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Stakeholder insights into embedding marine net gain for offshore wind farm planning and delivery

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ABSTRACT

The rapid expansion of offshore wind farms plays a key role in meeting global Net Zero targets by 2050 and if delivered sustainably could address the dual challenges of climate change and biodiversity loss. Many countries are embracing ambitious approaches to environmental impact reduction by implementing concepts such as Biodiversity Net Gain, Nature Positive and No Net Loss. Such policies are now recognized in European and UK legislation, although generally only applicable to terrestrial activities. For the marine realm, there is little consensus on how Marine Net Gain can provide optimal environmental and societal outcomes from marine activities such as offshore wind farm construction, operation and decommissioning. This study sought to clarify the key issues that need to be addressed for effective implementation of Marine Net Gain. Following recruitment through a stakeholder mapping exercise, in-workshop and follow-up questionnaires sought to elicit expert opinions from multi-sector UK offshore wind farm stakeholders on a range of aspects of Marine Net Gain policy formulation and delivery. Over 80 % of participants indicated that certain external inputs, including information for climate change adaptation options and habitat mapping data, were important to enable delivery of Marine Net Gain. The most important ecosystem services to include within Net Gain measures were perceived as those relating to fisheries (mean 4.50, SD 0.51), maintaining nursery habitats (mean 4.41, SD 0.59), and climate regulation (mean 4.20, SD 1.). Stakeholders felt the most important Net Gain actions for environmental restoration/enhancement for future offshore wind deployment were shellfish/mussel bed (ave rank score 4.06) and invertebrate habitat restoration (ave rank score 4.60), and actions supporting plankton communities (ave rank score 4.67). Stakeholders agreed (83 %) that Net Gain actions should be considered at the decommissioning stage, and the preferred decommissioning option was the complete removal or abandonment of all structures. Stakeholders felt that strategic Net Gain assessments should prioritize fishing pressures (dredging: mean 4.27, SD 1.03; line and net: mean 4.21, SD 0.89) and those arising from physical structures (mean 4.0, SD 0.85). Aquaculture farming was deemed most feasible to co-exist with fixed offshore wind farms (means 3.93–4.19), while floating wind farms were felt to be more co-locatable with fishing practices (means 3.94–4.06) and carbon capture storage devices (mean 3.87) compared to fixed structures. Recommendations are suggested for future policy development and scientific research in relation to the application of Marine Net Gain assessment for offshore wind farm projects.

1. Introduction

Two significant current global phenomena are i. the worsening biodiversity crisis, and ii. the expansion of marine renewable energy developments, particularly offshore wind farms (OWFs) (Hughes et al., 2022; Li et al., 2022). Such expansion represents a vital intervention among efforts by nations to address the ‘interlinked global crises of climate change and biodiversity loss in the broader context of achieving the Sustainable Development Goals’, as recognised by the Sharm el-Sheikh Implementation Plan which arose from the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) (UNFCCC 2022). National policies committing to achieve carbon neutrality have been demonstrated by several G7 economies entering into agreements to neutralize their ecosystems by 2050 (Akram et al., 2023). While renewable energy has been shown to contribute toward significant short and long-term reductions in CO_2 emissions (Akram et al., 2023), accelerated growth should not come at the cost of biodiversity or wider environmental

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quality. Environmental impacts at national or regional scales must be accounted for, with 'no net loss' (NNL) policies being adopted by multiple countries (e.g., France, UK, USA, Germany, Australia, Canada, Brazil, and Mexico) and organizations as the mechanism to achieve this (Bull and Strange, 2018; Quétier et al., 2014). These NNL policies aim to improve ecological quality and achieve equivalent biodiversity gains elsewhere to counterbalance habitat and biodiversity losses (Maron et al., 2018; Liu et al., 2023). However, there is increasing momentum globally for extending the concept of NNL to one of net gain (NG), mainly for terrestrial habitats, but progressively including the marine environment (Hooper et al., 2021). Marine net gain (MNG) is an emerging concept that is currently transitioning to policy in some countries and stakeholder input is important for that transition to occur in such a way that ensures the final measures and outcomes will be deliverable. Various definitions have started to appear within academic literature around the concept of MNG, hence Table A1, Appendix A, has been presented to show a series of acronyms and definitions to which this paper uses and adheres.

2. Literature review

2.1. Theoretical basis for study

In the context of biodiversity loss, the connection between offshore wind farms and MNG is a pivotal matter. Considerations of MNG will encompass the development and adoption of new technologies, processes, and practices that promote sustainable development and environmental well-being. The primary objective of MNG is not just to mitigate the adverse impacts of human activities on the ecosystem, but to generate positive impacts from those activities. Net Gain is based on the principle that the many benefits associated with development activities need not come at the expense of the environment. Indeed, net gain principles ensure that all development activities are accompanied by environmental improvements, leaving biodiversity in a better state and securing wider benefits for people and the environment (DEFRA 2018), through biodiversity net gain (BNG) - making sure that habitat for wildlife is in a better state than it was before development – and Environmental Net Gain (ENG) - achieving BNG first and going further to achieve net increases in the capacity of affected natural capital to deliver ecosystem services, the latter delivering wider ecosystem services benefits (DEFRA 2018; Greenhill and Howell, 2021). These concepts form the cornerstone of this study, within a marine context. The focus on the marine context by this study is justified by the fact that NG has been incorporated within terrestrial policy and practice to a much greater extent than for the marine realm. This study enables lessons learnt from knowledge of terrestrial NG to be applied to the development of emerging MNG policies, allowing certain aspects to be retained and others replaced by new marine specific elements, for example, what metrics to use. Where conversations around this issue have commenced, both in academic literature (Hooper et al., 2021), and in stakeholder consultations (DEFRA 2018), specific principles have emerged that have informed the choice of variables to include within the study. These include the ecosystem services to include within MNG assessments, the environmental pressures to prioritize for NG actions, and the biodiversity or habitat restorations which are deemed most important for NG actions.

2.2. Empirical studies

International policy drivers for MNG include the UN sustainability development goals, global biodiversity targets (Hughes et al., 2022; Obura et al., 2021), advocation of an ecosystem approach by the UN Decade of Ocean Science for Sustainable Development, and regional marine objectives (Greenhill and Howell, 2021). National Governments are responsible for implementing policies that respond to these drivers at a local level: input from different elements of society to ensure that resultant policies are appropriate and deliverable is critical to such implementation.

Adoption of MNG in various guises is more advanced in certain countries i.e., the USA (as restoration ecology, mitigation banking and Net Positive impact) (ABPmer 2019; Droste et al., 2022), while South Australia's Significant Environmental Benefit policy awards grants for vegetation restoration projects in lieu of on-ground offsets from developments (Maron et al., 2018). Restoration ecology involves active conservation or restoration through the rebuilding of degraded, damaged, or destroyed ecosystems and habitats by active human intervention. Restoration actions have increased globally over the last 20 plus years, notably in countries such as USA, Japan and Mexico. However, this approach is most commonly applied to coastal habitats and tends to rely on average survival of species as a measure of success (see Basconi et al. (2020) for a global review). Although some projects may aim for NG, restoration ecology is principally a means to achieve NNL. Similarly, mitigation banking policies, well established in the USA and explored more recently in countries such as France and South Africa (Quétier et al., 2014; Adam, 2019), have been used mainly for NNL from wetland projects, where an area of wetland has been restored, created, or conserved and then set aside to compensate for impacts on the habitat in the future (Adam, 2019).

There are few countries with established NG policies (France, Chile, UK) (Hooper et al., 2021). This may rapidly increase with the adoption of The Kunming-Montreal global biodiversity framework (GBF) at COP 15. Governments are urged to implement the framework across society for the period up to 2030 and towards the 2050 vision 'to take urgent action to halt and reverse biodiversity loss' (UN Convention for Biological Diversity 2022).

Net Gain policy developments in recent years in the UK have been predominantly terrestrial and focused on BNG (Hooper et al., 2021; Natural Capital Committee 2019). Since 2022 several UK and European marine projects (i.e., North Sea Net Gain project and Rich North Seas initiative) have begun developing solutions and data that can be adopted by OWF developers (Cooper et al., 2022) in lieu of specific NG policy guidance. There remain unknowns around the definition and application of NG within marine contexts (Government, 2018; ABPmer 2019); for example, how ecosystem services and natural capital can be factored into NG measures and mandated in legislation (Greenhill and Howell, 2021). Consultation with relevant stakeholders across sectors could provide invaluable insights to help address these unknowns.

