Renewables Grid Initiative

Essential Environmental Concepts for the Offshore Wind Energy Sector in Europe

Discussion Paper

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About RGI:

The Renewables Grid Initiative is a unique collaboration of environmental NGOs and Transmission System Operators from across Europe. We promote transparent, environmentally sensitive grid development to enable the further steady growth of renewable energy and the energy transition.

More information:

www.renewables-grid.eu

About OCEaN:

The Offshore Coalition for Energy and Nature (OCEaN) consists of 26 organisations from across Europe, bringing together NGOs, TSOs and the wind industry. Together they work towards a sustainable development of offshore energy and grid infrastructure, while ensuring alignment with nature protection and healthy marine ecosystems.

More information:

https://offshore-coalition.eu/

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Abbreviations and Acronyms

CBD	Convention on Biological Diversity
CIA	Cumulative impact assessment
EA	Ecosystem approach
EBA	Ecosystem-based approach
EEA	European Environmental Agency
EGD	European Green Deal
ERA	Environmental Risk Assessment
EU	European Union
GES	Good Environmental Status
HELCOM	Baltic Marine Environment Protection Commission
IFC	International Finance Corporation
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
MPA	Marine protected area
MSFD	Marine Strategy Framework Directive
MSP	Maritime spatial planning
NbS	Nature-based solutions
NID	Nature-inclusive design
OCEaN	Offshore Coalition for Energy and Nature
OWE	Offshore wind energy
SAC	Special Area of Conservation
SPA	Special Protection Area
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development

Summary

Offshore wind energy and the associated electricity grid are crucial in the transition to a renewable energy system but place pressures on marine ecosystems that are already being degraded by human activities. To address the complexity of protecting nature while developing energy infrastructure, it is essential that stakeholders have a shared understanding of relevant environmental challenges and solutions, and a common language to describe them. This report reviews the key environmental concepts relevant in guiding the sustainable development of the offshore wind energy sector.

Sixteen concepts were identified by OCEaN members as being relevant for their offshore work:

- Conservation
- Critical habitat
- Ecological opportunity
- Ecological risk
- Ecosystem approach
- Ecosystem restoration
- Ecosystem services
- Good Environmental Status
- Mitigation hierarchy
- Nature-based solutions
- Nature-inclusive design
- Nature positive
- Precautionary principle
- Pressures and impacts
- Seascapes approach
- Sustainability.

This paper defines each concept, explains why it is relevant to the offshore wind energy sector and summarises key issues, flagging the inter-linkages between them.

Some trends were identified in the concepts that require action.

- Common definitions need to be developed for each concept in the offshore wind energy context and the inter-linkages between concepts needs to be more thoroughly mapped and described.
- Most concepts were developed on land and some are newer than others, so many will require more testing, especially nature-inclusive design and nature positive.
- More research and data collection are required for several concepts, especially cumulative impacts, ecological risk, ecosystem restoration, good environmental status, and nature positive.
- How different stakeholders view and use different concepts within national Exclusive Economic Zones will vary, but finding ways of extending the use of concepts to the high seas would be beneficial.
- The most cross cutting concepts were conservation (with 14 links to other concepts), pressures and impacts (12), sustainability (12), ecosystem restoration (10) and the ecosystem approach (8), suggesting these key concepts should be a priority for further elaboration and harmonisation across the sector.

In conclusion, all 16 key concepts should be considered to some degree in maritime spatial planning going forward. Important next steps include harmonising definitions and terminology, and providing examples of the key concepts in action in the offshore wind energy sector. The best way forward might be to identify and produce a series of case studies highlighting how different concepts have led to improved sustainability and reduced environmental impacts in offshore wind farms.

1. Introduction

1.1 Background

Tackling the climate crisis requires a rapid development of renewable energy capacity. Offshore wind energy (OWE) and the associated electricity grid development play a crucial role in the transition to a renewable energy system (European Commission, 2020a). At the same time, development of offshore renewable energy infrastructure places additional pressures on marine ecosystems already being degraded by humans (IPBES, 2019; Korpinen et al., 2020). In light of this, the European Green Deal (EGD) has, on the one hand, set a binding target for achieving climate neutrality by 2050, with an intermediate target to cut emissions by at least 55% by 2030. On the other hand, the EGD has put in place a Biodiversity Strategy for 2030, aiming for long-term planning to protect nature and reverse biodiversity loss. Therefore, future offshore wind energy developments and its supportive grid should be aligned with European nature conservation and restoration targets, ensuring healthy ecosystems and the prevention of biodiversity loss.

The connection between climate change and biodiversity loss is increasingly recognised. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change stated that “biodiversity loss and climate change are both driven by human economic activities and mutually reinforce each other. Neither will be successfully resolved unless both are tackled together” (Pörtner et al., 2021). Addressing both crises simultaneously is crucial and it is at the heart of the efforts of the Offshore Coalition for Energy and Nature (OCEaN). OCEaN’s members, consisting of non-governmental organisations, wind industry and transmission system operators, aim to support a comprehensive, sustainable and collaborative planning approach for offshore wind energy infrastructure development.

1.2 Aim of the Paper

To address the complexity of protecting nature while developing energy infrastructure, it is essential that stakeholders have a shared understanding of the relevant environmental challenges and solutions, and a common language to describe them. This report therefore aims to identify and review the key concepts relevant to the offshore wind energy sector that can guide its sustainable development. Throughout the report, reference to offshore wind energy includes associated grid infrastructure.

We take the approach of Lindenmayer and Hunter (2010) by looking at concepts “that can help guide the discipline and… can be readily communicated to policy makers and managers”. However, we broaden the term to refer not only to “abstract ideas” (the definition in the Oxford English Dictionary) but also approaches and tools. The paper is a collaborative effort by members of OCEaN to describe how essential environmental concepts are understood and applied in the marine environment. To harmonise this work, an external expert was commissioned to review and edit the final version of the paper.

2. Review of Relevant Environmental Concepts

The concepts presented in this paper were selected by OCEaN's members as being relevant for their offshore work. Table 1 summarises why each concept is relevant to the OWE sector and provides a definition. The following sections then summarise key issues, citing relevant references, explain their relevance to OWE and flag the inter-linkages between them. This is not a comprehensive review of each concept, but rather a summary of key points, challenges, issues and linkages.

Table 1. List of concepts reviewed, with a definition and a summary of why each one is relevant to the offshore wind energy sector. For additional definitions of biodiversity-related words or terms, see UNEP-WCMC (2022).

Concept	Definition	Relevance to Offshore Wind Energy Sector
Conservation	*The protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence* (IUCN, 2021).	There are several European regional and national strategies and directives relating to the conservation of marine ecosystems that impact the choice of site and the operations of offshore wind farms, most notably the EU Biodiversity Strategy, the EU Habitats Directive, and the regional seas action plans (e.g., HELCOM, OSPAR). Similarly, species-specific conservation plans of relevance exist for bats, cetaceans and waterbirds.
Critical habitat	*Areas of high biodiversity conservation significance based on the existence of a habitat of significant importance to critically endangered or endangered species, endemic and/or range-restricted species, highly threatened and/or unique ecosystems and key evolutionary processes, as well as globally significant concentrations of migratory and/or congregatory species* (IFC, 2012).	All development on natural habitats involves some habitat loss. There are some parts of the marine biome that are more important for biodiversity than others, and the concept of critical habitats offers a framework against which to decide on those areas which need to be given the highest consideration during planning.
Ecological opportunity	*The availability of ecologically accessible resources that may be evolutionarily exploited* (Stroud & Losos, 2016).	Placing infrastructure in the marine environment provides new substrata that, whilst potentially posing an ecological risk, can also be an ecological opportunity. The level of ecological opportunity helps to determine the extent to which offshore wind farms and their grids are attractive for species to colonise, and to what extent this affects community composition, from native species to alien invasives.
Ecological risk	*The probability of the occurrence of an undesired ecological event* (Suter, 2016).	Constructing and operating offshore wind farms and grids will have some degree of environmental impact; ecological risk helps to frame the likelihood and extent to which this impact will occur.

Ecosystem (or ecosystem-based) approach	*An ecosystem approach is “a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way”* (CBD SBSTTA, 2000). *The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the goods and services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors*” (European Commission, 2020b).	Offshore wind energy will impact more than just a few species but will affect the entire marine ecosystem. The ecosystem[-based] approach provides a framework to gauge the effects and plan the necessary mitigation and conservation actions.
Ecosystem restoration	*The process of managing or assisting the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity* (CBD, 2016).	Ecosystem restoration will be a key approach in OWE developments where threatened habitats may have been disturbed or lost, or where stakeholders want to rehabilitate decommissioned sites or provide additional opportunities to attain net gain or nature- positive.
Ecosystem services	*Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services, such as recreational, spiritual, religious and other non-material benefits* (BBOP, 2012).	Maintaining a healthy marine environment is not only important for species and their habitats but also the ecosystem services on which humans depend. Therefore, consideration of ecosystem services will ensure the impacts of offshore wind energy on humans as well as nature are assessed and mitigated.
Good Environmental Status	Good Environmental Status is the status of the environment that EU Member States aspire to attain by applying an ecosystem-based approach in their marine waters (EU, 2008).	GES is the main concept used by the EU in maritime spatial planning and on delivering the MSFD and other directives. GES also specifically addresses seabed status and noise pressures, directly related to OWE.
Mitigation hierarchy	*The sequence of actions to anticipate and avoid and, where avoidance is not possible, minimise and, when impacts occur, restore and, where significant residual impacts remain, offset for biodiversity-related risks and impacts on affected communities and the environment* (Stephenson & Carbone, 2021)	The mitigation hierarchy can help with the planning of OWE developments by providing a framework to determine what type of mitigation is most appropriate, what sort of biodiversity goal is most appropriate (i.e., no net loss or et gain) and how avoidance and environmentally-friendly siting decisions can be taken.
Nature-based solutions	*Nature-based Solutions (NbS) are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits* (Cohen-Shacham et al., 2016).	Since NbS are designed to protect, manage, restore ecosystems and tackle climate change, they represent a potentially useful approach for maritime spatial planning in the context of OWE.
Nature-inclusive design	*Nature-inclusive design (NID) refers to options that can be integrated in, or added to, the design of an anthropogenic structure with the aim to enhance ecological functioning* (Hermans et al., 2020).	While NID was mainly conceived as an approach used for living shorelines or restoration of tidal wetlands and salt marshes, in recent years these principles have also started to address offshore wind infrastructure to increase habitat suitability of structures for native species.
Nature positive	*Nature-positive means halting and reversing nature loss by 2030, measured from a baseline of 2020* (Locke et al., 2021).	This concept is gaining in momentum and encourages all actors, including those in the OWE sector, to move towards net gain goals and targets, rather than no net loss.

