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Towards a strategy for offshore installations to enhance the environmental status of coastal seas: Multi-use concepts for ecosystem restoration

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ABSTRACT

In European coastal and shelf seas, concurrent and sometimes conflicting economic and conservation needs call for innovative spatial management approaches that take account of new use concepts. In highly degraded environments, large areas contemplated for offshore wind farm (OWF) development could be actively used for different ecosystem enhancement concepts such as habitat restoration or the establishment of artificial reefs as part of conventional scour protection systems. Simultaneously, different uses, such as extractive aquaculture or other offshore renewable energy could be located within OWFs to more efficiently use limited marine space while also maximizing the benefit of a site. However, to date the environmental and spatial enhancement potential of such multi-use approaches is rarely considered in OWF planning and development. One concern is that stronger focus on such enhancement approaches could lead to reduced efforts in other urgent nature protection needs such as Marine Protected Areas (MPAs). We argue that co-designed by knowledgeable stakeholders, and effectively implemented, appropriate forms of multi-use concepts could help with impact reduction of OWF areas and the improvement of the already floundering ecosystem status of coastal and shelf seas, all while maintaining urgently needed conservation schemes.

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1. Introduction

Coastal and shelf seas are subject to ever-increasing pressures, with climate change effects, biodiversity loss and aquatic pollution representing primary concerns. Productive shelf seas are essential for the provision of natural resources important to humans, such as food, raw materials, and energy. Balancing political and socio-economic interests while simultaneously striving to strictly protect and conserve, as well as restore and enhance marine ecosystems, is proving to be a formidable yet crucial societal challenge. In the past, all too often solutions have been sought in isolation by individual disciplines, frequently led by the technical sciences [25]. This does not do justice to the complexity of coastal and shelf sea socio-ecological systems which highlight different economic interests and stakeholder interactions, as well as the vulnerability and adaptive capacity of such systems [30].

Coastal zone management and maritime spatial planning (MSP) are widely used in governing coastal and shelf seas. They can be understood as vehicles for negotiating differing interests and values, resulting in decisions that represent diverse views, for example with regard to protection and use [33,41–43]. In European coastal regions, a future strategy for sustainable development is outlined in the European Green Deal [12,39]. However, implementing European guidelines remains challenging with conflicting sectoral policies and competing stakeholder interests on national and trans-national scales. A successful blue sustainability requires innovative approaches to planning and management that are centered around transdisciplinary cross-sectoral dialogues and aim to mitigate and adapt to climate change while simultaneously increasing marine biodiversity.

The rapid and large-scale development of offshore renewable energy (ORE) has become a major challenge for the marine environment and for coastal societies in Europe and globally [14,31,32]. The EU aspires to achieving climate neutrality by 2050 [15] and the deployment and sustainable operation of offshore wind farms (OWFs) is seen as key to achieving this. Politically, the importance of ORE has been further reinforced by the strategic need for energy independence in the wake of the Ukraine war. The Ostend Declaration [38] considers the North Sea the “green power plant of Europe” and sets a target of at least 300 GW of offshore wind capacity to be developed by 2050. The Marienborg Declaration [34] mirrors this for the Baltic Sea, foreseeing a capacity of 93 GW. Thus, large areas in the North Sea and Baltic Sea have been assigned for the installation of offshore wind farms (OWFs) [3,22]. Wave energy [21], tidal energy [26] as well as offshore floating solar power [20] are additional technologies currently being researched, developed and optimized by the engineering sector.

At the same time, nature conservation and biodiversity enhancement have become global priority, although they do not always sit comfortably with blue economic plans, even if they too are aimed at meeting environmental goals. The adoption of the Kunming-Montreal Global Biodiversity Framework [28] culminated in the EU Biodiversity Strategy 2030 which is supported by diverse European environmental directives and policies [13]. EU member states are obligated to evaluate the environmental state of their marine waters and enact measures to attain Good Environmental Status (GES) [11]. Recent assessments indicate that member states still fall short of realizing this objective [37]. Indeed, the poor overall status of European coastal seas with respect to eutrophication, pollution, noise emissions, and stability as per the Marine Strategy Framework Directive (MSFD) and the Habitat and Bird Directives, urgently calls for additional management actions and a revision of existing ones [2].

Coastal and shelf seas are the habitat of, and provide crucial food resources for key species such as seals, birds, and numerous fish species. The North Sea and Baltic Sea have long been subject to major anthropogenic impacts, and their overall ecosystem status is already highly alarming. Many habitats are classified as degraded and decreasing and are changing rapidly in response to climate change.