Currently, there is no formal requirement in the UK for NG as part of energy developments or Nationally Significant Infrastructure Projects in the marine environment (Offshore Wind Evidence and Change Programme Task and Finish Group (OWEAP T&F Group) 2021). In 2018 the UK's department of environment, food & rural affairs (DEFRA) announced its intention to develop a regime for the marine environment to enable delivery commitments from its 25 Year Environment Plan (Government, 2018; DEFRA 2022). BNG was mandated by the National Planning Policy Framework and the Environment Act 2021 (biodiversity to be enhanced by a factor of +10 %) and becomes mandatory from January 2024 for most terrestrial developments (Government, 2023). Marine NG is expected to follow suit in 2024–5. Different approaches are likely to be taken to MNG across the UK's devolved nations; however, while reviews are planned or underway, none of the national marine plans currently include explicit MNG policies (Greenhill and Howell, 2021). Expert stakeholder input to these processes are therefore at a crucial stage of policy formulation.

As well as a need for consistency in understanding of MNG, it is also important to fully appreciate why this approach is so important and how stakeholder engagement can contribute to its development. The degradation of ecosystems and biodiversity over recent decades has been linked to direct drivers such as land and sea-use change, exploitation of wild species, climate change, invasive alien species, and pollution, all driven indirectly by demographic and social changes and economic interests (McElwee et al., 2020). Such direct and indirect drivers will apply to the energy sector as much as any other industry. There is evidence of public support for a post-COVID-19 world to re-prioritize its values toward environment enhancement, tackling climate change, and promoting social equity by developing policies to promote better management of biodiversity and ecosystems (McElwee et al., 2020) among others. In parallel, many of the expectations set by environmental restoration policies, including offsetting biodiversity loss, remain unsupported by evidence (Maron et al., 2012). A key criticism of mitigation banking programs, for example, is the continued temporal loss of wetlands due to release of credits prior to ecological outputs gained, and a disconnect between impact sites and compensation sites (Adam, 2019). Marine NG offers a potentially effective mechanism to tackle global environmental challenges, including impacts of OWFs on natural capital. For ENG, this can include mitigation of climate change impacts, air and water quality improvements, and improving human resilience (Commission, 2021).

Human activities increasingly affect the provision of marine ecosystem services requiring evidence-based integrated assessment approaches that include ecosystem functioning and services. Although many existing methods measure single pressures and assess their impacts, evaluation of cumulative effects of multiple pressures remains scarce (Borja et al., 2016). The different metrics used in biodiversity offsetting often focus on habitats, species *or* ecosystem services, and use various change measures. A standardized unit of measurement would enable comparable assessments of change across ecosystems and places. Ecosystem services assessments have been used as alternatives to biodiversity metrics i.e., Germany, USA, UK (Natural England's 'eco-metric') but these are all still based on habitats and exclude species and cultural services (McVittie and Faccioli, 2020). Consideration of the broader ENG concept offers a potential approach that would enable greater inclusivity of impacts on a wider range of ecosystem services and benefits.

The International Energy Agency declared in 2021 that to meet energy transition goals global capacity of offshore wind needed to increase from 30GW total current installed capacity to 80GW per year by 2030. This acceleration of infrastructure deployment will require technological innovation and the use of deeper waters across the planet, and floating wind will play a key part in meeting these ambitious targets (Forum, 2021). With appropriate mitigation, floating wind farms could present a low risk to the marine environment (Farr et al., 2021). However, because very few floating wind farms are currently operational, their environmental impacts are still poorly understood, causing uncertainty amongst stakeholders as to how MNG can be achieved from such projects and how expectations differ to those for fixed infrastructure. Consultations on MNG with OWF stakeholders could usefully, therefore, include space for considering these differences and encouraging the collection of baseline data on environmental impacts of floating wind technologies.

2.3. Research gap

A rapid assessment of the studies discussed above revealed little empirical evidence that examines the concept and implementation of MNG policy from an offshore wind farm stakeholder perspective. Conversely, there is more existing evidence around contributions to environmental enhancement policy from, for example, decommissioning of structures in the oil and gas industry (Lemasson et al., 2022; Kennon et al., 2023). As shown previously, there is also more evidence in the literature around the application of NNL policies, and its variants, which have weaker ambitions for biodiversity and environmental enhancement than. These gaps are therefore addressed by the current study.

This study will inform the establishment of meaningful, deliverable MNG policies and measures which, in turn, are intended to lead to environmental enhancements and increased biodiversity. The need for research studies to consider various proxies for ecological decline has been highlighted (Liu et al., 2023). The detailed development of a MNG metric that will be effective as a single measure of environmental improvement across all marine activities is critical, and the robustness of baseline data of ecological condition will be an important aspect of successful MNG delivery. A standardized measure could also contribute to lowering transaction costs (Quétier et al., 2014). The offshore wind farm sector's rapid expansion will create challenges for accommodating deployment without negatively impacting marine ecosystem health and quality. MNG is a tool to facilitate solutions to these challenges and expert inputs to the development of MNG principles and mechanisms will help to ensure that the chances of successful delivery are maximized. Taking offshore wind farms as a representative industry of renewable energy, the insights of different aspects of MNG from a range of stakeholders across different sectors will provide valuable information for policy makers to determine what MNG will ultimately look like in their respective jurisdictions. While this study is explicitly framed within a current UK policy context, renewable energy, including offshore wind, is still emerging as a viable option for energy consumption across many countries across the world i.e. South Africa (Udeagha and Muchapondwa, 2022), India (Dawn et al., 2019). The findings from this study are therefore expected to have wider relevance, for other global locations and for other marine industries, with regard to the introduction of policy mechanisms aimed at ensuring marine developments do not negatively impact on the environment. Policies that strengthen environmental regulations and enforcement mechanisms, such as MNG, should help to ensure responsible and sustainable resource extraction practices and management by nations which look to balance economic development with environmental conservation, such as BRICS countries (Udeagha and Ngepah, 2023).

2.4. Objectives

To address the gaps identified above and provide additional evidence that could inform decision-making, we elicited relevant knowledge and expert opinion from a range of stakeholders on the application of MNG to OWF in the UK. A questionnaire was delivered via two online workshops and a follow-up email and was framed around four key themes: i. Perceptions of delivery of MNG and ecosystem services; ii. Strategic MNG restoration, enhancements and decommissioning of OWF; iii. Pressure reductions and BNG; and iv. Floating wind, BNG and co-location. Several quantitative analytical approaches provided novel insights into stakeholders' perceptions of the MNG concept, and the importance they placed on a range of relevant factors potentially impacting both practice and policy. The expert knowledge and assessment approach taken here is recognized for the value it can play in decision-making, particularly when the issue or question is time-sensitive but the state of knowledge is insufficient to effectively inform decision-making, requiring action to be taken despite uncertainty (Martin et al., 2012; Elliott et al., 2018).

3. Method

3.1. Stakeholder recruitment

A stakeholder mapping exercise was undertaken, drawing from the UK's marine energy community deemed to have influence or interest in the area of MNG. For this activity, stakeholders were defined as 'people with a professional interest in the field of offshore wind energy and related activities'. A list was built up from consultation with the multi-sectoral UK Energy Research Centre's (UKERC) independent advisory board, with further input from the UKERC academic research community and project partners. The resultant long-list consisted of the traditional quadruple helix of stakeholders (Hasche et al., 2020) - industry, government, academia, and civil society. A mapping process placed these stakeholders within an influence-interest matrix (Reed et al., 2009), further enabling the targeting of participants that would provide a representative group of marine and coastal stakeholders operating within the UK at different sectors, levels of experience, and regional seas. The matrix is accessible in Appendix B (Fig. B.1).

3.2. Questionnaire participants and delivery

The questionnaire (complete version available in Supplementary Materials) was delivered through two online workshops hosted by the authors in June 2022, and via a follow-up online version sent to individuals unable to attend the workshop. Twenty-two individuals completed the questionnaire, sixteen during the workshops and six online. A profile of work-related stakeholder characteristics is shown in Table 1. Within a sample of multiple sectors, the largest sector represented was the offshore renewable industry ($n = 6$). All but one of the participants considered themselves working at a senior or intermediate level of seniority. Half the sample spent 100 % of their work time on renewable energy, and over 80 % operated at a national level. Participants had interests in all seas around the UK, often operating in multiple seas, with the Celtic Sea attracting the greatest interest.

