

**Effects of marine
protected areas on
benthic habitat
condition and extent
and their associated
assemblages - a
systematic review**

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ENVIRONMENTAL
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Ìrean Àrainneachdail na h-Alba

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Glossary

CEE - Collaboration for Environmental Evidence

ESS – Environmental Standards Scotland

GES – Good Environmental Status

JNCC – Joint Nature Conservation Committee

MPA – Marine Protected Area

NCMPA – Nature Conservation Marine Protected Area

NGO – Non-governmental organisation

NTZ – No Take Zone

PICO – Population, Intervention, Comparator, Outcome

PoM – Programme of Measures

PMF – Priority Marine Feature

SAC – Special Area of Conservation

SEPA – Scottish Environment Protection Agency

SSSI – Site of Special Scientific Interest

UKMS – UK Marine Strategy

1. About this report

1.1 Environmental Standards Scotland's (ESS) Strategic Plan 2022 to 2025 identified several analytical priorities. One of these is 'developing a better understanding of threats to the marine environment'. Following systematic scoping and evaluation, seafloor integrity (meaning the extent to which seafloor habitats are functioning and healthy) was prioritised because of its importance for achieving overall Good Environmental Status (GES) under the UK Marine Strategy (UKMS) and the increasing exposure of seafloor habitats to human and climate-related pressures.

1.2 Section 20 of the UK Withdrawal from the European Union (Continuity) (Scotland) Act 2021 sets out the scope of ESS' functions. ESS' remit is to:

- ensure public authorities, including the Scottish Government, public bodies and local authorities, comply with environmental law
- monitor and take action to improve the effectiveness of environmental law and its implementation

1.3 ESS has prepared this technical report as part of its remit to assess compliance with environmental law, the effectiveness of environmental law or how it is implemented and applied. The relevant environmental law for this work is the Marine Strategy Regulations 2010. These regulations require the Scottish Government to set out how they will support achievement of GES through the UK Marine Strategy (UKMS).

1.4 This report presents the results of a systematic review to synthesise the current evidence on how Marine Protected Areas affect benthic habitat status. Technical reports are used by ESS to present detailed analytical evidence that underpin and inform our scrutiny work and decision-making processes. This technical report will be of interest to academics, public bodies and authorities responsible for setting and monitoring targets, and anyone interested in the scrutiny of these measures. Environmental Standards Scotland has used this work as part of its broader evidence base in examining how effectively Scottish public authorities are fulfilling their duties under the Marine Strategy Regulations 2010.

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2. Introduction

2.1 The EU Marine Strategy Framework Directive was transposed into UK legislation through the Marine Strategy Regulations 2010 (hereafter referred to as ‘the 2010 Regulations’). The 2010 Regulations place an obligation on the Secretary of State and devolved administrations to take measures to achieve or maintain Good Environmental Status (GES) in the marine environment by 2020. To deliver GES, the 2010 Regulations require the UK to produce, and periodically update, a Marine Strategy, consisting of three parts. **Part One** provides an assessment of the status of marine waters, defines the UK’s interpretation of GES characteristics and sets associated targets and indicators. **Part Two** establishes a monitoring programme to track progress against those targets and indicators. **Part Three** describes a ‘Programme of Measures’ (PoM) to achieve or maintain GES.

2.2 Under the Part One assessment, GES criteria, targets and indicators are defined for 11 qualitative descriptors. For descriptor 6 (seafloor integrity), the first Part One assessment, published in 2012, defined five GES criteria: habitat distribution, habitat extent, habitat condition, physical damage, and the condition of the seafloor (“benthic”) community. Individual targets were then set for the GES criteria across different seafloor habitats. In the updated Part One assessment (2019), GES criteria for seafloor integrity were revised to the following four: (1) spatial extent of physical loss; (2) extent of adverse effects; (3) spatial extent of habitat types adversely affected by physical disturbance; and (4) habitat condition. Under the 2010 Regulations, the status of marine waters is reassessed every six years, using these criteria and targets to determine whether GES has been achieved for the seafloor integrity descriptor as part of the benthic habitats assessment. The most recent Part One assessment was published in 2026, following the previous assessment in 2019.

2.3 Part Three of the UK Marine Strategy (UKMS) lists the actions or ‘measures’ that will be implemented by the Scottish Government (and other UK administrations) to achieve GES targets for the criteria set out in Part One. Under the 2010 Regulations, spatial protection measures are the only type of measures that must be included in the Part Three Programme of Measures. In both the 2015 and 2025 programmes, spatial protections or ‘marine protected areas’ (MPAs) are identified as a key measure for achieving seafloor integrity targets.