Precautionary principle (or approach)	*Pertains to risk management and states that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is not harmful, the burden of proof that it is not harmful falls on those taking an action. The principle is used to justify discretionary decisions when the possibility of harm from making a certain decision (e.g., taking a particular course of action) is not, or has not been, established through extensive scientific knowledge. The principle implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk or if a potential plausible risk has been identified* (IPBES, 2018).	The precautionary principle is an integral part of the EU's Maritime Spatial Planning Directive and therefore of direct relevance to offshore wind energy in Europe.
Pressures, impacts and cumulative impacts	*Pressures:* *Natural and anthropogenic threats that influence biodiversity and ecosystem processes* (Stephenson & Carbone, 2021). *Impacts:* *Impact: The effects an organisation or company has on the economy, the environment, or society, which in turn can indicate its contribution (positive or negative) to sustainable development* (Stephenson & Carbone, 2021). *Cumulative impacts:* *Total impacts resulting from the successive, incremental, and/or combined effects of a project when added to other existing, planned and/or reasonably anticipated future projects, as well as background pressures* (IFC, 2012).	Consideration of pressures, impacts and cumulative impacts is an essential and integral part of maritime spatial planning and marine spatial prioritisation and a vital consideration in the planning of sustainable OWE.
Seascapes approach	*The seascape approach aims at building coalitions among government, the private sector, and civil society to harmonise sustainable use and protection of oceans and coasts. It highlights the importance of achieving governance across sectors and at all levels, from local to regional* (Atkinson et al. 2011).	With growing concern about the cumulative impacts of large offshore wind farms, especially those that are contiguous, it is vital to bring government, private sector, and civil society stakeholders together to harmonise OWE developments in the context of broader maritime spatial planning. For that reason, the seascape approach is very pertinent.
Sustainability	*Sustainability is "a characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs"* (Millennium Ecosystem Assessment, 2005).	Sustainability is a concept at the core of all renewable energy; furthermore, OWE development and operations need to ensure they do not threaten the sustainability of the natural marine ecosystems they are located in.

2.1 Conservation

The International Union for Conservation of Nature (IUCN) defines conservation as "the protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence" (IUCN, 2021). Conservation implies a particular way of managing natural resources which keeps the natural structure and function of ecosystems intact and prevents unsustainable human impacts (Probert, 2017).

While the early history of conservation mainly reflected an attempt to conserve nature for economic reasons and for exploitation by humans (Grove, 1992), a shift in perception has taken place over time to place more emphasis on the conservation of ecosystems for the benefit of people as well as nature. Global conservation was markedly shaped by the Rio Summit in 1992 and the subsequent adoption of the Convention on Biological Diversity (CBD) with its main objective "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources" (Mackenzie & Jenkins, 2001). Notably, the Convention puts a strong focus on marine resources and emphasises the conservation of ecosystems rather than species per se.

Further goals for the protection and conservation of the marine environment were later defined in 2002 at the World Summit on Sustainable Development, where the idea of an ecosystem approach to sustainable development of the oceans was introduced. This led to commitments to establish networks of marine protected area under the overarching goal of reducing biodiversity loss (United Nations, 2002).

At the European level, the Biodiversity Strategy 2030 (European Commission, 2020a) sets conservation targets aimed at halting biodiversity losses, including goals to protect at least 30% of European seas, of which 10% should be strictly protected. Additionally, it aims to "effectively manage all protected areas by 2030, defining clear conservation objectives and measures, and monitoring them appropriately" (European Commission, 2020a). Further EU nature restoration targets are planned for degraded ecosystems, "in particular, those with the most potential to capture and store carbon and prevent and reduce the impact of natural disasters" (European Commission, 2020a).

Other international conventions also influence habitats and species that need to be conserved (see Soria-Rodríguez, 2021, for a review and key references). At the Europe-wide and regional level these include species identified in the EU Birds and Habitats Directives and species identified by the Convention on Migratory Species and its associated agreements on small cetaceans (ASCOBANS: Agreement on the Conservation of Small Cetaceans in the Baltic, North-East Atlantic, Irish and North Seas), seals (WSSA: Agreement on the Conservation of Seals in the Wadden Sea), bats (EUROBATS: Agreement on the Conservation of Populations of European Bats) and waterbirds (AEWA: Agreement on the Conservation of African–Eurasian Migratory Waterbirds), as well as wetland sites of international importance identified by the Ramsar Convention. The regional seas commissions (e.g., HELCOM, OSPAR) have also identified priority taxa for conservation.

Marine Protected Areas (MPA) are considered a key tool for conserving marine ecosystems and halting biodiversity loss (Probert, 2017; Day et al., 2019). Ecosystems protected through the establishment of MPAs may have greater capacity to withstand external stressors, recover more rapidly from disturbances and maintain initial populations also outside of a MPA (Probert, 2017). An MPA is a "clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Day et al., 2019). IUCN defines six management categories for protected areas (Table 2), with categories I and II ensuring strict protection, and categories III to VI allowing different levels of human access and use.

Table 2. IUCN protected area categories (Dudley, 2008).

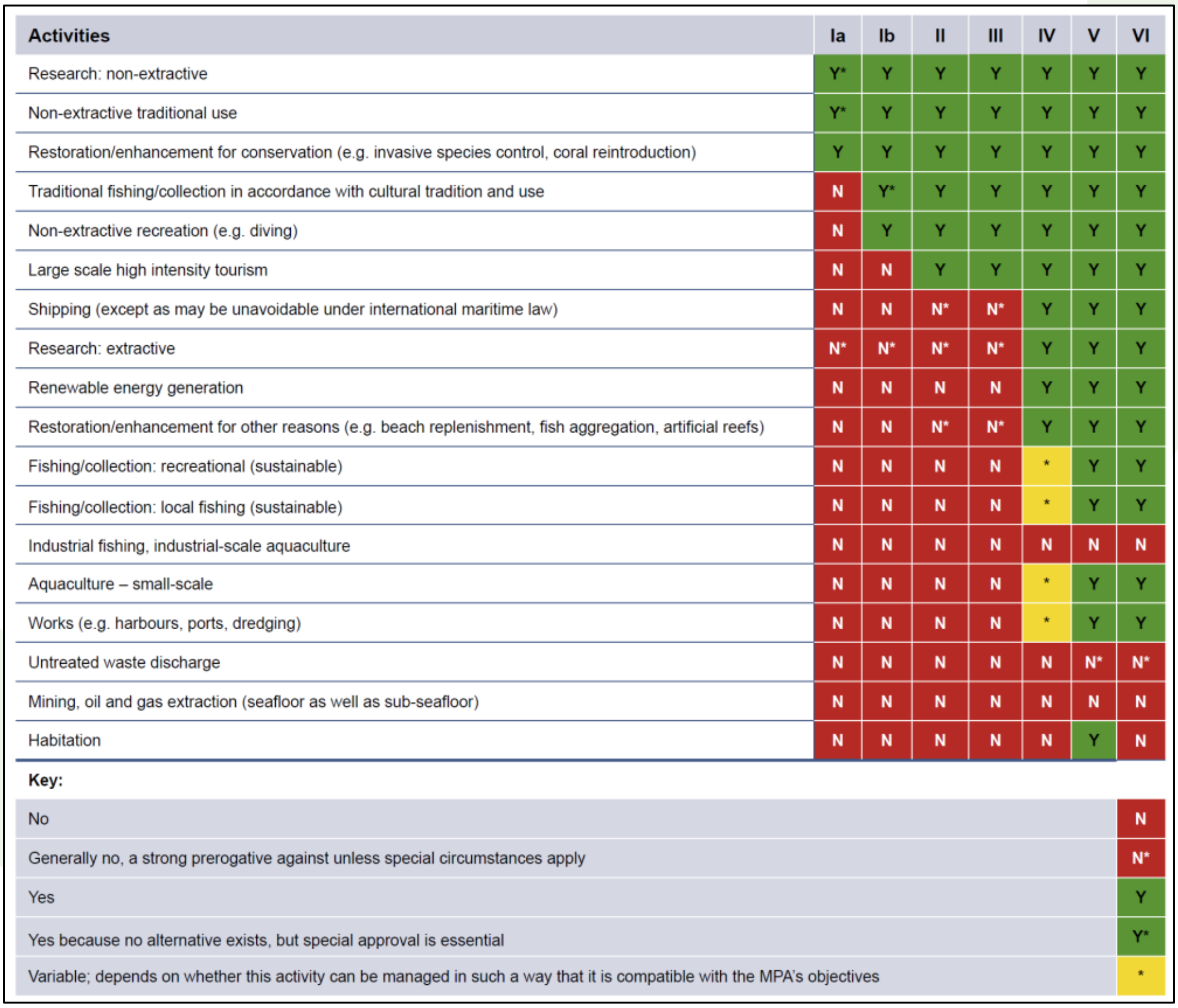
Category	Definition
Ia Strict Nature Reserve	Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphic features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Ib Wilderness Area	Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
II National Park	Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.
III Natural Monument or Feature	Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
IV Habitat/Species Management Area	Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
V Protected Landscape/ Seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value; and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected area with sustainable use of natural resources	Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

MPAs can exist in national jurisdiction within Exclusive Economic Zones or as part of different networks across different territories. Depending on the IUCN category, MPAs allow different levels of access and use (although it is noted that, like all protected areas, MPAs do not necessarily provide the full protection from exploitation as foreseen in legislation; White & Courtney, 2004). Table 3 demonstrates the types of activity allowed in each category of MPA, with renewable energy not considered an appropriate activity in the four categories with the strictest protection (Ia, Ib, II, III). In Europe, MPAs may become part of the Natura 2000 network of protected areas, including Special Protection Areas (SPAs) under the Birds Directive and Special Areas of Conservation (SACs) under the Habitats Directive (see European Commission, 2007). An SPA or an SCA may be in any one of the IUCN protected area categories.