Ethics approval for data collection via workshops and survey was granted by the University of Plymouth Faculty of Health Ethics Committee (Reference 2021–3409–2475). Information was sought from the participants' professional opinions framed by their roles within their organisations, although personal anonymity during dissemination of results was assured. Following pilot testing of the questionnaire with five members of the UKERC advisory board and subsequent refinements, the final version offered closed questions in sections that focused on:

i. *Perceptions of delivery of MNG and ecosystem services* – Starting with very brief definitions of the key terms this section focused on stakeholders' general perceptions of MNG as an important mechanism that could contribute to halting and reversing marine biodiversity loss. Questions included: binary options on whether BNG should be mandated for all OWF developments, and which taxonomic groups should be included within strategic MNG targets; the importance of a range of methods to support planning and policy activities for achieving NG (rated on a 5-point scale from very unimportant to very important); the frequency of using, and level of interest in, various tools or methods when defining NG policies or making management decisions (custom three-point scales); the level of agreement with the UK government's focus of strategic targets on 'biodiversity' rather than 'environmental' NG (rated on a 5-point scale from strongly disagree to strongly agree; and the importance of ecosystem services for improving measures of NG impacts and benefits of OWFs (using a 5-point Likert scale from very unimportant to very important, against a series of ecosystem services).

ii. *Strategic MNG restoration, enhancements and decommissioning of OWF* – This section identified strategic NG opportunities and suggestions for how these might be delivered. Questions covered: preferred approaches to the application of MNG (single option multiple choice); the importance of a series of NG actions for restoring and/or enhancing the marine and coastal environment in relation to future inshore and OWF deployment (applying a rank order where 1 is the most important); the importance of prioritizing a series of NG actions in relation to other factors affecting offshore wind deployment (applying a rank order where 1 is the most important); and the importance of various decommissioning options in relation to environmental and biodiversity impact (applying a rank order where 1 is the most important).

iii. *Pressure reductions and BNG* – Questions exploring stakeholders' thoughts on pressures required participants to express their opinions on whether floating and fixed OWFs should be built in marine protected areas (MPAs) if NG actions would offset environmental impacts; the importance of ecosystem services for estimating ENG impacts and benefits of OWFs (using a 5-point Likert scale from very unimportant to very important); the feasibility of various marine activities to co-exist within fixed OWFs (using a 5-point Likert scale from strongly disagree to strongly agree against a series of activities); and which marine pressures should be prioritized when developing strategic NG targets for OWFs (using a 5-point Likert scale from strongly disagree to strongly agree against a series of pressures).

iv. *Floating wind, BNG and co-location* – enabling comparison of several themes between fixed and floating OWFs.

Table 1
Work-related participant profile characteristics.

Work-related profile characteristics	N	Work-related profile characteristics	N
Sector		*Time spent on renewable energy*	
Offshore renewables	6	100 %	11
Central Government	3	76–99 %	3
Academia	2	51–75 %	2
Trade association	1	26–50 %	1
Green investment fund/Developer	1	1–25 %	4
Public Corporation	2	Not applicable	1
Public Body	1	*Geographical scope*	
Marine Industries Group	1	Local	2
Research Centre	2	Regional	6
Consultancy	1	National	18
NGO	1	Global	2
Local Government	1	*Locations of operational interest*	
Level of seniority		Celtic Sea	18
Junior	1	Irish Sea	14
Intermediate	13	North Sea	13
Senior	8	North Atlantic	11
Area of interest		English Channel	11
All aspects of MRE or offshore wind	18	Other	3
Floating offshore wind	1		
Fixed offshore wind	1		
Wave and tidal	1		
None of the these	1		

3.3. Data analysis

Frequency statistics and trends are reported for all quantitative data, obtained from a combination of dichotomous, multiple choice, single scale, and Likert scale questions (including means and standard deviations). One-sample t-tests were applied to all Likert-type questions. Analysis aimed to determine whether responses were statistically different ($p<0.05$) from the mid-point of the scale used in each case.

For the ranking questions to determine strategic NG priorities for the stakeholder group, Microsoft Excel's RANK AVERAGE function was used to rank a series of NG actions within each question, based on the means of individual response scores within each action. To look at how the different responses related to one another in selected questions, non-metric multidimensional scaling (NMDS) was applied to better visualize similarity between responses. NMDS was performed using the PRIMER package v6 (Clarke and Gorley, 2006).

4. Results

4.1. Perceptions of delivery of MNG and ecosystem services

When asked to rate their level of interest in BNG on a scale of 1 (no interest) to 4 (high interest), 95 % of the stakeholders expressed considerable to high interest.

4.1.1. Priority taxonomic groups to include in BNG

The stakeholders' views on whether BNG should be mandated for all future OWF developments were noticeably split, 59 % agreeing that it should and the remaining 41 % unsure. All those that agreed, and six of the nine that were unsure, also felt that species should be included within MNG targets. Over 75 % of stakeholders thought that fish, birds, and marine mammals should be included within these targets, while 40–60 % felt that invertebrates, reptiles, and bats should be included. Fig. 1 shows that, within these figures, there is consistency across the broad organizational sectors calling for fish to be included, but variation between the sectors for all other taxonomic groups. Most notably, non-government stakeholders were more interested in including invertebrates and bats within targets than Government and Industry participants. All the Government stakeholders ($N = 7$) felt that birds and mammals should be included, while the renewable energy industry representatives ($N = 6$) were divided with respect to including invertebrates, birds, mammals, and reptiles.

4.1.2. Data needs to support planning and policy activities for achieving MNG

The researchers were keen to obtain stakeholders' thoughts on which methods might support planning and policy activities for achieving NG in the marine area. To this end, participants were asked to indicate the level of importance they attached to a number of inputs their organizations might need to meet the requirements of BNG. Over 80 % of participants indicated that i/ information for climate change adaptation options, ii/ the involvement of stakeholders, iii/ guidance for the design of adaptive policies, iv/ habitat mapping data and v/ additional biodiversity data, were all important or very important. Less relevant inputs were socio-economic data ($M = 3.68$, $SD = 0.89$) and tools with multiple choice elements for NG ($M = 3.41$, $SD=1.01$), the latter with considerable variation within their ratings. Other useful inputs identified by participants included some indication of the likelihood of other external pressures damaging implemented net gain solutions, and clear robust guidance for industry (including test and trial deployment opportunities). With regards to biodiversity data, more scientific evidence to underpin biodiversity benefits is called for, such evidence potentially relating to 'incidental' environmental benefits from offshore wind (e.g., artificial reef effect), as well as the effectiveness of marine environmental improvement works. Another stakeholder thought it would be useful to understand how local impacts could translate to larger scales, for example, scaling up rock protection measures from one OWF to a broader multi-farm special area of conservation (SAC) level. Despite the low rating for socio-economic data, there was a suggestion that knowledge of socio-economic impacts of NG interventions would be useful, such as how fishing could be used to deliver NG, and how community ownership of nature-based projects could be encouraged and facilitated.

4.1.3. Usefulness of tools and models in quantifying MNG

Stakeholders were asked to identify any specific tools or methods their organizations used when defining net gain policies and applying management decisions. All approaches (ecosystem models, tools for guiding adaptive policies, tools facilitating stakeholder selection and involvement, and tools for valuation and scoring) were used regularly by less than 30 % of participants. The point was made by one participant that because NG was not yet a legislative requirement, their organization had not yet used any tools to make management decisions related to this concept. There was interest in using ecosystem models (73 %), scenario building methods (68 %) and tools for guiding adaptive policies (64 %), for management decisions, but still a reasonable degree of uncertainty about other approaches, one participant suggesting that any requirements would need to relate to the mandatory process once a framework had been set.

4.1.4. Ecosystem services and ENG

Stakeholders were divided in their views that the UK Government had, to date, focused on the identification of strategic targets for BNG, as opposed to ENG. While 32 % agreed/strongly agreed and 23 % disagreed/strongly disagreed with this assumption, nearly half of the respondents were unable to agree or disagree ($M = 3.13$, $SD = 0.99$). An exploration of ecosystem services that could be developed and used to improve measures of ENG impacts and benefits of OWF afforded greatest importance to fisheries (mean 4.50, SD 0.51), maintaining nursery habitats (mean 4.41, SD 0.59), climate regulation (mean 4.20, SD 1.15), and seaweed aquaculture (mean 3.89, SD 0.57)(Table 2). The least important service was aesthetic value (mean 2.47, SD 0.94). Although 'unsure' responses were excluded from the analysis of means, it is worth noting the extent of uncertainty around most of the ecosystem services; for example, 27 % of participants were unsure whether sediment composition and flows could be useful for demonstrating environmental offsets.

Fig. 2 shows self-clustering of ecosystem services from a two-dimensional non-metric multidimensional scaling plot (NMDS), with a low stress figure (0.07) indicating high reliability. When the ecosystem services were re-ordered according to similarities in levels of

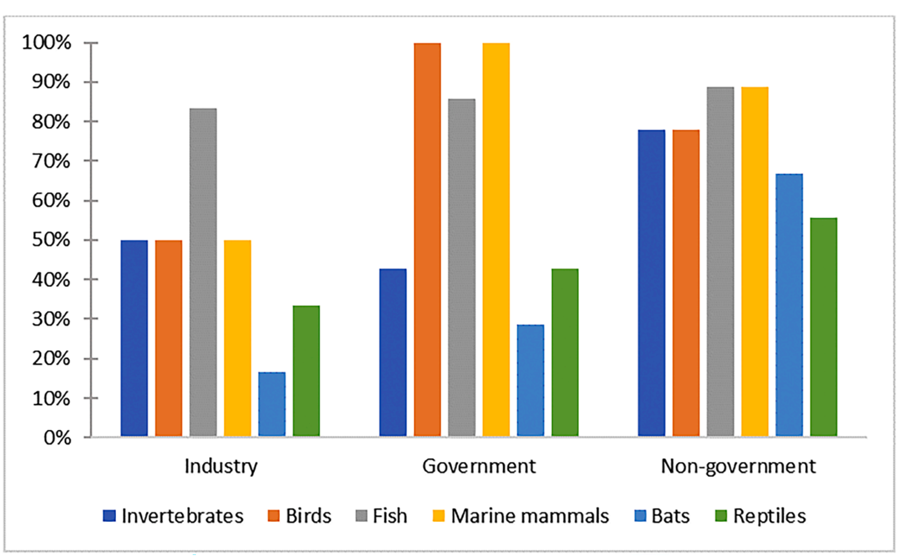

Fig. 1. Views of organizational sectors on which taxonomic groups to include within MNG targets ($N = 22$).

