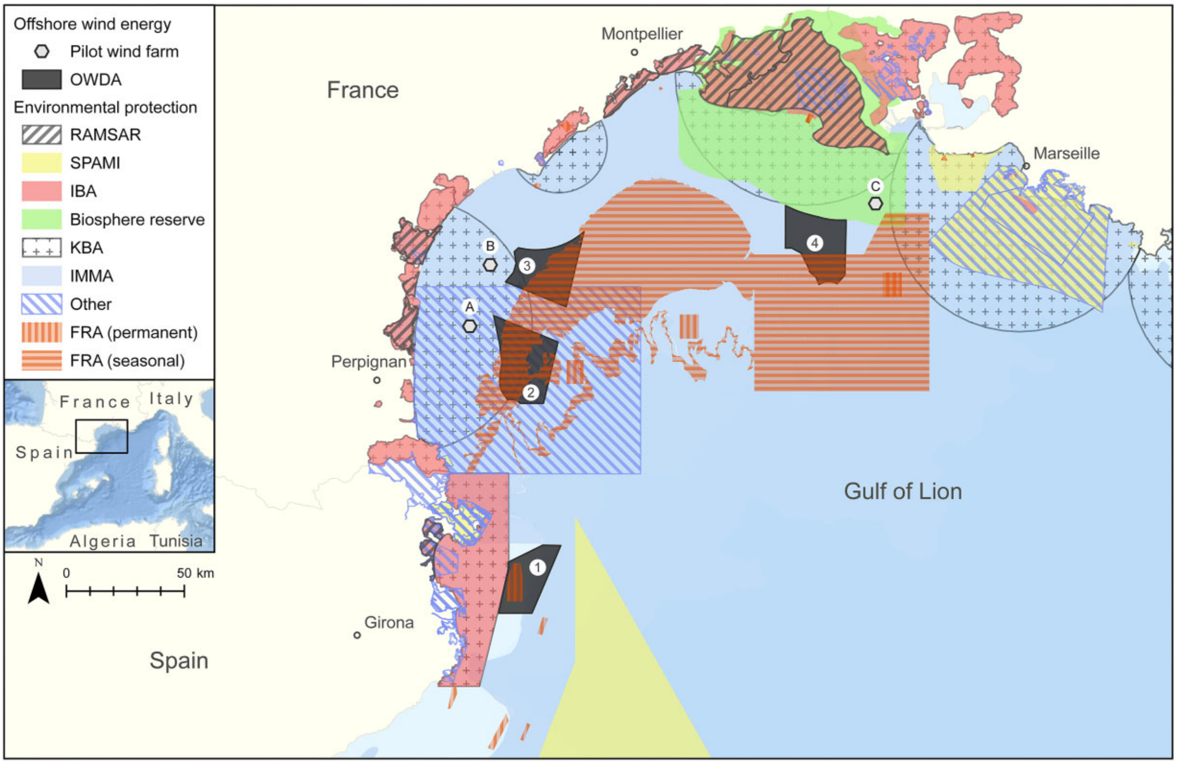

Figure 3. Map displaying the interactions between OWDA (1–4) and pilot wind farms (A–C) with protected areas in the NW Mediterranean: RAMSAR sites, Specially Protected Area of Mediterranean Importance (SPAMI), Important Bird Area (IBA), Biosphere Reserve, Key Biodiversity Areas (KB), Marine Mammal Protected Area (IMMA), regional and national protected areas (Other), and permanent and seasonal Fisheries Restricted Area (FRA). Notes: The IMO Particularly Sensitive Sea Area "North-Western Mediterranean Sea" was proposed by the Marine Environment Protection Committee in December 2022, encompassing two SPAMIs (the Pelagos Sanctuary and the Spanish Cetacean Corridor), and therefore is not shown on the map. The Important Shark and Ray Areas (ISRA) "Costa Brava-Canyons", "Roses" and "Eastern Gulf of Lion" in the NW Mediterranean were proposed by the IUCN SSC Shark Specialist Group after February 2023 and therefore are not shown on the map.