Issues around critical habitat and offshore wind energy

While construction and operation of offshore wind energy may pose some threats to certain species and habitats and work against conservation goals, the exclusion of human activities – especially fishing – from many wind farms or submarine power cables can lead to positive impacts on biodiversity through a "reserve effect" or "fisheries reserve effect" (Bergstrom et al., 2013; Hammar et al., 2016). Offshore wind energy farms can also provide marine organisms with hard substrate, creating an artificial reef effect that enhances habitats, although, attracting invasive species remains a risk (Langhamer, 2012). It has been suggested that, in some cases, "wind farms may even be more efficient means of conservation than ordinary marine protected areas" (Hammar et al., 2016). In the future, the conservation benefits of offshore wind farms may also be linked to the environmental objectives on the sustainable use and protection of water and marine resources and the protection and restoration of biodiversity and ecosystems under the EU taxonomy for sustainable activities (European Commission, 2022).

Table 3. Matrix of marine activities that may be appropriate for each IUCN management category (Day et al., 2019).



Activities	Ia	Ib	II	III	IV	V	VI
Research: non-extractive	Y*	Y	Y	Y	Y	Y	Y
Non-extractive traditional use	Y*	Y	Y	Y	Y	Y	Y
Restoration/enhancement for conservation (e.g. invasive species control, coral reintroduction)	Y	Y	Y	Y	Y	Y	Y
Traditional fishing/collection in accordance with cultural tradition and use	N	Y*	Y	Y	Y	Y	Y
Non-extractive recreation (e.g. diving)	N	Y	Y	Y	Y	Y	Y
Large scale high intensity tourism	N	N	Y	Y	Y	Y	Y
Shipping (except as may be unavoidable under international maritime law)	N	N	N*	N*	Y	Y	Y
Research: extractive	N*	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons (e.g. beach replenishment, fish aggregation, artificial reefs)	N	N	N*	N*	Y	Y	Y
Fishing/collection: recreational (sustainable)	N	N	N	N	*	Y	Y
Fishing/collection: local fishing (sustainable)	N	N	N	N	*	Y	Y
Industrial fishing, industrial-scale aquaculture	N	N	N	N	N	N	N
Aquaculture – small-scale	N	N	N	N	*	Y	Y
Works (e.g. harbours, ports, dredging)	N	N	N	N	*	Y	Y
Untreated waste discharge	N	N	N	N	N	N*	N*
Mining, oil and gas extraction (seafloor as well as sub-seafloor)	N	N	N	N	N	N	N
Habitation	N	N	N	N	N	Y	N

Key:

No	N
Generally no, a strong prerogative against unless special circumstances apply	N*
Yes	Y
Yes because no alternative exists, but special approval is essential	Y*
Variable; depends on whether this activity can be managed in such a way that it is compatible with the MPA's objectives	*

Links to other concepts:

- All of the other key concepts described here are linked in some way to defining or managing biodiversity conservation priorities in and around OWE developments, influencing the placement of new offshore wind farms and determining which pressures to mitigate or offset.

2.2 Critical Habitat

Critical habitats are defined as “areas of high biodiversity conservation significance based on the existence of habitat of significant importance to critically endangered or endangered species, endemic and/or range-restricted species, highly threatened and/or unique ecosystems and key evolutionary processes, as well as globally significant concentrations of migratory and/or congregatory species” (IFC, 2012).

The International Finance Corporation (IFC) is a member of the World Bank Group and provides investment services to promote development in emerging economies. Within IFC’s Sustainability Framework are a number of Performance Standards on Environmental and Social Sustainability which are an integral part of IFC’s approach to risk management. IFC Performance Standard 6 (IFC, 2012) defines the responsibilities of IFC’s clients towards biodiversity and recognises that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development. Habitat is defined in the Standard as “a terrestrial, freshwater, or marine geographical unit or airway that supports assemblages of living organisms and their interactions with the non-living environment”. For the purposes of implementation of this standard, habitats are divided into modified, natural, and critical. Critical habitats are a subset of modified or natural habitats. Activities must be avoided in critical habitats and the company’s actions must lead to a net gain in such habitats. The World Bank Environmental and Social Standard 6 (World Bank, 2017) also requires an assessment of critical habitat to determine the biodiversity importance of an area (e.g., threatened and restricted-range species and ecosystems, protected areas) in comparison to their global distributions or population sizes. Many biodiversity screening tools and standards further reinforce the need to identify critical habitats (e.g., Natural Capital Coalition, 2016; TBC, 2017).

Issues around critical habitats and offshore wind energy

If the offshore wind energy sector is to follow business best practices, such as applying IFC and World Bank standards, then it is important to consider critical habitats. Furthermore, the concept provides a useful framework against which to identify those areas where risk must be assessed as a matter of priority and any potential impacts mitigated. In the marine context, critical habitats relevant to offshore wind would usually include those with high biodiversity and a relatively high abundance and diversity of threatened species (e.g., coral reefs, mangroves, seagrass beds), those habitats that sequester large amounts of blue carbon as well as cetacean migration corridors and seabird flyways.

Links to other concepts:

- conservation – critical habitats are one of the highest priorities for conservation.
- mitigation hierarchy – net gain needs to focus on critical habitats.
- pressures and impacts – on critical habitat are some of the priorities for marine spatial planning.

- sustainability – is a specific goal of the IFC performance standards that promote identification of critical habitats.

2.3 Ecological Opportunity

The term ecological opportunity describes the processes that can produce a diverse group of species from a single colonising ancestor. Even though the term ecological opportunity has a long history, there is currently no widely accepted definition and the term is used with a variety of descriptions and frameworks and a lot of ambiguity (Wellborn & Langerhans, 2015).

Definitions include:

- "The availability of ecologically accessible resources that may be evolutionarily exploited" (Stroud & Losos, 2016);
- "A prospective, lineage-specific characteristic of an environment that contains both niche availability, allowing a population to persist in the environment, and niche discordance, causing diversifying selection within the lineage" (Wellborn & Lagerhans, 2015).

Ecological opportunities are governed by interactions between resources, competitors, predators, mutualists, and the full array of biotic and abiotic community (Wellborn & Langerhans, 2015).

Ecological opportunity arises from two fundamental elements:

- Niche availability: the ability of a population with a phenotype previously absent from a community to persist within that community.
- Niche discordance: the diversifying selection generated by the adaptive mismatch between a population's niche-related traits and the newly encountered ecological conditions (Wellborn & Langerhans, 2015).

Literature on the topic of ecological opportunity raises the question of whether human-induced environmental perturbations can increase ecological opportunity and contribute to widespread ecological diversification (Wellborn & Langerhans, 2015).

Issues around ecological opportunity and offshore wind energy

Placing infrastructure in the marine environment provides new substrata that can have an impact on the ecological opportunity for species and habitats, depending on the infrastructure's composition, construction type and post-life plans, such as decommissioning. For example, the underwater structure and foundation of an offshore wind farm can act as an artificial reef if constructed in an appropriate way (Lacroix & Pioch, 2011). The level of ecological opportunity therefore helps to determine the extent to which offshore wind farms and their grids are attractive for species to colonise and to what extent this affects community composition, from native species to alien invasives.

Links to other concepts:

- conservation – high ecological opportunity in and around areas of conservation importance will help attain conservation goals.
- ecosystem restoration – high ecological opportunity will help facilitate restoration of certain species and habitats.

- nature-inclusive design – some NIDs aim to increase ecological opportunity.
- pressures and impacts – high ecological opportunity will help mitigate pressures and impacts.

2.4 Ecological Risk

Ecological risk "refers to the probability of the occurrence of an undesired ecological event" (Suter, 2019). Ecological risks are factors that can have a negative influence on ecosystems. They can therefore be described as the likelihood and magnitude of adverse effects from stressors to ecological receptors, or as the potentially reduced ability of providing ecosystem services. Ecological risk is a complex phenomenon, which can be quantitatively described through selected measurable indicators (Baumann, 2001).

The term is most often used in the context of Ecological Risk Assessments (ERAs) which are used to characterise uncertainty and impacts associated with one or more pressures (Holsman et al., 2017). The use of ERAs has been highly recommended for environmental decision-making and can be considered "a critical link between identifying indicators, quantifying reference levels, and evaluating potential management strategies" (Levin et al., 2014). ERA is the process used for evaluating how likely it is that the environment might be impacted as a result of exposure to one or more environmental stressors (Maltby et al., 2018). The most commonly used ecological risk framework is the US EPA framework (US EPA, 1992) which consists of planning, problem formulation, analysis, risk characterisation, and risk management.