Table 2
Mean ratings and standard deviations for importance of ecosystem services for improving measures of NG impacts and benefits.

Ecosystem Service	N	Mean	SD	% Uncertain
Aesthetic value	17	2.47***	0.94	23 %
Aquaculture (seaweed & other plant materials)	19	3.89***	0.57	14 %
Aquaculture (shellfish)	19	3.84***	0.50	14 %
Climate regulation (carbon sequestration & storage	20	4.20***	1.15	9 %
Cultural heritage	20	3.35	1.09	9 %
Fisheries and wild fish stocks	22	4.50***	0.51	0 %
Flood and storm protection effects	19	3.14	1.07	14 %
Hydrodynamic regimes	18	2.77	1.09	18 %
Invasive or alien species prevention	20	3.41***	0.72	9 %
Maintaining nursery habitats	22	4.41***	0.59	0 %
Primary production and nutrient cycling	18	3.09	1.00	18 %
Remediation of wastes, chemicals, toxins, & other nuisances	17	2.82	1.17	23 %
Research and educational values	21	3.32	1.03	5 %
Sediment composition and flows	16	2.64	0.89	27 %
Tourism and recreation	18	2.55	1.08	18 %

Note: scale ranged from very unimportant (1) to very important (5) with a mid-point of neither unimportant or important (3). N varies with number of unsure responses excluded. ***Denotes statistically significant to the mid-point to a p-value <0.05.

importance, two clusters emerged, with three other single-item clusters. The largest cluster consists mostly of regulating and supporting services (e.g. sediment composition and flows, flood and storm protection effects and nutrient cycling) and reflecting lower importance scores, while the smaller cluster includes predominantly provisioning services (e.g. aquaculture (shellfish and plants) and fisheries) with strong links to nursery habitats provisioning and the prevention of invasive species, and which were ranked medium to high importance by stakeholders. Climate regulation (relating to carbon sequestration and storage) plots in isolation of both clusters, while the cultural ecosystem services (research and education, aesthetic value, and cultural heritage) are distanced from each other and without clear pattern. Tourism and recreation, while also distant from other cultural services is regarded as being of similar importance to other regulating services quality such as waste remediation, hydrodynamic regimes and sediment composition and flows.

4.2. *Strategic MNG restoration, enhancements and decommissioning of OWFs*

A series of six questions were put to stakeholders that attempted to identify strategic MNG opportunities and preferences for how these might be delivered.

4.2.1. *Views on measuring and developing a metric for MNG*

Given several possible approaches for the application of MNG, participants ($N = 19$) favoured the design of a new metric for the offshore marine environment (42 %), and an industry levy to support a strategic fund with NG delivered either regionally or nationally (32 %), while just 5 % voted explicitly for a similar metric to that used for terrestrial NG (i.e. DEFRA's biodiversity 3.1 metric). Eleven percent of participants thought all three approaches should be used, and an additional suggestion was for a hybrid between the metric and levy fund depending on the scale of the NG required. One person suggested that a levy fund shouldn't exist in isolation, and that while strategic priorities are important there should still be site-level efforts to measure gains. Looking at the types of organization, it is notable that those from industry and non-government organizations preferred a new metric (3 of 5 and 4 of 7 respectively), while government organizations leant toward application of an industry levy (4 of 7). Two non-government stakeholders observed that all three options were necessary.

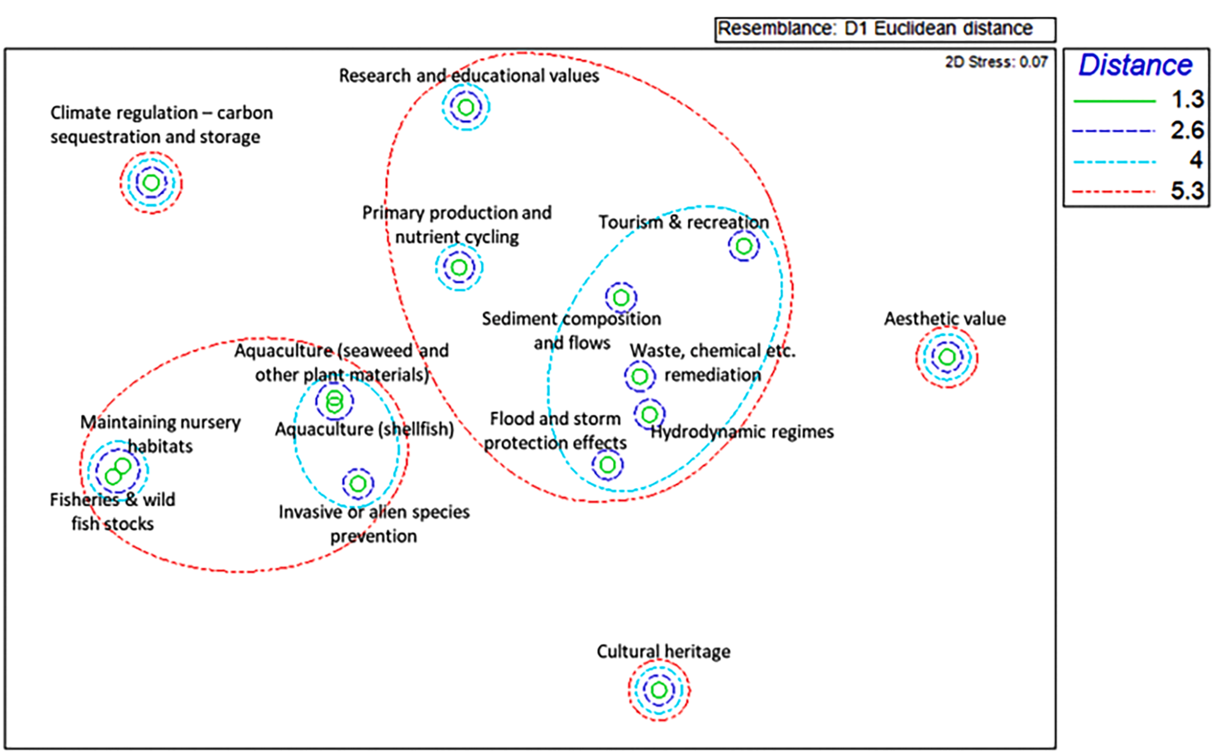

Fig. 2. NMDS ordination of ecosystem services by importance of inclusion in ENG metrics. Goodness of fit calculated using Kruskal's Stress. Distance metric = Euclidean.

Net Gain Action	Ave Rank Scores	Ave Ranked
Action to restore and/ or create intertidal/near coastal habitats (Shellfish/mussel beds)	5.36	1.5
Actions to support (Plankton and Zooplankton)	5.36	1.5
Action to support populations of inshore and coastal (Fish)	5.43	3
Action to restore and/ or create intertidal/near coastal habitats (Mudflat/sandflat)	5.47	4
Action to restore and/ or create intertidal/near coastal habitats (Kelp/seaweeds)	5.64	5
Action to restore and/ or create intertidal/near coastal habitats (Intertidal under-boulder communities)	5.77	6
Action to restore and/ or create intertidal/near coastal habitats (Invertebrates)	6.15	7
Action to restore and/ or create intertidal/near coastal habitats (Saltmarsh/reedbed/seagrass)	6.80	8
Action to support populations of inshore and coastal (Birds and bats)	7.47	9
Action to support populations of inshore and coastal (Marine mammals)	7.63	10
Other	9.09	11

Fig. 3. The importance of various MNG actions in relation to future inshore and coastal wind farm deployment. The Ave Rank Scores column indicates the mean rank score for each option across the sample, where 1 is the most important. The Ave Ranked column then orders the options for the sample, with 1 as the most important. Variation among the options = SD 0.88. N ranged between actions from 11 to 16.

4.2.2. *Priority NG actions*

Stakeholders were asked to rank several NG restoration or supporting actions by their importance in relation to future inshore and coastal OWF deployment.

