JNCC Report 773

Assessing additional natural capital benefits to area-based management of marine protected areas: how fisheries restrictions affect ecosystem service delivery in Lyme Bay

Matthews, S., Blanchard, S., Booth, J. and Anderson, L.

July 2024

ISSN 0963 8091

JNCC's report series serves as a record of the work undertaken or commissioned by JNCC. The series also helps us to share, and promote the use of, our work and to develop future collaborations.

For further information on JNCC's report series please contact:
Joint Nature Conservation Committee, Quay House, 2 East Station Road, Fletton Quays
Peterborough, PE2 8YY

https://jncc.gov.uk/

Communications@jncc.gov.uk

This report should be cited as:
Matthews, S.[1], Blanchard, S.[1], Booth, J.[1] & Anderson, L.[1] 2024. Assessing additional natural capital benefits to area-based management of marine protected areas: how fisheries restrictions affect ecosystem service delivery in Lyme Bay. *JNCC Report 773*, JNCC, Peterborough, ISSN 0963-8091.
https://hub.jncc.gov.uk/assets/30100b2d-72ae-4f60-bc0d-b730b323ffc9

Author Affiliation:
[1] JNCC, Quay House, 2 East Station Road, Fletton Quays, Peterborough, PE2 8YY

Evidence Quality Assurance:
This report is compliant with JNCC's Evidence Quality Assurance Policy.

Whilst every effort is made to ensure that the information in this resource is complete, accurate and up-to-date, JNCC is not liable for any errors or omissions in the information and shall not be liable for any loss, injury or damage of any kind caused by its use. Whenever possible, JNCC will act on any inaccuracies that are brought to its attention and endeavour to correct them in subsequent versions of the resource but cannot guarantee the continued supply of the information.

This report and any accompanying material is published by JNCC under the Open Government Licence (OGLv3.0 for public sector information), unless otherwise stated. Note that some images may not be copyright JNCC; please check sources for conditions of re-use. Please note the following copyright information applies to the maps presented in the report (Figures 3, 4, 5, 6 and 7): '© JNCC 2023. The site boundaries include sections of UK Exclusive Economic Zone © Crown copyright. The exact limits of the EEZ are set out in The Exclusive Economic Zone Order 2013. If you re-use this information, you must acknowledge the source in your product or application by including or linking to the following attribution statement: Contains Joint Nature Conservation Committee data © copyright and database right [2023]. Contains Natural England data © copyright and database right [2023]. Contains UK Hydrographic Office data © copyright and database right [2023]. Contains Ordnance Survey data © copyright and database right [2023]. Information contained in the map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).'

The views and recommendations presented in this report do not necessarily reflect the views and policies of JNCC.

Summary

The role of natural capital asset condition in mediating the delivery of ecosystem services is not well-understood. The removal of pressures (i.e. marine protected area (MPA) management) provides a useful opportunity to assess whether recovering ecological condition over time is linked to the improved delivery of ecosystem services. Here, we use a well-researched case study to explore the interactions between asset condition and ecosystem service delivery. Our findings form the basis for initial recommendations to support ecosystem service and natural capital-based approaches in MPA management.

Using the Lyme Bay MPA as an in-depth case study, we conducted a targeted literature review of how protecting natural assets may confer changes to service delivery. From JNCC's universal Asset Service Matrix (uASM – see note below), we developed a bespoke ASM to identify assets and ecosystem services relevant to the case study area. This, in turn, defined the scope of the literature review on documented changes to these services after MPA designation. We found that ecosystem service delivery across several services has changed positively with the implementation of the MPA, though the nature of the evidence and the confidence associated with these changes varies significantly.

Whilst there is strong evidence for the improved condition of marine assets following MPA designation and management, our understanding of the implications for ecosystem service delivery remains highly variable and focussed on a few core services. The assessment of ecosystem service delivery in the context of MPAs is connected to broader challenges across the natural capital space in better understanding the relationships between asset condition and service delivery. We recommend including approaches to monitoring ecosystem services linked to asset condition to inform adaptive MPA management.

Note: JNCC's universal Asset Service Matrix describes and catalogues linkages between UK marine natural assets (habitats and species) and the ecosystem services that they provide. It can be found at https://www.marlin.ac.uk/asm.

Contents

Acronyms

Acronym	Full description
25 YEP	25 Year Environment Plan
ALBs	Arm’s Length Bodies
ASM	Asset Service Matrix
CICES	Common International Classification for Ecosystem Services
CO_2	carbon dioxide
EBM	Ecosystem-based management
EIP	Environmental Improvement Plan
ES	Ecosystem services
HPMA	Highly Protected Marine Area
MCZ	Marine Conservation Zone
MESO	Marine Ecosystem Services and Optimisation tool
mNCEA	marine Natural Capital and Ecosystem Assessment Programme
MPA	Marine Protected Area
NC	Natural Capital
ncMPA	Nature Conservation Marine Protected Area
NGOs	Non-governmental organisations
NTZ	No-take zone
OECMs	Other effective area-based conservation measures
PAME	Protected area management effectiveness
RAS	reef associated species
SAC	Special Area of Conservation
SACO	Supplementary advice on conservation objectives
SCUBA	Self-contained underwater breathing apparatus
SPA	Special Protection Area
uASM	universal Asset Service Matrix
WTP	Willingness to pay

List of Tables

List of Figures

1 Introduction

1.1 Natural capital and ecosystem services

Natural capital refers to the natural environment and how it underpins human needs and wellbeing. This includes ecosystems, species, water, soils and all natural processes and functions (Natural Capital Committee 2019). Elements of the natural environment that provide ecosystem services (ES) are called assets (Natural Capital Committee 2019). Ecosystem services are simply the benefits that people obtain from natural assets (MEA 2003). These include provisioning services (e.g. food and water), regulating and maintenance services (e.g. flood protection, nutrient cycling) and cultural services (e.g. spiritual connections, recreational activities) (MEA 2003).

Natural capital underpins four other types of capital in a ‘five capitals’ framework (Figure 1). These are manufactured, financial, human, and social capital. Collectively, they have the capacity to produce desirable outputs for humans, and all are necessary for sustainable development (Goodwin 2003; Natural Capital Committee 2019). Natural capital is a useful concept for understanding and properly valuing the contribution that nature makes to human wellbeing, integrating this valuation into trade-offs and decision making around other societal needs. In this way, natural capital approaches seek to prevent the continued undervaluation and overexploitation of the natural world. Understanding and measuring the delivery of ecosystem services is fundamental to applying natural capital approaches to the conservation and management of natural resources.

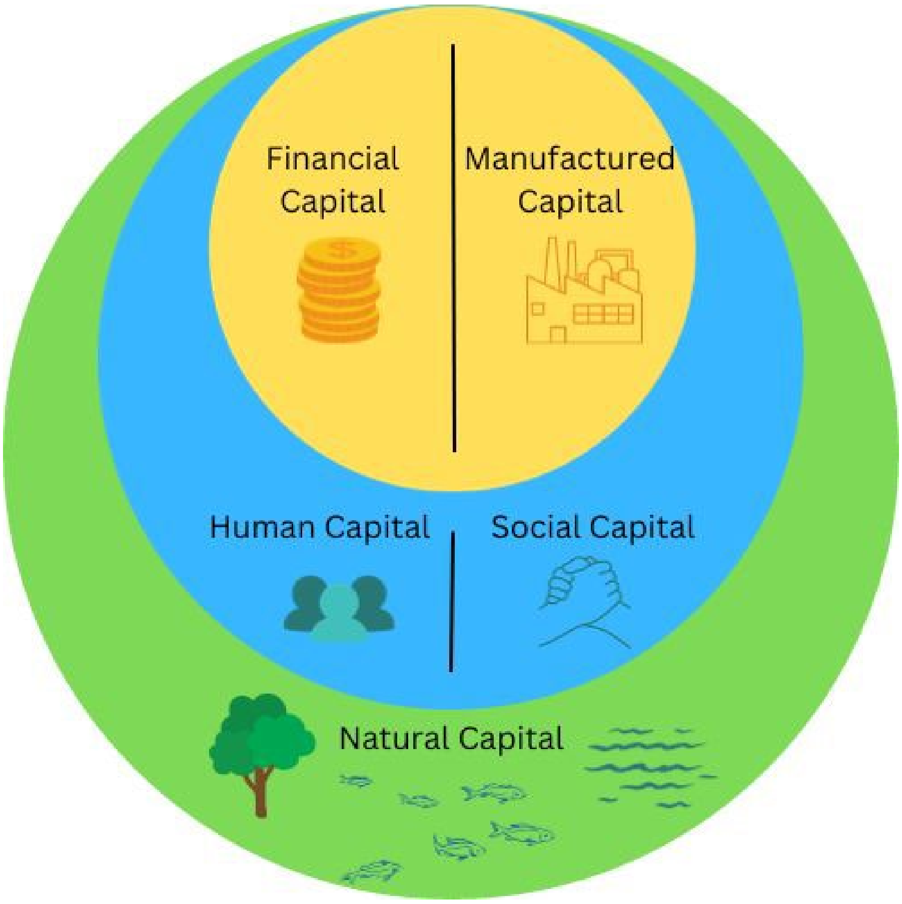


Figure 1. The five capitals (adapted from Natural Capital Committee 2019).

1.1.1 Policy context for marine natural capital and ecosystem services

The 25 Year Environment Plan (YEP), UK Marine Strategy, Fisheries and Environment Acts have collectively set out a need for more integrated, ecosystem-wide approaches to marine management and conservation (Rees *et al.* 2020). A whole ecosystem perspective, with an appreciation of the services and benefits we derive from healthy, functioning ecosystems is foundational to natural capital approaches. Also central to the implementation of natural capital is the need to recognise the social and economic interactions we have with the marine environment and to include these in decision-making (Rees *et al.* 2020). Research and policy applications for UK marine natural capital include Defra's marine Natural Capital and Ecosystem Assessment (mNCEA) Programme, Scotland's Blue Economy Vision and the Scottish Marine Environmental Enhancement Fund. While there is clear policy appetite for these approaches, they have not yet been fully put into practice (Hooper *et al.* 2019).

1.1.2 Applications for marine management

In this receptive policy context, natural capital and ecosystem service perspectives are increasingly considered in the conservation and management of the marine environment. Concurrently, discourse around spatial protections (MPAs) for the marine environment is in some cases exploring whole-site approaches with the goal of enabling ecosystem recovery (Rees *et al.* 2020). In England, these whole-site approaches are implemented as Highly Protected Marine Areas (HPMAs) (Defra 2023).

MPAs are one avenue for protecting features or ecosystems. Of these, no-take zones (NTZs) are the most effective option for protecting and recovering biodiversity (Sala & Giakoumi 2018). MPAs sit within a suite of other options that includes modification of fishing gears, seasonal closures, targeting specific activities or pressures of concern, or the use of other effective area-based conservation measures (OECMs) (IUCN WCPA Task Force on OECMs 2019). In this report, we look at how the pressure alleviation afforded by MPAs improves the condition of assets (habitats and species) and subsequent ecosystem service delivery. This is important for understanding how an ecosystem-based, natural capital approach may support future marine conservation decision-making.

However, a key challenge remains in understanding how the condition of an asset mediates the delivery of ecosystem services. Marine ecosystems are inherently complex, and significant knowledge gaps remain around ecosystem functioning, spatial dynamics, cumulative effects, and interactions between different ecosystems (Hooper *et al.* 2019). This presents additional challenges to effective ecosystem-based management of marine ecosystems.

1.2 Project aim

In this review, we examine how asset condition across management regimes can mediate ecosystem service delivery and produce recommendations for how our findings can support natural capital approaches in MPA management. We use the Lyme Bay MPA as a case study to explore the interactions between marine ecosystem condition and service delivery.

1.2.1 Research questions

This project is guided by three key research questions:

1. How does protection (and improved condition) affect ecosystem service delivery by UK marine assets?

2. What evidence is there for how ecosystem services have been affected by protection in the Lyme Bay MPA?
3. What do the findings from this case study tell us about integrating ecosystem services into management?

1.2.2 Deliverables

Answering these questions supports the following deliverables, all contained in this report:

- Review the benefits of protection and condition of assets for ecosystem service delivery.
- Case study (before/after, inside/outside) to examine ecosystem service delivery against management approaches.
- Recommendations to support conservation advice around ecosystem service and natural capital approaches.

2 Methods

This report is a targeted literature review exploring how asset protection confers changes to ecosystem service delivery. We begin with a broad review of the evidence and then consider the Lyme Bay MPA as an in-depth case study. We selected this case study due to the wealth of research that has arisen through long-standing collaborations between scientists, fishers, NGOs, and regulators (Renn *et al.* 2024).

2.1 Case Study

The Lyme Bay Fisheries and Conservation Reserve is an MPA on the South-West coast of England and is an early example of a whole ecosystem approach to management in the UK, established to protect and recover reef biodiversity (Davies *et al.* 2021b; Renn *et al.* 2024). The site covers 2,460 km² and stretches across 120 km of coastline from Seaton to Abbotsbury. It consists of a variety of habitats that host a high level of biodiversity (Renn *et al.* 2024). Initial spatial protection was implemented in 2001 due to concerns about the impact of demersal-towed fisheries, before being given a designated area order in 2008 that closed 206 km^2 to scallop dredgers and trawlers (Blue Marine Foundation 2023; Renn *et al.* 2024). It has since been subject to long-term ecological and socio-economic monitoring (Renn *et al.* 2024).

Rees *et al.* 2016 recorded ecosystem services that theoretically should be delivered by the natural assets present in Lyme Bay (habitat types and commercial species) and their estimated ecosystem service delivery. We used this model as a starting point and expanded upon it with updated resources and standardised tools (i.e. JNCC's uASM (Cordingley *et al*. 2023)). We also applied CICES (Common International Classification of Ecosystem Services), a hierarchal ecosystem service classification system that is widely used across the mNCEA and UK Arm's Length Bodies (ALBs). This enables easier, more consistent incorporation of natural capital into decision making processes (Makowska *et al.* 2022).

2.1.1 Assets and Ecosystem Services

To identify habitat assets in Lyme Bay we used the EU Sea Map, which provides all EUNIS habitats present within Lyme Bay MPA down to EUNIS level 4 (Vasquez *et al*. 2021). Species associated with the relevant EUNIS habitats were identified by reviewing Rees *et al.* 2016. This includes commercial species that had clear linkages to habitats within Lyme Bay as well using designated species of conservation importance for the site (e.g. pink sea fans (*Eunicella verrucosa*) and sunset cup coral (*Leptopsammia pruvoti*) (Potts *et al.* 2014; Rees *et al.* 2016). We also reviewed the wider literature to identify any key species that had good abundance data for Lyme Bay. This included any species of conservation importance to MPAs (e.g. pink sea fans*)* that would be strong indicators of improved condition.

For identified species, we assessed whether they had any association with delivering or benefitting from ecosystem services provided by their associated habitats (Table 6). Through identifying species with strong associations to both habitat type and ecosystem service delivery, an increase in species abundance was assumed to correspond to an increase in ES delivery.

These species and habitat assets were entered into the universal Asset Service Matrix (uASM) tool to generate a bespoke ASM. An ASM is a tool to describe and catalogue relationships between ecosystem services and the assets that provide them (Cordingley *et al.* 2023). The bespoke ASM described here is derived from a database of over 4,000 standardised linkages extracted from the wider scientific literature (Cordingley *et al.* 2023). It was only possible to extract a bespoke ASM for habitat assets. Due to its early stages of development, the uASM did not have data on relevant species for Lyme Bay. The full generated bespoke ASM can be found in Table 10, with a summarised version to EUNIS level 3 and CICES level 2 in Table 4. To create a map of potential ecosystem service delivery across Lyme Bay, we clipped the whole Lyme Bay region from the EU Sea Map. EUNIS habitats present in the extracted bespoke ASM were joined to create a spatial map of potential ecosystem service delivery across Lyme Bay (Cordingley *et al*. 2023; Vasquez *et al*. 2021).

2.1.2 Assessing changes to ecosystem service delivery

There are numerous approaches and challenges associated with measuring the supply of ecosystem services. Some cultural services like ‘using the environment for recreation’ (3.1.1.1) can be assessed through surveys and willingness to pay (WTP) studies. Other ecosystem services that are just as valuable can also be difficult to quantify (e.g. ‘maintaining nursery populations’ (2.2.2.3) or ‘controlling and preventing sediment loss’ (2.2.1.1)).

We identified key species that are associated with habitats present within the MPA that are known to provide specific ecosystem services. These were then mapped for each habitat type to ease visualising connections (Figure 2). We reviewed the literature to identify key changes in abundance and condition of these species within the Lyme Bay MPA. Increased abundance or quality of these measures was used as an indicator of improved habitat condition and thus improved theoretical ability to provide relevant ecosystem services. Where available, we assessed quantifiable examples of ecosystem service delivery. Based on the available evidence, our confidence that ecosystem service delivery had changed was categorised into three levels, ranging from quantitative to theoretical ecosystem service delivery.

1. Quantified ecosystem service change in Lyme Bay MPA (high confidence).
    - Ecosystem service is known to be supplied by habitat, species or traits present in Lyme Bay.
    - Recorded change in habitat, species or trait that has direct link to Lyme Bay.
    - Quantifiable example of ecosystem service in Lyme Bay (e.g. faster recovery from storms or increased fishery landings).
2. Qualitative ecosystem service change with example outside Lyme Bay MPA (medium confidence).
    - Ecosystem service is known to be supplied by habitat, species, or traits present in Lyme Bay.
    - Recorded change in habitat, species or trait that has direct link to Lyme Bay.
    - Qualitative example of ecosystem service delivery change inside Lyme Bay (e.g. Anglers self-reporting increased usage of MPA).
3. Expected ecosystem service change but no quantified example (low confidence)
    - Ecosystem service is known to be supplied by habitat, species or traits present in Lyme Bay.
    - Recorded change in habitat, species or trait that has direct link to Lyme Bay.
    - Lack of quantified or qualitative example can be due to difficulty in measuring or lack of measurements to demonstrate effectiveness (e.g. no monitoring of water quality).