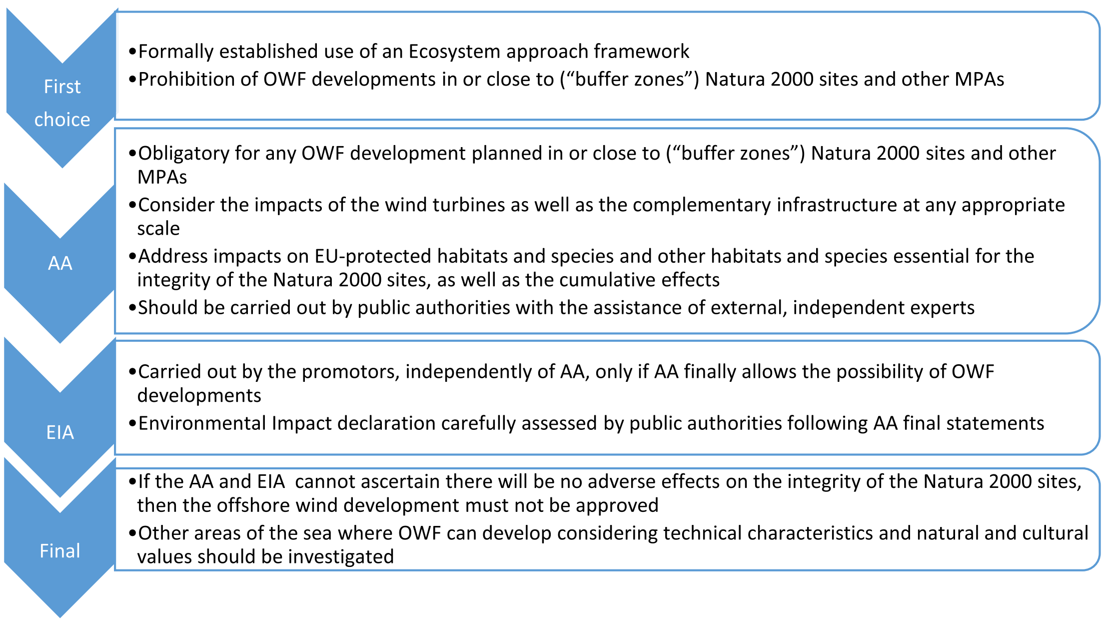

Figure 4. Flowchart of the recommended procedure for wind farm projects potentially affecting Natura 2000 sites. AA: Appropriate Assessment. EIA: Environmental Impact Assessment. OWF: Offshore Wind Farms. MPA: Marine Protected Areas.

sion, 2020b). This document acknowledges that the best way to minimize negative effects of OWFs on EU-protected habitats and species is to locate them away from vulnerable habitats and species. From a legal point of view, this also concerns projects of relevance outside Natura 2000 sites that may significantly affect the integrity of the Natura 2000 sites according to Article 6.3 of the Habitats Directive, which should not be overlooked. The recent international experience references underline that arbitrary buffer sizes proposed for different MPA may be inadequate to maintain the integrity of these areas (UNDP, 2013). The exclusion of OWF within MPA needs to be developed in the Strategic Environmental Assessment (SEA) that is needed for offshore wind plans and programmes.

Pilot (experimental) wind farms should also be excluded from Natura 2000 sites and their buffer zones. Energy companies can carry out their tests in degraded areas, avoiding areas of high ecological value. Pilot projects are mainly devoted to testing several technical issues regarding the floating infrastructure, such as testing and validation of materials, components and prototypes, digitalization, automation, robotics, open data and models, training and potential to develop commercial wind farms (Cruz and Atcheson, 2016). Since the biodiversity issue only forms a small part of these pilot projects, all technical tests could easily be carried out on degraded seabeds. Nevertheless, the floating pilot wind farm inside a French Natura 2000 site, which is already under construction (pilot wind farm C in Figure 3), would constitute an exception and would present an opportunity for gathering the first real data and knowledge required for AA.

The recommendation to exclude OWF developments from Natura 2000 sites and their buffer zones should be reinforced in sites where natural values coexist with important cultural sites and seascapes/landscapes, given the need to protect the cultural heritage (European Commission, 2019). A real integration of the cultural dimension, cultural ecosystem services and seascapes and landscapes into biodiversity policies and decisions is needed in order to promote marine spatial planning that takes both natural and cultural dimensions into account in an integrated way (Seardo, 2015; Roe and Stead, 2022).