Large-scale nature conservation mostly relies on the establishment of Marine Protected Areas (MPAs), which are primarily managed as passive recovery strategies (Fig. 1). However, the continued degradation of North Sea and Baltic Sea ecosystems in the face of increasing anthropogenic pressure calls for more active counter-measures and compensation to improve the environmental status (Fig. 1). Although vital, MPAs represent only one approach in maintaining and improving marine ecosystem functions. The higher the level of degradation, the more and diverse efforts are required to improve the ecological status of the marine environment [5,10,19]. Mere prevention of specific anthropogenic impacts in selected MPAs will likely prove insufficient in guaranteeing long-term improvements and a reversal of environmental degradation in the North Sea and Baltic Sea ecosystems, especially against a background of increased use. The rapid expansion of OWFs is a source of considerable further pressure and highlights the need for improved management of these already degraded and poorly monitored environments.

In this short communication, we summarize the outcome of two workshops of the German strategy group “Marine protection | Multi-use” (https://www.deutsche-meeresforschung.de/en/strategy/strategy-groups/strategy-group-mpasmu/). In these workshops, the potential for multi-use within OWFs was explored as a way to improve the status of coastal seas.

2. A way forward: multi-use in OWFs

Multi-use in OWFs is already considered as a tool to minimize spatial conflict in European coastal waters [29]. However, little consideration has been given to how areas already designated or with potential for OWF expansion might practically be used for multiple purposes and how this could contribute to biodiversity and ecosystem improvement (Table 1, No 1). Developing ideas for multi-use including ecological enhancement could be progressed in a targeted way to benefit multiple users and reduce overall pressure on the marine environment [40]. On the one hand, these areas could be actively used for ecosystem enhancement programmes, for instance via habitat restoration, the establishment of artificial reefs, and exclusion of fishing and other resource extractive uses. OWFs could be used to foster the restoration and regeneration of species (e.g., Native European cysters and European lobsters) which have been shown to benefit from the solid structures of OWFs due to the loss of reef substrate in past centuries [35,46] (Table 1, No 1 and 2). Recent research initiatives on floating offshore wind developments have adopted the concept of nature-inclusive design; these design initiatives are explicitly addressing needs and requirements for marine life through the provision of artificial reef structures and contact surfaces located either at floating steel structures on the surface, or at anchoring locations [6]. On the other hand, different uses such as aquaculture, floating solar, blue hydrogen production or other ORE could be co-located within OWFs to use the extremely limited marine space more efficiently and reduce anthropogenic impacts outside of these densely used locations (Table 1, No 2). Low trophic aquaculture (LTA) [4] with environment enhancing species at low trophic levels could increase the rate of de-eutrophication and improve water quality in the North Sea and Baltic Sea [27]. Furthermore, LTA species could serve as a temporary nursery, creating a valuable resource for enhancing human food security [16] or to benefit biotechnological applications. This could include species with potential for blue-pharmacy applications (e.g., species which contain bioactive compounds with potential as agrochemicals or pharmaceuticals). Co-locating passive gear fisheries in OWFs is increasingly debated and already implemented in some cases; this can support local marine food supply while also reducing pressure on trawled fishing grounds [1].

Co-designed by knowledgeable stakeholders, and effectively implemented, appropriate forms of “multi-use” could therefore mitigate the ecological impacts of large-scale OWFs while also improving the ecosystem status of coastal and shelf seas. Embracing transdisciplinary research, designing locally appropriate multi-use options could result in

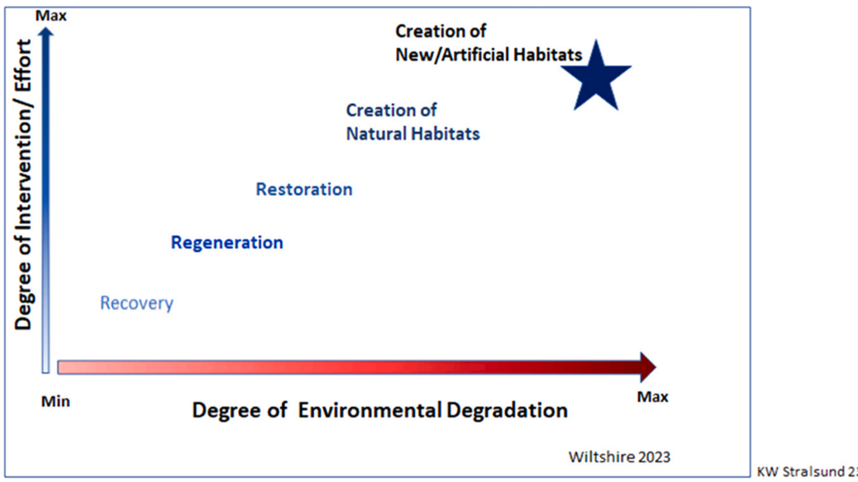

Fig. 1. Synopsis of the different management and intervention strategies with regard to the degree of environmental degradation and necessary efforts for improving the status. The star represents the estimated degradation level of the North Sea and Baltic Sea. In this sense, all forms of intervention are urgently needed to improve the environmental status.