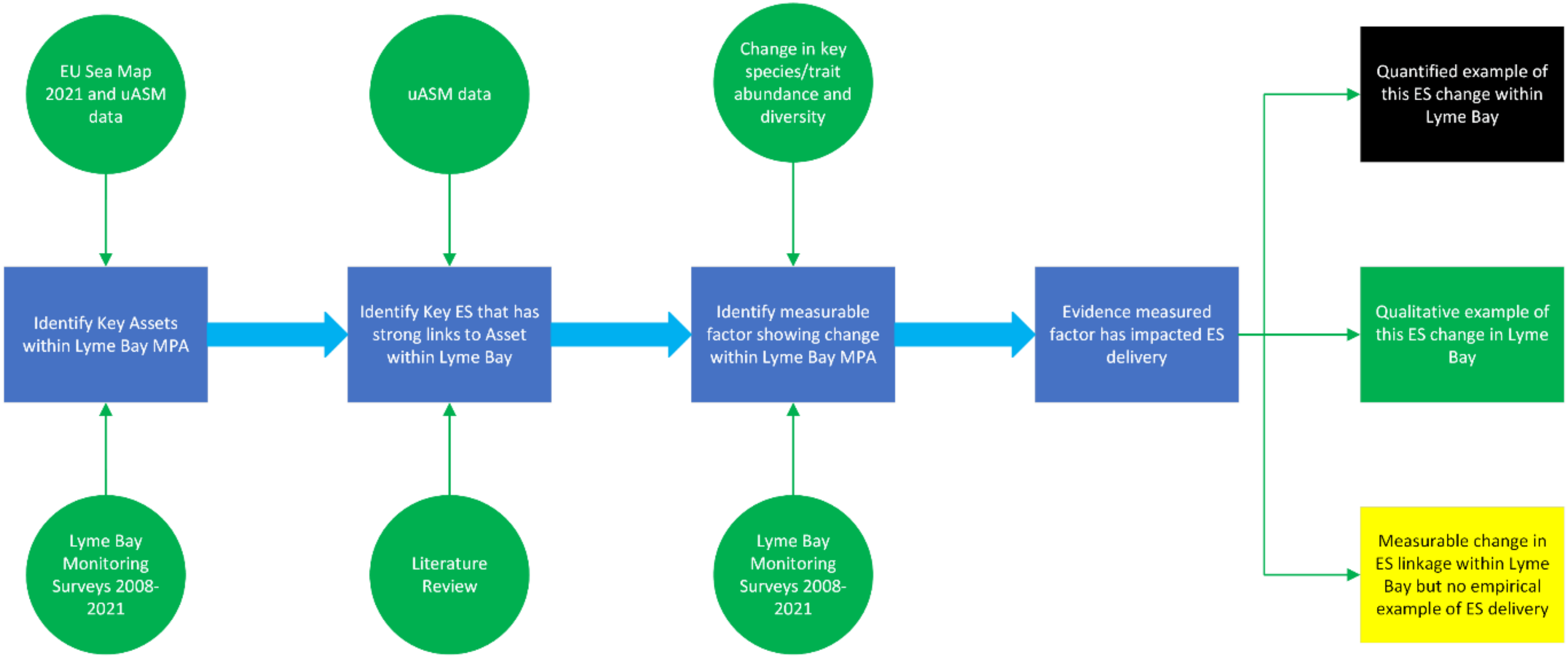


Figure 2. Methodological logic chain for the review of the Lyme Bay MPA case study.

3 Removal of pressures, asset condition and ecosystem service delivery

Ecosystem service delivery is impacted by the condition of the overall ecosystem and its components, and ecosystem condition is defined as the overall quality of a natural asset (habitats and species) (United Nations *et al.* 2012). While it is broadly assumed that reduced condition reduces the delivery of ecosystem services, in most cases the quantitative evidence for these relationships is limited (Potts *et al.* 2014). An emerging area of research is the understanding, and ultimately quantification, of the capacity of ecosystems to deliver a service in relation to changes in condition due to pressures.

Pressures are the mechanism through which multiple human activities exert effects on an ecosystem (Robson *et al.* 2018). There is a suite of pressures that impact marine ecosystems, and cumulative human disturbance constrains ecosystem recovery and affects ecological resilience. Human impacts affect environmental components sensitive to pressure and can arise from a number of activities that subsequently lead to an altered environmental condition or state (Tillin & Tyler-Walters, 2013). Importantly, human impacts are frequently linked to the realisation of goods and/or benefits, thus affecting condition of a component of the system (Zhang *et al.* 2022). Disturbances cannot be considered to affect all species or habitats similarly, and this also applies to effects of disturbance on ecosystem service delivery (Cacela *et al.* 2005).

There is a wealth of literature to demonstrate how through modifying condition, anthropogenic disturbance interrupts the flow of ecosystem services; disturbance can be categorised into direct human impacts, biotic pressure (i.e. exotic sp.), and environmental changes (Mouillot *et al.* 2013; Tillin 2023). Ecosystem condition can be assessed either indirectly, through analysis of pressures, or directly by assessing habitat condition, biodiversity, and environmental quality (Tillin 2023). Indirect approaches for assessing condition combine information about ecosystem component sensitivity and exposure to pressures (i.e. a risk-based approach). Indirect risk-based approaches are widely used, and typically theoretically based, in terms of using an indicator to assess condition by looking at the sensitivity of the ecosystem to human pressures to ascertain potential alterations to ecosystem service delivery (Table 1).

Table 1. Example measures of condition for species and habitats, alongside examples of linked ecosystem services (asset-service relationships). Ecosystem services described using Common International Classification for Ecosystem Services (CICES). Adapted from Tillin 2023.

Condition measures	Example ecosystem services
Presence and abundance, population structure and biomass of species that provide goods and benefits	Abundance of commercially exploited fish (CICES 1.1.6. Wild animals (terrestrial and aquatic) for nutrition, materials or energy). Biomass of harvestable kelps (CICES 1.1.5 Wild plants (terrestrial and aquatic) for nutrition, materials or energy).
Presence, extent, and density of foundation species (those that form biogenic habitat),	Provision of wave attenuation (CICES 2.2.1 Regulation of baseline flows and extreme events). Provision of erosion protection (CICES 2.2.1 Regulation of baseline flows and extreme events). Provision of carbon capture and storage (CICES 2.2.6.1 Atmospheric composition and conditions).
Habitat presence and extent	Provision of wave attenuation (CICES 2.2.1 Regulation of baseline flows and extreme events). Provision of erosion protection (CICES 2.2.1 Regulation of baseline flows and extreme events). Provision of carbon capture and storage (CICES 2.2.6.1 Atmospheric composition and conditions).

Direct approaches for assessment of condition (proposed by (Tillin *et al.* 2008)) include: species specific measurements; approaches for habitat that use baseline reference conditions; and approaches that consider functioning. In this report, we focus on direct assessments of condition because our review is around the removal of pressures.

Interest is increasingly focused on the opportunity to improve the flow of ecosystem services through protection and the associated improved condition of natural assets. The assessment of how condition is linked to the flow of ecosystem services is not straightforward – it is difficult to quantify, and certain goods and services are easier to monitor than others. For a given ecosystem, its capacity for ecosystem service provision and the flow of these ecosystem services should be considered separately. For example, ecosystem degradation can clearly result from the unsustainable use of provisioning services (e.g. aggregate removal or fishing), whereas the flow of regulating services such as carbon sequestration occurs in, and is evidence of, pristine condition (Tillin 2023). Understanding is also not distributed evenly across provisioning, regulation and maintenance, and cultural services, and focus has tended to be directed towards things that are easy to monitor and for services that have been historically prioritised. Typically, this has been provisioning services, tangible goods that can be harvested from the environment.

3.1 Marine Protected Areas (MPAs)

Marine Protected Areas are areas set up to protect part, or all, of a marine system (Sala & Giakoumi 2018), to protect biodiversity, and to maintain ecosystem functions and flow of ecosystem services. MPAs are an essential tool for reversing the global degradation of ocean life. Hence, it is important to know which types of MPA are more effective, and under which conditions. Well-protected MPAs are very effective in restoring and preserving biodiversity, and in enhancing ecosystem resilience (Claudet *et al.* 2008; Lester *et al.* 2009; Lester & Halpern, 2008). In some contexts, protection confers improved recovery capacity following disturbance events such as marine heatwaves (Sandin *et al.* 2008) and storms (Sheehan *et al.* 2021). Biomass of whole fish assemblages in marine reserves is, on average, 670% greater than in adjacent unprotected areas, and 343% greater than in partially protected MPAs (Sala & Giakoumi 2018; Sheehan *et al.* 2021). Protected areas also help restore the complexity of ecosystems through a chain of ecological effects (trophic cascades) as the abundance of large animals recovers. MPAs are not immune to the effects of climate change, but to date reserves with complex ecosystems exhibit greater resilience than unprotected areas. Although MPAs were conceived to protect ecosystems within their boundaries, they have also been shown to enhance local fisheries and create jobs and new incomes through ecotourism (Gaines *et al.* 2010; Sala & Giakoumi 2018).

The protective measures associated with these areas vary, from partial protection often restricting certain activities to protect a specific feature or species, to NTZs where all extractive activities are restricted (Sala & Giakoumi 2018). In the UK, few MPAs are true NTZs and most allow some level of extractive activity, adding an additional layer to the complexity of determining the impacts of protection on habitats and species. MPAs are increasingly recognised as providing important benefits and ecosystem services (Potts *et al.* 2014), ranging from large-scale ecosystem services such as carbon sequestration down to local-scale services such as fisheries. Studies have looked at the role of MPAs in ecosystem service delivery to determine these relationships between the features protected by MPAs and their delivery of ecosystem services, with the assumption that features in good condition will support better flow of these service (Potts *et al.* 2014). However, due to the variability in the level of protection, type of MPA, and its age and size, a blanket statement that designation of an MPA will ensure the improvement of a good or delivery of service cannot be applied.

There are several challenges in assessing the effectiveness of an MPA. First, it is difficult to separate the effects of protection from the inherent spatial-temporal variability of the marine environment; comparison of communities inside and outside of the protected area both before and after protection is impeded by the fact that useful data from before an MPA has been implemented rarely exist and it is therefore difficult to detect recovery (Elliott & Whitfield 2011). However, where data are available, the comparison of trends is the most widely used approach to assess the impact of protection. The relationships between features protected by MPAs and the delivery of ecosystem services suggests that maintaining or achieving good condition will have beneficial effects on service delivery – this would occur where the designation of an MPA results in the management, reduction, or cessation of a degrading activity. The UK MPA network comprises various types of protected area due to different types of legislation (Table 2). There are 377 MPAs in UK waters which cover 338,729 km^2 (38%) of the EEZ (JNCC 2023).

Table 2. The structure of the UK MPA network. The total UK MPA coverage is less than the individual MPAs combined due to overlap of sites. Table contains Joint Nature Conservation Committee data © copyright and database right [2023], Natural England data © copyright and database right [2023], NatureScot data © copyright and database right [2023], Natural Resources Wales data © copyright and database right [2023, Northern Ireland Environment Agency data © copyright and database right [2023], United Kingdom Hydrographic Office data © Crown copyright and database right [2023], and Ordnance Survey data © Crown copyright and database right.

Marine Protected Area (MPA) designation type	**UK Legislation behind the designation**	**Number of sites and area (to the nearest hectare (ha)**
Special Areas of Conservation (SACs) with marine components (including candidate Special Areas of Conservation (cSACs)	The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended), The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2011, both transposing Habitats Directive 92/43/EEC	116 13,686,021 ha
Special Protection Areas (SPAs) with marine components	The Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended), The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2011, both transposing Birds Directive 2009/147/EC	125 3,844,333 ha
Marine Conservation Zones (MCZs)	Marine and Coastal Access Act (2009), The Marine Act (Northern Ireland) 2013	109 3,267,904 ha
Highly Protected Marine Areas (HPMAs)	Marine and Coastal Access Act (2009)	3 98,525 ha
Nature Conservation Marine Protected Areas (ncMPAs)	Marine (Scotland) Act, UK Marine and Coastal Access Act	35 6,801,015 ha
Marine Protected Areas (MPA)	Marine and Coastal Access Act (2009)	1 10,771,800 ha

3.2 Role of species traits

Species traits are the morphological, behavioural, phenological or physiological characteristics that determine how species respond to their environment through growth, reproduction, and survival (Cadotte *et al.* 2011; Mouillot *et al.* 2013; Violle *et al.* 2007). Traits influence the range of a species and how species interact with each other, shaping ecological performance (McGill *et al.* 2006; Violle *et al.* 2007). Example traits include body size, plant height, selective leaf area, duration of larval stages, sociability and nutrient concentration of tissues (Froese & Pauly 2023; Gustafsson & Norkko 2019; MarLIN 2006). The variation of traits within a community is widely referred to as functional diversity (Violle *et al.* 2007). Functional diversity is crucial for the maintenance of key ecosystem processes and services, such as nutrient recycling and regulating water quality in marine ecosystems. Species traits are integral to our understanding of ecosystem function and, consequently, the maintenance of the flow of ecosystem services (Mouillot *et al.* 2021).

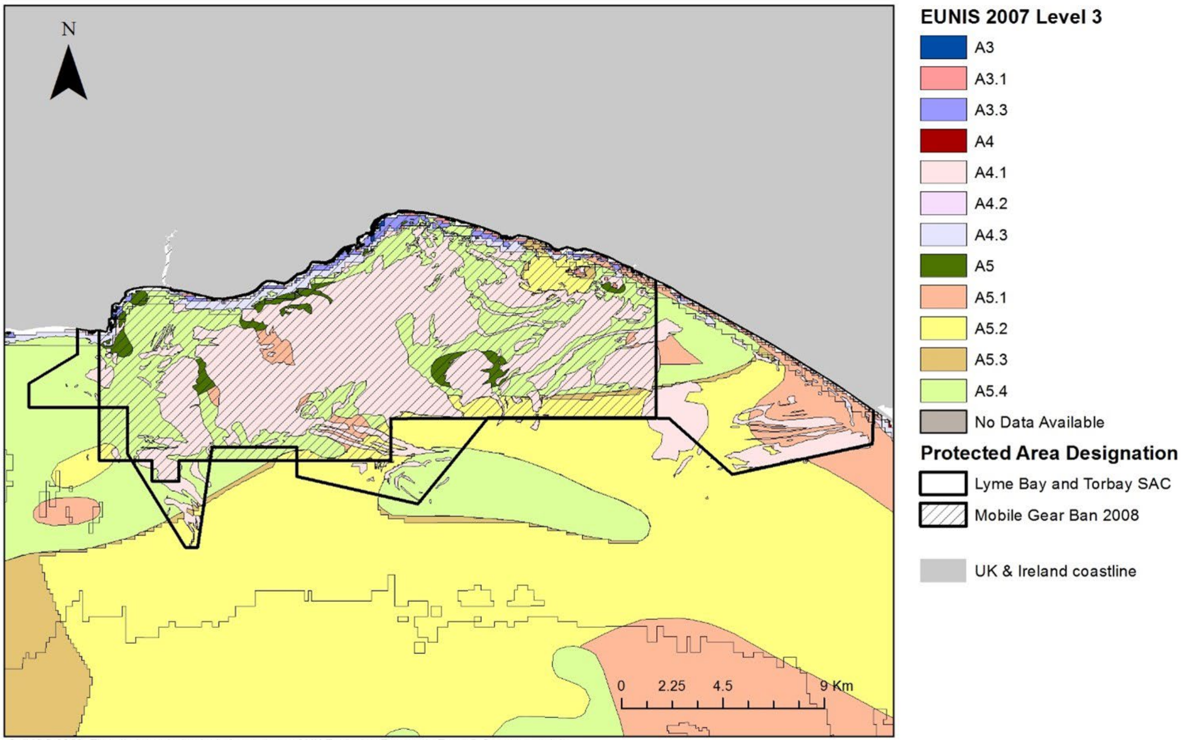
A trait-based approach to assessing disturbance can provide information on ecosystem functioning based on measurable characteristics of organisms (such as size, mobility, longevity, fragility, flexibility and feeding method), which facilitates defining ecological groups with similar sensitivities to different pressures (Tillin & Tyler-Walters 2013). A link between an effect trait (involved in ecosystem functions) and response trait (involved in response to disturbance) can be used to predict disturbance effects on an ecosystem function (Suding *et al.* 2008). The sensitivity of ecological groups will differ for pressures that cause hydrological changes, pollution, physical loss, and physical damage, among others (Tillin 2023).

Species traits can be a useful tool for conservation, restoration, and management purposes in addition to the use of species richness and diversity indices based on the taxonomic definition of species. Biological traits analysis has been used for assessment of marine benthic ecosystem function (Bremner *et al.* 2006, 2003), and as a tool to demonstrate that anthropogenically caused changes in species composition affect ecosystem functioning by linking species functional traits to support delivery of ecosystem services (Hewitt *et al.* 2008; Tillin *et al.* 2006). Trait-based approaches can thus be useful in understanding and assessing impacts from the introduction or removal of disturbance and human pressures on ecosystems, and can help establish links between disturbance, diversity and functions (Cadotte *et al.* 2011; McGill *et al.* 2006), and therefore between ecosystem service provision and ecological change that may have occurred due to protection. Where pressures are alleviated, species traits can be used to monitor recovery processes. Recovery trajectories are closely related to species traits; for example, systems with stress-tolerant or resilient species may recover faster (Elliott & Whitfield 2011). A study of the effectiveness of marine reserves in protecting temperate reef fauna following closure to the use of towed bottom fishing gear, for example, found that longer-lived species such as pink sea fans and ross coral had a projected recovery time of 17–20 years, while king scallops and soft corals with high dispersal potential and broader habitat requirements recovered almost fully in less than three years (Kaiser *et al.* 2018).

4 Ecosystem service delivery changes and protection in the Lyme Bay MPA

4.1 History of protections in Lyme Bay

The Lyme Bay Fisheries and Conservation Reserve on the South-West coast of England was established to protect and recover reef biodiversity. Lyme Bay is incorporated into the Lyme Bay and Torbay Special Area of Conservation (SAC). Along the coastline, there is a mixture of rock, sand, and gravel intertidal substrate. The site consists of circalittoral rock, infralittoral rock, intertidal coarse sediment, and submerged sea caves (Figure 3). The west of the site overlaps with Gannet and Great Cormorant foraging areas.