Although the recommendations detailed in this section are mostly directed at Natura 2000 sites, they could also apply to other MPA types found in the Mediterranean, such as RAMSAR sites, SPAMIs, IBAs, Biosphere Reserves, FRAs, ISRAs and those regional and national MPAs where offshore wind energy developments are not forbidden. In order to preserve the connectivity between sites, and unless the AA assures there will be no significant effects on this connectivity, we particularly recommend excluding OWF from areas where Natura 2000 sites coincide with multiple MPAs, as occurs in the northern Catalan Sea and the Gulf of Lion. It is acknowledged that the rise in global terrestrial and marine infrastructure has the capacity to disrupt ecological connectivity pathways of species between different habitats or areas (see e.g. Bliss-Ketchum, 2019; Komyakova *et al.*, 2022). Connectivity between MPAs may be impaired by offshore energy infrastructure since the potential barriers that species encounter and interact with at sea—such as floating structures, chains, and cables—might be fully permeable to some species (e.g. pelagic fish), could present an obstacle to others (e.g. marine mammals). Furthermore, changes in local or regional winds and currents induced by OWFs (Akhtar *et al.*, 2021) may affect the larval transport of key commercial species (Sabatés *et al.*, 2007; Clavel-Henry *et al.*, 2020), and the ecological connectivity among MPAs (Planes *et al.*, 2009; Christie *et al.*, 2010; Roberts *et al.*, 2021). These as-yet-unknown potential connectivity impacts from offshore wind infrastructure merit future research.

Conservation research has long highlighted the need for ensuring connectivity between protected areas, not only for highly mobile taxa (Magris *et al.*, 2014; Balbar and Metaxas, 2019), but also for sessile or less mobile species (Assis *et al.*, 2021). Maintaining effective connectivity is particularly relevant in offsetting the impacts of climate change and human disturbances (Metaxas, 2019; Virtanen *et al.*, 2020). Well-connected networks of MPAs can reduce and reverse disturbances through the replenishment of the impacted populations from external sources, thus enhancing their resilience and decreasing the risk of local extinctions (Magris *et al.*, 2014). We therefore recommend avoiding any connectivity loss between MPAs as a result of OWF developments, especially given that the existing set of Mediterranean MPAs lacks coherence, connectivity, and representativeness, and little progress has been made towards MPA designation for open and deep-sea areas (IUCN, 2019), where most Mediterranean OWF are being planned (Soukissian *et al.*, 2017; Defingou *et al.*, 2019).

We especially recommend the careful evaluation of the impact of OWF on habitats of the deep continental shelf within or close to Natura 2000 sites and other MPAs. These habitats might constitute biodiversity refugia of high conservation value, and hence their protection should be considered a priority in the Mediterranean, as is being implemented for mesophotic reefs in other oceans (Rocha *et al.*, 2018). The protection of such shelf habitats could compensate for the loss of biodiversity in coastal areas due to, for example, persistent heat waves (Garrabou *et al.*, 2009; 2022). These types of protection measures should be therefore considered nature-based solutions in our fight against the potential effects of climate change in marine ecosystems.

We also recommend scrutinizing any potential effect of OWFs on the functionality of FRAs implemented by the General Fisheries Commission for the Mediterranean and Black Sea (GFCM, 2006) or EU Member States. These geographically defined areas have all or some fishing activities temporarily or permanently banned or restricted in order to improve the conservation and sustainable exploitation of living aquatic resources and the protection of marine ecosystems. Hence, it must be guaranteed that OWFs will not derail the recovery of marine resources for which these areas have been dedicated.