2.4 The 2015 Programme of Measures lists a variety of protected area designations, under different statutory frameworks, as measures for seafloor integrity. These are Special Areas of Conservation (SACs), Nature Conservation Marine Protected Areas (NCMPAs) and Sites of Special Scientific Interest (SSSI). The updated 2025 Programme of Measures also includes spatial restrictions to bottom-contacting mobile fishing to protect 11 benthic 'Priority Marine Features' in Scotland.

2.5 All of the MPA designations in the Programme of Measures define specific geographic sites for the protection and conservation of marine habitats, species and/or ecosystem functions. Protection is achieved by regulating human activities within the site. Commonly, such regulation involves managing or mitigating impacts from developments, e.g. offshore energy generation or aquaculture and/or restricting marine activities such as fishing. However, the degree and type of protection applied varies between designation types, reflecting different management objectives and legal frameworks. Both Programmes of Measures state that MPAs are expected to make a significant contribution to achieving GES for seafloor integrity.

2.6 To evaluate whether actions in the Programme of Measures are sufficient to achieve GES, it is necessary to establish whether scientific evidence indicates that the included measures are effective in delivering progress against the seafloor integrity criteria. On this basis, ESS has assessed published research on the effectiveness of MPAs for improving benthic habitat condition and extent. The assessment uses a systematic review of 55 studies from the UK, Continental Europe, and the Mediterranean published between 2000 and 2025. Evidence from these studies provides insight into the conditions under which spatial measures can improve benthic habitats. It also identifies key factors, such as enforcement, management design, and protection level, that influence ecological outcomes. The analysis forms part of broader scrutiny by ESS to examine how effectively Scottish Ministers and other public authorities are fulfilling their duties under the 2010 Regulations.

3. Methodology

Protocol

3.1 This report aims to synthesise available evidence on the effect of MPAs on the extent, distribution and condition of benthic habitats. To achieve this, a systematic literature review was conducted, involving the identification and evaluation of both primary literature from peer-reviewed academic sources and grey literature sources. To ensure a systematic appraisal of the evidence, the review followed the principles set out in the Collaboration for Environmental Evidence (CEE) Guidelines.[1] These guidelines provide a robust, evidence-based framework for the conduct of systematic reviews addressing environmental topics. The CEE protocol was selected because it was specifically developed for application in environmental management and is widely endorsed as best practice for producing rigorous and transparent evidence syntheses in this field.

3.2 To ensure the credibility of findings, systematic reviews must follow clearly defined methodological standards, including the systematic identification and mitigation of potential sources of bias within both the evidence base and the review process itself. The CEE protocol promotes transparency through the clear documentation of key methodological components such as inclusion and exclusion criteria, search strategies, data extraction procedures, and synthesis methods. By supporting methodological rigour and transparency, the CEE protocol's structured framework strengthens the reliability of findings and conclusions, encouraging consistency and clarity in the reporting methods and results. In doing so, it enables independent replication of the review and provides a solid foundation for future updates or extensions that build on its evidence base.

3.3 The CEE protocol is subject to ongoing development, with continuous efforts to refine and improve the guidelines and standards in evidence synthesis methodology. This report specifically follows the principles set out in Version 5.1 of the CEE Guidelines and Standards for Evidence Synthesis in Environmental Management.[1]

Limitations

3.4 While the CEE protocol offers a structured and reproducible approach that improves the reporting quality of systematic reviews, certain limitations are

nonetheless inherent to the process. Publication bias is a well-recognised limitation in systematic reviews, arising from the tendency for studies with positive or statistically significant findings to be published more frequently than those reporting negative or null results. This selective availability of evidence can skew the overall understanding of a topic by overrepresenting favourable outcomes and underrepresenting studies that report little, no or negative results. Consequently, the evidence base may present an unbalanced view, potentially leading to biased conclusions even when a systematic review is conducted rigorously.

3.5 The inclusion of grey literature in systematic literature reviews is an effective approach to help mitigate this bias. Grey literature refers to materials produced outside of traditional academic publishing and commercial distribution, such as government reports, technical documents, policy briefs, environmental assessments, and publications from non-governmental organisations (NGOs). These sources can offer valuable insights, particularly in environmental research, where important monitoring data and impact assessments are often disseminated through non-academic channels. In this review, grey literature was incorporated through the inclusion of sources from two major organisations actively involved in marine management. However, due to project constraints, it was not feasible to include a broader range of organisations, which may limit the comprehensiveness of the grey literature included and represents a potential limitation of this review.