Fig. 3 shows that shellfish/mussel bed restoration and actions supporting plankton were ranked as the most important NG actions, closely followed by providing support to fish populations and the creation or restoration of mudflats/sandflats. Of least importance to participants were supporting actions for birds, bats, and marine mammal populations.

For OWF deployment, shellfish/mussel bed restoration was again ranked as highest importance, but invertebrates were given greater importance for offshore developments (Fig. 4). Actions supporting plankton remained important, as did restoration of subtidal sediments. Actions to support birds and bats, and marine mammals were once again deemed of least importance.

When asked to rank the importance of a series of other factors affecting offshore wind deployment, in relation to NG, stakeholders determined that life cycle financial budgets of wind farm structures were the most important consideration, followed by education and engagement, and BNG actions (Fig. 5). Protection, for example, via marine protected area management or species protection measures, was felt to be the least important factor, slightly below climate change and spatial planning policy.

4.2.3. *Views on decommissioning options and MNG*

Eighty-three per cent of participants agreed that NG actions (biodiversity or environmental) should be considered at the decommissioning stage of offshore wind structures, and of those remaining, 11 % were unsure. The complete removal of all structures was the preferred decommissioning option for stakeholders, followed by the abandonment of all structures. The least favoured listed option was to repurpose structures (i.e., as artificial reefs or for other activities). Three participants noted that the best solution was largely dependent on the type of structure and its location, with any of the given options (other than abandonment) potentially suitable in the right conditions. One person commented that only complete removal truly fits with the NG concept. Where structures have been designed to be left as a reef, then it would be acceptable to partially remove or topple them.

Given the opportunity to comment on any other aspect of NG, one stakeholder (consultancy) felt that any NG approach needed to have a mechanism for identifying priority species for a site, claiming it was 'just too hard to have net gain for everything.' Another participant (Non-government organisation (NGO)) pointed out that there are existing obligations, via numerous laws or treaties, that required a number of actions to be put in place by 2020, therefore a NG approach "whilst very interesting, feels a little like kicking the can down the road (again!)".

4.3. *Pressure reductions and BNG*

Stakeholders thought that fishing (dredging) (mean 4.27, SD 1.03), fishing (line and net) (mean 4.21, SD 0.89), and physical structure (mean 4.0, SD 0.85) were the most important pressures to prioritise when developing strategic NG for OWFs (Table 3). Quite a lot of uncertainty was shown for several listed pressures, particularly eutrophication (24 %), recreational activities (18 %), fishing (line and net) (18 %), aquaculture (18 %) and aggregate extraction (18 %). One participant suggested that in a time of biodiversity crisis, recreation must be afforded lower importance, even if temporarily.

Stakeholders were divided on whether fixed OWFs should be allowed to be built in MPAs, even where NG actions could sufficiently offset any negative environmental effects. Forty-four per cent felt they should be, while 17 % were unsure. The types of activities that stakeholders felt

Net Gain Actions	Ave Rank Scores	Ave Ranked
Action to restore and enhance (Shellfish/mussels)	4.06	1
Action to restore and enhance offshore (Invertebrates)	4.60	2
Actions to support offshore (Plankton and zooplankton)	4.67	3
Action to restore offshore (Subtidal sediments)	4.75	4
Action to support populations of offshore (Fish)	5.13	5
Action to restore offshore biogenic reefs (e.g., Cold water coral reefs, Maerl beds)	5.19	6
Action to support populations of offshore (Marine mammals)	6.00	7
Other (please specify in comment box below)	6.55	8
Action to support populations of offshore (Birds and bats)	6.81	9

Fig. 4. The importance of various MNG actions in relation to future OWF deployment. Variation among the options = SD 0.94. N ranged between 11 and 16.

Other Factors Affecting Offshore Wind Development	Ave Rank Scores	Ave Ranked
Life-cycle financial budget of structures	4.06	1
Education/ Engagement	4.53	2
Biodiversity Net Gain actions	4.94	3
Other	5.00	4
Economic (Jobs/employment)	5.12	5
Research and development (Enhancing structures)	5.18	6
Policy (Spatial planning)	5.65	7
Climate change	5.76	8
Protection (MPA management, species protection)	5.94	9

Fig. 5. The importance of various factors affecting offshore wind deployment. Variation among the options = SD 0.60. N ranged between 13 and 17.

Table 3
Mean ratings and standard deviations for prioritising human pressures to consider when developing strategic NG targets.

Marine Pressure	N	Mean	SD	% Uncertain
Aggregate extraction	14	2.93	1.07	18 %
Aquaculture	14	3.50	1.09	18 %
Cables (entanglement)	15	3.53	1.25	12 %
Chemical contamination	15	3.27	0.88	12 %
Electro Magnetic Fields	16	3.25	1.00	6 %
Eutrophication	13	3.08	1.12	24 %
Fishing (line and net)	14	4.21***	0.89	18 %
Fishing (dredging)	15	4.27***	1.03	12 %
Invasive species	15	3.73***	0.96	12 %
Marine litter and debris	16	3.75***	0.86	6 %
Physical structure (inc. cables)	15	4.00***	0.85	12 %
Recreational activities	14	3.36***	0.63	18 %
Shipping	15	3.60***	0.83	12 %
Underwater noise	16	3.88***	0.62	6 %

Note: scale ranged from very unimportant (Hughes et al., 2022) to very important (Bull and Strange, 2018) with a mid-point of nether unimportant or important (UNFCCC 2022). N varies with number of unsure responses excluded and 5 participants did not answer. ***Denotes statistically significant to the mid-point to a p-value <0.05.

were most feasible to co-exist within fixed OWFs were seaweed, mussel, and oyster farming, although one participant (NGO) advocated against aquaculture practices in areas where the farmed species do not naturally exist, and another (Government agency) advised that the geographical conditions needed to be right for aquaculture farms to be successful. Stakeholders also agreed that hydrogen and carbon capture storage, and line & net fishing could work alongside OWFs. There were mixed views about the feasibility of co-existence of recreational activities and floating solar arrays while 83 % of participants did not agree that trawl fishing could operate alongside turbines.

4.4. Floating wind, BNG and co-location

There is growing developmental and research significance of floating wind alongside other types of development. As such, while not the main topic explored by the questionnaire on this occasion, it was felt useful to identify any floating-wind specific perceptions from stakeholders. As table 1 shows, although only one participant indicated they were exclusively interested in floating wind, all but one stakeholder highlighted that they were interested in all aspects of marine renewable energy.

A similar proportion of participants agreed that both fixed (44 %) and floating (42 %) wind farms should be allowed to be built in UK MPAs; however, fewer stakeholders (32 % compared to 39 %) were explicitly against the notion, and more (26 % to 17 %) were unsure about floating wind compared to fixed.

The major difference between the perceptions of the two types of construction was the degree to which stakeholders saw fishing activities (particularly trawling (mean 3.94)) co-existing with floating wind farms, as well as hydrogen or carbon capture storage devices (mean 3.87). Stakeholders were also slightly less convinced of the feasibility of co-existence between floating wind farms and aquaculture farming practices (means from 3.5 to 3.56). There was no statistical difference between the means for scoring the level of feasibility for floating solar parks or recreational activities co-existing with floating or fixed wind farms. There was, though, less variance between the activities for floating wind. (Table 4). Less than half (45 %) of stakeholders agreed or strongly agreed that floating wind farms should co-exist with floating solar parks. The relationships between marine activities were explored further using a two-dimensional NMDS ordination, showing self-clustering of marine activities, with low stress figures (0 and 0.02) indicating high reliability. When the activities were re-ordered according to similarities in levels of feasibility, one clear cluster became evident for fixed OWFs, with fishing (trawling) distanced from all other activities (Fig. 6a), clearly indicating stakeholders' clarity regarding the unsuitability of this activity for co-location. For floating wind farms (Fig. 6b) tight clustering of the three aquaculture farming practices is still evident indicating very similar feasibility scoring, and reinforcing the perception that these activities could exist alongside windfarms, whether fixed or floating. The remaining activities show more dispersed distances between them indicating greater variability across the data for responses regarding floating wind.

5. Discussion

In a world where management decisions and measuring, valuing, and monitoring mechanisms that tackle the global biodiversity crisis are rapidly becoming critical across all sectors, including those governing and impacting the marine environment (for example, (Magurran, 2021; UN Convention on Biological Diversity (CBD) 2021)), this paper presents useful insights on various aspects of MNG from a marine renewable energy stakeholders' perspective. Specifically, the paper considers responses to a series of questions around the future delivery of BNG, and possibly wider ENG, in anticipation of these becoming mandatory

Table 4
Feasibility of marine activities co-existing with fixed and floating wind farms. Means of Likert-scale values where 1=strongly disagree and 5=strongly agree. N varied between 15 and 16 for fixed, 14–16 for floating. ***Denotes statistically significant to the mid-point to a p-value <0.05.