Issues around ecological risk and offshore wind energy

Constructing and operating offshore wind farms and grids will have some degree of environmental impact; ecological risk (perhaps measured through a suitable EPA process) helps to frame the likelihood and extent to which this impact will occur.

Links to other concepts:

- conservation – high ecological risk will jeopardise conservation action.
- pressures, impacts and effects – ecological risk is a direct assessment of the probability of pressures and impacts occurring.

2.5 Ecosystem (or ecosystem-based) approach

An ecosystem is a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (IUCNM, 2021). In 2000, parties to the Convention on Biological Diversity adopted as their primary framework for action the "ecosystem approach" (EA) and defined it as "a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way" (CBD SBSTTA, 2000). Since then the term has become more widespread and is often linked with various initiatives relating to understanding or managing natural resources (Waylen et al., 2014). The twelve Malawi Principles encourage decision-making that takes into account how ecosystem processes will be affected over space and time and were entrenched in the CBD (CBD SBSTTA, 2000). Other organisations such as the EU have talked more of an "ecosystem-based approach" and "ecosystem-based management", using a similar definition to the one used by the CBD for EA.

From an ocean perspective[1], the EA has been applied to various policies, including fisheries, management of marine areas, and integrated coastal management and, as the approach considers the marine space as an integrated system, it also includes marine protection (WWF, 2020). As explained by IPBES (2018), "the key binding legal instrument in the European Union aimed at formalising an ecosystem-based approach to marine environmental management is the European Union Marine Strategy Framework Directive…" which "specifically requires regional and transboundary cooperation" (EU, 2008). The application of the EBA is therefore a key requirement of maritime spatial planning (MSP) as described in the 2014 European Maritime Spatial Planning Directive (EU, 2014). The United Nations, the Organisation for Economic Co-operation and Development, and the Baltic Marine Environment Protection Commission (HELCOM) have also all dedicated special efforts to engage and further operationalise the EBA. The ecosystem approach is now a central principle in European fisheries management (IPBES, 2018).

Issues around ecosystem(-based) approach and offshore wind energy

Offshore wind energy will affect the entire marine ecosystem and impact more than just a few species; the ecosystem[-based] approach provides a framework against which to gauge the effects more holistically and plan the necessary mitigation and conservation actions. The EA also holds the potential to make the energy transition compatible with marine biodiversity conservation objectives, and to help identify synergies between maritime sectors. However, a review of twelve European MSP case studies showed that several key features of the EA were rarely included, "such as the standardisation of pressures from human activities, the integration of frameworks to assess ecosystem services, and the implementation of precautionary and adaptive management approaches" (Domínguez-Tejo et al., 2016). This highlights the fact that discussions continue on definitions and implementation of the ecosystem(-based) approach and how it relates to ecosystem services (UNEP, 2011; Waylen et al., 2014; Domínguez-Tejo et al., 2016).

There has also been a call for more effort to be made to address three main types of sticking points that prevent implementation: (1) institutional, arising from previous ways of working; (2) cognitive, arising from ways of framing and knowing; and (3) political, arising from pre-existing power relations (Waylen et al., 2015).

Links to other concepts:

- conservation – is an integral part of the EA.
- ecosystem services – some people advocate an ecosystem services-based approach similar to ecosystem(-based) approach; The goal of EA is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the goods and services humans want and need (European Commission, 2020b) and so has direct links to ecosystem services.
- ecosystem restoration – will help operationalise the EA.
- Good Environmental Status – in the MSFD, the EBA is mentioned explicitly as a means to attain GES.
- nature-based solutions - the NbS framework emerged from the ecosystem approach.
- precautionary principle – the EU specifically links the two: "Programmes of measures and subsequent action by Member States should be based on an ecosystem-based approach to the management of human activities and on… the precautionary principle" (EU, 2008).
- pressures and impacts – the ecosystem(-based) approach considers the cumulative impacts of different sectors (European Commission, 2020b).
- seascape approach – the large multi-dimensional scale of the EA means it is applicable across

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[1] Ecosystem-based management and ecosystem-based integrated ocean management (sensu UNEP, 2011 and Lieberknecht, 2020) are acknowledged as being the same or similar to the ecosystem approach (UNEP, 2011).

ocean basins and seascapes.

- sustainability – is a key goal for the EA.

2.6 Ecosystem restoration

Restoration of the species, habitats or ecosystems that are lost or disturbed by development is one of the four options in the mitigation hierarchy. In this context, restoration refers to “measures taken to repair degradation or damage to specific biodiversity features and ecosystem services of concern (which might be species, ecosystems/habitats or particular ecosystem services) following project impacts that cannot be completely avoided and/or minimised” (Ekstrom et al., 2015).

There are many forms and definitions of restoration, with the two main ones being:

- ecosystem restoration – “the process of managing or assisting the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity” (CBD, 2016), which frames “ecological restoration in the context of biodiversity and resilience” (Mansourian, 2018); and
- ecological restoration – “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (McDonald et al., 2016).

Given the United Nations is leading a UN Decade on Ecosystem Restoration “to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean” (UNEP, 2022), and given that we have identified the ecosystem(-based) approach as a key concept for OWE, we consider “ecosystem restoration” as the key concept, although it is inherently linked to (and often a synonym for) ecological restoration.

Issues around ecosystem restoration and offshore wind energy

The rapid degradation of marine ecosystems, combined with often low natural recovery rates, means restoration efforts need to be increased for degraded marine areas (Bayraktarov et al., 2016). Ecosystem restoration is a key approach in OWE developments where threatened habitats may have been disturbed or lost, or where stakeholders want to rehabilitate decommissioned sites or provide additional opportunities to attain net gain or nature positive. As OWE expands, restoration efforts will need to be scaled up.

However, ecosystem restoration is complex. Sheaves et al. (2021) note that “precise, well considered and accountable decision-making is needed to determine the specific focus for restoration, the scale of restoration, the location for deploying restoration activities, and indeed whether or not restoration is necessary or even possible”. Abelson et al. (2016) “recommend using existing management frameworks to identify clear restoration targets, to apply quantitative tools for assessment, and to make the re-establishment of ecosystem services a criterion for success”. Marine restoration is still relatively new and lessons need to be learned from experience restoring terrestrial ecosystems (Quigley et al., 2022). “Defining and predicting ecological success in marine ecosystem restoration projects is a consistent challenge” (Eger et al., 2022). However, what we do know of marine restoration suggests that success depends “primarily on the ecosystem, site selection, and techniques applied” (Bayraktarov et al., 2016). Restoration efforts also vary between habitat types, with coral reefs and seagrass among the most expensive marine ecosystems to restore (Bayraktarov et al., 2016). Conservation is usually a more efficient and cost-effective strategy than restoration so preventing biodiversity loss is better than trying to restore it later.

Links to other concepts:

- conservation – as well as assisting in the recovery of ecosystems that have been degraded or destroyed, ecosystem restoration entails conserving the ecosystems that are still intact (see UNEP, 2022).
- ecosystem(-based) approach – will include restoration in its operationalisation.
- ecological opportunity – if high will help facilitate restoration of certain species and habitats.
- ecosystem services – will be restored through ecosystem restoration.
- Good Environmental Status – attaining GES will support ecosystem restoration goals especially for the seafloor.
- mitigation hierarchy – restoration is one of the four mitigation options.
- nature-based solutions – some restoration efforts can be seen as NbS.
- nature positive – restoration will be a key approach for delivering nature positive.
- pressures and impacts – will be mitigated or offset by ecosystem restoration.
- seascapes approach – ecosystem restoration will more likely be successful at scale through a seascapes approach.
- sustainability – can be at least partly attained through ecosystem restoration.

2.7 Ecosystem services

Ecosystem services are the benefits people obtain from ecosystems. These services include: provisioning services such as food and water, regulating services such as the regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services, such as recreational, spiritual, religious and other non-material benefits (BBOP, 2012). Increasingly ecosystem services are seen through the lens of "nature's contributions to people" (IPBES, 2018). If natural capital is the stock of assets, ecosystem services are the flows of benefits derived from those assets (Daily et al., 2011).

Marine ecosystems "provide a constellation of services: they produce food, receive and assimilate wastes, protect shorelines from storms, regulate the climate and atmosphere, generate tourism income, and provide recreational opportunities" (Palumbi et al., 2009), and key goods produced include fish harvests, wild plant and animal resources, and abstracted water (Barbier, 2017). Theoretical frameworks for the assessment of marine goods and services have been tested (e.g., Beaumont et al., 2007).

Issues around ecosystem services and offshore wind energy

Maintaining a healthy marine environment is not only important for species and their habitats but also the ecosystem services on which humans depend. Assessing ecosystem services "has the capacity to play a fundamental role in the ecosystem approach, by enabling the pressures and demands of society, the economy and the environment to be integrated into environmental management" (Beaumont et al., 2007). Therefore, consideration of ecosystem services will ensure the impacts of offshore wind energy on humans as well as nature is assessed and mitigated.

Links to other concepts:

- conservation – marine conservation includes species, habitats and ecosystem services (see Stephenson & Carbone, 2021).
- ecosystem(-based) approach – assessing ecosystem services can help implement ecosystem (-based) approaches and some people advocate for an ecosystem services-based approach similar to ecosystem(-based) approach.
- ecosystem restoration – will often include or contribute to ecosystem services.
- mitigation hierarchy – ecosystem services are considered in applying the mitigation hierarchy.
- nature-based solutions – will benefit ecosystem services.
- nature positive – ecosystem services are considered part of nature in nature positive.
- seascape approach – the broader scale of the seascape approach means it ensures conservation of ecosystem services as well as species and habitats.