3.6 Another important limitation concerns the quality and validity of the included studies. Even when studies meet the predefined eligibility criteria, they may still contain methodological flaws – such as weak study design, poor reporting, or insufficient detail on data collection and analysis. These can affect the strength and reliability of their findings. These weaknesses, if not accounted for, have the potential to influence the overall conclusions of the review. Where such flaws are evident, they will be noted and discussed within the synthesis to provide context and ensure transparency in how the evidence has been interpreted.

3.7 A further challenge in conducting systematic reviews across environmental topics is the heterogeneity of study designs, methodologies, and outcome measures. Studies often vary widely in terms of spatial and temporal scale, data collection methods, ecological indicators, and how outcomes are measured and reported. This diversity reflects the complex, context-specific nature of environmental systems but

can significantly reduce the ability to draw clear, comparable conclusions across studies. To address this challenge, this review applies a standardised framework for data extraction and categorisation. It groups studies by shared characteristics (e.g. habitat type, geographic region, or methodological approach) and explicitly accounts for differences in study quality and design in the interpretation of results. While heterogeneity cannot be eliminated, acknowledging and transparently managing it enhances the relevance and credibility of the review's conclusions.

3.8 The protocol requires detailed documentation at every stage of the review process and recommends independent double screening of all records during both the title and abstract screening, full-text screening, and data extraction stages. This is designed to maximise consistency, reduce bias, and enhance the overall reliability of the review. However, due to the practical constraints of this project, full double screening and data extraction were not feasible. Instead, a subset of 10% of studies were independently screened by a second reviewer at both the title and abstract stage, and again at the full-text stage. This served as a consistency check to ensure that the inclusion and exclusion criteria were being applied and interpreted consistently. This approach represents a pragmatic compromise which maintains a reasonable level of rigour under constrained conditions.

3.9 Finally, systematic reviews provide a snapshot in time, capturing the state of knowledge up to the point when the final searches are completed. In rapidly evolving fields, such as marine conservation and management, the evidence base is dynamic and continually expanding, meaning that new and potentially relevant studies may emerge after this review has been conducted. Without regular updates, the conclusions of this review may eventually become outdated, particularly given the time lag between conducting this review and its eventual publication, which could result in the exclusion of recent findings. This could limit the report's usefulness as a source of evidence for informing policy or management decisions over the longer term (e.g. 5 to 10 years).

Research questions

3.10 This report addresses the following research question, framed using the PICO (Population, Intervention, Comparator, Outcome) framework:

What is the effect of Marine Protected Areas (MPAs) (I) on the extent and condition (O) of benthic habitats and their associated communities (P)?

Eligibility criteria

3.11 Eligibility criteria for the inclusion of studies are detailed in Table 3.1.

Table 3-1 Inclusion and exclusion criteria

Criteria	Inclusion/Exclusion Rule
Language	Only literature published in the English language was included.
Publication Type	For academic sources, peer-reviewed journal articles and review articles were included, while standalone data sets were excluded. For grey literature, research reports, monitoring reports, and baseline environmental observations were included in this review. Editorial articles, opinion pieces, blog posts, and legislative documents such as MPA designation orders were excluded.
Temporal Scope	Only literature (academic and grey) published between 2000 and 2025 was included to ensure relevance of evidence to current marine management and conservation practices.
Geographical Scope	Studies were included if they were conducted in marine environments around the UK, Continental Europe, and the Mediterranean Sea. These regions were included because each region’s legislation governing marine protection has been derived from the EU marine strategy framework directive, and/or they have a comparable marine environment to Scotland Studies conducted outside of this geographic scope – including those based in the Americas, Asia, Africa, Oceania, or European overseas territories (e.g. St. Helena, Azores, Maderia, and the Canary Islands) – were not included.
Study Focus	Studies were included if they examined the effects of MPA or other forms of spatial protection on the extent or condition of benthic habitats and their associated communities. Studies that focused exclusively on non-benthic species or ecosystems, or those that involved benthic species but did not assess the effect of MPA designation were excluded.

Search strategy

3.12 The search strategy was developed through an iterative process, beginning with the compilation of a test set of literature known to be relevant to the research question. These articles, identified independently of the databases used in the formal search, focused on the effects of MPAs on benthic habitats and their associated communities. This test set was used to extract key terms from the title, abstract, and author-defined keywords to guide the development of an initial search string.