Information contained in this map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

Figure 3. Lyme Bay habitat map (EUNIS Level 3, EU Sea Map) with Marine Protected Area (MPA) and Special Area of Conservation (SAC) boundaries (Vasquez *et al.* 2021). See Table 4 for details of the EUNIS habitats.

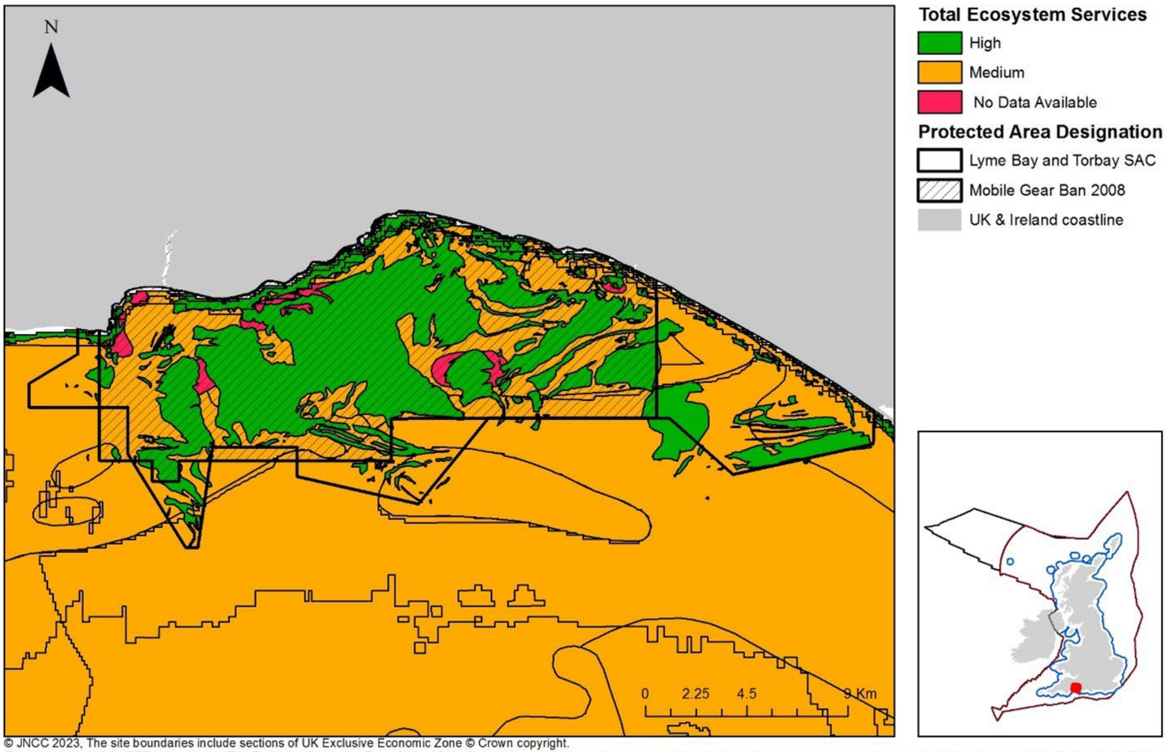
Prior to any fishing restrictions at the site, there were an estimated 25 trawlers and scalloper vessels below 10 m in size, 25 vessels above 10 m and a further 90 vessels using the area for netting, potting and whelking (Andrews 2008). Initial protection began in 2001, with two voluntary closed areas agreed by local stakeholders (Rees *et al.* 2016). In July 2008, the UK Government closed a 206 km^2 area of Lyme Bay to bottom towed fishing gear which is defined as an MPA (Attrill *et al.* 2012; Rees *et al.* 2016). In 2010, a larger area of reef was put forward as a cSAC (312 km^2) as part of the Lyme Bay and Torbay cSAC (SCI) with protected features of Annex 1 reef and submerged and partially submerged sea caves (Natural England 2013; Rees *et al.* 2016). In 2013, Southern, and Devon and Severn, IFCAs introduced spatial closure restrictions for mobile gear which extended the closed area to 236 km^2 (Table 3) (Blue Marine Foundation 2023).

Table 3. History of the Lyme Bay Reserve (Blue Marine Foundation 2023).

Year	Change within Lyme Bay
1988	Inshore reefs in Lyme Bay Identified as an area of marine conservation interest.
1998	Devon Wildlife Trust starts Lyme Bay Reefs Project with local fishers, 86 sites were surveyed showing large number of important and fragile habitats.
2000 to 2001	Southern Sea Fisheries Committee suggests voluntary approach to protect reef features as bylaw, had a lot of resistance.
2001	Devon Wildlife Trust, South Western Fishers org. and local fishers develop a voluntary closed area to protect reefs closing Lanes Ground and Saw Tooth Ledges to bottom trawling and scallop dredging.
2005	Scallop boats increase from 9 to 20 from other UK ports causing breakdown of voluntary agreement
2006	Natural England applies for ministerial stop order to close 206 km^2 to scallop dredgers and trawlers.
2008	**Lyme Bay Designated Area Order 2008 closes 206 km^2 to scallop dredgers and trawlers**
2011	Lyme Bay and Torbay designated as cSAC that covers 312 km^2 (trawling ban applies to 236 km^2). Lyme Bay Working Group created
2012	Code of Conduct agreed for commercial fishers. Lyme Bay Reserve Working Group Memorandum of Understanding signed
2013	Southern and Devon and Severn IFCAs introduce spatial closure restrictions
2014	Code of Conduct agreed for recreational anglers. Fisheries Management Plan Published
2022	Lyme Bay Fisherman’s Community Interest Company established

4.2 Assets and ecosystem services in Lyme Bay

We generated a bespoke ASM for Lyme Bay (Table 4, Table 10) (Cordingley *et al.* 2023). Food provisioning (fisheries) is delivered at a high level and with high confidence. A wide range of regulation and maintenance service are delivered, including life-cycle maintenance and habitat protection, water quality, and climate regulation. Cultural services include recreation and wildlife watching. Regulatory and cultural services are provisioned at varying levels of delivery and confidence depending on the asset (Table 10). Rocky reef has the highest delivery of total ecosystem services, and sediment has moderate delivery (Figure 4). Some areas could not be assessed for service delivery, as high level EUNIS habitat designations were too broad to meaningfully assess service provision from the bespoke ASM.



Information contained in this map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

Figure 4. Total potential ecosystem service delivery by habitats in Lyme Bay (Cordingley *et al.* 2023; Vasquez *et al.* 2021).

Table 4. Bespoke Asset Service Matrix of habitats present in Lyme Bay MPA. Extracted from the uASM and (Galparsoro *et al.* 2014). Blue (#) = Negligible ecosystem service (ES) Delivery, Red (*) = Low ES Delivery, Yellow (**) = Medium ES Delivery, Green (***) = High ES Delivery (Cordingley *et al.* 2023). See Table 10 for ASM at all CICES/EUNIS levels.

EUNIS 07 Level 3	**EUNIS 07 Classification**	**Common International Classification of Ecosystem Services (CICES) V5.1**					
		Provisioning (Biotic)		**Regulation & Maintenance (Biotic)**		**Cultural (Biotic)**	
		Biomass (1.1.x.x)	Genetic material from all biota (including seed, spore or gamete production) (1.2.x.x)	Transformation of biochemical or physical inputs to ecosystems (2.1.x.x)	Regulation physical, chemical, biological conditions (2.2.x.x)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting (3.1.x.x)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting (3.2.x.x)
A3	Infralittoral rock and other hard substrata	*** Medium Confidence	N/A	** Medium Confidence	*** Medium Confidence	*** Medium Confidence	*** Medium Confidence
A3.1	Atlantic and Mediterranean high energy infralittoral rock	*** Medium Confidence	N/A	** Low Confidence	*** Medium Confidence	** Medium Confidence	*** Low Confidence
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	*** Medium Confidence	N/A	** Low Confidence	*** Medium Confidence	** Medium Confidence	*** Low Confidence
A3.3	Atlantic and Mediterranean low energy infralittoral rock	** Medium Confidence	* Medium Confidence	** Medium Confidence	*** Medium Confidence	** Medium Confidence	*** Medium Confidence

EUNIS 07 Level 3	**EUNIS 07 Classification**	**Common International Classification of Ecosystem Services (CICES) V5.1**					
		Provisioning (Biotic)		**Regulation & Maintenance (Biotic)**		**Cultural (Biotic)**	
		Biomass (1.1.x.x)	Genetic material from all biota (including seed, spore or gamete production) (1.2.x.x)	Transformation of biochemical or physical inputs to ecosystems (2.1.x.x)	Regulation physical, chemical, biological conditions (2.2.x.x)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting (3.1.x.x)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting (3.2.x.x)
A4	Circalittoral rock and other hard substrata	*** Medium Confidence	N/A	*** Medium Confidence	*** Medium Confidence	** Medium Confidence	** Medium Confidence
A4.1	Atlantic and Mediterranean high energy circalittoral rock	*** Medium Confidence	N/A	*** Medium Confidence	*** Medium Confidence	** Medium Confidence	** Medium Confidence
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	** Medium Confidence	N/A	*** High Confidence	** Medium Confidence	** Medium Confidence	** Medium Confidence
A4.3	Atlantic and Mediterranean low energy circalittoral rock	*** Medium Confidence	N/A	*** Medium Confidence	*** Medium Confidence	*** Medium Confidence	*** Medium Confidence
A5.1	Sublittoral coarse sediment	** Medium Confidence	# Low Confidence	** Medium Confidence	** Medium Confidence	* Medium Confidence	* Medium Confidence

EUNIS 07 Level 3	**EUNIS 07 Classification**	**Common International Classification of Ecosystem Services (CICES) V5.1**					
		Provisioning (Biotic)		**Regulation & Maintenance (Biotic)**		**Cultural (Biotic)**	
		Biomass (1.1.x.x)	Genetic material from all biota (including seed, spore or gamete production) (1.2.x.x)	Transformation of biochemical or physical inputs to ecosystems (2.1.x.x)	Regulation physical, chemical, biological conditions (2.2.x.x)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting (3.1.x.x)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting (3.2.x.x)
A5.2	Sublittoral sand	** Medium Confidence	# Low Confidence	** Medium Confidence	** Medium Confidence	* Medium Confidence	* Medium Confidence
A5.3	Sublittoral mud	** Medium Confidence	# Low Confidence	** Medium Confidence	** Medium Confidence	* Medium Confidence	* Medium Confidence
A5.4	Sublittoral mixed sediments	** Medium Confidence	N/A	** Medium Confidence	** Medium Confidence	* Medium Confidence	* Medium Confidence
A5.5	Sublittoral macrophyte-dominated sediment	*** Medium Confidence	* Medium Confidence	N/A	*** Medium Confidence	** Medium Confidence	N/A

4.3 Impacts of protection on ecosystem service delivery

This review highlights that ecosystem service delivery across a wide range of services has changed with the implementation of the MPA, though the nature of the evidence and the confidence associated with it varies widely (Table 5). Three years after implementing the towed demersal gear ban within the MPA, there was a marked increase (158%) in sessile and mobile reef associated species (RAS) with clear evidence of early recovery (Sheehan *et al.* 2021, 2013) (Table 6). There was a divergence between assemblage structure found in the MPA compared to areas still open to fishing (Attrill *et al.* 2012; Sheehan *et al.* 2016). Species richness increased in both the MPA and voluntary closed area in comparison to sites open to bottom towed gear (Attrill *et al.* 2012).

Eleven years after implementing the ban on towed demersal fishing gear (2008) there has been a marked increase in both the number of taxa (430%) and abundance of fish (370%) within the MPA (Davies *et al.* 2021b). This increase in abundance and species diversity is similarly reflected in the species traits present in the MPA (Davies *et al.* 2021a; Kaiser *et al.* 2018). For traits affected by mobile demersal fishing (response traits: longevity, scavenger and filter feeders, sessile, crawler and swimmer motility), functional richness and redundancy both increased, perhaps reflecting increased resistance to disturbance and with positive implications for broader ecosystem function (Davies *et al.* 2021a). Notably, both metrics exhibited a decline outside the MPA (Davies *et al.* 2021a). Sessile filter feeders that are vulnerable to trawling increased within the MPA, and the overall composition of the trait space moved to reflect that of a rocky reef (Davies *et al.* 2021a). Species with shorter life histories and more generalist habitat needs recovered most quickly (< 3 years), while those with traits reflective of longer life histories and more specialist habitat needs (e.g. pink sea fans) have increased in abundance but will take longer to recover fully (Kaiser *et al.* 2018). Species trait information is, in this way, an important element of our understanding of ecosystem-wide versus feature-based management actions.

During the winter of 2013–2014, Lyme Bay experienced extreme storm disturbances that damaged the seabed and returned the seabed assemblage back to a pre-MPA designation state (Sheehan *et al.* 2021). By 2017, the area within the MPA had improved recovery towards pre-storm species assemblages compared to outside the MPA (Sheehan *et al.* 2021). Stabilisation of sediment by epifaunal benthos is likely to reduce storm damage through ‘buffering and attenuation of mass sediment movement’ (2.2.1.1) and ‘control of erosion rates’ (2.2.1.2) (Bradshaw *et al.* 2003). As the MPA continues to protect the seabed, more well-established epifaunal populations take hold and stabilise sediment, increasing future storm resilience (Sheehan *et al.* 2021).

Table 5. Summary of confidence in ecosystem service (ES) change in Lyme Bay. Ecosystem services described using CICES v5.1 (Haines-Young & Potschin 2018). Ecosystem services identified through uASM, see Table 10 for full list of services where no relevant evidence found.

CICES v5.1		**Description**	**ES Change Confidence Lyme Bay MPA**
Provisioning (Biotic)	1.x.x.x	Provisioning (Biotic)	**High**
	1.1.6.x	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	**High**
Regulatory and Maintenace (Biotic)	2.1.1.2	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	**Low**
	2.2.1.1	Control of erosion rates	**High**
	2.2.1.2	Buffering and attenuation of mass movement	**High**
	2.2.2.3	Maintaining nursery populations and habitats	**High**
	2.2.2.x	Lifecycle maintenance, habitat and gene pool protection	**High**
	2.2.5.x	Water conditions	**Low**
	2.2.6.1	Regulation of chemical composition of atmosphere and oceans	**Low**
	2.2.6.x	Atmospheric composition and conditions	**Low**
Cultural (Biotic)	3.1.1.1	Using the environment for sport and recreation	**High**
	3.1.1.2	Watching plants and animals where they live; using nature to destress	**High**
	3.1.2.1	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	**Medium**
	3.1.2.2	Characteristics of living systems that enable education and training	**Medium**
	3.1.2.3	Characteristics of living systems that are resonant in terms of culture or heritage	**Medium**
	3.1.2.x	Intellectual and representative interactions with natural environment	**Medium**
	3.2.1.x	Spiritual, symbolic and other interactions with natural environment	**Medium**

Table 6. Abundance changes of key Lyme Bay species, habitat associations, species traits and links to ecosystem services. Habitats and ES delivery links (Potts *et al.* 2014; Rees *et al.* 2016). Traits from BIOTIC (MarLIN 2006) and trait – ES delivery links by (Rees *et al.* 2012). Ecosystem services extracted by trait are in **bold** (and prefixed with *) in the ES Linkage column

Common Name	**Species Name**	**Change within Lyme Bay**	**Habitat linkage**	**Traits**	**ES Linkages** (* **Trait**, Habitat linkage)
King scallop	*Pecten maximus*	Increased Abundance	A3.1, A3.2, A4.1, A4.2, A5.1, A5.2	Burrower, Swimmer, Active suspension feeder, Epibenthic, Epifaunal, Demersal, Free living	1.1.6.1, * **2.1.1.2,** 2.2.1.x, 2.2.1.1, 2.2.1.2, 2.2.2.x, 2.2.2.3, 2.2.3.x, 2.2.5.x, 2.2.6.1, 3.1.2.3
Native oyster	*Ostrea edulis*	N/A	A5.1, A5.4	Permanent attachment, Active suspension feeder, Epifaunal, Attached	1.1.6.1, * **2.1.1.2,** 2.2.1.x, 2.2.1.1, 2.2.1.2, 2.2.2.x, 2.2.3.x, 2.2.5.x, 2.2.6.1, 3.1.2.x, 3.1.2.2, 3.1.2.3,
White furrow shell	*Abra alba*	N/A	N/A	Burrower, Passive and Active suspension feeder, surface and subsurface deposit feeder, Infaunal	* **2.1.1.2**
Common whelk	*Buccinum undatum*	N/A	A3.1, A3.2, A4.1, A4.2, A5.1, A5.2, A5.3, A5.4	Crawler, Burrower, Predator, Scavenger, Epifaunal, Epibenthic	* **2.1.1.2**
Pink sea fan	*Eunicella verracosa*	Increased Abundance (not sig)	A3.1, A3.2, A4.1, A4.2	Permanent attachment, Passive suspension, feeder, Epibenthic, Epifaunal, Attached	* **2.1.1.2,** 2.2.1.x, 2.2.2.x, 3.1.2.x, 3.1.2.2, 3.1.2.3
Dead man's fingers	*Alcyonium digitatum*	Increased Abundance	N/A	Permanent attachment, Active suspension feeder, Predator, Epifaunal, Epilithic	* **2.1.1.2**

Common Name	**Species Name**	**Change within Lyme Bay**	**Habitat linkage**	**Traits**	**ES Linkages** (* **Trait**, Habitat linkage)
Ross coral	*Pentapora fascialis*	Increased Abundance	N/A	Permanent attachment, Active suspension feeder, Epibenthic, Epilithic,	* **2.1.1.2**
Common lobster	*Homarus Gammarus*	Increased abundance	A3.1, A3.2, A4.1, A4.2, A5.1, A5.2, A5.3, A5.4	Crawler, Scavenger, Omnivore, Demersal, Epifaunal, Epibenthic, Free living	* **2.1.1.2,** 1.1.6.1, 2.2.2.3
Edible crab	*Cancer pagurus*	No Significant Change	A3.1, A3.2, A4.1, A4.2, A5.1, A5.2, A5.4	Crawler, Predator, Epibenthic, Free living	* **2.1.1.2,** 1.1.6.1
Spider crab	*Maja squinado*	N/A	A3.1, A3.2, A4.1, A4.2, A5.1, A5.2, A5.4	Crawler, Omnivore, Scavenger, Predator, Epibenthic, Free Living,	* **2.1.1.2,** 1.1.6.1
Sunset cup coral	*Leptopsammia pruvoti*	N/A	A3.1, A3.2, A4.1, A4.2	Permanent Attachment, Passive suspension feeder, Epifaunal, Epilithic, attached	* **2.1.1.2,**2.2.1.x, 2.2.2.x, 3.1.2.2,
Branching sponges	*e.g.* Axinella dissimilis	Increased abundance	N/A	Permanent Attachment, Colonial, Active suspension feeder, Epibenthic, Epilithic, Erect	2.2.1.1, * **2.1.1.2,** 2.2.1.2, 2.2.2.3
Hydroids	*e.g.* Nemertesia ramosa and *Obelia* longissima	Increased Abundance (not sig)	N/A	Permanent Attachment, Passive suspension feeder, Epifaunal, Epibenthic	* **2.1.1.2**

Common Name	Species Name	Change within Lyme Bay	Habitat linkage	Traits	ES Linkages (* **Trait**, Habitat linkage)
Maerl beds	*Phymatolithon calcareum and Lithothamnion glaciale*	N/A	N/A	Photoautotroph, Epifloral, Epilithic, Bed forming	* **2.1.1.x**
Sand mason	*Lanice conchilega*	N/A	N/A	Swimmer, Crawler, Burrower, Passive + Active suspension feeder, surface + subsurface deposit feeder, Infaunal	* **2.1.1.2**

4.3.1 Provisioning services

Here, we use landings as a proxy for understanding food provisioning services. There was a significant increase in food provisioning services (landings) by target species both inside and outside the MPA. However, this was not uniformly observed across all species reviewed (Table 7). The consistent, detailed monitoring combined with clear instances of increased abundance of target species suggests with high confidence that the introduction of the mobile gear ban has strengthened food provisioning. The presence and size of this effect on food provisioning varies by target species (Table 7). Importantly, the realisation of benefits provided by increased food provisioning has been unevenly distributed across the fishing industry; with mobile gear fishers most disadvantaged (Rees *et al.* 2016). Inshore boats under 10 m and static gear fishermen in contrast have benefitted from reduced competition and displacement of mobile gear activity (Rees *et al.* 2016).