2.8 Good Environmental Status

In response to the human pressures and impacts on marine ecosystems, the European Union drafted the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) in 2008 as part of its Integrated Maritime Policy. The aim of the MSFD is to create a "holistic policy to protect the marine environment of Member States while enabling the sustainable use of marine goods and services" (EU, 2008). Through the MSFD, EU Member States were required to design and establish strategies to achieve or maintain Good Environmental Status (GES) of the EU's marine waters (EU, 2008).

GES is the status of the environment that EU Member States aspire to attain by applying an ecosystem-based approach in their marine waters. "By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration" (EU, 2008). Good environmental status is not defined in detail; rather, Member States are encouraged to determine a set of characteristics that defines GES for their marine waters. However, a set of eleven qualitative descriptors for determining GES are provided (EU, 2008). All descriptors are based on biodiversity and ecosystem functioning (Fraschetti et al., 2019). The EU maritime spatial planning framework went on to adopt the use of GES as well (EU, 2014). Through MSP, EU Member States should activate responses if the GES is not achieved (Inglesias-Campos et al., 2021).

To help decision makers understand the importance of GES, the EU Commission amended the MSFD in 2017 and introduced new criteria and methodological standards relating to marine ecosystem functions, detailing when GES is achieved and how it can be achieved (European Commission, 2017). The guidance proposes that each country determines threshold values for GES criteria: "Member States should express the extent to which Good Environmental Status is being achieved as the proportion of their marine waters over which the threshold values have been achieved or as the proportion of criteria elements (species, contaminants, etc.) that have achieved the threshold values" (European Commission, 2017).

A report on the implementation of the MSFD by the European Environmental Agency (EEA, 2020) concluded that the targets of the Directive were not achieved and the impacts of contaminants, eutrophication, invasive alien species, commercial fishing and marine litter are some of the key reasons why GES could not be achieved. Another review highlighted legislative challenges with attaining GES across the EU (Boyes et al., 2016).

Issues around Good Environmental Status and offshore wind energy

Of the eleven qualitative descriptors for determining GES (EU, 2008), two are relevant to OWE. Descriptor 6 states that “sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected” (EU, 2008). The MSFD task group looking at this descriptor noted that “Good Environmental Status of the sea floor requires that diversity and productivity are maintained and the uses do not cause serious adverse impacts to the natural ecosystem structure and functioning in both space and time” (Rice et al., 2010). However, the same group noted that “serious problems of sampling and measurement and high scientific uncertainty about aspects of benthic ecology and tolerances of benthic ecosystems to perturbations pose challenges to application of good environmental status”.

Descriptor 11 states that the “introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment” (EU, 2008)[2]. MSFD Task Group 11 identified three types of underwater noise of relevance: low and mid-frequency impulsive sound; high frequency impulsive sounds; and low frequency continuous sound (Tasker et al., 2010). They also developed indicators to measure the three types, but noted that it is difficult to define when an organism’s behaviour is not “good”.

Links to other concepts:

- conservation – attaining GES will support conservation goals especially for seabed communities.
- ecosystem(-based) approach – in the MSFD, EBA is mentioned explicitly as a means to attain GES.
- ecosystem restoration – attaining GES will support ecosystem restoration goals especially for seabed communities.
- precautionary principle – the EU explicitly states that the precautionary principle needs to be used in maritime spatial planning.
- pressures and impacts – GES can only be achieved if pressures and impacts are identified and addressed in MSP.
- sustainability – is an explicit aim of the MSFD that calls for attainment of GES (see above).

2.9 Mitigation Hierarchy

The mitigation hierarchy is a tool to help limit, as far as possible, the negative impacts of development projects on biodiversity and ecosystem services (Mitchell, 1997; BBOP, 2012; Arlidge et al., 2018; Figure 1). It involves a sequence of four key actions (avoid, minimise, restore and offset) and provides a best practice approach to aid in the sustainable management of living natural resources by establishing a mechanism to balance conservation needs with development priorities (Ekstrom et al., 2015). The model is also the foundational concept for key frameworks that companies can draw on to monitor, govern, and control their biodiversity footprint, namely the Natural Capital Protocol and the Science-Based Targets for Nature initiative (Natural Capital Coalition, 2016; Science-Based Targets Network, 2020). The mitigation hierarchy helps companies set goals for no net loss or net gain (Figure 1).

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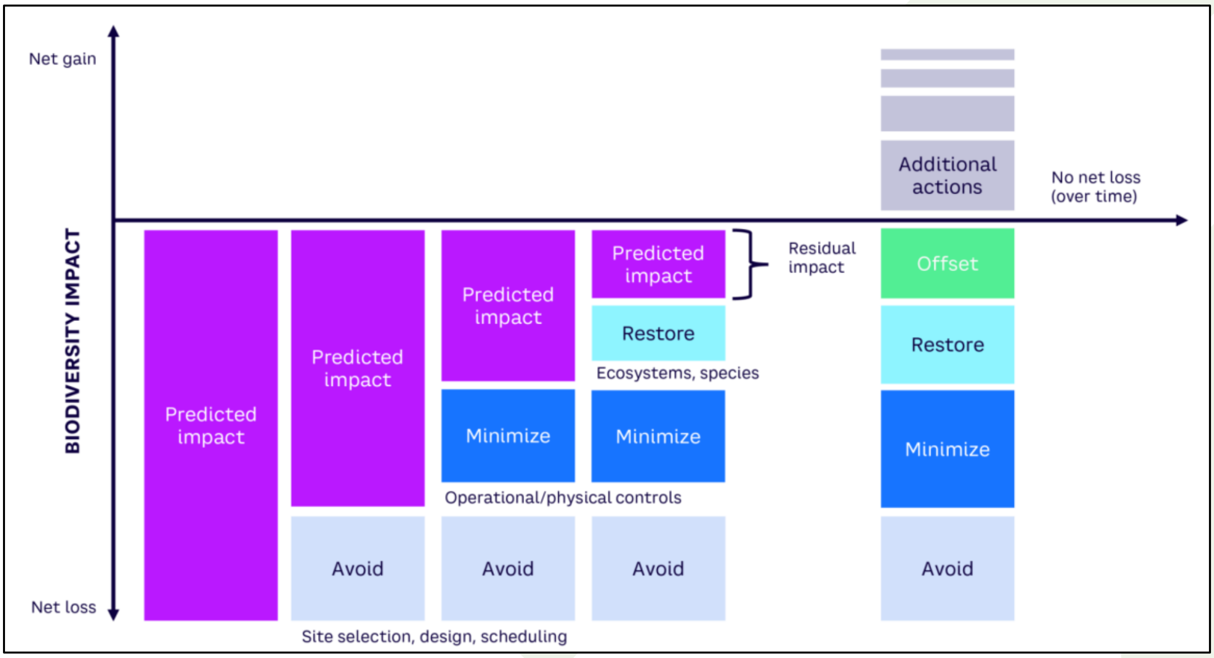
[2] Noise is defined by the Task Group 11 as “anthropogenic sound that has the potential to cause negative impacts on the marine environment” (Tasker et al. 2010).

Figure 1. A summary of the mitigation hierarchy. From Stephenson & Walls (2022).



Although the mitigation hierarchy has been used most commonly on land, there is increasing discussion of its use in marine ecosystems (e.g., Jacob et al., 2016; Milner-Gulland et al., 2018; Hooper et al., 2021).

Issues around the mitigation hierarchy and offshore wind energy

The mitigation hierarchy can help with the planning of OWE developments by providing a framework against which to determine what type of mitigation is most appropriate and what sort of biodiversity goal is most appropriate (i.e., no net loss or net gain). Marine offsets pose some challenges (see Ekstrom et al., 2015) but could be considered in some rare cases. Bennun et al. (2021) propose a range of mitigation approaches in line with the mitigation hierarchy that are relevant to offshore wind energy at the design, construction, operation and end-of-life phases. Restoration will also be key in some offshore wind farms close to important natural habitats, and may also be applied in some countries as part of decommissioning.

Links to other concepts:

- conservation – priorities are identified as part of the mitigation hierarchy.
- critical habitat – is relevant for deciding on how to address different steps in the mitigation hierarchy.
- ecosystem services – are considered in applying the mitigation hierarchy.
- ecosystem restoration – is directly related to one of the four steps in the mitigation hierarchy.
- precautionary principle – can be used to predict the gains expected from avoidance, minimisation, restoration and offsets (Ekstrom et al., 2015).
- pressures and impacts – assessing biodiversity impact, and addressing the pressures that cause it, is central to using the mitigation hierarchy.
- sustainability – of business operations is the main aim of the mitigation hierarchy.

2.10 Nature-based solutions (NbS)

“Nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016).

As summarised by Cohen-Shacham et al (2018), NbS are being adopted widely at least partly because “the concept of nature providing solutions is simple in construct and logical for non-specialist understanding”. This has encouraged its uptake in policy, practice and by the private sector (Nesshöver et al., 2017), and facilitates opportunities to bring together diverse sectors and stakeholders (Van Ham & Klimmek, 2017).

While there was some concern about the risk of NbS remaining a vague term without operational rigour (Cohen-Shacham et al., 2018), this has largely been addressed by IUCN which produced both a standard for NbS (IUCN 2020a) and guidelines on applying the standard (IUCN, 2020b). Nonetheless, “the interpretation and implementation of the NbS concept is very context specific, depending on a variety of factors influencing the societal challenges being addressed, including the ecosystem types in the landscape/seascape in which the NbS is being implemented, the socioeconomic-cultural system and the composition and relations of stakeholder groups” (IUCN, 2020b).

Nesshöver et al (2017) reviewed NbS in the European context and noted that “a central challenge for an umbrella concept like NbS… is where to draw the line as to what is considered as ‘nature’ or ‘natural’”. They concluded that NbS “should be perceived as an opportunity, but also as a challenge since a good understanding of ecosystem processes is needed, a diversity of actors must be engaged, and a broad set of societal facts/issues needs to be included and integrated”.