3.13 To further expand the search string, additional terms were sourced from the OSPAR List of Threatened and/or Declining Habitats and the Scottish Priority Marine Features (PMF) list.[2, 3] Latin species names were included where relevant, particularly for biogenic habitats formed by reef-building or aggregating species such as flame shells (*Limaria hians*), horse mussels (*Modiolus modiolus*), and red tubeworms (*Serpula vermicularis*). A list of synonyms for each habitat type was developed, and different combinations of habitat search terms were tested (e.g. “flame shell bed”, “flame shell reef”). Terms that consistently returned null or irrelevant results—such as “flame shell aggregation”—were excluded to improve the efficiency, precision, and relevance of the final search strategy. Acronyms were intentionally avoided in the search string to minimise false positive hits. For example, including the term “MPA” risked highlighting irrelevant words such as “impact”, which could reduce the overall precision of the results. A complete list of the search terms used can be found in Appendix 1.

3.14 Search terms were developed to represent the population and intervention components of the PICO question, ensuring the search addressed both the benthic habitats of interest and the spatial protection measures being assessed. Search terms for the comparator and outcome elements were not included. This was primarily because the absence of protection (i.e. no MPA designation) is difficult to define in searchable terms, making it challenging to construct effective keywords or search phrases. Additionally, the potential outcomes of interest – such as changes in habitat extent, physical condition of the habitat, community composition – were highly diverse. Including a comprehensive list of all possible outcomes risked making the search overly restrictive and could have excluded relevant studies because they used alternative language or measured outcomes not initially anticipated. Therefore, to maximise sensitivity and avoid missing potentially relevant literature, the decision

was made to focus the search string on the population and intervention components only.

3.15 Within each category (population and intervention) the search terms were combined using the Boolean operator 'OR'. The two categories were then combined into a single search string using the Boolean operator 'AND', ensuring that only articles addressing both components were retrieved. The wildcard operator '*' was also used to account for variations in word endings and to search for any group of characters (e.g. reef and reefs), further increasing the flexibility and sensitivity of the search. The full search string can be found in Appendix 2.

Academic database search

3.16 The search was conducted across multiple academic databases using the Web of Science platform, accessed through the National Library of Scotland. The databases searched were the Web of Science Core Collection, BIOSIS Citation Index, and the Zoological Record. Results were filtered to include only studies published between January 2000 and April 2025, and datasets were excluded from the results.

Grey literature search

3.17 The grey literature search targeted two key sources: NatureScot (Scotland's Statutory Nature Conservation Body) and the Scottish Government's Marine Directorate. These sources were prioritised due to their direct involvement in marine environmental monitoring, protection, and policy implementation. Other relevant organisations – such as the Joint Nature Conservation Committee (JNCC), Scottish Environment Protection Agency (SEPA), and The Crown Estate Scotland – were initially considered for inclusion in the grey literature search. However, due to time constraints and the resource-intensive nature of grey literature searches, these sources were not included in this review. These organisations should be included in any future searches to ensure a more comprehensive evidence base.

3.18 Due to limited and inconsistent internal search functionality on the target websites, the grey literature search was instead conducted using the Google Chrome search engine. However, during preliminary testing, there was uncertainty regarding how the search engine processed complex, combined search strings. As a result, the full Boolean search string was not applied. Instead, each search term

representing the population and intervention categories was entered individually to identify relevant grey literature sources, ensuring greater control over the search process and maximising the identification of usable documents.

3.19 Before applying the inclusion criteria, a total of 1,447 records were retrieved, 1,331 from database searches and 116 from grey literature, of which 77 were identified as duplicate entries.

Study/evidence selection

3.20 The systematic review platform CADIMA was used to manage the title and abstract screening process.[4] Bibliographic records retrieved from Web of Science and targeted grey literature searches were exported as .ris files and imported into the platform, where both automatic and manual deduplication were performed.