	Fixed	Floating
Fishing (trawling)	2.25***	3.94***
Fishing (line and net)	3.75***	4.06***
Oyster farming	3.93***	3.50***
Mussel farming	4.07***	3.50***
Seaweed farming	4.19***	3.56***
Floating solar park arrays	3.33	3.36
Hydrogen/Carbon Capture Storage devices	3.80***	3.87***
Recreation activities	3.47	2.87

Fig. 6. NMDS ordination of feasibility for co-existing marine activities with a/ fixed OWFs and b/ floating OWFs. Goodness of fit calculated using Kruskal's Stress. Distance metric = Euclidean.

requirements of marine developments in England, and more broadly within the next decade as nations strive to meet their Sustainability Development Goals (United Nations, 2022).

Several clear and important points emerged from this study, specifically:

5.1. Perceptions of delivery of MNG and ecosystem services

While stakeholder interest in BNG policy and planning was high, few felt they held much power to change or affect policy development. Uncertainty around several aspects of MNG may reflect the relative novelty of the concept, the extent of unknowns surrounding its delivery, and the challenges of developing effective new strategies (Hooper et al., 2021).

Participants agreed with current views that species should be included within MNG targets, in addition to habitats (Hooper et al., 2021; Offshore Wind Evidence and Change Programme Task and Finish Group (OWEAP T&F Group) 2021), addressing the concern that marine habitats offer weaker proxies for species compared to terrestrial environments due to higher levels of species mobility (DEFRA 2022). While fish received unanimous support for inclusion in assessments, birds and marine mammals were favoured by Government agency representatives while non-government organisations felt invertebrates needed to be included.

Methods adopted to enable translation of strategic planning objectives to the site level need to be addressed (Hooper et al., 2021). In this study stakeholders identified several priority inputs needed to meet NG requirements and support planning and policy activities. These include regional or site-specific climate change adaptation options and modelling studies which provide valuable information on climate change impacts on the offshore wind energy sector (Pryor et al., 2020; Susini et al., 2022). Models can also provide data on the potential impacts of clustered OWFs on near sea surface characteristics (Akhtar et al., 2022). Stakeholders also require access to information on stakeholder involvement, habitat mapping data, and additional biodiversity data, to which Jacob et al. (2020) stress the need for a baseline and counterfactual to measure project losses and offset gains, noting that reliable marine biodiversity data are often limited and that assessments often under-represent marine species. Participants from this study suggested risk data from external pressures would be useful, such as the potential for invasive species using offshore wind structures as artificial reefs (Lloret et al., 2022). There was also a call for the restoration potential of specific habitats to be identified; for example, by revealing which habitats would deliver the greatest resilience to climate change.

While there are recent calls for ecosystem services to be used in habitat valuations (Offshore Wind Evidence and Change Programme Task and Finish Group (OWEAP T&F Group) 2021), this study went further by asking stakeholders to indicate which ecosystem services they felt were the most important to consider when developing NG measures in relation to offshore wind, with fisheries, the maintenance of nursery habitats, seaweed aquaculture, and climate regulation emerging as the most important. The NMDS ordination showed a distinct separation of climate regulating services (such as carbon sequestration) from the main cluster of ecosystem services, likely reflecting the higher importance placed on them by stakeholders, in turn potentially responding to the topicality of blue carbon at the time of the engagement activity. The authors note, therefore, potential topicality bias for this outcome. The cultural ecosystem services are distanced from each other and without clear pattern, possibly a product of uncertainty about cultural services indicated by stakeholders. The ordination did, however, place tourism and recreation within the same cluster as regulating and supporting services, potentially reflecting the close links with some of these services i.e., connections to weather regulation (Pueyo-Ros, 2018), and the appeal of biodiverse environments to recreational users (Barton et al., 2019).

5.2. Strategic MNG restoration, enhancements and decommissioning of OWF

Industry and non-governmental stakeholders favoured development of a new metric to measure MNG for the offshore marine environment, while an industry levy for contributing to a strategic fund was also acceptable, particularly with government agencies. A metric based on measures applied to terrestrial NG, such as DEFRA's biodiversity 4.0 metric, was not popular. These findings are broadly in line with the offshore wind enabling actions programme (OWEAP) (Offshore Wind Evidence and Change Programme Task and Finish Group (OWEAP T&F Group) 2021) survey responses which concluded that MNG would have greater impact on environmental recovery if funding was pooled into a national fund for delivery of strategic NG targets. Stakeholders contested that strategic measures shouldn't come at the exclusion of site-level considerations.

The most important NG actions for environmental restoration and/or enhancement were determined by stakeholders to be shellfish/mussel bed restoration, mudflat/sandflat restoration, invertebrate habitat restoration, and actions supporting plankton and fish communities. Net gain actions to support birds and marine mammals were considered least important, perhaps reflecting the ecological understanding of the stakeholders on the significance of ecosystem functions provided by key habitats and lower trophic levels associated with inter-tidal and subtidal environments. This differs from OWEAP's (Offshore Wind Evidence and Change Programme Task and Finish Group (OWEAP T&F Group) 2021) view that both intertidal and offshore birds should be afforded high priority for NG, at least for intertidal habitat restoration. The priorities determined in the current study reflect an extension of ambition for NG outcomes beyond that commonly experienced to date where mitigation strategies aligned to different stages of offshore wind development have been limited to revegetation of temporary use areas and reinstatement of original vegetation following decommissioning (Bennun et al., 2021). Such motivational shifts could be considered a major benefit arising from MNG policies. The priority habitats highlighted by this study might inform the current debate on which 'irreplaceable habitats' should fall outside the scope of MNG. ABP Marine Environmental Research Ltd (2019) made the case for some subtidal habitats to be excluded, such as maerl beds, cold water corals and carbonate mounds, and emphasized the importance to marine ecosystem functioning of restoring lost intertidal habitats. The OWF development stakeholders from this study ranked some of these habitats (maerl beds, coldwater corals) relatively low compared to other habitats and taxonomic groups, which might be considered contrary to current academic thinking. For example, the Marine Biological Association of the UK's definition of coastal and marine irreplaceable habitats scored thirteen habitats particularly highly against their assessment criteria, including deep sea sand, deep sea mud, and circalittoral coral reefs (Tillin et al., 2022).

On being asked to consider OWF decommissioning options, the majority of the stakeholders were in favour of complete removal and abandonment of all structures, while acknowledging that the best solutions are likely to depend on local conditions and structure type (Lemasson et al., 2023). This is contrary to prevailing opinion that complete removal may not be the most beneficial option for decommissioning marine artificial structures (Knights et al., 2023), and that societal or environmental benefits might be better achieved through more sustainable options such as re-use and multi-repurposing (Capobianco et al., 2022; Sommer et al., 2019). For any decommissioning option, the financial cost of the action will need to be accounted against the value of potential BNG. Also, any potential impacts on biodiversity will need to be given more detailed consideration than they are for present environmental impact assessments.

5.3. Pressure reductions and BNG

The open, connected nature of marine environments means that human activity pressures may be expressed over wide spatial scales, affecting not just marine habitats but also key taxonomic groups (Halpern et al., 2019). Restoration of some marine ecological features may require active intervention where it is ecologically feasible but for other features recovery may need to be facilitated through removal of existing pressures. In contrast to the terrestrial environment where NG is focused solely on habitat lost to development, there is greater opportunity within the marine environment to consider wider possibilities for NG, including species restoration and removal or reduction of pressures. Fishing (dredging), fishing (line and net) and physical structure were thought by stakeholders to be the priority human activity pressures to include within strategic NG assessments for OWFs, which is relevant considering the UK Government's plans for MNG, as it stands, would exclude fisheries. The need for measures to reduce fishing pressures that contribute to biodiversity loss featured prominently in responses to DEFRA's consultation (DEFRA 2022; UN Convention on Biological Diversity (CBD) 2022), a point supported by the findings here, and elsewhere (Hooper et al., 2021; Office for Environmental Protection (OEP) 2022).

The lowest priority was afforded to aggregate extraction, eutrophication, EMF, chemical contaminants, and recreational activities, aligning well to the OWEAP survey results, although underwater noise was afforded a comparatively higher priority in this study. With a requirement to include underwater noise assessments within environmental impact assessments, it is perhaps an expectation that stakeholders would be sensitized to placing some priority on this pressure.

With the UK Government's commitment to accelerate offshore wind deployment over the coming years (Office for Environmental Protection (OEP) 2022), competition for seabed space will increase between marine sectors. There has been some reluctance toward multi-use solutions from

Table 5
Heat map of responses to similar questions included in both the OWF stakeholder consultation (led by Plymouth Marine Laboratory (PML) and DEFRA's consultation of their proposed principles of MNG. Green cell = high consensus; amber cell = fair consensus; red cell = low consensus.