Issues around nature-based solutions and offshore wind energy

Since NbS are designed to protect, manage and restore ecosystems they represent a potentially useful approach for maritime spatial planning in the context of OWE. Examples of marine NbS include climate change risk mitigation initiatives such as beach nourishment and reef and mangrove revivals (IUCN, 2020a). For OWE, an example is that “the creation of reef substrate on offshore wind farm foundations can enhance biodiversity whilst reducing the negative effects of scouring” (Bennun et al., 2021). NbS promote the provision of a full range of ecosystem services or are complementary to other actions, such as a mixture of sea walls and mangroves protecting a coastline from ocean surge (Cohen-Shacham et al., 2018).

Links to other concepts:

- conservation – NbS can contribute to conservation goals.
- ecosystem(-based) approach – the NbS framework emerged from the ecosystem approach.
- ecological opportunity – some NbS aim to increase ecological opportunity.
- ecosystem restoration – some restoration efforts can be seen as NbS.
- ecosystem services – will benefit from application of NbS and ecosystem services concepts can be an excellent way to consider solutions during NbS design and appraisal (Nesshöver et al., 2017).
- nature-inclusive design – is essentially a type of NbS.
- pressures and impacts – NbS will help address biodiversity pressures and impacts.
- sustainability – is a central concept in the definition of NbS.

2.11 Nature-inclusive Design

Nature-inclusive design (NID) refers to options that can be integrated in, or added to, the design of an anthropogenic structure with the aim to enhance[3] ecological functioning (Hermans et al., 2020). NID arose from ecological engineering (Mitsch, 2012) and aims to develop anthropogenic structures in ways that reduce risks and increase ecological opportunities by, for example, increasing complexity of a habitat to increase biodiversity and/or species diversity. In the context of OWE development, nature-inclusive designs refer to nature-inclusive construction, in which the design and construction of wind farms include the potential to enhance biodiversity and natural resources.

Issues around nature-inclusive design and offshore wind energy

While NID was mainly conceived as an approach used for living shorelines or restoration of tidal wetlands and salt marshes, in recent years these principles have also started to address offshore infrastructure to increase habitat suitability of structures for native species (Perkol-Finkel et al., 2017; Sella et al., 2021). As summarised by Hermans et al (2020), there are now several options available for NID in the context of OWE which can be part of, but not limited to, a wind turbine (foundation), an offshore substation, a scour protection layer, or a cable protection measure (Hermans et al., 2020).

Opportunities for NID around offshore wind farms (Steins et al., 2021) include:

- Catalysts for nature recovery (e.g.: monopiles form hard substrates for settlement of sea life; design scour protection and pipeline constructions can increase biodiversity; artificial reefs can be established as they are safe from bottom-trawling)
- Shelters for marine life (e.g.: resting platforms for seals; crevices for use by crustaceans)
- Physical borders (e.g., construction of offshore wind farms around nature conservation areas, to form a physical border)
- Multi-uses with food production (e.g., seafood production, potentially in combination with underwater habitat restoration).

Some technical and ecological challenges have been identified with the approach, especially relating to the risk of structural failure, biofouling or the settlement of alien invasive species (Hemans et al., 2020). The differences between NID and restoration are sometimes confused in discussions around Maritime Spatial Planning. While NID is about improving the composition of human structures added to marine nature, enhancing its environment beyond the intended function for human needs (e.g., energy production), restoration is about recovering damaged natural ecosystems and so, by definition, is not NID.

Links to other concepts:

- ecological opportunity – NID essentially increases ecological opportunity for native organisms around OWE infrastructure.
- nature-based solutions – NID is essentially a type of NbS.
- sustainability – is a central concept in NID, especially when the NID is an NbS.

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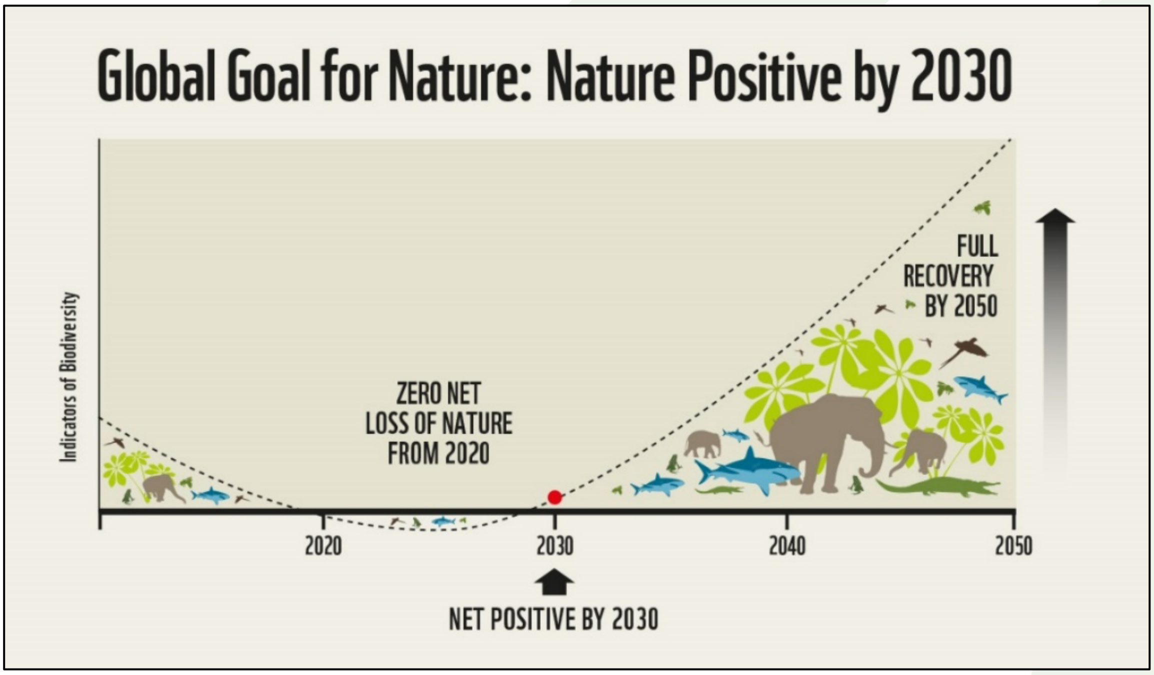
[3] Enhance in this context refers to deliberate attempts to ensure the success of a wider range of direct and indirect positive outcomes to biodiversity or the biophysical environment (João et al, 2011).

2.12 Nature Positive

The World Business Council for Sustainable Development (WBCSD) notes that “there is increasing recognition that protection and sustainable production approaches to avoid and minimise loss are not enough to reverse nature loss. It is necessary to go beyond ‘less bad’ and no net loss and aim for a nature-positive economy as part of a nature-positive world” (WBCSD, 2021).

Figure 2. A graphical representation of a global goal for nature positive. From Nature Positive (2022), derived from Locke et al. (2021).



The term “nature positive” has therefore emerged as “a rallying term, a beacon, to guide and to transform action across all sectors of society, including business” (WBCSD, 2021). A number of conservation and business organisations have proposed a global goal for nature which is based around the world’s governments and businesses committing to becoming nature positive by 2030 (Locke et al., 2021; Nature Positive, 2022; Figure 2). The aim is for zero net loss of nature from 2020, net positive by 2030, and full recovery by 2050.

Issues around nature positive and offshore wind energy

The nature positive concept is gaining momentum and encourages all actors, including those in the OWE sector, to move towards net gain ambitions, rather than no net loss, to help attain the overall global nature positive. WBCSD (2021) notes that “businesses should consider both the living (i.e., biodiversity) and non-living elements that are potentially relevant within all realms of nature (land, freshwater and oceans)”, which emphasises the importance of oceans as well as their biodiversity. The degree to which European countries in general, and the OWE sector in particular, decide to aim collectively for net gain rather than no net loss will influence the extent to which nature positive is embraced.

Links to other concepts:

- conservation – will be a key approach for delivering nature positive.
- ecosystem services – are considered part of nature in nature positive.

- ecosystem restoration – will be a key approach for delivering nature positive.
- mitigation hierarchy – nature positive means aiming for net gain when applying the mitigation hierarchy.
- pressures and impacts – will need to be reduced significantly if nature positive is to be attained.
- sustainability – is a central concept in nature positive and nature positive goals aim to enhance sustainability.

2.13 Precautionary principle (or approach)

The CBD Strategic Plan for Biodiversity 2011-2020 explicitly states that, in order to deliver global biodiversity targets, decision-making needs to be based on sound science and the precautionary approach (CBD, 2010). IPBES (2018) explains that the precautionary principle “pertains to risk management and states that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is not harmful, the burden of proof that it is not harmful falls on those taking an action”.

The precautionary principle is used to justify discretionary decisions when the possibility of harm from making a certain decision (e.g., taking a particular course of action) is not, or has not been, established through extensive scientific knowledge. The principle implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk or if a potential plausible risk has been identified (IPBES, 2018). The principle has four central components: taking preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision-making (Kriebel et al., 2001). In a broader context, precautionary approaches can help manage the fast-changing, multiple, systemic challenges the world faces (EEA, 2013).

Application of the precautionary approach or principle is central to ecosystem management and species management, especially in the marine context (EU, 2008; Thompson et al., 2000; Cooney & Dickson, 2012; Lieberknecht, 2020).

Issues around the precautionary principle and offshore wind energy

The EU Marine Strategy Framework Directive states that measures to maintain Good Environment Status “should be devised on the basis of the precautionary principle and the principles that preventive action should be taken, that environmental damage should, as a priority, be rectified at source and that the polluter should pay” (EU, 2008). Therefore, all European MSP will need to use this approach. The lack of understanding of many OWE pressures (e.g., electromagnetic fields) and of cumulative impacts on broader ecosystems (see Stephenson, 2021) makes application of the precautionary principle even more important for OWE. At the same time, the sooner the full impacts and cumulative impacts of OWE can be understood, the more decisions can be taken based on data, reducing reliance on the precautionary principle.