Table 7. Summarised fishery landings and earnings by gear and species type following the mobile gear ban, from Rees *et al.* 2016; * indicates statistical significance in the original study (Rees *et al.* 2016).

Indicators	Lyme Bay MPA (static gear)	Lyme Bay MPA (mobile gear) (Not including towed gear from 2007-2008)	Lyme Bay (static gear)	Lyme Bay (mobile gear)
Scallop (Divers) (Landings)	Increase *	N/A	Decrease *	N/A
Scallop (Divers) (Earnings)	Increase *	N/A	Decrease	N/A
Scallop (Dredging) (Landings)	N/A	Decrease *	N/A	Increase *
Scallop (Dredging) (Earnings)	N/A	Decrease *	N/A	Increase *
Whelk (Landings)	Decrease *	Decrease	Decrease *	Increase *
Whelk (Earnings)	Decrease *	Decrease	Increase *	Increase
Lemon Sole (Landings)	Increase	Increase	Decrease	Increase *
Lemon Sole (Earnings)	Increase *	Decrease	Decrease	Increase *
Sole (Landings)	Decrease *	Increase	Increase	Decrease *
Sole (Earnings)	Decrease *	Increase	Increase	Decrease *
Plaice (Landings)	Increase *	Decrease	Decrease	Decrease *
Plaice (Earnings)	Increase *	Increase	Decrease	Decrease *
Lobster (Landings)	Increase	Increase	Increase	Increase
Lobster (Earnings)	Increase *	Increase	Decrease	Increase *
Crabs (Landings)	Increase *	Decrease	Increase *	Increase *
Crabs (Earnings)	Increase *	Decrease	Increase *	Increase *

4.3.2 Regulation and maintenance services

4.3.2.1 Mediation and filtering of waste (2.1.1.2) and water conditions (2.2.5.2)

Species traits associated with waste remediation and improved water quality (e.g. suspension feeders) became more prevalent in the benthic community after the MPA was established (Davies *et al.* 2021a; Rees *et al.* 2012) (Table 6). Species with these traits and that perform these services are present on rock (high energy circalittoral, moderate energy infralittoral) and in soft sediments in Lyme Bay and have exhibited changes in abundance since the closure.

High energy circalittoral rock (A4.1) is the dominant hard substrate present in Lyme Bay MPA and is an important substrate for sponges. Sponge abundance increased inside the MPA and they are active suspension feeders (Salomidi *et al.* 2012, Rees *et al*. 2012, Sheehan *et al*. 2013). Soft sediments foster populations of infaunal burrowers like white furrow shell (*Abra alba*) and blow lugworm (*Arenicola marina*), which deliver waste remediation services (Rees *et al.* 2012). Bivalves (white furrow shell, king scallop and native oyster) also play an important role in waste removal and maintaining water quality. These filter feeders directly remove suspended material and nutrients from the water column (Beck *et al.* 2011; Williams & Davies 2018). This mechanism transports nutrients, carbon, and nitrogen to the seabed (Williams & Davies 2018). Nutrient removal also helps buffer against harmful algal blooms caused by excessive nitrogen (Williams & Davies 2018). Bivalves primarily remove nitrogen from the water column through denitrification and phytoplankton ingestion (Grabowski *et al.* 2012; Williams & Davies 2018). Bivalves delivering these services are not collectively monitored. However, we know that king scallop abundance has increased within Lyme Bay since restrictions were put in place (Table 6). King scallop are epibenthic, epifaunal burrowers which also contribute towards waste mediation (MarLIN 2006; Rees *et al.* 2012). Literature tends to use native oyster to assess service delivery in this context. For example, a hectare of oyster beds avoids an estimated cost of $1,385–$6,716 per year to reach the local Clean Water Act (1972) pollution standards in the USA (Grabowski *et al.* 2012). King scallop do not form the same dense beds as oysters, so the extent they can improve water quality per hectare would be significantly less. A quantitative understanding of the extent to which these species provide improved water quality and waste remediation services in a UK context would deepen our knowledge of changing service delivery.

The introduction of the mobile gear ban has enhanced the ability of soft sediments to deliver waste mediation and improve water quality through recovery of species with traits to perform these services. The ability of hard substrates to contribute towards these services are constrained by species needs for light, limiting its ability to perform waste mediation to shallow coastal waters of Lyme Bay (Rees *et al.* 2012). However, these services are difficult to quantify based on current local data. While there are clear increases in potential to provide these services, there remains low confidence overall that the ability of the MPA to filter waste (2.1.1.2) and improve water quality (2.2.5.2) has increased from implementing mobile gear restrictions in 2008.

4.3.2.2 Sediment stabilisation and buffering of extreme weather events (CICES 2.2.1.1 and 2.2.1.2)

Sediment stabilisation and coastal protection services provided by structurally complex marine habitats are vitally important. Protected areas that exclude bottom towed fishing gear and have complex habitats in good condition (e.g. Lyme Bay's rocky reefs) have greater potential to deliver these ecosystem services. Delivery of these services, and resilience to extreme weather is an increasingly important aspect of MPAs as climate change escalates the frequency and severity of storm events (Sheehan *et al.* 2021). In 2013–2014 Lyme Bay was exposed to an extreme storm season with higher-than-average wave power recorded, providing an opportunity to assess whether the ability to buffer storm events has increased (Sheehan *et al.* 2021). Storm damage occurred both inside and outside the MPA, with an increased occurrence of loose sediment observed in areas that were previously biogenic crusts. Clear evidence of sand scouring was seen on pink sea fans and a reduction of vulnerable species like ross coral (Sheehan *et al.* 2021). Storm damage from sediment scour was likely a major factor in the damage reported in both sedimentary and bedrock reef within Lyme Bay (Sheehan *et al.* 2021; Woodley *et al.* 1981). 29% of coastal MPAs in the UK are as exposed as Lyme Bay to similar wave pressures, so lessons learnt from Lyme Bay can be applied elsewhere (Sheehan *et al.* 2021).

Where the MPA protects the seabed, more well-established epifaunal populations take hold and stabilise sediment, increasing future storm resilience (Sheehan *et al.* 2021). Community functional richness, and abundance of branching sponges, king scallop and ross coral was higher in areas which had been protected for longer (Davies *et al.* 2021a; Sheehan *et al.* 2021). An important element of assessing this service is that species that provide sediment stabilisation and buffering have different recovery times. King Scallop is expected to achieve faster recovery times (3 years) compared to pink sea fans with a projected full recovery time of 17–20 years (Kaiser *et al.* 2018). As multiple species sharing the same traits that contribute to sediment stabilisation and storm protection recover and functional richness increases, redundancy will develop within the ecosystem (Rees *et al.* 2012). This increased redundancy will mean that if any one species providing sediment stabilisation and storm resilience is removed, the overall ability for the ecosystem to provide this service can theoretically be maintained (Rees *et al.* 2012).

The storm disturbance event and subsequently accelerated recovery of habitat within the MPA highlights that protection enhanced disturbance recovery. The observed effect was starting from a relatively low baseline, as the 2013-14 storms came only five years after the closure order. There is high confidence that delivery of coastal protection services has increased from the introduction of measures in 2008 (Sheehan *et al.* 2021).

4.3.2.3 Maintaining nursery populations and habitats (CICES 2.2.2.3)

There are multiple nursery habitats within Lyme Bay. High energy circalittoral rock (A4.1) is the most dominant rocky reef habitat within the MPA and is important for sponges, bryozoans, hydroids, ascidians, sea anemones and pink sea fans (Salomidi *et al.* 2012). These create three dimensional complex structures that enhance biodiversity, provide settlement sites for larvae (Howarth *et al.* 2011; Jones *et al.* 1994) and niches for species like the nudibranch *Tritonia nilsodhneri* (Hall-Spencer *et al.* 2007). They also act as nurseries for commercial fish and shellfish species like king scallops (Bradshaw *et al.* 2003; Lindholm *et al.* 2004, 2001; Rees *et al.* 2016; Salomidi *et al.* 2012). The abundance of branched sponges and hydroids has increased inside the MPA, indicating increased provision of this nursery habitat service (Sheehan *et al.* 2013).

Flatfish (*Solea solea, Pleuronectes platessa*) and common lobster nursery habitats include sublittoral coarse sediment (A5.13–A5.15), sublittoral sand (A5.23–A5.26) and sublittoral mud (A5.33 and A5.35) (Rees *et al.* 2016; Salomidi *et al.* 2012). Since the closure to mobile gear in 2008, the juvenile population of Common Lobster has increased by 450% with an overall population increase of 246% (Blue Marine Foundation 2016; Rees *et al.* 2016).

Shellfish, particularly in high densities, both through their shells and while living, promote the creation of hard substrate for organisms to settle, and use as refuge (Beck *et al.* 2011; Williams & Davies 2018). The increased abundance in king scallop may contribute to providing nursery habitat.

Maerl beds are also important nursery habitats for juvenile king scallop and other commercial fish species that use its complex three-dimensional structure for protection (Howarth *et al.* 2011; Kamenos *et al.* 2004; Lindholm *et al.* 2001). Maerl beds have been recorded within the Lyme Bay area, but extent is poorly understood (Marine Planning Consultants Ltd 2014; Wood 2007). Maerl has a very slow growth rate of 0.5–1.5 mm a year and evidence suggests that if maerl beds are significantly fragmented, killed or removed they have almost no ability to recover (Blake & Maggs 2003; Perry & Tyler-Walters 2023). Maerl is also very sensitive to trawling damage with a study showing that a single scallop dredge can kill 70% of maerl present (Hall-Spencer & Moore 2000).

The abundance of exploited fish in the MPA has increased by around 370% despite increased static fishing pressure; however, non-exploited fish saw no net change (Davies *et al.* 2021b). Examples of commercial species that have been closely monitored in the MPA (lobster and king scallop), saw increased abundance alongside recovery of important nursery providing species (pink sea fans, sponges, and bryozoans). There is high confidence that Lyme Bay MPA has improved its ability to maintain nursery populations and habitats. However, without carrying out regular abundance studies of key nursey species it is very difficult to fully quantify this change. It also important to note maerl beds have shown no indication of returning or recovering within the MPA.

4.3.2.4 Air quality and climate regulation (CICES 2.2.6.1)

Sublittoral coarse sediment (A5.1) is a species rich habitat often dominated by thick-shelled bivalves (e.g. king scallop*, Circomphalus casina, Ensis arcuatus and Clausinella fasciata*) (Salomidi *et al.* 2012). Bivalve shells are constructed from calcium carbonate and can act as a long-term sink for carbon (Williams & Davies 2018). Shells that become buried deeply into sediment will store carbon indefinitely, however processes including seawater erosion and disposal of shells by the fishery have potential to re-release this stored carbon (Peterson *et al.* 2010; Rees *et al.* 2016). This significant variability hinders our understanding of how much and how effectively bivalves sequester carbon, and should only be considered as a possible sink at present (Grabowski *et al.* 2012; Williams & Davies 2018).

The modest storage and sequestration services that may be provided by elements of the marine environment may be protected by disturbance removal in MPAs. Stopping bottom trawling may reduce carbon dioxide release (CO_2), as some work suggests that sediment disturbance releases previously stored CO_2 into the water column (Sala *et al.* 2021). Sediment disturbance also influences mineralisation processes, with evidence that carbon uptake increases after disturbance so the exact extent of net carbon release from trawling is not fully understood (Hiddink *et al.* 2023). Importantly, there is no broad consensus on the scale, mechanisms and net impact of carbon storage and release in relation to bottom trawling and assumptions about the benefits of MPAs from this perspective should be avoided.

Recovery of key species within the MPA tenuously suggests that air quality and climate regulation services may improve. However, our understanding of whether this has any meaningful effect on carbon storage and sequestration is poor. In this report we assign low confidence to whether protections in Lyme Bay have influenced climate regulation services.

4.3.3 Cultural services

4.3.3.1 Wildlife watching/enjoyment and using nature for sport and recreation (3.1.1.1 and 3.1.1.2)

Rocky reefs (A3.1, A3.2, A4.1, A4.2) deliver a high level of cultural services (Table 10). Sedimentary habitat in contrast has low provision at medium confidence (Table 10). The two main recreational industries that utilise Lyme Bay are SCUBA divers and recreational angling (Table 8) (Kenter *et al.* 2013; Rees *et al.* 2015). Data on other recreational activities in Lyme Bay is currently limited.

Table 8. Perceived use rates of recreational operators inside and outside the Lyme Bay MPA. From Rees *et al*. (2015).

Activity	Inside MPA	Outside MPA	Perceived value for operator
SCUBA	Increase	Increase	No change
Recreational fishing	Increase	Decrease	MPA has influenced activity

A willingness to pay (WTP) assessment of visitors to the region has a quantified proxy for changing ecosystem service delivery, with increased WTP values inferring increased ES delivery. Annual recreational WTP values from SCUBA diving activities was predicted to be the same between a no restrictions scenario and the 2008 MPA scenario banning bottom trawled gear (£3,110–£5,183) (Kenter *et al.* 2013). The highest predicted annual recreational value was under the bottom trawl, anchoring and mooring ban scenario (Table 9) (Kenter *et al.* 2013). Following the closure, MPA dive operators reported increased activity both inside and outside the MPA; however, dive operators only use the MPA 10% of the time (Sheehan et al 2015). Due to minimal use of the MPA by dive operators they perceived no change in their income (Table 8), which aligns with the predicted no change in annual recreation value (Table 9) (Kenter *et al.* 2013). However, predicted non-use value highlights SCUBA divers still value restriction of fishing types regardless of whether they would pay more to utilise the site (Kenter *et al.* 2013). Both SCUBA and angling users respond positively with higher WTP values associated with fishery restrictions. However, anglers have lower WTP related to mooring restrictions which illustrates that delivery of cultural services varies across activities and management scenarios (Kenter *et al.* 2013).

The same study found that annual recreational willingness to pay values only increased for recreational angling in the bottom trawl, pots and gillnet ban scenario (Table 9) (Kenter *et al.* 2013). When mobile gear restrictions were introduced, recreational angling increased in the MPA and declined outside it between 2008 and 2011 (Rees *et al.* 2015). Recreational fishing turnover has remained the same or increased (Rees *et al.* 2015). This clear preference for recreational use inside the MPA suggests that predictive, scenario-based work may have underestimated the use value. However, it is unclear whether management interventions have affected overall income in the recreational angling industry (Kenter *et al.* 2013; Rees *et al.* 2015). For both activities, predicted non-use value increases in all restriction scenarios, with bottom trawl, pot and gillnet ban scenarios having the highest value (Kenter *et al.* 2013). This indicates that anglers and divers may have similar non-use values. Charter boat activity (SCUBA and angling) increased in the MPA since the closure (Rees *et al.* 2015). However, economic growth of the sector is influenced by outside factors such as retiring operators or available infrastructure that are not related to the ecological condition of the MPA (Rees *et al.* 2015).

Given the quantitative values of change in both SCUBA and recreational angling there is high confidence that the introduction of the MPA has impacted delivery of “Wildlife watching/enjoyment and using nature for sport and recreation”. However, it is important to understand that other recreational activities in the area have not been widely assessed in this report, so it cannot be used to understand changes in other activities. Applying a similar approach to leisure activities that are being implemented in Plymouth marine park may improve understanding of how the public use the area and improve ways to promote engagement (Pittman *et al.* 2018).

Table 9. Summary of willingness to pay values of SCUBA divers and recreational anglers under different commercial fishery restriction scenarios in Lyme Bay. Extract from Kenter *et al.* 2013. To calculate annual recreational value a travel cost choice experiment was used. Non-use value of protection of each site was calculated using a contingent valuation method.