	Comparison of results	
	PML consultation	DEFRA consultation
Should MNG/BNG be mandatory for future developments?	59% yes	81% yes
Should MNG include species as well as habitats?	86% yes	89% yes
Which environmental benefits/ES should be included?	Most important are fisheries, maintaining nursery habitats, climate regulation and aquaculture	Fishing practices, climate change control, habitat benefits
Which approach for measuring MNG is preferred?	40% yes to new metric, 30% yes to industry levy	51% yes to contributions-style approach; other options include a measure of cumulative impacts
Which marine pressures/pressure reduction activities should be prioritised?	Underwater noise, fishing (dredging), structures, marine litter, fishing (line & net)	Marine litter, water and air quality improvements, spill prevention, noise reduction; fishing pressure; restoration measures; industry pressures (inc. structures);
What strategic interventions should be encouraged (DEFRA)/prioritised (PML)?	Restoration of shellfish/mussel beds; supporting plankton communities; supporting fish populations	Mostly fisheries-related e.g., removal of trawling pressures, incentivizing sustainable fishing, noise reduction strategies, improving fish spawning habitats

the offshore wind industry to date, except where zero risk is identified to their operations (Schupp et al., 2021). The cross-sector stakeholders in this study agreed that seaweed, mussel, and oyster farming were the most feasible marine activities to co-exist within fixed OWFs. This matches findings in other studies, such as Abhinav et al.'s (2020) review of offshore multi-purpose platforms in which the authors concluded there was significant potential in economizing capital and operational costs for the offshore energy and aquaculture industry through co-location planning and shared infrastructure. Other feasible activities included carbon/hydrogen capture storage facilities (as assessed by (Robertson and McAreavey, 2021)) and line and net fishing. A body of evidence in the literature examines the potential for co-existence of OWFs and various fisheries (Hooper and Austen, 2014, Kafas, 2017, Roach et al., 2022), and there are calls on planning systems to give greater prioritization to co-existence and to enable earlier-stage strategic considerations of wind farm design and location (National Federation of Fishermen's Organisations (NFFO) 2021).

5.4. Floating wind, BNG and co-location

Research and development of innovative technologies and mechanisms to incentivize their deployment has been promoted in recent energy literature (Ullah et al., 2023). The inclusion of floating wind in this study is therefore timely, as a promising emerging technology that is likely to experience rapid deployment over the next 5–10 years globally but for which the environmental impacts are still largely unknown due to a lack of empirical studies (Farr et al., 2021). There was, perhaps unsurprisingly, greater uncertainty around potential impacts of floating wind developments, for example, on whether they might have negative effects if located within MPAs. There were, however, some notable differences in the industries stakeholders felt could co-exist with floating wind farms compared to fixed. Stakeholders felt differently about the feasibility of co-locating trawl fishing with fixed OWFs compared with floating technology. In the UK, although fishing will unlikely be banned around all floating wind farms outright, certain methods, particularly trawling, are likely to be prohibitive due to potential cabling impacts. Recreational activities were also deemed less feasible alongside floating infrastructure compared to fixed. These perceptions may be challenged when the results of a survey undertaken by Marine Scotland in 2022 become available, in which the use of different types of fishing gear around the Hywind Scotland floating wind farm have been tested with a view to recommending safe fishing operations (Penman, 2021).

5.5. MNG and UK policy

In 2022 DEFRA consulted a range of stakeholders on their proposed high-level principles for MNG with a view to constructing a final framework for a MNG policy. The consultation included a degree of commonality with the research reported in this paper with explorations of several similar themes (mandating NG for marine developments, the scope and application of MNG, potential adoption of an ENG approach). Comparing responses can provide insight into how perceptions of MNG concepts differ between OWF stakeholders and those from the wider marine community (Table 5). On definitions of MNG, an equally high proportion of respondents across the samples agreed that species should be included within assessments, and there was also consensus on the environmental benefits (ecosystem services) that should be considered (particularly fisheries, maintaining nursery habitats and climate regulation). The DEFRA consultation identified recommendations from its respondents that ecosystem functions should be included within MNG impact.

There was disparity on the preferred mechanism for measuring MNG with 51 % of DEFRA respondents supporting a levy-style contributions-based approach compared to 30 % of OWF stakeholders in the present study - the latter showing a predilection for a new metric specifically applicable to the marine environment.

Although 59 % of OWF stakeholders agreed that BNG should be mandated for all future OWF developments, much uncertainty was expressed across the sample, a less convincing response than DEFRA's consultation where 81 % of respondents agreed with this mandate, and 14 % opposed, reflecting a more binary view of the issue. This is potentially explained by the OWF stakeholders still needing to be convinced of some of the technical aspects and success criteria that can be applied to BNG measures for this industry.

The stakeholders of both studies identified similar priorities for marine pressure reduction activities – commercial fishing practices, underwater noise reduction, industry pressures (including structures), and marine litter – with the DEFRA exercise also highlighting the need for air and water quality improvements and spill prevention.

Both consultations sought to identify the strategic interventions that could be incentivized through MNG, with the DEFRA respondents highlighting mostly fisheries-related actions while the OWF stakeholders prioritised the restoration of shellfish/mussel beds and actions supporting plankton and fish populations.

This opportunistic comparison provides additional evidence on perceptions of the current proposals for MNG delivery in the UK, adding perspective from a sector of marine development that is set to dominate marine policy for the foreseeable future. The insights from this study should go some way toward tackling several of the outstanding questions that still need to be addressed for the design and implementation of MNG and how this approach relates to existing UK policy and decision-making mechanisms in the marine area. The significance of the MNG policy extends into responses to calls for action to reverse biodiversity loss from the UN Decade of Ocean Science for Sustainable Development and UN Decade of Ecosystem Restoration, and contributing to the UK's commitments to delivering the Sustainability Development Goals, particularly SDG 14 around the conservation and sustainable use of marine resources.

The support evidenced in this study for embracing wider environmental benefits as part of MNG strategy also aligns with OSPAR's promotion of the ecosystem approach within marine environmental assessments through its Convention for the Protection of the Marine Environment of the North-East Atlantic. A revision of the UK National Biodiversity 2020 strategy is planned and will provide an opportunity to integrate these international and regional commitments, as well as align with the national marine strategy, which should help to address the unknowns around MNG within marine contexts (Greenhill and Howell, 2021), many of which have been addressed in this paper.

5.6. Generalizability and limitations of the study

Although the sample used for this study was limited to OWF stakeholders, many of the agencies represented by the study participants work across the renewable energy sector, while the government agencies that participated operate more broadly within the marine realm. It is therefore reasonable to assume that many of the insights and opinions of MNG from OWF stakeholders will be applicable to developments within other marine sectors. Drawing insights from the OWF industry, many of the details explored in this study in relation to the development of a mechanism for assessing MNG will be applicable to other marine activities, such as oil and gas platforms and wave energy technologies. The key findings and recommendations from this study may therefore be of interest to all marine industries.

Globally, attention has turned from ecological conservation to restoration, away from halting destructive practices toward active recovery and repair (Decade of Ecosystem Restoration, 2019, Usher, 2023). Restoration programmes are being scaled up to meet UN targets (United Nations Environment Programme (UNEP) 2021) and in the UK ecological restoration has moved front and centre of debate in the environment sector (Usher, 2023). However, as Governments find that biodiversity targets become harder to meet from existing NNL policies, including restoration and mitigation banking approaches, alongside limited economic resource allocations, it is likely to be evident that net gain approaches will become more critical to enable nations to 'catch up' with their commitments to international drivers.

Simultaneously, biodiversity enhancement is increasingly being considered in a context of wider environmental improvements to realise cumulative benefits toward sustainability targets. To this end, findings from this study included the view that MNG should incorporate environmental enhancements that include species as well as habitats. While the inputs reported here are limited to OWF stakeholders, they should be considered in tandem with other industries and marine activities in order to identify stacked environmental and social benefits from, for example, co-location of activities. This study touched upon this theme by extracting perceptions around optimal activities to co-exist with OWFs, but further research to provide baseline data on impacts from co-located activities is required to determine which activities are best located to provide mutual benefits and how this can be most effectively developed in practice.

The authors acknowledge that although the study intentionally adopted an elicitation approach to data collection from a modest number of stakeholders, it does present a small sample for a questionnaire format. While this meant a broad range of sectors was represented across the data, there was some imbalance between those sectors which may have influenced responses. The academic literature base may benefit from similar questions being put to stakeholders through surveys aimed at broader geographic scales and different marine activities.

6. Conclusion and policy implications

6.1. Conclusion

This study examines the insights of multi-agency UK OWF stakeholders on the principles and delivery of MNG. The key findings from an interactive stakeholder engagement activity included the view that species and wider ecosystem services should be considered within MNG measures, with fisheries, maintaining nursery habitats, and climate regulation identified as most important. The most important NG actions for environmental enhancement for future OWF deployment were perceived to be shellfish/mussel bed and invertebrate habitat restoration, and actions supporting plankton communities. Strategic NG assessments should prioritize pressures arising from fishing practices and physical structures. While stakeholders agreed that NG actions should be considered for OWF decommissioning, they countered prevailing preferences for complete removal or abandonment of all structures as decommissioning options. Aquaculture farming was felt to be the most feasible activity to co-exist with fixed OWFs, while possible co-location of floating wind farms with fishing practices and carbon capture storage devices was well-supported.