Links to other concepts

- conservation – a precautionary approach is explicitly encouraged by the CBD to attain global biodiversity goals.
- ecosystem(-based) approach – the EU specifically links the two: “Programmes of measures and subsequent action by Member States should be based on an ecosystem-based approach to the management of human activities and on… the precautionary principle” (EU, 2008).

- Good Environmental Status – the EU explicitly states that the precautionary principle needs to be used in maritime spatial planning.
- mitigation hierarchy – a precautionary approach can be used to predict the gains expected from avoidance, minimisation, restoration and offsets (Ekstrom et al., 2015).
- pressures and impacts – the lack of understanding of many OWE pressures and cumulative impacts makes application of the precautionary principle even more important for OWE; more knowledge of pressures and impacts and their causes would reduce the need for its use.
- sustainability – may be jeopardised if the precautionary principle is not applied.

2.14 Pressures, impacts and cumulative impacts

About 93% of Europe's marine area is under multiple pressures from human activities and "the combined effect of multiple pressures on marine species and habitats reduces the overall resilience of marine ecosystems" (EEA, 2019). Pressures and impacts on the environment of different activities therefore need to be understood for planning purposes. However, there is some confusion over terminology.

The EU Environmental Impact Assessment Directive (EU, 1985) talks of environmental effects of projects, a term not applied by the conservation or development community. The Directive specifies that pressures such as pollution lead to environmental effects and so, in this context, the term "effect" is being used as a synonym for "impact" as understood by conservationists. In other literature, the term impact is used to mean pressure and effect is again used as a synonym for impact (e.g., IEMA, 2012; Brady et al., 2013).

Therefore, to maintain consistency and avoid confusion, here we use the IUCN definitions (Stephenson & Carbone, 2021):

- Pressures[4]. – Natural and anthropogenic threats that influence biodiversity and ecosystem processes.
- Impacts – The effects a company has on the environment which in turn can indicate its contribution (positive or negative) to sustainable development.

This is consistent with the press-state-response-benefit model employed by the United Nations for the global biodiversity targets and Sustainable Development Goals (see Stephenson & Carbone, 2021).

Another key concept, especially for OWE, is cumulative impact. IUCN (Bennun et al., 2021) use the IFC definition:

- Cumulative impact – Total impacts resulting from the successive, incremental, and/or combined effects of a project when added to other existing, planned and/or reasonably anticipated future projects, as well as background pressures (IFC, 2012).

The EU sees cumulative impacts as "effects on the environment caused by the combined action of past, current and future activities" (European Commission, 2020b).

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[4] Note that pressures are also sometimes know as threats, and indirect threats can be referred to as drivers.

Issues around pressures, impacts and offshore wind energy

The construction, operation and decommissioning of OWE and associated grid infrastructure causes a range of pressures on biodiversity which in turn lead to impacts on species, habitats and ecosystems (Stephenson, 2021). Consideration of pressures, impacts and cumulative impacts is therefore an essential and integral part of maritime spatial planning and a vital consideration in the planning of sustainable OWE. Bennun et al. (2021; Fig. 3) provide a detailed breakdown and identify fourteen key environmental impacts of OWE. So far, most research has focused on the impacts of OWE on the abundance of species, pollution and biodiversity behaviour and migration (Kulkarni & Edwards, 2022).

Figure 3. Potential impacts on biodiversity and the associated ecosystem services due to fixed-bottom offshore wind developments. From Bennun et al. (2021).

1. Bird and bat collision with, a) wind turbines and b) onshore transmission lines
2. Seabed habitat loss, degradation and transformation
3. Hydrodynamic change
4. Habitat creation
5. Trophic cascades
6. Barrier effects or displacement effects due to presence of wind farm
7. Bird mortality through electrocution on associated onshore distribution lines
8. Mortality, injury and behavioural effects associated with vessels
9. Mortality, injury and behavioural effects associated with underwater noise
10. Behavioural effects associated with electromagnetic fields of subsea cables
11. Pollution (e.g. dust, light, solid/liquid waste)
12. Indirect impacts offsite due to increased economic activity and displaced activities, such as fishing
13. Associated ecosystem service impacts
14. Introduction of invasive alien species

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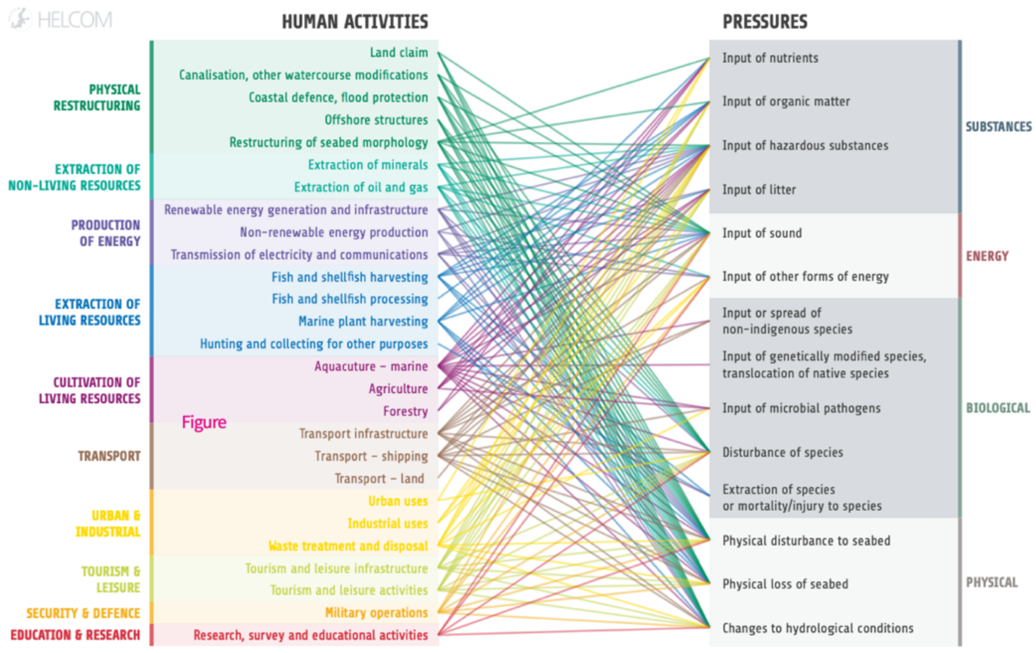
Figure 4. Links between human activities and marine pressures (HELCOM, 2018). Multiple pressures will lead to cumulative impacts.



Offshore wind turbines are usually clustered in wind farms and, if wind farms are placed close together, they can lead to cumulative impacts on biodiversity within and beyond the area covered by turbines , multiplying effects as well as compounding other anthropogenic pressures such as shipping and oil and gas exploitation (King et al., 2015; Nogues et al., 2021; Fig. 4).

Cumulative Impact Assessment (CIA) was originally developed to provide an overview of the human imprint on ocean ecosystems (Hammar et al., 2020). The assessment of the cumulative effects from human activities at sea and on land is a requirement of the MSFD. Maritime spatial planning has the potential to lower net cumulative environmental impact, both locally and across sea basins, “as long as prevailing pressures derive from activities that are part of MSP” (Hammar et al., 2020). The knowledge derived by CIA assessments is needed to build a solid base for managing human activities and achieving the MSFD’s Good Environmental Status. In spite of some methods being developed for CIA (Nabe-Nielsen et al 2018; Bergstrom et al., 2019; Hammar et al., 2020; Brignon et al., 2022) more studies are needed to better understand cumulative impacts. More sharing of biodiversity data between OWE developers and between the broader European marine community would also enhance cumulative impact assessments and monitoring (Stephenson, 2021).

Links to other concepts:
Work to assess, mitigate and monitor pressures, impacts and cumulative impacts is essential for all elements of maritime spatial planning, including for OWE. It therefore links closely to most other concepts, especially:

- conservation – can only be achieved by addressing pressures and impacts.
- critical habitat – pressures and impacts on critical habitat are some of the priorities for MSP.
- ecological opportunity – will help mitigate pressures and impacts.
- ecological risk – is a direct assessment of the probability of pressures and impacts occurring.
- ecosystem(-based) approach – considers the cumulative impacts of different sectors.
- ecosystem restoration – pressures and impacts will be mitigated or offset by ecosystem restoration.
- Good Environmental Status – can only be achieved if pressures and impacts are identified and addressed in MSP.
- mitigation hierarchy – assessing biodiversity impact, and addressing the pressures that cause it, is central to using the mitigation hierarchy.
- nature-based solutions – NbS will help address biodiversity pressures and impacts.
- nature positive – pressures and impacts will need to be reduced significantly if nature positive is to be attained.
- precautionary principle – the lack of understanding of many OWE pressures and cumulative impacts makes application of the precautionary principle even more important for OWE; more knowledge of pressures and impacts and their causes would reduce the need for its use.
- seascape approach – pressures and impacts, an in particular cumulative impacts, will more likely be attained with a seascape approach.
- sustainability – understanding pressures and impacts is key to ensuring the sustainability of OWE.

2.15 Seascapes approach

A seascape is a spatially heterogeneous area of coastal environment that can be perceived as a mosaic of patches, a spatial gradient, or some other geometric patterning (IPBES, 2018). The tropical coastal seascape often includes a patchwork of mangroves, seagrass beds, and coral reefs that produces a variety of natural resources and ecosystem services (IPBES, 2018).