Exclusion of OWFs from MPAs and their vicinity necessarily entails searching for alternative sites where OWF expansion can be effectively reconciled with environmental goals without slowing the deployment of renewable energy. Although at first it would seem that finding these alternative places should be easier in the Mediterranean compared to other European seas (e.g. the North Sea and the Baltic Sea) since the percentage of EU waters covered by Natura 2000 sites in the Mediterranean is approximately half that of the Baltic Sea or a third of the North Sea (EEA, 2023), the narrow continental shelf and steep bathymetry in many parts of the Mediterranean largely constrains its offshore wind energy potential compared to the Baltic and the North Sea (Lloret *et al.*, 2022). When alternative places to install OWFs cannot be found, in every site, managers should analyse the trade-offs between the potential benefits (CO_2 reduction and energy security) and environmental risks linked to the offshore wind energy proposal against the current natural values and benefits (in terms of ecosystem services) provided by MPAs (Kaldellis and Apostolou, 2017). In this regard, it is important to stress the capacity of MPAs to serve as nature-based solutions in mitigating the impacts of climate change. MPAs have the natural potential to remove carbon from the atmosphere and to strengthen the adaptability and resilience of the ocean though the enhancement of genetic diversity, population sizes, and habitat complexity by limiting anthropogenic stressors (reviewed by Roberts *et al.*, 2017). Finally, by helping to mitigate and promote adaptation to climate change, MPAs can protect the many economic and social benefits deriving from marine ecosystems, as well as providing a net increase in environmental and human well-being.

Some studies carried out in northern European Seas have shown that fixed OWF could contribute to the protection and/or restoration of particular species and habitats via (i) an increase in the available substrate for attachment for sessile species (although new artificial substrates may also favour the colonization by opportunistic species such as jellyfish and toxic microalgae, and the arrival of non-indigenous species; Airoldi and Bulleri, 2011; De Mesel *et al.*, 2015) and (ii) the limitation of damaging activities such as bottom trawling based on spatial measures to ensure their functioning (Krone *et al.*, 2013; Vaissière *et al.*, 2014; Hammar *et al.*, 2016; Degraer *et al.*, 2020). However, it should not be taken for granted that offshore wind developments in the Mediterranean Sea could be beneficial for Natura 2000 sites or any other type of MPA. There is no reliable scientific evidence to ascertain that offshore wind developments, and particularly those with floating turbines (which are the most common due to the characteristics of the Mediterranean Sea; Soukissian *et al.*, 2017; Defingou *et al.*, 2019), will contribute positively to the conservation of biodiversity and its associated ecosystem services in the Mediterranean. Therefore, considering floating wind farms as a tool for biodiversity conservation is, as a general rule, unwarranted (this should be proved case by case), and public authorities should continue to enlarge the network of MPAs in the Mediterranean Sea as a way to reach EU's 30% target of European seas being effectively protected by 2030 (European Commission, 2020b).

Finally, when planning the implementation of OWF, the ecosystem approach framework should be undertaken on the appropriate temporal and spatial scale. On the spatial scale, it should be taken at a smaller size than the large maritime demarcations that serve as a reference for maritime spatial planning and marine strategies in countries such as Spain. On the temporal scale, the varying timescales and lag effects that characterize ecosystem processes should be recognized, and objectives for ecosystem management should be set for the long term.

Considerations and recommendations for managers and policy makers relating to Appropriate Assessments (AA)

Despite the recommendations made in the previous section, if public authorities ultimately decide to implement new OWFs inside Natura 2000 sites or inside other MPAs, or in their buffer zones, we propose that the AA, which is mandatory for plans and projects to be carried out in Natura 2000 sites according to Article 6 of the Habitats Directive, must be established separately from the SEA or EIA. Under these circumstances, the challenge is to balance environmental issues and OWF deployments in MPAs in order to rigorously assess the compatibility of each energy project within each site. Measured levels of environmental pressures (on species, habitats, and related ecosystem services) during the AA cannot be influenced in any way by OWF developers. Leaving the AA to be just a part of the EIA of a particular project, means the AA could be flawed. We recommend that the AA is carried out by the competent authorities at the planning or project level with the assistance of external, independent experts from different fields (marine biologists, oceanographers, ornithologists, energy experts, engineers, economists, geographers, and other scientists with expertise in different environmental and social issues). Experts should consider the benefits and risks, and how cost-effective the project or plan is.

If this recommendation is not retained, and the AA is carried out in conjunction with the SEA or EIA, it should be clearly distinguishable from these and generate specific duties for the promoter of a plan or project. In any case, more attention should be paid to Article 6 of the Habitats Directive, which states that any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to an AA of its implications for the site in view of the site's conservation objectives.