6.2. Policy implications

Reflecting the fact that many governments are still considering, or are not yet ready, to introduce a BNG requirement for marine OWF developments, this is very much a "first principles" consultation setting out the aims of NG policy for the marine environment and seeking views on the scope and application of MNG. From these outcomes, the following recommendations are offered for consideration alongside future policy development and scientific research:

1. **Understanding of MNG concepts:** To improve consistency on understanding of terminology, greater clarity on terms and opportunities for engagement should be made available for interested parties. Focused stakeholder engagement should be

undertaken to identify the most useful formats and data transfer mechanisms for the provision of specific information needs required for effective ENG assessments, such as adaptive policy guidelines, spatial habitat data, and biodiversity data. To maximize the likelihood of successful NG solutions, enable greater awareness for stakeholders of development-specific risks of external pressures as well as guides to the restoration potential for specific habitats likely to be impacted by proposals.

2. **MNG to measure impacts on habitats and species**: Acknowledging the dynamic nature of the marine environment, this study proposes including coastal and offsite impacts in MNG assessments, which should include taxonomic groups e.g. birds and invertebrates, while more discussion is needed around small marine organisms (such as plankton) whose importance has been highlighted in this study, as well as irreplaceable habitats such as corals, deep sea sand and deep sea mud which were ranked with relatively low importance by OWF experts.
3. **MNG to incorporate environmental benefits:** The view that MNG should expand on BNG to incorporate a wider ENG approach is supported to include the social, environmental and economic value of natural assets where these extra benefits are underpinned by biodiversity.
4. **Priority ecosystem services for inclusion in ENG measures:** Specific ecosystem services to focus on should include: i/ fisheries, ii/ maintaining nursery habitats, and iii/ climate regulation. Cultural services are poorly understood by stakeholders, hence guidance on their definition, assessment, and valuation as part of NG is required.
5. **Developing metrics for MNG:** The preference by offshore energy stakeholders in this consultation is to develop a new NG metric that is nuanced for a marine context. A secondary option is to rely on an industry levy for a strategic fund.
6. **Prioritizing pressure reduction actions for MNG**: Pressure reductions can have an important role to play in successful MNG strategies. Reducing impacts from some fishing methods and the disturbance effects of the physical structures (including cables) were of high priority for consideration within strategic NG assessments for OWFs.
7. **MNG to incentivize active restoration measures:** Actions to restore or enhance shellfish/mussel and mudflat/sandflat beds while also supporting plankton and zooplankton populations were of high importance to stakeholders in the coastal and offshore zones. Intertidal invertebrates and offshore fish populations were also raised as important to consider within future MNG compensatory actions.
8. **MNG preferences during decommissioning:** Specifically, the consultation supports complete removal of offshore wind structures for decommissioning, where possible, but encourages solutions that best fit site conditions and character, with abandonment of structures also consider positively as an option for biodiversity and environmental benefits.
9. **MNG to incentivize strategic interventions:** acknowledging that while site-based interventions should not be overlooked, they may not always be appropriate or desirable, hence the paper envisages developers having the flexibility to bring forward either site-based or strategic interventions. The paper acknowledges the perceived feasibility of co-locating seaweed, mussel, and oyster farming, as well as Hydrogen/Carbon Capture Storage devices, with both fixed and floating wind farms. Research and collaborative explorations around co-existence of fishing methods with, in particular, floating wind technology, should continue to be encouraged.
10. **MNG or improvements to designated and non-designated features of MPAs (MPAs):** NG interventions will be permitted within MPAs if opportunities outside these areas are not feasible. While just over 40 % of participants agreed that both fixed and floating wind farms should be allowed to be built in UK MPAs there was a high degree of uncertainty (26 %) around the impacts of floating OWF, highlighting an area of priority research need.

Implementation of these recommendations should inform strategic considerations around natural resource management in the marine environment; for example, by prioritising certain marine activities for co-existence, while also strengthening the consent process for OWF proposals. In doing so, better planned OWF projects have a better chance of, not just protecting, but restoring and enhancing seabed habitats and acting as refuges for marine species.

CRediT authorship contribution statement

Andrew Edwards-Jones: Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Stephen C.L. Watson:** Conceptualization, Supervision, Validation, Data curation, Visualization, Writing – review & editing. **Claire L. Szostek:** Formal analysis, Visualization. **Nicola J. Beaumont:** Conceptualization, Data curation, Funding acquisition, Methodology, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2023.100814.

Appendix A

Table A.1
Definitions of frequently used acronyms. *Terms in italics are shown for information only.*

Terminology	Used in this paper	Definition
Net Gain (NG)	Yes	An approach to development that leaves the environment in a better state than before. It can include concepts such as BNG as well as wider environmental gains including natural capital benefits and ecosystem services. Its application is designed to leave biodiversity in a better state and secure wider benefits for people and the environment (DEFRA 2018). The NG approach is additional to the mitigation hierarchy where it aims to offset impacts that are residual, those that cannot be avoided or mitigated.
Biodiversity Net Gain (BNG)	Yes	A way to contribute to the recovery of nature while developing land or sea. It is making sure the habitat for wildlife is in a better state than it was before development (UK Government, 2023). Where a development has an impact on biodiversity it encourages developers to provide an increase in appropriate natural habitat and ecological features over and above that being affected in such a way it is hoped that the current loss of biodiversity through development will be halted and ecological networks can be restored (CIEEM, 2019).
Marine Net Gain (MNG)	Yes	The application of the NG principle, as defined above, applied to the marine environment. MNG should expand on BNG to incorporate a wider ENG approach that seeks to include the social, environmental and economic value of marine natural assets where these extra benefits are underpinned by biodiversity (DEFRA 2022).
Environmental Net Gain (ENG)	Yes	Improving all aspects of environmental quality through a scheme or project. Achieving ENG means achieving BNG first and going further to achieve net increases in the capacity of affected natural capital to deliver ecosystem services (DEFRA 2018).
No Net Loss (NNL)	Yes	NNL requires that biodiversity losses associated with development are quantified and any unavoidable impacts fully compensated for by commensurate gains (Bull et al., 2016).
Natural Capital Net Gain	No	Very similar to ENG – an approach that measures changes to biodiversity units using a natural capital approach as well as quantifying direction of change to specific ecosystem services (Holt & Roquette, 2020).
Ecosystem Services Net Gain	No	Factors in the potential for restored habitats to provide a wide range of ecosystem service co-benefits, whose achievement should not be to the detriment of biodiversity objectives (McVittie & Faccioli, 2020).
Net Positive Impact	No	The point at which project-related impacts are outweighed by measures taken according to the mitigation hierarchy, resulting in a NG of the relevant biodiversity features. The aim is to improve the state of the environment relative to its predevelopment state (Moilanen & Kotiaho, 2021).
Offshore Wind Farm (OWF)	Yes	Offshore wind farms are wind farms located in water bodies at sea (Abramic et al., 2022).

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Appendix B

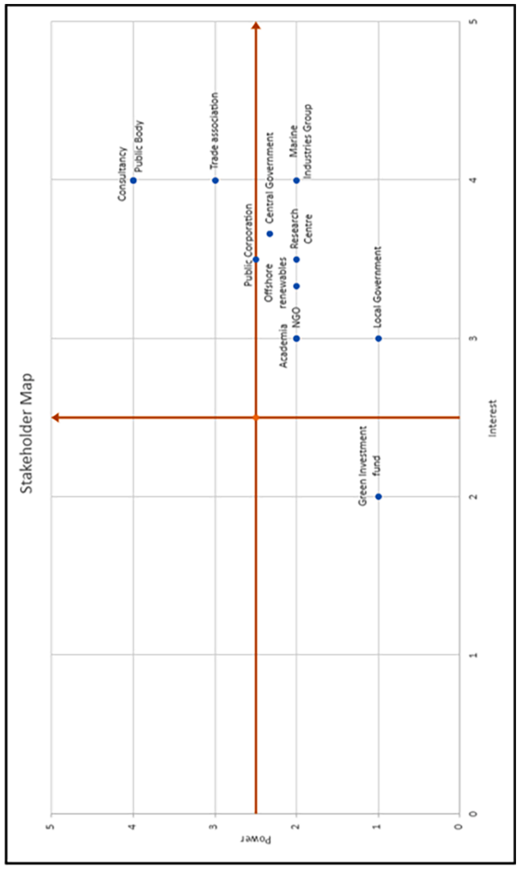

Fig. B.1. Power-influence matrix for recruitment of offshore wind farm experts to participate in stakeholder workshop.

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