Table 1
Summary of the identified research and management requirements to improve the status of coastal and shelf seas using multi-use concepts.

No	Open demands	Recommendation for future
1	Improve environmental status	Investigate the full potential of all types of restoration and conservation in degraded coastal and shelf seas.
2	Multi-use concepts for OWFs	Investigate multi-use concepts for socio-ecological systems in OWFs with respect to improving spatial efficiency. In particular, assess their potential to contribute to ecosystem and biodiversity enhancement as well as other sustainable forms of utilisation.
3	Monitoring with open data policy	Implement and improve long-term assessment and monitoring of all ecosystem effects of OWFs including abiotic and biotic changes using field data and modelling approaches, based on an open data policy. This also includes cumulative pressures and resulting environmental changes outside OWF areas, in the sense of a holistic ecosystem assessment in the light of ongoing change and increased human use.
4	Support transdisciplinary research	Dedicate more research funding to areas vital to improving governance, planning and management. Foster transdisciplinary research and stakeholder engagement to design better approaches for marine protection in multi-use areas.
5	Dialogue of affected stakeholders	Define specific topics within science, administration, sectors and stakeholders and recognise specific concerns and needs; develop new formats of dialogue that bring together affected stakeholders.
6	Facilitate implementation of multi-use	Establish standardized processes for application and approval processes for multi-use projects in OWFs including flexibility for new approaches and techniques.
7	Joint biodiversity and green energy strategy	Develop criteria for a joint biodiversity and green energy strategy including spatial scenarios and synergies.
8	Link science and technology	Improve the understanding of interdependencies of and interactions between natural and technical marine systems related to multi-use concepts, enabling forecasting and predictions.

new knowledge and management systems, including how to deal with impacts of OWFs on marine biodiversity and ecosystems and the opportunities and challenges associated with different enhancement strategies as part of multi-use options.

MPAs and no-take zones will remain crucial refuges for marine flora and fauna. We therefore emphasise that this form of ecosystem enhancement is complementary and should not replace or diminish efforts towards the protection goal (i.e., 30 % of coastal and shelf seas to be protected by 2030, with 10 % strictly protected areas) of the European Biodiversity Strategy.[1] Nor should it replace the intended targets of the Nature Restoration Law.[2] The specific benefit of using OWFs for ecological enhancement is that this can help mitigating the effects of OWFs themselves, adding biodiversity value to a concept that is otherwise solely focused on energy, thus avoiding further degradation of the ecosystem. For this approach to be successful, however, marine resource utilisation and protection must be closely coordinated and monitored by an integrated system of marine governance that effectively links strategic spatial planning, sector-based planning, licensing and conservation management.

OWF areas are likely to vary in terms of their structural installation concepts and geometries (bottom-fixed vs floating). Still, all OWF installation will lead to some degradation of the marine environment. Multi-use for ecosystem enhancement will therefore need to be tailored to the specific conditions of each area, including surrounding uses and long-range and long-term influences. Where OWF areas do not allow for explicit ecosystem enhancement programmes, they should be made available for commercial co-use, thereby contributing to spatial efficiency by concentrating marine use in specific areas. Both concepts of co-use can be complementary and do not need to be seen as competing options when developing the potential (additional) utilisation of an OWF site.

Each anthropogenic intervention needs to be considered with caution regarding its environmental impact, as all forms of human intervention, including co-use of OWFs for ecological enhancement, have uncertain long-term outcomes in a complex natural system.

3. Research requirements and management recommendations

Research has shown that large-scale OWF installation has varying effects on ecosystem components, structures and functions, including habitat alteration and loss, displacement, attraction and avoidance

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380
[2] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en

behavior, noise and light pollution, chemical emissions from corrosion protection, collision mortality, and indirect effects on the ecosystem [8,18,24]. It can also be expected to result in long-term and regional scale changes in North Sea and Baltic Sea environmental conditions including lower atmosphere, hydrography, seabed and biology [7,9,44]. While OWF energy is an important pillar of climate change mitigation, the speed of its implementation since 2022 has meant that environmental management strategies, spatial planning and the development of new and updated concepts for co-use have struggled to keep pace. Additionally, research is missing on the cumulative and cascading effects of large-scale OWF installation, particularly in relation to higher OWF densities, interactions with climate change effects, and future operating options.