Activity	Willingness to Pay (WTP)	No Restrictions (Base scenario)	Bottom Trawled gear ban (2008 scenario)	Bottom Trawled gear, potting and gillnet ban	Bottom Trawled gear, anchoring and mooring ban
SCUBA divers	Annual recreational value	£3,110 – £5,183	£3,110 – £5,183	£3,328 – £5,547	£3,422 – £5,704
	Non-use value of protection	£911 – £1,518	£1,036 – £1,726	£1,065 – £1,775	£1,006 – £1,676
Recreational Anglers	Annual recreational value	£71,338 – £129,706	£71,338 – £129,706	£76,654 – £139,372	£71,338 – £129,706
	Non-use value of protection	£5,979 – £10,871	£6,811 – £12,383	£7,007 – £12,740	£6,610 – £12,019

4.3.3.2 Educational and scientific benefits of nature (3.1.2.1 and 3.1.2.2)

Rocky reefs have high provision and sedimentary habitat has low provision of educational and scientific benefits of nature, at low confidence (Table 10). No quantitative evidence indicates improved educational and scientific benefits of mobile gear restrictions. However, there are good qualitative examples that may suggest increased scientific and educational benefits from improved ecological status of the MPA.

The Lyme Bay Fisherman’s Community Interest Company (CIC) (established in 2022) represents fishers’ interests in food provisioning services and contributes to educating the local community in the economic and heritage value of the small-scale fishery in Lyme Bay (Lyme Bay Fisherman’s CIC 2022). Current work taking place in Lyme Bay using novel approaches to fisheries management, community engagement and scientific research is providing educational benefits. Over 25 peer-reviewed papers and reports have been published on Lyme Bay from organisations including Blue Marine Foundation and the University of Plymouth (Blue Marine Foundation 2024). This work has directly contributed to understanding increased ecological status within Lyme Bay MPA to incorporate into MPA management and marine planning (Fletcher *et al.* 2012). This is arguably the most data rich MPA in the UK alongside other projects like the Isle of Arran NTZ in terms of understanding community influence and ecosystem service approaches in marine management (Stewart *et al.* 2020). Quantifying educational and scientific benefits that are directly linked to mobile gear restrictions within the MPA can be challenging. However, the increased scientific input and community initiatives that resulted from the MPA imply medium confidence that delivery of educational and scientific benefits of nature has increased.

4.3.3.3 Heritage, Spiritual, symbolic, and other interactions with natural environment (3.1.2.3 and 3.2.1.x)

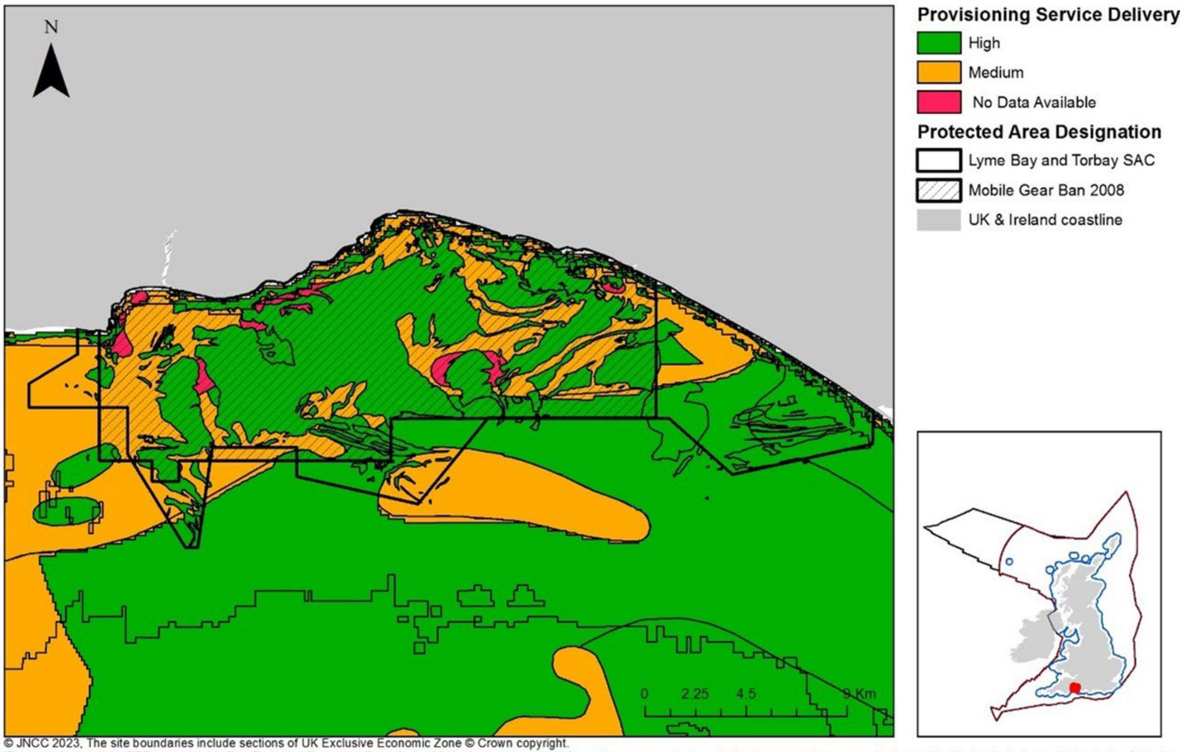
There is high provision in rocky reefs and low provision in sedimentary habitats for spiritual and symbolic interactions in nature at a low confidence (Table 10). Interviews of SCUBA divers show some increased spiritual and symbolic value of the area through increased desire to move to the area due to introduced changes from the MPA (Rees *et al.* 2015). Certain symbolic species within the MPA have increased in abundance, for example king scallop (2.1.2) which has particularly important identity value to the small-scale fishery in the area (Potts *et al.* 2014). Increased abundance of symbolic species alone does not translate into delivery of cultural services if users are unaware of the species' recovery or cannot access benefits. In terms of wellbeing value of UK MPAs, Lyme Bay scored in the lower third ranking in 5 out of 6 categories and suggests the cultural value of Lyme Bay was not being fully realised when their assessment took place (Kenter *et al.* 2013). Since 2013, considerable effort has gone into promoting the heritage value of Lyme Bay and its fisheries (Blue Marine Foundation 2023; Bull 2021; Lyme Bay Fisherman's CIC 2022). Quantifying the impacts of these projects and linking them to ecological improvements in the area is difficult without re-surveying visitors and local stakeholders. Although clear effort has been applied in realising these ecosystem service benefits, it is unclear if spiritual and heritage connection has quantitatively increased in Lyme Bay. Due to this there is a medium confidence that spiritual, heritage and symbolic value has changed due to the mobile gear ban in 2008.

5 Conclusion

5.1 Provisioning services

The highest delivery of provisioning services in Lyme Bay are in high energy circalittoral rock (A4.1) and sublittoral sand (A5.2) areas (Figure 5). Fisheries are the main provisioning service delivered, and most regulation and code of conduct changes within the MPA have been to manage this activity. We jointly approach provisioning services from the perspective of changing abundance of target species as well as landings because landings are influenced by factors external to the MPA.

The impact of the 2008 towed gear ban lands differently across different fisheries. Mobile gears and larger vessels have been disadvantaged, whilst inshore boats (< 10 m) and static gear fishers have broadly benefitted (Rees *et al.* 2016). For example, increased scallop abundance inside the MPA is reflected in improved landings and value of this species in contrast with national trends (Rees *et al.* 2016). Understanding the heterogenous economic impacts of management decisions on fisheries is crucial to inform sustainable and equitable management of the MPA. Engagement of fishers and policy makers is integral to this (Lyme Bay Fisherman's CIC 2022). Our findings indicate that there has been an improved ability of the MPA in its capacity for food provision. However, ensuring this is maintained sustainably and in a way that equitably benefits all fishers is ongoing. Pioneering projects like the Lyme Bay Fisherman's CIC and the Lyme Bay Fisheries and the Conservation Reserve (LBFCR) Consultative Committee are important steps to drive forward standards and frameworks (Blue Marine Foundation 2023; Lyme Bay Fisherman's CIC 2022).



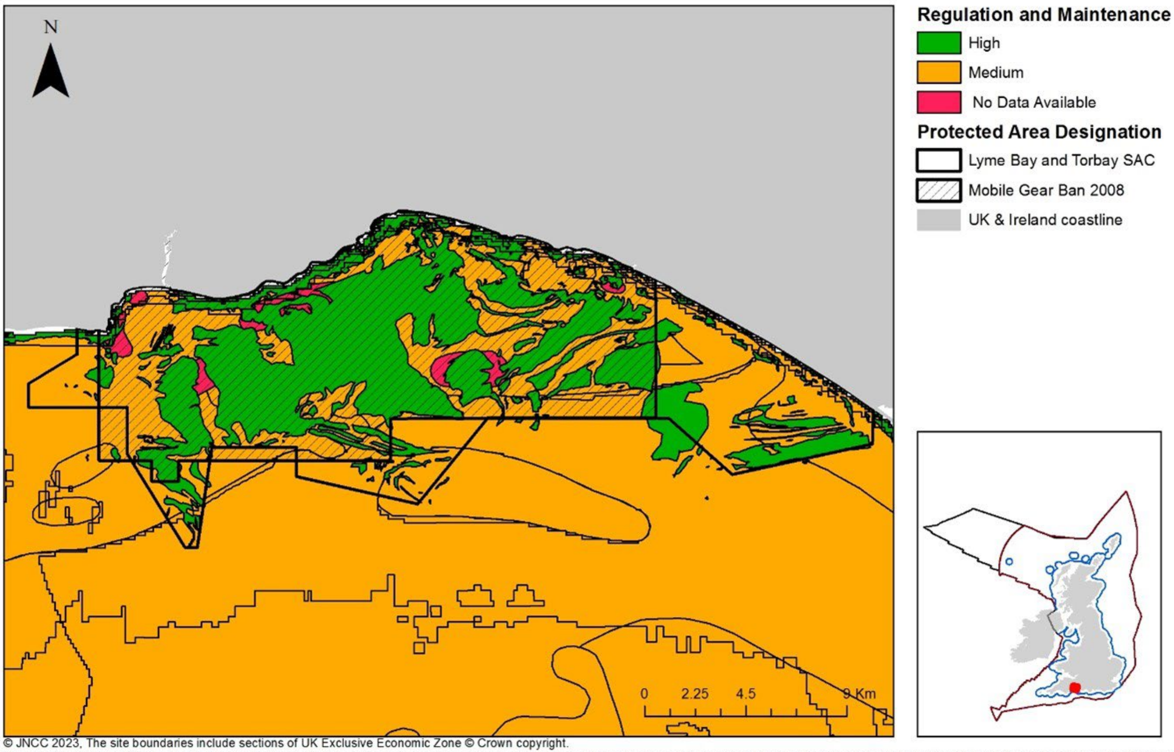
© JNCC 2023, The site boundaries include sections of UK Exclusive Economic Zone © Crown copyright.
The exact limits of the EEZ are set out in The Exclusive Economic Zone Order 2013. If you re-use this information, you must acknowledge the source in your product or application by including or linking to the following attribution statement: Contains Joint Nature Conservation Committee data © copyright and database right [2023]. Contains Natural England data © copyright and database right [2023].
Contains UK Hydrographic Office data © copyright and database right [2023]. Contains Ordnance Survey data © copyright and database right [2023].
Information contained in this map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

Figure 5. Potential provisioning ecosystem service delivery in Lyme Bay (Cordingley *et al.* 2023; Vasquez *et al.* 2021).

5.2 Regulation and maintenance services

Rocky reefs (A3.1, A3.2, A4.1 and A4.2) have the highest estimated ES delivery, with sedimentary habitat (A5.1–A5.4) having a moderate level of delivery (Figure 6). There was an increase in species abundances and changes to community composition that suggest the ability to deliver regulation and maintenance ecosystem services has increased. However, quantifying direct delivery of regulation and maintenance services is challenging, due to the indirect nature of benefits and challenges in monitoring them (Rees *et al.* 2012). However, occurrences like the 2013/2014 storms clearly highlight differences in recovery capacity inside and outside the MPA.

Improved condition and increased species abundances (particularly of juvenile life history stages) suggest enhanced provision of nursery habitat services within the MPA. However, these findings are primarily around target fishery species and care should be taken around assumptions that this reflects improved nursery habitat provision across the whole system (Davies *et al.* 2021b). We did not find evidence of changes to either climate regulation or water quality mediation services. These services are difficult to quantify, delivered across large spatial scales and are driven by external factors not necessarily linked to the management measures discussed here.



© JNCC 2023, The site boundaries include sections of UK Exclusive Economic Zone © Crown copyright.
The exact limits of the EEZ are set out in The Exclusive Economic Zone Order 2013. If you re-use this information, you must acknowledge the source in your product or application by including or linking to the following attribution statement: Contains Joint Nature Conservation Committee data © copyright and database right [2023]. Contains Natural England data © copyright and database right [2023].
Contains UK Hydrographic Office data © copyright and database right [2023]. Contains Ordnance Survey data © copyright and database right [2023].
Information contained in this map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

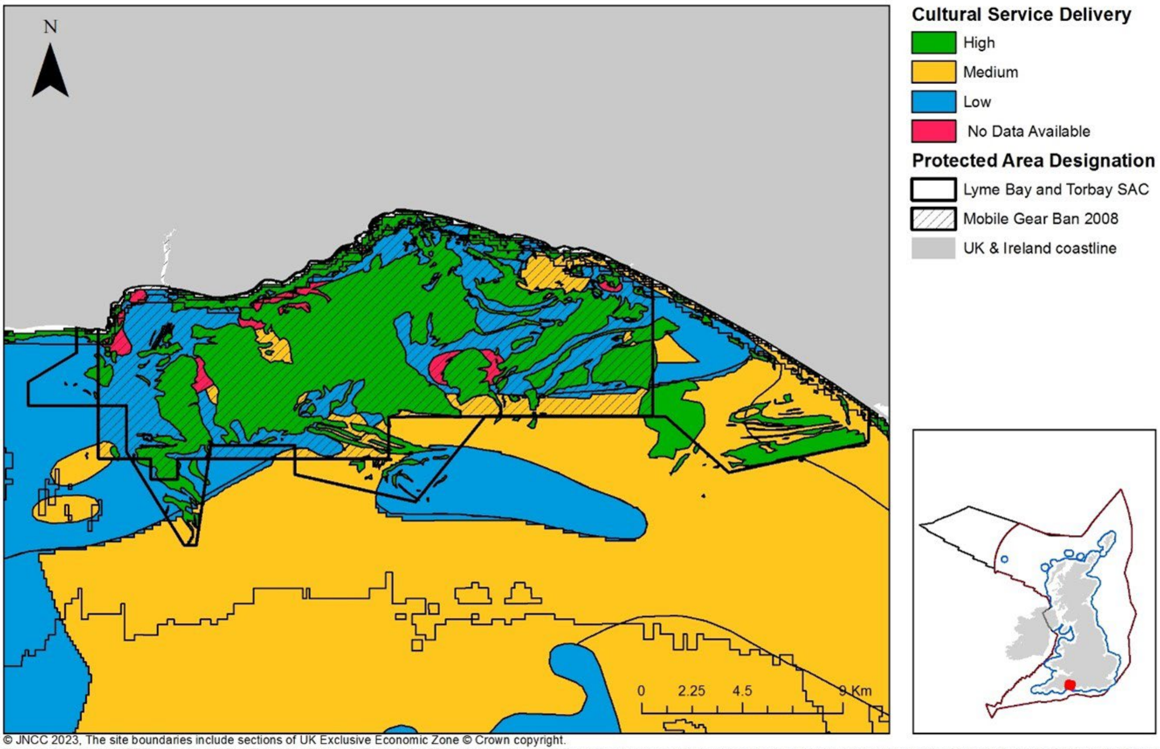
Figure 6. Potential regulatory and maintenance ecosystem service delivery in Lyme Bay (Cordingley *et al.* 2023; Vasquez *et al.* 2021).

5.3 Cultural services

Rocky reefs (A3.1, A3.2, A4.1 and A4.2) have the highest potential ES delivery for cultural services, and sedimentary habitat (A5.1–A5.4) has the lowest level of delivery (Figure 7). Projections suggested that the introduction of the 2008 bottom trawl gear ban should have had no increase in recreation value, with a positive increase in non-use value (Kenter *et al.*

2013). Work to assess the impact to cultural services suggests mobile gear restrictions did increase recreation activity in the MPA after the closure (Section 4.3.3). The value of angling and diving inside the MPA increased by £2.2 million between 2008 and 2011 (where value refers to proportional turnover and expenditure). This is coupled with a near-equivalent decline in value outside the MPA, reflecting changing locational preferences by recreational users (Rees *et al.* 2015). Anglers increased activity in the MPA and reduced activity outside. However, there was limited impact on SCUBA behaviour which is likely due to limited dive sites within the MPA which account for less than 10% of diving (Rees *et al.* 2015). When surveyed, divers and anglers supported extending MPAs and protecting the marine environment with divers being slightly more supportive. Anglers on average spent more days participating in their activity than divers and the increased usage of the MPA by anglers could be their increased tendency to utilise the water and less cost per visit (Kenter et al. 2013).

The introduction of the MPA in 2008 has had a significant scientific impact, leading to over 25 peer-reviewed papers and reports assessing impacts of the MPA (Blue Marine Foundation 2024). This in turn has encouraged the formation of the Lyme Bay Fisherman's CIC that is realising the educational, heritage and spiritual benefits of the MPA to the local community (Lyme Bay Fisherman's CIC 2022).



© JNCC 2023, The site boundaries include sections of UK Exclusive Economic Zone © Crown copyright.
The exact limits of the EEZ are set out in The Exclusive Economic Zone Order 2013. If you re-use this information, you must acknowledge the source in your product or application by including or linking to the following attribution statement: Contains Joint Nature Conservation Committee data © copyright and database right [2023]. Contains Natural England data © copyright and database right [2023].
Contains UK Hydrographic Office data © copyright and database right [2023]. Contains Ordnance Survey data © copyright and database right [2023].
Information contained in this map has been derived from data that is made available under the European Marine Observation Data Network (EMODnet) Seabed Habitats project (www.emodnet-seabedhabitats.eu), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

Figure 7. Potential cultural ecosystem service delivery in Lyme Bay (Cordingley *et al.* 2023; Vasquez *et al.* 2021).

6 Discussion

6.1 Research questions

This review set out to answer three core research questions:

1. How does protection (and improved condition) affect ecosystem service delivery by UK marine assets?
2. What evidence is there for how ecosystem services have been affected by protection in the Lyme Bay MPA?
3. What do the findings from this case study tell us about integrating ecosystem services into management?