Since the type and severity of the effects caused by OWF will depend to a large extent on the species and habitats present in the area, as well as on the size, location, and design of the wind farm development, it is important to carry out the AA specifically for each plan/project on a case-by-case basis. The effects of floating wind turbines on vulnerable species and habitats of the Mediterranean Sea (Lloret *et al.*, 2022) and other seas (Farr *et al.*, 2021) remain poorly known and therefore further studies need to be developed. Cautiousness is particularly required where there is limited information about the true historic baseline conditions in order to assess the impact of OWF on the conservation objectives of Natura 2000 sites.

In addition to assessing the possible impacts that the offshore wind project/plan may have through the different phases (preparation, construction, operation, and decommissioning), as endorsed by the European Commission (European Commission, 2020b), we also recommend that the AA should also consider the impacts of complementary elements such as offshore or onshore electric substations, new port infrastructure, and any future industry components associated with the OWF, for example, onshore or offshore hydrogen plants to produce so-called "green hydrogen". The various components of the hydrogen production system may pose specific risks to the environment. For example, such risks may be linked to water and land use and brine release (i.e. very "heavy" saline water that will rapidly sink to the seabed and form a stratified layer) (GIZ, 2020). The implementation of OWF in different areas and ecosystems can involve a number of territorial land-use changes that can deeply alter the long-term socioeconomic vision of particular territories. We also propose that AA should not only address the direct and indirect impacts on EU-protected habitats (e.g. loss, degradation, and fragmentation of the habitats) and EU-protected species (e.g. disturbance and mortality), but also the effects on other habitats and species that are essential for the integrity of the Natura 2000 site beyond those listed in the Habitats Directive, including vulnerable fish species such as elasmobranchs (sharks and rays), teleosts and invertebrates included in international conventions for the protection of flora and fauna (e.g. Barcelona and Bern Conventions).

If, after the AA, competent authorities finally determine the possibility of installing an OWF inside or close to a Natura 2000 site, then developers must present an EIA, which will ultimately be evaluated by the granting authority. If the authority grants the permit, a regular and detailed monitoring plan to evaluate all ecological processes must be implemented for all stages of the OWF development. In this case, several guidelines should be thoroughly considered and applied by policy makers and private companies: (i) international guideline documents such as the technical recommendations for avoiding or mitigating the environmental impacts of OWF in the Mediterranean Sea (WWF, 2019); (ii) the guidelines for project developers to mitigate biodiversity impacts associated with wind energy development of the IUCN (Bennun *et al.*, 2021); (iii) the recommendations of EASME/EMFF of the European Commission to avoid impacts of OWF on fisheries and aquaculture (Van Hoey *et al.*, 2021), and (iv) the WWF and IMR recommendations for OWF developments (De Jong *et al.*, 2020; WWF, 2021).

Conclusions

In the first instance, our study suggests that offshore wind energy developments in the Mediterranean should be excluded from Natura 2000 sites and other MPAs and their buffer zones. Where this is not possible, we advocate for rigorous and independent AA to be carried out for OWF proposals that could affect MPAs. Further studies aimed at assessing how offshore wind energy development in the Mediterranean can be compatible with the preservation of the Natura 2000 sites and other types of MPAs should be a policy of highest priority. The final goal of these studies should be to balance wind potential and technical requirements with the preservation of natural values and cultural heritage.

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Data availability

Data underlying this article were provided by third parties (BirdLife International and IUCN) by permission (in this case, data can be shared on request to the corresponding author with permission of the third parties), or were derived from public repositories or sources in the public domain (https://www.eea.europa.eu/; https://emodnet.ec.europa.eu/en; http://keybiodiversityareas.org/kba-data/request; http://www.marinemammalhabitat.org/imma-eatlas/; https://www.boe.es/diario_boe/txt.php?id=BOE-A-2023-5704; https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000045381641; https://va.mite.gov.it/it-IT; https://www.guardiacostiera.gov.it/; https://www.mnhn.fr/fr; https://www.miteco.gob.es/).

Conflict of interest

The authors have no conflict of interest to declare.

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