The seascape approach (Atkinson et al., 2011) aims at building coalitions among government, the private sector, and civil society to harmonise sustainable use and protection of oceans and coasts. It highlights the importance of achieving governance across sectors and at all levels, from local to regional, and "aims to show improvement in critical habitat restoration, threatened species recovery, and social/cultural and economic human well-being" (Murphy et al., 2021). The approach also encourages multi-use management at the seascape scale, and multiple management tools are typically used across the seascape, including MPAs, other effective area-based conservation measures, fisheries and species management areas, and locally managed marine areas (Murphy et al., 2021). Note that one IUCN protected area category (V) particularly targets seascapes (see section 2.1). IPBES considers proactively using instruments such as seascape-scale participatory scenarios and spatial planning, including transboundary conservation planning, as key to biodiversity conservation and considers promoting sustainable governance and management of seascapes, oceans and marine systems one of the main approaches to use (IPBES, 2019).

Sustainable delivery of ecosystem services requires the maintenance of genetic diversity, species diversity, and the diversity of ecosystems and landscapes and seascapes (IPBES, 2018). Therefore, the seascape approach is closely aligned with conservation of ecosystem services.

Issues around seascapes and offshore wind energy

With growing concern about the cumulative impacts of large offshore wind farms, especially those that are contiguous, it is vital to bring government, private sector, and civil society stakeholders together to harmonise OWE developments in the context of broader maritime spatial planning. For that reason, the seascape approach is very pertinent. The growing discipline of seascape ecology (Pittman, 2017; Pittman et al., 2021) should help provide the science and knowledge to further develop and apply the approach.

Links to other concepts:
- conservation – will more likely be successful at scale through a seascapes approach.
- ecosystem(-based) approach – the seascape approach, like the EA, is based at a large scale but the emphasis in seascape approach is more on the governance and coalition-building aspects.
- ecosystem restoration – will more likely be successful at scale through a seascapes approach.
- ecosystem services – the broader scale of the seascape approach means it ensures conservation of ecosystem services as well as species and habitats.
- pressures and impacts – and, in particular, cumulative impacts, will more likely be attained with a seascapes approach.
- sustainability – is a key goal for the seascapes approach.

2.16 Sustainability

Sustainability is "a characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs" (Millennium Ecosystem Assessment, 2005). Sustainability is often associated with the concept of sustainable development or sustainable management of natural resources, where use of those resources is not depleted in the long-term as a result of human exploitation or use. The CBD (1992) defines sustainable use as "the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations".

Sustainability is enshrined in many directives and strategies of the EU. For example, the aim of the MSFD is to create a “holistic policy to protect the marine environment of Member States while enabling the sustainable use of marine goods and services” (EU, 2008). “By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status in the Community’s marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration” (EU, 2008).

The European Commission (2020b) also states: “The Maritime Spatial Planning Directive aims to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. Spatial planning approaches should adopt an ecosystem-based approach with Member State’s spatial plans contributing to the sustainable development of the energy sector at sea, maritime transport, fisheries and aquaculture, and the preservation, protection and improvement of the environment”.

As shown in previous sections, many other key environmental concepts are also firmly grounded in the concept of sustainability. For example, “nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016).

Issues around sustainability and offshore wind energy

Sustainability in the context of the OWE sector can be interpreted in two ways. Firstly, OWE is a renewable energy so, by definition, is sustainable in that it can be used without reducing the energy available to others (unlike oil and gas, for example, which cannot be replenished). Secondly, OWE development and operations need to ensure they do not threaten the sustainability of the natural marine ecosystems they are located in. The main challenge with the concept is the difficulty of knowing precisely at what point and at what scale OWE development could become unsustainable, which is linked to the challenge in measuring cumulative impacts.

Links to other concepts:

- conservation – is one of the main approaches to attain sustainability.
- critical habitat – sustainability is a specific goal of the IFC performance standards that promote identification of critical habitats.
- ecosystem approach – can be attained through sustainability.
- ecosystem restoration – is one of the main approaches to attain sustainability.
- good environmental status – is part of the MSFD that that has an explicit aim of attaining sustainability.
- mitigation hierarchy – helps ensure the sustainability of business operations.
- nature-based solutions – include sustainability as a key concept.
- nature-inclusive design – includes sustainability as a central concept.
- nature positive – includes sustainability as a central concept and nature positive goals aim to enhance sustainability.
- precautionary principle – helps ensure sustainability is not jeopardised by development.
- pressures and impacts – need to be understood to ensure the sustainability of OWE.
- seascapes approach – can be attained through sustainability.

2.17 Additional concepts considered

In addition to the concepts summarised above, a number of other concepts were discussed and reviewed. Although some of these concepts may have some relevance to offshore wind energy in some circumstances, they were not felt to be as relevant as the key ones.

These additional concepts were not elaborated on for various reasons, but mostly because they were either not seen as among the most relevant or else they were covered by other concepts reviewed. These other concepts included:

- **Ecological carrying capacity** (e.g., of an ecosystem). The term carrying capacity "remains vague and elusive… and environmental heterogeneity restrains its measurement and application" (del Monte-Luna et al., 2004). While ecological carrying capacity has been proposed in some European contexts for developments such as coastal tourism (European Commission, 2007), the concept is more theoretical than practical and is not proposed by the EU or other bodies for maritime spatial planning, especially in the context of OWE, The number of wind turbines an ocean can tolerate before the ecosystem is damaged irreparably is the sort of questions better addressed using key concepts such as cumulative impacts and the ecosystem-based approach.
- **Marine restoration ecology** is covered by ecosystem restoration.
- **Natural capital** is essentially another term for biodiversity which is already an integral part of all the key concepts.
- **No net loss and net gain** are important concepts across corporate sectors, but are covered by the key concepts of mitigation hierarchy and nature positive.
- The concepts of **vulnerability, sensitivity, and adaptability** (or adaptive capacity) are interrelated and have wide applications in global change science (Smit & Wandel, 2006); however, they are mostly associated with climate change (Paul, 2013) and less relevant to the pressures and impacts posed to marine ecosystems by OWE.

3. Trends and looking ahead

The environmental concepts presented in this paper are characterised by the fact that they are frequently seen as part of the debate on the environmentally sustainable development of oceans and coasts and are all relevant to offshore wind energy.

Some trends were identified across the concepts that will require action if the concepts are to be applied.

Unclear definitions. For many concepts there is no single agreed definition applied by all users. This confusion is not uncommon in concepts and approaches around sustainability; for example, Kirchherr et al. (2017) found at least 114 definitions of the concept of circular economy. Significantly varying definitions and approaches, however, increase confusion and add to the difficulty in applying the concepts, and may even lead to the eventual collapse of the concepts. Therefore, common definitions need to be developed for each concept in the OWE context and the inter-linkages between concepts more thoroughly mapped and described.

Development on land. Most concepts were developed and tested in terrestrial ecosystems, and many are still relatively new in marine ecosystem management. This means there is still scope for testing and improving the concepts and their definitions, and for providing more examples, pilot projects and case studies that help demonstrate and communicate their relevance and applicability to policymakers. Some concepts have only been developed recently and will require more testing, especially nature-inclusive design and nature positive.

Data and knowledge gaps. We still require more data on applying many of the concepts in the marine context in general and the OWE sector in particular. More research is required for several concepts and, in many cases, improved monitoring of their application, especially cumulative impacts, ecological risk. ecosystem restoration, good environmental status, and nature positive (see Stephenson, 2021, for more detail on OWE data needs).

Relevance beyond national boundaries. How different stakeholders view and use different concepts within national Exclusive Economic Zones will vary. However, finding ways of extending the use of key concepts to the high seas would be beneficial.

Table 4. Summary of linkages between key concepts.

Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Conservation	■	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
2 Critical habitat	√	■							√					√		√
3 Ecological opportunity	√		■			√					√			√		
4 Ecological risk	√			■										√		
5 Ecosystem approach	√				■	√	√	√		√			√	√	√	√
6 Ecosystem restoration	√		√		√	■	√	√	√	√		√		√	√	√
7 Ecosystem services	√				√	√	■		√	√		√			√	
8 Good Environmental Status	√				√	√		■					√	√		√
9 Mitigation hierarchy	√	√				√	√		■			√	√	√		√
10 Nature-based solutions	√				√	√	√			■	√			√		√
11 Nature-inclusive design	√		√							√	■					√
12 Nature positive	√					√	√		√			■		√		√
13 Precautionary principle	√				√			√	√				■	√		√
14 Pressures and impacts	√	√	√	√	√	√		√	√	√		√	√	■	√	√
15 Seascapes approach	√				√	√	√							√	■	√
16 Sustainability	√	√			√	√		√	√	√	√	√	√	√	√	■

Cross linkages. All of the key concepts reviewed had direct links and relationships with several other key concepts (Table 4). Those concepts most cross cutting were conservation (with 14 links to other concepts), pressures and impacts (12), sustainability (12), ecosystem restoration (10) and the ecosystem approach (8). Although this is a preliminary review, it suggests these key concepts should be a priority for further elaboration and harmonisation for the OWE sector.

Many concepts are already an integral part of, or a consideration in, maritime spatial planning and all 16 key concepts should be considered to some degree in MSP going forward. However, as explained above, in some cases that will mean seeking clarity on definitions and proper testing in the marine biome.

In conclusion, important next steps in widening discussions and applying key environmental concepts to the OWE sector include harmonising definitions and terminology (priorities including pressures and impacts), and providing more OWE-specific examples of the key concepts in action. The best way forward might be to identify and produce a series of case studies highlighting how different concepts have led to improved sustainability and reduced environmental impacts in offshore wind farms. While lessons should be shared from across Europe, examples should also be found in other regions using OWE.

If the 16 key concepts identified here could be developed and tested more thoroughly and consistently, many have the potential to provide a strong basis for more holistic approaches to ocean basin management and offshore wind energy development in the future.

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