We have found that while there is strong evidence for the improved condition of marine assets following protection both within Lyme Bay and further afield, our understanding of the implications for ecosystem service delivery remains focussed on a few core services. This means that there are important gaps to address to better round out our assessment of ecosystem service delivery in the context of MPAs. The Lyme Bay case study is a powerful example of how whole-site approaches to conservation can help integrate an understanding of ecosystem services (and subsequently natural capital) into marine management and conservation. Future work could apply similar approaches to other MPAs and benthic habitats. Lyme Bay is a good example for circalittoral rock, infralittoral rock, intertidal coarse sediment, and submerged sea caves, but other MPAs will deliver different services depending on the natural assets they contain.

MPAs in the UK are usually designated to protect specific features (habitats and/or species), while Lyme Bay is an early example of a whole-ecosystem approach. There has been an improvement in the environmental status in Lyme Bay since management measures began. For example, there has been an increase in the diversity and abundance of species of conservation importance such as the pink sea fan. The wider impact of protections established for features of conservation concern is an illustration of how management measures put in place for specific features can also provide wide reaching benefits to the environment and society through improved delivery across a range of ecosystem services.

An understanding of the relationships between ecosystem services and spatial protection by MPAs has implications for management and conservation advice. This case study can be used as an example of how ecosystem service delivery may be enhanced through management. However, confidence in integrating different ES into management regimes remains variable due to limited evidence around specific asset-service delivery relationships. For example, measuring changes in regulatory and maintenance services (e.g. coastal protection services) remains challenging to quantify and relevant data is not necessarily targeted by most monitoring programs. In contrast, the link between spatial protection, improved habitat condition and the provision of nursery habitat for species of commercial and conservation importance is much more readily elucidated.

In this review, we assign low-medium-high (categorical) confidence levels to our findings around ecosystem service change. These categories could be further developed to provide procedures, thresholds, and recommendations for other MPAs, based on similarities in the data available in the ASM. The methods used here could similarly be applied to indicate which ecosystem services are delivered in other MPAs across the UK, depending on the features found and management measures implemented. This could help develop indirect approaches for the assessment of condition and ecosystem service delivery for other sites.

The Lyme Bay MPA is a well-researched site where there has been significant stakeholder engagement, support from environmental NGOs and research institutes. It started as a voluntary reserve, and the coastal nature of the site means voluntary measures are largely well-supported. This high level of engagement means there is a large amount of literature and evidence to inform the management of the site. Specifically, this work demonstrates the value of monitoring both inside and outside an MPA, and before and after its implementation. This type of monitoring is crucial to understand whether management measures are producing the desired ecological impact. However, this level of data collection is not reflective of the wider monitoring situation in the UK which may present barriers to ecosystem-based approaches in other areas.

6.2 Recommendations for assessing additional natural capital benefits of MPAs

The Lyme Bay case study is a good example of how ecosystem service benefits can be identified from area-based fisheries restrictions. Based on this review, we recommend integrating tools and approaches that embed ecosystem services into management decisions and assessment planning. Environmental impacts from other types of human activities have not been reviewed in this study, and these can exert different pressures onto the environment. Resources such as JNCC's Pressures-Activities Database (Robson *et al.* 2018), could be used to compare pressures to provide evidence of the benefits for implementing different management approaches. JNCC's Marine Ecosystem Services and Optimisation (MESO) tool assesses the probability of impacts of anthropogenic pressures on sub-littoral habitats and the ecosystem services they provide (Tillin *et al.* 2019). In the absence of quantitative asset-service delivery relationships, MESO provides useful insight into how pressure removal mediates service delivery. Further studies should be conducted to review the benefits of pressure alleviation from other human activities such as shipping, renewable and fossil fuel energy industries, recreational water boat activities, and other types of fishing (e.g. mariculture). Defra's Natural Capital and Ecosystem Assessment programme has both terrestrial (tNCEA) and marine (mNCEA) strands of work. This programme aims to collect data and integrate natural capital and ecosystem service assessments into policy and decision-making. This report provides a useful case study to how an ecosystem-wide approach to management might be supported by natural capital and ecosystem service assessments and enable integration into planning and management decision-making. The uASM is an evidence product from the mNCEA programme which has been integrated into this work. Ongoing findings and outputs from the mNCEA should be included in future applications of this work.

There is an increasing global need to move beyond reporting area-coverage alone towards including how effective management is. Target 3 of the Kunming-Montreal Global Biodiversity Framework states that: "by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas… are effectively conserved and managed …" (Convention on Biological Diversity 2022). By only reporting on the effective management of specific protected features, there is a gap in the evidence gathered for the additional ES and NC benefits that MPAs provide. This report provides evidence of the wider benefits to the environment that area-based management (i.e. the designation of MPAs) can have, as shown in Section 5.

The UK has committed to ensuring that:

- by 2030 at least 30 per cent of coastal and marine areas, are effectively conserved and managed through protected areas and other effective area-based conservation measures.

- by 2030 at least 30 per cent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration.

These commitments are further backed by the UK Marine Strategy and the Environment Act target of 70% of protected features in MPAs to be in favourable condition by 2042 with the remainder in recovering condition (Defra 2019; HM Government 2021). There is a wide range of different methodologies to monitor protected area management effectiveness (PAME) around the world. Some methodologies incorporate ecosystem service questions into their assessments (e.g. the Management Effectiveness Tracking Tool (METT-4) (Stolton *et al.* 2007)). Quantifying ES is a useful perspective to understand the effectiveness of management measures over time, helping to recognise whether conversation commitments and targets are being met. To do this, there should be a greater focus on identifying key species, or trait/functional groups, that could be monitored to inform our understanding of and to quantify ecosystem service delivery.

6.2.1 Integrating ecosystem services into area-based management

The pressure alleviation afforded by MPAs improves the condition of assets (habitats and species) and subsequently ecosystem service delivery. In Lyme Bay, the alleviation of pressure by certain fishing gears has improved the condition of key species and habitats (e.g. king scallop abundance, community composition of soft sediments). Environmental protection is a devolved matter in the UK, meaning each devolved administration can legislate environmental principles individually, conservation advice is produced by statutory advisors to the government and forms part of the MPA cycle (JNCC 2019) (Figure 8). The advice is based on the best available evidence and sets out the ecological aims for the protected habitats and species within MPAs. UK legislation requires the reporting of MPA condition and the effectiveness of measures. Where there is sufficient evidence to provide further detail, conservation advice includes objectives and management recommendations for the attributes of protected features (habitats and/or species).

For offshore MPAs, JNCC’s conservation advice packages include supplementary advice on conservation objectives (SACOs), which provide further detail on the attributes (extent and distribution, structure and function, and supporting processes) of the protected features. The structure and function attributes are broken down into:

- Physical structure,
- Biological structure,
- Function (e.g. nutrition, culture, climate regulation)

The SACO could be expanded to provide detail on the additional benefits to ecosystem services that are delivered through the management of protected features if evidence is suitable. As seen in this case study, the confidence of the ES delivery varies due to the available evidence, ranging from quantitative to theoretical ES delivery. Treating features as part of the wider ecosystem makes it possible to provide advice on the wider benefits to the environment. This supplementary advice is currently a qualitative assessment of function but has relevance for a more quantitative understanding of some ecosystem services. This would facilitate the application of natural capital approaches for marine planning and conservation.

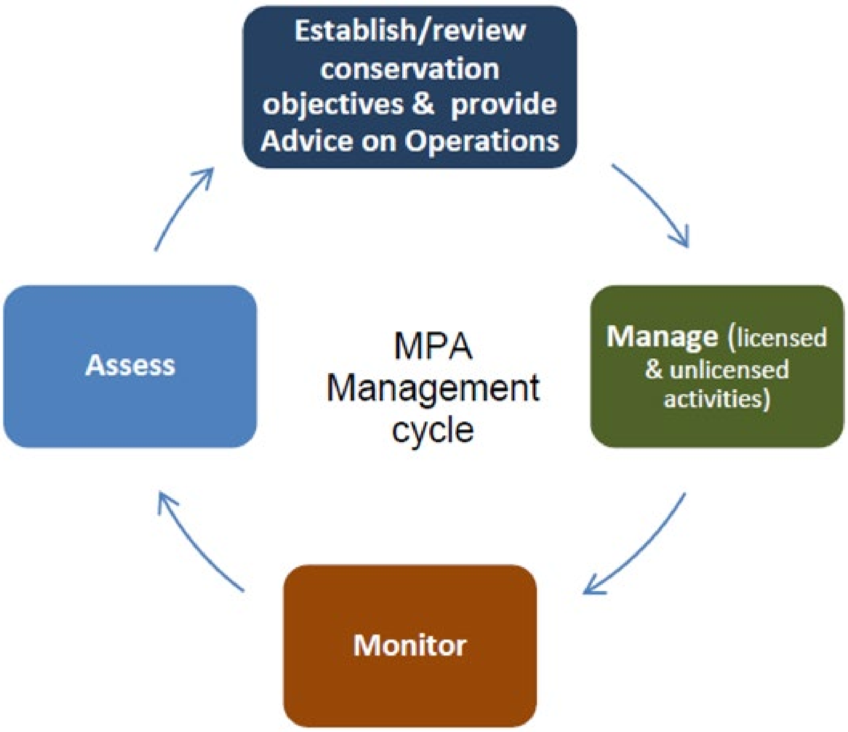


Figure 8. The MPA management cycle, illustrating the integral role of conservation advice plays in supporting the MPA in achieving its objectives (Cornick 2016).

Recognising OECMs could be another method of delivering long-term biodiversity conservation (including ES and NC) in the UK, if existing policies and procedures for MPAs make it challenging to incorporate ES into management. Other Effective area-based Conservation Measures (OECMs) are defined by IUCN as “areas that are achieving the long term and effective in-situ conservation of biodiversity outside of protected areas.” The UK’s Environmental Improvement Plan (EIP) 2023 highlights the importance of ES across several of its goals (HM Government 2023). There are already some marine OECMs in the UK, and these are reported on at a regional level through the OSPAR Assessment Reports (OSPAR 2024). Examples include the Scottish Closed Area Sea Fisheries Order 2012 No. 2571 and the seasonal Irish Sea Cod Box.

The benefits to ecosystem services from OECMs will depend on robust guidelines for their identification, effective monitoring, and whether the devolved administrations designate the areas they govern as OECMs (Alves-Pinto *et al.* 2021). If the UK wanted to recognise OECMs to help monitor ecosystem services, several steps would be needed, such as:

- Buy-in from a range of stakeholders (including government departments, industry, environmental NGOs and users).
- Agreeing why certain ecosystem services cannot be accounted for in existing MPAs, and subsequently where designating OECMs could bridge gaps in the network.
- Agreeing which types of sites should or should not be included as potential OECMs. An example is offshore wind farms; the industry has potential biodiversity positives, such as creating artificial reefs and restricting fishing effort, however they may also damage the seabed and create hazards for migrating birds) (Lloret *et al.* 2022; Soukissian *et al.* 2023).

6.2.2 Developing ecosystem-based management plans

Feature-specific protection presents challenges and gaps in managing the marine environment. Ecosystem-based management (EBM) (also known as the ecosystem approach) is a more flexible view of management that enables uncertainties to be built into decision-making (Delacámara *et al.* 2020). This integrated approach acknowledges the links between society and ecosystems, and actively assessing cumulative impacts on ecosystems (Halpern *et al.* 2010). Good governance is crucial for EBM to be successful. This relies on incentives, cooperation and coordination between various sectors and stakeholders. An agreed upon definition of EBM would be a key factor in developing new management policies which could incorporate ecosystem service assessments. Lyme Bay is a good example of EBM, where there has been good governance of the area and support of management measures from a range of stakeholders. The management measures put in place for specific features have also provided wide reaching benefits to the environment and society.

Good ocean governance is about managing and using the world’s oceans and their resources in ways that keep them healthy, productive, safe, secure, and resilient (EEA 2022). Environmental protection is a devolved matter in the UK, meaning each devolved administration can legislate environmental principles individually. For an ecosystem approach to be effective in the UK, it is important for all stakeholders to work in cooperation towards a common goal. This reflects the wider importance of international cooperation in the conservation and management of inherently transboundary marine ecosystems.

Highly Protected Marine Areas (HPMAs) are one of the first examples of using an ecosystem approach in the UK for site-based management. HPMAs use an EBM regime as there is no specific habitat or species which is protected. Three sites have been designated in English waters to protect the “whole marine ecosystem”, including all habitats, species, and associated ecosystem processes within the site boundaries. The explicit focus on ecosystem processes is a clear link to assessing ecosystem service delivery. Monitoring and assessment of HPMAs provides an important opportunity to better understand how protection confers improved ecosystem service delivery, informing future management decisions.

It is important to understand how the pressure alleviation afforded by the wide range of area-based management tools (MPAs, HPMAs, OECMs) as well as industry measures (modification of fishing gears, seasonal closures) work together in the marine space. This is crucial for understanding how an ecosystem-based, natural capital approach may support future marine conservation decision-making.

References

Alves-Pinto, H., Geldmann, J., Jonas, H., Maioli, V., Balmford, A., Ewa Latawiec, A., Crouzeilles, R. & Strassburg, B. 2021. Opportunities and challenges of other effective area-based conservation measures (OECMs) for biodiversity conservation. *Perspectives in Ecology and Conservation* 19, 115–120. https://doi.org/10.1016/j.pecon.2021.01.004

Andrews, T. 2008. Impact Assessment of measures to protect marine biodiversity in Lyme Bay (UK Impact Assessment Summary: Intervention & Options). Legislation.gov.uk.

Attrill, M.J., Austen, M.C., Cousens, S.L., Gall, S.C., Hattam, C.E., Mangi, S., Rees, A., Rees, S., Rodwell, L.D., Sheehan, E.V. & Stevens, T.F. 2012. Lyme Bay - A case study: measuring recovery of benthic species, assessing potential spill-over effects and socio-economic changes; 3 years after the closure (No. 1). University of Plymouth.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. & Silliman, B.R. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81, 169–193. https://doi.org/10.1890/10-1510.1

Beaumont, N.J., Jones, L., Garbutt, A., Hansom, J.D. & Toberman, M. 2014. The value of carbon sequestration and storage in coastal habitats. *Estuarine, Coastal and Shelf Science* 137, 32–40. https://doi.org/10.1016/j.ecss.2013.11.022

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., Defeo, O., Edgar, G.J., Hancock, B., Kay, M.C., Lenihan, H.S., Luckenbach, M.W., Toropova, C.L., Zhang, G. & Guo, X. 2011. Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *BioScience* 61, 107–116. https://doi.org/10.1525/bio.2011.61.2.5

Blake, C. & Maggs, C.A. 2003. Comparative growth rates and internal banding periodicity of maerl species (Corallinales, Rhodophyta) from northern Europe. *Phycologia* 42, 606–612. https://doi.org/10.2216/i0031-8884-42-6-606.1

Blue Marine Foundation. 2024. https://lymebayreserve.co.uk/.

Blue Marine Foundation. 2023. BLUEPrint for Marine Protected Areas: A guide to establishing and managing MPAs, Lyme Bay Reserve Case Studies. Blue Marine Foundation.

Blue Marine Foundation. 2016. Lyme Bay Fisheries and Conservation Reserve Ecological and Fisheries Data. Blue Marine Foundation.

Borsje, B.W., Van Wesenbeeck, B.K., Dekker, F., Paalvast, P., Bouma, T.J., Van Katwijk, M.M. & De Vries, M.B. 2011. How ecological engineering can serve in coastal protection. *Ecological Engineering* 37, 113–122. https://doi.org/10.1016/j.ecoleng.2010.11.027

Bradshaw, C., Collins, P. & Brand, A.R. 2003. To what extent does upright sessile epifauna affect benthic biodiversity and community composition? *Marine Biology* 143, 783–791. https://doi.org/10.1007/s00227-003-1115-7

Bremner, J., Rogers, S. & Frid, C. 2003. Assessing functional diversity in marine benthic ecosystems: a comparison of approaches. *Mar. Ecol. Prog. Ser.* 254, 11–25. https://doi.org/10.3354/meps254011

Bremner, J., Rogers, S.I. & Frid, C.L.J. 2006. Matching biological traits to environmental conditions in marine benthic ecosystems. *Journal of Marine Systems* 60, 302–316. https://doi.org/10.1016/j.jmarsys.2006.02.004

Bull, G. 2021. Time & Tides Short Film.

Cacela, D., Lipton, J., Beltman, D., Hansen, J. & Wolotira, R. 2005. Associating Ecosystem Service Losses with Indicators of Toxicity in Habitat Equivalency Analysis. *Environmental Management* 35, 343–351. https://doi.org/10.1007/s00267-004-4117-4

Cadotte, M.W., Carscadden, K. & Mirotchnick, N. 2011. Beyond species: functional diversity and the maintenance of ecological processes and services. *Journal of Applied Ecology* 48, 1079–1087. https://doi.org/10.1111/j.1365-2664.2011.02048.x

Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J., Pérez-Ruzafa, Á., Badalamenti, F., Bayle-Sempere, J., Brito, A., Bulleri, F., Culioli, J., Dimech, M., Falcón, J.M., Guala, I., Milazzo, M., Sánchez-Meca, J., Somerfield, P.J., Stobart, B., Vandeperre, F., Valle, C. & Planes, S. 2008. Marine reserves: size and age do matter. *Ecology Letters* 11, 481–489. https://doi.org/10.1111/j.1461-0248.2008.01166.x

Convention on Biological Diversity. 2022. COP15: Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement. By 2030: Protect 30% of Earth's lands, oceans, coastal areas, inland waters; Reduce by $500 billion annual harmful government subsidies; Cut food waste in half [WWW Document]. Convention on Biological Diversity. URL https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022 (accessed 3.20.24).

Cordingley, A., Anderson, L., Matthews, S., Beach, M., Molloy, L., Whittaker, L., Van Rein, H., McNulty, J., Reeve, N., Parsons, J. & Morgan, V. 2023. The universal Asset Service Matrix (uASM).

Cornick, L. 2016. JNCC's Approach to Improving Conservation Advice for UK Offshore Marine Protected Areas. Joint Nature Conservation Committee.