Due to the complex effects of potentially even larger OWF areas, continuous, long-term research efforts on system components before and after OWF installation are required. Data should include socio-economic data and should be made freely available to scientists and other stakeholders for further analyses (Table 1, No 3). These data and engagement with key stakeholder groups provide the necessary base for transdisciplinary research, which in turn is essential for the development of knowledge-based management recommendations including multi-use opportunities (Table 1, No 4). However, social science research based on dialogue with and between multiple users, interests and values requires transparency, the capacity to participate, willingness to learn, and the ability to integrate different forms of knowledge [36] (Table 1, No 5). Furthermore, it is imperative that strategies to offset environmental degradation resulting from OWF installation gain high priority in national and regional marine governance (Table 1, No 4, 5).

While there is a long way to go to overcome social barriers and to link socio-cultural perspectives and emotions with economic and ecological perspectives, the environment and the rapid deployment of OWFs cannot wait for dialogue to evolve slowly. Dialogue needs to become urgent and more effective (Table 1, No 5)). This, in turn, requires sufficient resources and transparent approaches. We propose that combining OWFs with ecological enhancement and management measures has considerable potential for developing new formats for a more effective and inclusive debate. Supported by transdisciplinary research and implementation, an action-oriented debate can lead to management measures which enhance the ecological benefits of OWF infrastructure [45] or support active restoration measures within OWFs (Table 1, No 4 and 5).

Several studies and projects have focused on addressing the impacts of multi-use concepts and identifying barriers to their success including e.g., gaps in ecological knowledge, social acceptance, financing, and regulatory frameworks (e.g., MARINA, ORECCA, TROPOS, H2OCEAN, MERMAID, MUSES, OLAMUR). Upcoming studies should focus more on the implementation of multi-use approaches and demonstrate the feasibility and sustainability of existing concepts (Table 1, No 6). This also means that more funding needs to be dedicated to exploring governance-related dimensions. The obvious conflict between nature conservation and green energy production in the North Sea and Baltic Sea requires a systems-based discussion and willingness for innovation to achieve a joint strategy for ecosystem improvement and ORE development (Table 1, No 7). This should firstly focus on avoiding or reducing OWF impacts, but secondly, it should also consider potentially positive effects of OWFs on different taxa and habitats and analyse the potential of different multi-use concepts for ecosystem enhancement (Table 1, No 8). For example, in the Netherlands, OWF turbines are obliged to be built in a nature-inclusive design [29], and the German OWF site development plan for its exclusive economic zone expressly calls for better and transdisciplinary research-led exchange between relevant users and stakeholders [3]. Such exchanges urgently need to be implemented at the national and European level, with the aim of facilitating and coordinating a multi-national OWF development plan and conservation plans for all European seas and coastal zones.

As a first step, we recommend that pilot studies should be set up within selected OWFs. This would allow different integrated multi-use strategies to be tested, e.g., in form of a (scientific) living lab [17,23]. Site-specific monitoring of potential ecosystem-effects could be tested, new forms of data obtained, and various stakeholders could be involved to overcome existing concerns about the expansion of OWFs and multi-use of such areas. Sustainable strategies and new forms of management for reducing adverse environmental impacts and improving the environmental footprint of OWFs can only be developed if living labs attract and engage academic, political, social and economic stakeholders.

In the long term, different multi-use concepts and especially ecosystem enhancing approaches within OWFs could help resolve conflicts between economic demands and ecosystem and biodiversity stabilisation. Localised concentration of high intervention measures paired with innovative management approaches could support environmental enhancement in highly disturbed coastal ecosystems and reduce pressure on MPAs, thereby helping to move degraded marine ecosystems towards GES.

CRediT authorship contribution statement

Torsten Schlurmann: Writing – review & editing, Conceptualization. **Ben Boteler:** Writing – review & editing. **Alexander Schendel:** Writing – review & editing. **Rudolf Amann:** Writing – review & editing, Conceptualization. **Kimberley Peters:** Writing – review & editing. **Bela H. Buck:** Writing – review & editing, Conceptualization. **Carsten Lemmen:** Writing – review & editing. **Sabine Horn:** Writing – original draft, Project administration, Conceptualization. **Kira Gee:** Writing – review & editing. **Vanessa Stelzenmüller:** Writing – review & editing. **Maurits Halbach:** Writing – review & editing, Conceptualization. **Peter J. Schupp:** Writing – review & editing, Conceptualization. **Nils Goseberg:** Writing – review & editing. **Corinna Schrum:** Writing – review & editing. **Dietmar Kraft:** Writing – review & editing, Conceptualization. **Karen H. Wiltshire:** Writing – original draft, Visualization, Conceptualization. **Andreas Kannen:** Writing – review & editing. **Ute Wilhelmsen:** Writing – review & editing. **Katja Heubel:** Writing – review & editing. **Vera Sidorenko:** Writing – review & editing. **Anneke Heins:** Writing – review & editing.

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Data availability

No data was used for the research described in the article.

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