Davies, B.F.R., Holmes, L., Bicknell, A., Attrill, M.J. & Sheehan, E.V. 2021a. A decade implementing ecosystem approach to fisheries management improves diversity of taxa and traits within a marine protected area in the UK. *Diversity and Distributions* 28, 173–188. https://doi.org/10.1111/ddi.13451

Davies, B.F.R., Holmes, L., Rees, A., Attrill, M.J., Cartwright, A.Y. & Sheehan, E.V. 2021b. Ecosystem Approach to Fisheries Management works—How switching from mobile to static fishing gear improves populations of fished and non-fished species inside a marine-protected area. *Journal of Applied Ecology* 58, 2463–2478. https://doi.org/10.1111/1365-2664.13986

Defra. 2023. Highly Protected Marine Areas (HPMAs) (Policy Paper). Department for Environment Food and Rural Affairs.

Defra. 2019. Marine Strategy Part One: UK updated assessment and Good Environmental Status (Policy Paper). Department for Environment Food and Rural Affairs.

Delacámara, G., O'Higgins, T.G., Lago, M. & Langhans, S. 2020. Ecosystem-Based Management: Moving from Concept to Practice, in: O'Higgins, T.G., Lago, M., DeWitt, T.H. (Eds.), Ecosystem-Based Management, Ecosystem Services and Aquatic Biodiversity. Springer International Publishing, Cham, pp. 39–60. https://doi.org/10.1007/978-3-030-45843-0_3

EEA. 2022. Ocean Governance [WWW Document]. European Environment Agency. URL https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/ocean-governance (accessed 3.7.24).

Elliott, M. & Whitfield, A.K. 2011. Challenging paradigms in estuarine ecology and management. *Estuarine, Coastal and Shelf Science* 94, 306–314. https://doi.org/10.1016/j.ecss.2011.06.016

Everard, M., Jones, L. & Watts, B. 2010. Have we neglected the societal importance of sand dunes? An ecosystem services perspective. *Aquatic Conservation* 20, 476–487. https://doi.org/10.1002/aqc.1114

Fletcher, S., Saunders, J., Herbert, R. & Roberts, C. 2012. Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area. (No. NECR088), Natural England Commissioned Reports. Natural England.

Ford, H., Garbutt, A., Ladd, C., Malarkey, J. & Skov, M.W. 2016. Soil stabilization linked to plant diversity and environmental context in coastal wetlands. *Journal of Vegetation Science* 27, 259–268. https://doi.org/10.1111/jvs.12367

Froese, R. & Pauly, D. 2023. FishBase. https://fishbase.se/home.php

Gaines, S.D., Lester, S.E., Grorud-Colvert, K., Costello, C. & Pollnac, R. 2010. Evolving science of marine reserves: New developments and emerging research frontiers. *Proc. Natl. Acad. Sci*. U.S.A. 107, 18251–18255. https://doi.org/10.1073/pnas.1002098107

Gamble, C., Debney, A., Glover, A., Bertelli, C., Green, B., Hendy, I., Lilley, R., Nuuttila, H., Potouroglou, M., Ragazzola, F., Unsworth, R. & Preston, J. 2021. Seagrass Restoration Handbook. Zoological Society of London, London, UK.

Godinho, A.L. 2015. Coastal Sand Dunes: A Potential Goldmine of Bioresources, in: Borkar, S. (Ed.), Bioprospects of Coastal Eubacteria. Springer International Publishing, Cham, pp. 1–24. https://doi.org/10.1007/978-3-319-12910-5_1

Goodwin, N. 2003. Five Kinds of Capital; Useful Concepts for Sustainable Development. GDAE, Tufts University, GDAE Working Papers 03–07.

Goudie, A.S. 2002. Aesthetics and relevance in geomorphological outreach. *Geomorphology* 47, 245–249. https://doi.org/10.1016/S0169-555X(02)00090-9

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F., Keeler, A.G., Opaluch, J.J., Peterson, C.H., Piehler, M.F., Powers, S.P. & Smyth, A.R. 2012. Economic Valuation of Ecosystem Services Provided by Oyster Reefs. *BioScience* 62, 900–909. https://doi.org/10.1525/bio.2012.62.10.10

Gustafsson, C. & Norkko, A. 2019. Quantifying the importance of functional traits for primary production in aquatic plant communities. *Journal of Ecology* 107, 154–166. https://doi.org/10.1111/1365-2745.13011

Haines-Young, R. & Potschin, M.B. 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.

Hall-Spencer, J. & Moore, P.J. 2000. Scallop dredging has profound, long-term impacts on maerl habitats. *ICES Journal of Marine Science* 57, 1407–1415. https://doi.org/10.1006/jmsc.2000.0918

Hall-Spencer, J., Pike, J. & Munn, C. 2007. Diseases affect cold-water corals too: Eunicella verrucosa (Cnidaria: Gorgonacea) necrosis in SW England. *Dis. Aquat. Org*. 76, 87–97. https://doi.org/10.3354/dao076087

Halpern, B.S., Lester, S.E. & McLeod, K.L. 2010. Placing marine protected areas onto the ecosystem-based management seascape. *Proc. Natl. Acad. Sci.* U.S.A. 107, 18312–18317. https://doi.org/10.1073/pnas.0908503107

Hewitt, J.E., Thrush, S.F. & Dayton, P.D. 2008. Habitat variation, species diversity and ecological functioning in a marine system. *Journal of Experimental Marine Biology and Ecology* 366, 116–122. https://doi.org/10.1016/j.jembe.2008.07.016

Hiddink, J.G., Van De Velde, S.J., McConnaughey, R.A., De Borger, E., Tiano, J., Kaiser, M.J., Sweetman, A.K. & Sciberras, M. 2023. Quantifying the carbon benefits of ending bottom trawling. *Nature* 617, E1–E2. https://doi.org/10.1038/s41586-023-06014-7

HM Government. 2023. Environmental Improvement Plan 2023. First revision of the 25 Year Environment Plan. (Corporate Report). Department for Environment Food and Rural Affairs.

HM Government. 2021. Environment Act 2021, 2021 c. 30.

Hooper, T., Börger, T., Langmead, O., Marcone, O., Rees, S.E., Rendon, O., Beaumont, N., Attrill, M.J. & Austen, M. 2019. Applying the natural capital approach to decision making for the marine environment. *Ecosystem Services* 38, 100947. https://doi.org/10.1016/j.ecoser.2019.100947

Howarth, L.M., Wood, H.L., Turner, A.P. & Beukers-Stewart, B.D. 2011. Complex habitat boosts scallop recruitment in a fully protected marine reserve. *Mar Biol* 158, 1767–1780. https://doi.org/10.1007/s00227-011-1690-y

Hudson, T., Keating, K. & Pettit, A. 2015. Cost estimation for coastal protection – summary of evidence. Environment Agency.

Ingram, J.C., Franco, G., Rio, C.R. & Khazai, B. 2006. Post-disaster recovery dilemmas: challenges in balancing short-term and long-term needs for vulnerability reduction. *Environmental Science & Policy* 9, 607–613. https://doi.org/10.1016/j.envsci.2006.07.006

IUCN WCPA Task Force on OECMs. 2019. Recognising and reporting other effective area-based conservation measures. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2019.PATRS.3.en

JNCC. 2023. UK Marine Protected Area network statistics [WWW Document]. JNCC Our Work. URL https://jncc.gov.uk/our-work/uk-marine-protected-area-network-statistics (accessed 3.7.24).

JNCC. 2019. Conserving Marine Protected Areas [WWW Document]. JNCC Our Work. URL https://jncc.gov.uk/our-work/conserving-marine-protected-areas/ (accessed 3.7.24).

Jones, C.G., Lawton, J.H. & Shachak, M. 1994. Organisms as Ecosystem Engineers. *Oikos* 69, 373. https://doi.org/10.2307/3545850

Kaiser, M.J., Hormbrey, S., Booth, J.R., Hinz, H. & Hiddink, J.G. 2018. Recovery linked to life history of sessile epifauna following exclusion of towed mobile fishing gear. *Journal of Applied Ecology* 55, 1060–1070. https://doi.org/10.1111/1365-2664.13087

Kamenos, N.A., Moore, P.G. & Hall-Spencer, J.M. 2004. Nursery-area function of maerl grounds for juvenile queen scallops Aequipecten opercularis and other invertebrates. *Mar Ecol Prog Ser* 274, 183–189.

Kenter, J.O., Bryce, R., Davies, A., Jobstvogt, N., Watson, V., Ranger, S., Solandt, J.-L., Duncan, C., Christie, M., Crump, H.L., Irvine, K.N., Pinard, M. & Reed, M.S. 2013. The value of potential marine protected areas in the UK to divers and sea anglers, in: UNEP-WCMC. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge.

Lester, S. & Halpern, B. 2008. Biological responses in marine no-take reserves versus partially protected areas. *Mar. Ecol. Prog. Ser*. 367, 49–56. https://doi.org/10.3354/meps07599

Lester, S., Halpern, B., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B., Gaines, S., Airamé, S. & Warner, R. 2009. Biological effects within no-take marine reserves: a global synthesis. *Mar. Ecol. Prog. Ser.* 384, 33–46. https://doi.org/10.3354/meps08029

Lindholm, J., Auster, P. & Valentine, P. 2004. Role of a large marine protected area for conserving landscape attributes of sand habitats on Georges Bank (NW Atlantic). *Mar. Ecol. Prog. Ser.* 269, 61–68. https://doi.org/10.3354/meps269061

Lindholm, J.B., Auster, P.J., Ruth, M. & Kaufman, L. 2001. Modeling the Effects of Fishing and Implications for the Design of Marine Protected Areas: Juvenile Fish Responses to Variations in Seafloor Habitat. *Conservation Biology* 15, 424–437. https://doi.org/10.1046/j.1523-1739.2001.015002424.x

Lloret, J., Turiel, A., Solé, J., Berdalet, E., Sabatés, A., Olivares, A., Gili, J.-M., Vila-Subirós, J. & Sardá, R. 2022. Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea. *Science of The Total Environment* 824, 153803. https://doi.org/10.1016/j.scitotenv.2022.153803

Lyme Bay Fisherman's CIC. 2022. Lyme Bay Fisherman's CIC. https://lbfcic.com/home/

Makowska, A., Kharadi, N., Kuyer, J., Tinch, R., English, D., Hull, S., Armstrong, S., Middleton, A., Baruah, L., Beaumont, N., Molloy, L., Morgan, V., Merayo, E., Judd, A., Proudfoot, R., 2022. Review of approaches for the assessment of marine Natural Capital in the content of UK marine environmental policy and management. *JNCC Report 702*. JNCC, Peterborough. ISSN 0963-8091. https://hub.jncc.gov.uk/assets/a0a9b99c-823c-4396-9445-325a99502876

Marine Planning Consultants Ltd. 2014. Lyme Bay Fisheries and Conservation Reserve: Integrated Fisheries Management Plan. A report produced for the Lyme Bay Fisheries and Conservation Reserve Working Group, UK. Marine Planning Consultants Ltd.

MarLIN. 2006. Biological Traits Information Catalogue. Marine Life Information Network. Marine Biological Association of the United Kingdom., Plymouth.

Martínez, F., Merino, O., Martín, A., García Martín, D. & Merino, J. 1998. Belowground structure and production in a Mediterranean sand dune shrub community. *Plant and Soil* 201, 209–216. https://doi.org/doi.org/10.1023/A:1004389329411

McGill, B., Enquist, B., Weiher, E. & Westoby, M. 2006. Rebuilding community ecology from functional traits. *Trends in Ecology & Evolution* 21, 178–185. https://doi.org/10.1016/j.tree.2006.02.002

MEA. 2003. Millenium Ecosystem Assessment. Ecosystems and human well-being: a framework for assessment. Island Press, Washington, DC.

Mouillot, D., Graham, N.A.J., Villéger, S., Mason, N.W.H. & Bellwood, D.R. 2013. A functional approach reveals community responses to disturbances. *Trends in Ecology & Evolution* 28, 167–177. https://doi.org/10.1016/j.tree.2012.10.004

Mouillot, D., Loiseau, N., Grenié, M., Algar, A.C., Allegra, M., Cadotte, M.W., Casajus, N., Denelle, P., Guéguen, M., Maire, A., Maitner, B., McGill, B.J., McLean, M., Mouquet, N., Munoz, F., Thuiller, W., Villéger, S., Violle, C. & Auber, A. 2021. The dimensionality and structure of species trait spaces. *Ecology Letters 24*, 1988–2009. https://doi.org/10.1111/ele.13778

Natural Capital Committee. 2019. Natural Capital Terminology. https://www.gov.uk/government/publications/natural-capital-committee-natural-capital-terminology

Natural England. 2013. Lyme Bay and Torbay candidate Special Area of Conservation Formal advice under Regulation 35(3) of The Conservation of Habitats and Species (Amendment) Regulations 2012 (Conservation Advice).

OSPAR. 2024. Assessment Reports. The biennial status assessments of the OSPAR MPA network [WWW Document]. OSPAR Assessment Portal. URL https://oap.ospar.org/en/ospar-assessments/committee-assessments/biodiversity-committee/status-ospar-network-marine-protected-areas/assessment-reports-mpa/ (accessed 3.20.24).

Perry, F. & Tyler-Walters, H. 2023. Maerl beds. In Tyler-Walters H. - Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom.

Peterson, C.H., Costa-Pierce, B., Dumbauld, B., Friedman, C., Hoffmann, E., Kite-Powell, H., Manahan, D., O'Beirn, F., Paine, R., Thompson, P. & Whitlatch, R. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. National Academies Press, Washington, D.C. https://doi.org/10.17226/12802

Pittman, S.J., Williams, M., Rodwell, L., Lowther, J., Shellock, R. & Rees, S. 2018. Plymouth marine park: The UK's first marine National Park. https://doi.org/10.13140/RG.2.2.23248.97281

Potts, T., Burdon, D., Jackson, E., Atkins, J., Saunders, J., Hastings, E. & Langmead, O. 2014. Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy* 44, 139–148. https://doi.org/10.1016/j.marpol.2013.08.011

Read, D.J. 2011. Mycorrhizas and nutrient cycling in sand dune ecosystems. Proceedings of the Royal Society of Edinburgh, Section B: *Biological Sciences* 96, 89–110. https://doi.org/doi.org/10.1017/S0269727000010873

Rees, S., Ashley, M., Evans, L., Mangi, S., Rodwell, L.D., Attrill, M.J., Langmead, O., Sheehan, E. & Rees, A. 2016. An evaluation framework to determine the impact of the Lyme Bay Fisheries and Conservation Reserve and the activities of the Lyme Bay Consultative Committee on ecosystem services and human wellbeing. University of Plymouth.

Rees, S.E., Ashley, M., Cameron, A., Mullier, T., Ingle, C., Oates, J., Lannin, A., Hooper, T. & Attrill, M.J. 2022. A marine natural capital asset and risk register—Towards securing the benefits from marine systems and linked ecosystem services. *Journal of Applied Ecology* 59, 1098–1109. https://doi.org/10.1111/1365-2664.14121

Rees, S.E., Austen, M.C., Attrill, M.J. & Rodwell, L.D. 2012. Incorporating indirect ecosystem services into marine protected area planning and management. *International Journal of Biodiversity Science, Ecosystem Services & Management* 8, 273–285. https://doi.org/10.1080/21513732.2012.680500

Rees, S.E., Mangi, S.C., Hattam, C., Gall, S.C., Rodwell, L.D., Peckett, F.J. & Attrill, M.J. 2015. The socio-economic effects of a Marine Protected Area on the ecosystem service of leisure and recreation. *Marine Policy* 62, 144–152. https://doi.org/10.1016/j.marpol.2015.09.011

Rees, S.E., Sheehan, E.V., Stewart, B.D., Clark, R., Appleby, T., Attrill, M.J., Jones, P.J.S., Johnson, D., Bradshaw, N., Pittman, S., Oates, J. & Solandt, J.-L. 2020. Emerging themes to support ambitious UK marine biodiversity conservation. *Marine Policy* 117, 103864. https://doi.org/10.1016/j.marpol.2020.103864

Renn, C., Rees, S., Rees, A., Davies, B.F.R., Cartwright, A.Y., Fanshawe, S., Attrill, M.J., Holmes, L.A. & Sheehan, E.V. 2024. Lessons from Lyme Bay (UK) to inform policy, management, and monitoring of Marine Protected Areas. *ICES Journal of Marine Science* fsad204. https://doi.org/10.1093/icesjms/fsad204

Robson, L.M., Fincham, J., Peckett, F.J., Frost, N., Jackson, C., Carter, A.J. & Matear, L. 2018. UK Marine Pressures-Activities Database "PAD": Methods Report. *JNCC Report 624*. JNCC, Peterborough. ISSN 0963-8091. https://hub.jncc.gov.uk/assets/16506231-f499-408f-bdc8-ea9a6dfbf8b5

Roelvink, D., Reniers, A., Van Dongeren, A., Van Thiel De Vries, J., McCall, R. & Lescinski, J. 2009. Modelling storm impacts on beaches, dunes and barrier islands. *Coastal Engineering* 56, 1133–1152. https://doi.org/10.1016/j.coastaleng.2009.08.006

Sala, E. & Giakoumi, S. 2018. No-take marine reserves are the most effective protected areas in the ocean. *ICES Journal of Marine Science* 75, 1166–1168. https://doi.org/10.1093/icesjms/fsx059

Sala, E., Mayorga, J., Bradley, D., Cabral, R.B., Atwood, T.B., Auber, A., Cheung, W., Costello, C., Ferretti, F., Friedlander, A.M., Gaines, S.D., Garilao, C., Goodell, W., Halpern, B.S., Hinson, A., Kaschner, K., Kesner-Reyes, K., Leprieur, F., McGowan, J., Morgan, L.E., Mouillot, D., Palacios-Abrantes, J., Possingham, H.P., Rechberger, K.D., Worm, B. & Lubchenco, J. 2021. Protecting the global ocean for biodiversity, food and climate. *Nature* 592, 397–402. https://doi.org/10.1038/s41586-021-03371-z

Salomidi, M., Katsanevakis, S., Borja, A., Braeckman, U., Damalas, D., Galparsoro, I., Mifsud, R., Mirto, S., Pascual, M., Pipitone, C., Rabaut, M., Todorova, V., Vassilopoulou, V. & Vega Fernandez, T. 2012. Assessment of goods and services, vulnerability, and conservation status of European seabed biotopes: a stepping stone towards ecosystem-based marine spatial management. *Medit. Mar. Sci*. 13, 49. https://doi.org/10.12681/mms.23

Sandin, S.A., Smith, J.E., DeMartini, E.E., Dinsdale, E.A., Donner, S.D., Friedlander, A.M., Konotchick, T., Malay, M., Maragos, J.E., Obura, D., Pantos, O., Paulay, G., Richie, M., Rohwer, F., Schroeder, R.E., Walsh, S., Jackson, J.B.C., Knowlton, N. & Sala, E. 2008. Baselines and Degradation of Coral Reefs in the Northern Line Islands. *PLoS ONE* 3, e1548. https://doi.org/10.1371/journal.pone.0001548

Sheehan, E.V., Cousens, S.L., Gall, S.C., Bridger, D.R., Cocks, S. & Attrill, M.J. 2016. Lyme Bay - A case study: Response of the benthos to the zoned exclusion of towed demersal fishing gear in Lyme Bay; 6 years after the closure (No. 219), Natural England Commissioned Reports.

Sheehan, E.V., Holmes, L.A., Davies, B.F.R., Cartwright, A., Rees, A. & Attrill, M.J. 2021. Rewilding of Protected Areas Enhances Resilience of Marine Ecosystems to Extreme Climatic Events. *Front. Mar. Sci.* 8, 671427. https://doi.org/10.3389/fmars.2021.671427

Sheehan, E.V., Stevens, T.F., Gall, S.C., Cousens, S.L. & Attrill, M.J. 2013. Recovery of a Temperate Reef Assemblage in a Marine Protected Area following the Exclusion of Towed Demersal Fishing. *PLoS ONE* 8, e83883. https://doi.org/10.1371/journal.pone.0083883

Soukissian, T., O'Hagan, A.M., Azzellino, A., Boero, F., Brito e Melo, A., Comiskey, P., Gao, Z., Howell, D., Le Boulluec, M., Maisondieu, C., Scott, B., Tedeschi, E., Maheri, A. & Pennock, S. 2023. European offshore renewable energy: Towards a sustainable future. https://doi.org/10.5281/ZENODO.7561905

Stewart, B.D., Howarth, L.M., Wood, H., Whiteside, K., Carney, W., Crimmins, É., O'Leary, B.C., Hawkins, J.P. & Roberts, C.M. 2020. Marine Conservation Begins at Home: How a Local Community and Protection of a Small Bay Sent Waves of Change Around the UK and Beyond. *Front. Mar. Sci.* 7, 76. https://doi.org/10.3389/fmars.2020.00076

Stolton, S., Hockings, M., Dudley, N., MacKinnon, K., Whitten, T., Leverington, F., 2007. Reporting Progress in Protected Areas: A Site-Level Management Effectiveness Tracking Tool: second edition. World Bank/WWF Forest Alliance published by WWF, Gland, Switzerland.

Suding, K.N., Lavorel, S., Chapin, F.S., Cornelissen, J.H.C., Díaz, S., Garnier, E., Goldberg, D., Hooper, D.U., Jackson, S.T. & Navas, M. 2008. Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. *Global Change Biology* 14, 1125–1140. https://doi.org/10.1111/j.1365-2486.2008.01557.x

Tempera, F., Liquete, C. & Cardoso, A.C. 2016. Spatial distribution of marine ecosystem service capacity in the European seas. Joint Research Centre, Institute for Health and Consumer Protection, Publication Office of the European Union Luxembourg.

Tillin, H. 2023. Relationship between asset condition and ecosystem service delivery: Bridging the gap between the Foundational Evidence and GES projects. JNCC.

Tillin, H., Hiddink, J., Jennings, S. & Kaiser, M. 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. *Mar. Ecol. Prog. Ser.* 318, 31–45. https://doi.org/10.3354/meps318031

Tillin, H.M., Langmead, O., Pegg, S., Carr, S., Gibson-Hall, E., La Bianca, G., Luff, A., Keen, P.W., Wilding, C., Nicholson, J.C., Ivory, P. & Van Rein, H. 2019. Development of JNCC Marine Ecosystem Services Optimisation models. JNCC.

Tillin, H.M., Rogers, S.I. & Frid, C.L.J. 2008. Approaches to classifying benthic habitat quality. *Marine Policy* 32, 455–464. https://doi.org/10.1016/j.marpol.2007.06.008

Tillin, H.M. & Tyler-Walters, H. 2013. Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities. Phase 1 Report: Rationale and proposed ecological groupings for Level 5 biotopes against which sensitivity assessments would be best undertaken. *JNCC Report 512A*. https://hub.jncc.gov.uk/assets/4204b127-cda2-418c-abd1-ba3589341535

United Nations, European Union, Food and Agriculture Organisation of the United Nations, Organisation for Economic Cooperation and Development, World Bank, 2012. System of Environmental Economic Accounting 2012 — Experimental Ecosystem Accounting.

Vaisman, I., Shalhevet, J., Kipnis, T. & Feigin, A. 1981. Reducing Ground-Water Pollution from Municipal Waste-Water Irrigation of Rhodes Grass Grown on Sand Dunes. *J of Env Quality* 10, 434–439. https://doi.org/10.2134/jeq1981.00472425001000040002x

Vasquez, M., Allen, H., Manca, E., Castle, L., Lillis, H., Agnesi, S., Al Hamdani, Z., Annunziatellis, A., Askew, N., Bekkby, T., Bentes, L., Doncheva, V., Drakopoulou, V., Duncan, G., Gonçalves, J., Inghilesi, R., Laamanen, L., Loukaidi, V., Martin, S., McGrath, F., Mo, G., Monteiro, P., Muresan, M., Nikilova, C., O'Keeffe, E., Pesch, R., Pinder, J., Populus, J., Ridgeway, A., Sakellariou, D., Teaca, A., Tempera, F., Todorova, V., Tunesi, L. & Virtanen, E. 2021. EUSeaMap 2021. A European broad-scale seabed habitat map. https://doi.org/10.13155/83528

Violle, C., Navas, M.-L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I. & Garnier, E. 2007. Let the concept of trait be functional! *Oikos* 116, 882–892. https://doi.org/10.1111/j.0030-1299.2007.15559.x

Williams, C. & Davies, W. 2018. A valuation of the Provisioning Ecosystem Services provided by shellfish for priority shellfish waters in the Solent. Southern IFCA and Environment Agency.

Wood, C. 2007. Seasearch Surveys in Lyme Bay - June 2007. Seasearch.

Woodley, J.D., Chornesky, E.A., Clifford, P.A., Jackson, J.B.C., Kaufman, L.S., Knowlton, N., Lang, J.C., Pearson, M.P., Porter, J.W., Rooney, M.C., Rylaarsdam, K.W., Tunnicliffe, V.J., Wahle, C.M., Wulff, J.L., Curtis, A.S.G., Dallmeyer, M.D., Jupp, B.P., Koehl, M.A.R., Neigel, J. & Sides, E.M. 1981. Hurricane Allen's Impact on Jamaican Coral Reefs. *Science* 214, 749–755. https://doi.org/10.1126/science.214.4522.749

Zhang, C., Li, J. & Zhou, Z. 2022. Ecosystem service cascade: Concept, review, application and prospect. *Ecological Indicators* 137, 108766. https://doi.org/10.1016/j.ecolind.2022.108766

Appendix 1

Table 10. Bespoke ASM for habitats in the Lyme Bay MPA. Data extracted from Galsparo 2014, Tillin et al 2019 and the universal Asset Service Matrix (uASM) (Cordingley *et al.* 2023; Galparsoro *et al.* 2014; Tillin *et al.* 2019) (Barbier *et al.* 2011; Beaumont *et al.* 2014; Borsje *et al.* 2011; Burdon, n.d.; Everard *et al.* 2010; Ford *et al.* 2016; Gamble *et al.* 2021; Godinho 2015; Goudie 2002; Haines-Young & Potschin 2018; Hudson *et al.* 2015; Ingram *et al.* 2006; Martínez *et al.* 1998; Potts *et al.* 2014; Read 2011; Rees *et al.* 2022; Roelvink *et al.* 2009; Tempera *et al.* 2016; Vaisman *et al.* 1981) (3 = High Confidence, 2 = Medium Confidence, 1 = Low Confidence), (Green (***) = High ES Delivery, Yellow (**) = Medium ES Delivery, Red (*) = Low ES Delivery) (All EUNIS rock habitats are Atlantic and Mediterranean).

CICES V5.1		**EUNIS 07**												
		Infralittoral rock and other hard substrata	High energy infralittoral rock	Moderate energy infralittoral rock	Low energy infralittoral rock	Circalittoral rock and other hard substrata	High energy circalittoral rock	Moderate energy circalittoral rock	Low energy circalittoral rock	Sublittoral coarse sediment	Sublittoral sand	Sublittoral mud	Sublittoral mixed sediments	Sublittoral macrophyte-dominated sediment
		A3	**A3.1**	**A3.2**	**A3.3**	**A4**	**A4.1**	**A4.2**	**A4.3**	**A5.1**	**A5.2**	**A5.3**	**A5.4**	**A5.5**
Provisioning (Biotic)	Plant cultivation for nutrition, materials, or energy (1.1.1.x)		*** 1	*** 1	*** 1	*** 1	*** 1	*** 1		*** 1	*** 1	*** 1		*** 1
	Plant cultivation for materials (1.1.2.2)				* 3									** 3
	Plant cultivation for energy (1.1.2.3)									*** 3	*** 3	*** 3		
	Seed collection for population maintenance (1.2.1.1)													** 3
	Genetic material from animals (1.2.2.x)				** 3									
	Provisioning (Biotic) (1.x.x.x)				* 3									
	Wild plants for nutrition, materials, or energy (1.1.5.x)		** 2	** 2	* 2									*** 2
	Wild animals for nutrition, materials, or energy (1.1.6.x)		*** 2	** 2	*** 2		*** 2	*** 2	*** 2	** 2	** 2	** 2	** 2	*** 2

CICES V5.1		**EUNIS 07**												
		Infralittoral rock and other hard substrata	High energy infralittoral rock	Moderate energy infralittoral rock	Low energy infralittoral rock	Circalittoral rock and other hard substrata	High energy circalittoral rock	Moderate energy circalittoral rock	Low energy circalittoral rock	Sublittoral coarse sediment	Sublittoral sand	Sublittoral mud	Sublittoral mixed sediments	Sublittoral macrophyte-dominated sediment
		A3	**A3.1**	**A3.2**	**A3.3**	**A4**	**A4.1**	**A4.2**	**A4.3**	**A5.1**	**A5.2**	**A5.3**	**A5.4**	**A5.5**
Regulation & Maintenance (Biotic)	Mediation of wastes or toxic substances of anthropogenic origin by living processes (2.1.1.x)		* 2	* 2	* 2			* 2	* 2	* 2	* 2	** 2	** 2	*** 2
	Filtering wastes (2.1.1.2)	** 2	** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	** 2	** 2	** 2	** 2	
	Controlling or preventing soil loss (2.2.1.1)		** 2	** 2	** 2		* 2	* 2	* 2	* 2	* 2	* 2	* 2	** 2
	Regulating the flows of water in our environment (Including flood control, and coastal protection) (2.2.1.3)		** 2	** 2	** 2		*** 3	*** 3	* 2	** 3	** 3	** 3	* 2	*** 2
	Regulation of baseline flows and extreme events (2.2.1.x)	*** 2	*** 2	** 2	** 2	*** 2	*** 2	* 2	* 2	* 2	* 2	* 2	* 2	
	Gamete dispersal (2.2.2.1)		** 2	** 2	** 2		** 2	** 2	** 2	** 2	** 2	** 2	** 2	** 2
	Seed dispersal (2.2.2.2)		** 2	** 2	** 2		** 2	** 2		** 2				** 2
	Maintaining nursery populations and habitats (2.2.2.3)		*** 2	*** 2	*** 3		** 2	** 2	** 2	** 2	** 2	** 2		*** 3

CICES V5.1		**EUNIS 07**												
		Infralittoral rock and other hard substrata	High energy infralittoral rock	Moderate energy infralittoral rock	Low energy infralittoral rock	Circalittoral rock and other hard substrata	High energy circalittoral rock	Moderate energy circalittoral rock	Low energy circalittoral rock	Sublittoral coarse sediment	Sublittoral sand	Sublittoral mud	Sublittoral mixed sediments	Sublittoral macrophyte-dominated sediment
		A3	**A3.1**	**A3.2**	**A3.3**	**A4**	**A4.1**	**A4.2**	**A4.3**	**A5.1**	**A5.2**	**A5.3**	**A5.4**	**A5.5**
	Lifecycle maintenance, habitat and gene pool protection (2.2.2.x)	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	** 2	** 2	** 2	*** 2	
	Pest and disease control (2.2.3.x)		** 2	** 2	** 2		** 2	** 2	** 2					
	Controlling pests and invasive species (2.2.3.1)				* 1									** 3
	Water conditions (2.2.5.x)	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	* 2	* 2	** 2	** 2	
	Regulating our global climate (2.2.6.1)		** 2	** 2	** 3		+ 2	** 2		** 3	** 3	** 3		** 3
	Atmospheric composition and conditions (2.2.6.x)	*** 2	*** 2	*** 2	*** 3	** 2	* 2	** 2	*** 2	** 2	* 2	* 2	* 2	*** 3
Cultural (Biotic)	Physical and experiential interactions with natural environment (3.1.1.x)		** 2	** 2	** 2		** 2	** 2	** 2					** 2
	Using the environment for sport and recreation (3.1.1.1)	*** 2	*** 2	*** 2	*** 2	** 2	** 2	** 2	*** 2	* 2	* 2	* 2	* 2	
	Watching nature to destress (3.1.1.2)	*** 2	*** 2	** 2	** 2	** 2	** 2	** 2	** 2	* 2	* 2	* 2	* 2	*** 1

CICES V5.1		**EUNIS 07**												
		Infralittoral rock and other hard substrata	High energy infralittoral rock	Moderate energy infralittoral rock	Low energy infralittoral rock	Circalittoral rock and other hard substrata	High energy circalittoral rock	Moderate energy circalittoral rock	Low energy circalittoral rock	Sublittoral coarse sediment	Sublittoral sand	Sublittoral mud	Sublittoral mixed sediments	Sublittoral macrophyte-dominated sediment
		A3	**A3.1**	**A3.2**	**A3.3**	**A4**	**A4.1**	**A4.2**	**A4.3**	**A5.1**	**A5.2**	**A5.3**	**A5.4**	**A5.5**
	Researching Nature (3.1.2.1)				** 2			* 1						
	The Beauty of Nature (3.1.2.4)		* 1	* 1	** 2		*** 3	** 2		* 1	* 1	* 1		* 1
	Intellectual and representative interactions with natural environment (3.1.2.x)	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	*** 2	* 2	* 2	* 2	* 2	
	Educational value of Nature (3.1.2.2)		* 2	* 2	* 2		* 2	* 2	* 2	* 2	* 2	* 2	* 2	* 2
	Spiritual, symbolic and other interactions with natural environment (3.2.1.x)	*** 2	** 2	** 2	** 2	*** 2	** 2	** 2	** 2	* 2	* 2	* 2	* 2	* 2

Table 1 Summary of confidence in ecosystem service change in Lyme Bay. N/A: No relevant information found. Ecosystem services described using CICES v5.1 (Haines-Young & Potschin 2018).

CICES v5.1		**Description**	**ES Change Confidence Lyme Bay MPA**
Provisioning (Biotic)	1.1.1.x	Cultivated terrestrial plants for nutrition, materials or energy	**N/A**
	1.1.2.2	Plants that are cultivated in fresh or salt water that we can use as a material	**N/A**
	1.1.2.3	Plants that are cultivated in fresh or salt water that we can use as an energy source	**N/A**
	1.2.1.1	Seeds, spores and other plant materials collected for maintaining or establishing a population	**N/A**
	1.2.2.x	Genetic material from animals	**N/A**
	1.x.x.x	Provisioning (Biotic)	**High**
	1.1.5.x	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	**N/A**
	1.1.6.x	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	**High**
Regulation & Maintenance (Biotic)	2.1.1.x	Mediation of wastes or toxic substances of anthropogenic origin by living processes	**N/A**
	2.1.1.2	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals **(Filtering wastes)**	**Low**
	2.2.1.1	Control of erosion rates **(Controlling or preventing soil loss)**	**High**
	2.2.1.3	Regulating the flows of water in our environment (Including flood control, and coastal protection)	**N/A**
	2.2.1.x	Regulation of baseline flows and extreme events	**N/A**
	2.2.1.2	Buffering and attenuation of mass movement	**High**
	2.2.2.1	Pollination (or 'gamete' dispersal in a marine context)	**N/A**
	2.2.2.2	Seed dispersal	**N/A**
	2.2.2.3	Maintaining nursery populations and habitats	**High**

CICES v5.1		Description	ES Change Confidence Lyme Bay MPA
Regulation & Maintenance (Biotic) (continued)	2.2.2.x	Lifecycle maintenance, habitat and gene pool protection	**High**
	2.2.3.x	Pest and disease control	**N/A**
	2.2.3.1	Controlling pests and invasive species	**N/A**
	2.2.5.x	Water conditions	**Low**
	2.2.6.1	Regulation of chemical composition of atmosphere and oceans	**Low**
	2.2.6.x	Atmospheric composition and conditions	**Low**
Cultural (Biotic)	3.1.1.x	Physical and experiential interactions with natural environment	**N/A**
	3.1.1.1	Using the environment for sport and recreation	**High**
	3.1.1.2	Watching plants and animals where they live; using nature to destress	**High**
	3.1.2.1	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	**Medium**
	3.1.2.2	Characteristics of living systems that enable education and training	**Medium**
	3.1.2.3	Characteristics of living systems that are resonant in terms of culture or heritage	**Medium**
	3.1.2.4	Characteristics of living systems that enable aesthetic experiences	**N/A**
	3.1.2.x	Intellectual and representative interactions with natural environment	**Medium**
	3.2.1.x	Spiritual, symbolic and other interactions with natural environment	**Medium**