3.21 Following de-duplication, titles and abstract screening was carried out within CADIMA using predefined inclusion and exclusion criteria. All records were initially screened by a single reviewer. In line with the CEE protocol, a subset of 10% of records were independently screened by a second reviewer to assess consistency in the application of the inclusion and exclusion criteria. Any discrepancies in decisions were resolved through discussion between the screeners to reach a consensus, ensuring a consistent interpretation of the predefined inclusion and exclusion criteria. The rationale for each final decision was recorded within CADIMA, supporting transparency and reproducibility in the screening process

3.22 All articles meeting the inclusion criteria were retrieved for full-text screening. Full-text screening was conducted in parallel with data extraction to enhance efficiency. Under ideal circumstances, a subset of 10% of full-text records would have been independently assessed by a second reviewer to evaluate consistency, as was done during the title and abstract screening stage. However, due to time constraints, this additional check was not feasible in the present review. Given the high level of agreement observed during the earlier inter-reviewer consistency check, the lack of dual screening at the full-text stage was considered unlikely to introduce significant bias or compromise the integrity of the inclusion process.

3.23 After all stages of screening were completed, a total of 55 studies met the inclusion criteria and were retained for full analysis in the review.

Data extraction

3.24 A standardised data extraction form was developed to capture relevant information from the included studies. In addition to CADIMA's default bibliographic fields, such as author details, title, and publication year, the following data items were extracted from each study where available:

- **study location:**
 - country: nation where study was conducted
 - water body: named marine or coastal feature (e.g. North Sea)
 - general region: broader geographic area (e.g. western Scotland)

- **MPA details:**
 - MPA name: official name of the MPA
 - year of designation: when the MPA was legally established
 - MPA size: spatial extent of the MPA
 - type of protection: legal or administrative category (e.g. NCMPA, SAC), including relevant legislation
 - level of protection: degree of restriction on human activities (e.g. activities allowed or prohibited, no-take zones, buffer zones)
 - anthropogenic pressures: human impacts present within or near the MPA (e.g. fishing, shipping, pollution)

- **study setting and aim:**
 - target population: taxa, habitats, or communities studied
 - habitat type: physical environment where the study took place (e.g. rocky reef, seagrass meadow)
 - study aim: primary research objective (e.g. assess recovery, evaluate biodiversity change)

- **study design and sampling:**
 - study design: experimental or observational framework (e.g. BACI, Control–Impact)
 - sampling methods: techniques used to collect data (e.g. diver surveys, ROVs, video transects)
 - sampling duration: start and end dates of the study period
 - temporal replication: frequency and timing of sampling events
 - spatial replication: number of sampling sites and subsamples, including their protection status
 - control/reference sites: information on comparison sites

- **findings and outcomes:**
 - detected change: whether a change was observed and its direction (positive/negative/neutral)
 - attribution to MPA: whether changes were linked to MPA designation
 - covariates: environmental or anthropogenic factors considered in analysis
 - attribution to MPA: whether changes were linked to MPA designation
 - effect sizes/quantitative comparisons: statistical estimates or quantified change or impact
 - habitat outcomes: changes to habitat structure, extent or condition
 - species/assemblage outcomes: population or community-level biological responses
 - other outcomes: non-ecological findings (e.g. socioeconomic, carbon storage)

- **interpretation and implications:**
 - key findings: summary of main results
 - study limitations: constraints affecting interpretation or validity

- management implications: relevance to policy, enforcement, or conservation action
- other notes: additional relevant contextual or interpretative information
- **additional information:**
 - snowballing references: other potentially relevant studies cited within the paper that may warrant follow-up or inclusion
 - internal validity: rigor and reliability of the study's design and execution, ranked as high, moderate, or low, with justification based on methodological soundness and control of bias
 - external validity: generalisability of the study's findings to other MPAs or ecological contexts, ranked as high, moderate, or low, with justification based on ecological representativeness, transferability, and broader applicability

Critical appraisal

3.25 A formal risk-of-bias assessment was not undertaken for this review. Instead, critical appraisal was embedded within the data extraction process. All included studies were assessed by an experienced researcher with domain expertise, who assessed study methodology, design, and reporting as part of the extraction process. Where potential limitations or concerns relating to study validity (e.g. lack of appropriate controls, limited replication, or unclear analytical methods) were identified, these were recorded qualitatively in the data extraction framework. These observations were subsequently considered during evidence synthesis and interpretation of findings but were not used as formal exclusion criteria or to generate quantitative study quality scores.

4. Results

4.1 A total of 1,370 unique records were identified through searches of both academic databases and grey literature searches (Figure 4.1). Of these, 1,135 records were excluded following a review of titles and abstracts, leaving 235 records for full-text screening. Before full-text screening commenced, one record was excluded due to the full-text being inaccessible. An additional four records were excluded because the full text was not available in English, although English-language abstracts were accessible and used in the title and abstract screening. This left 230 for full-text screening, of which 55 met the inclusion criteria and were included in this review.

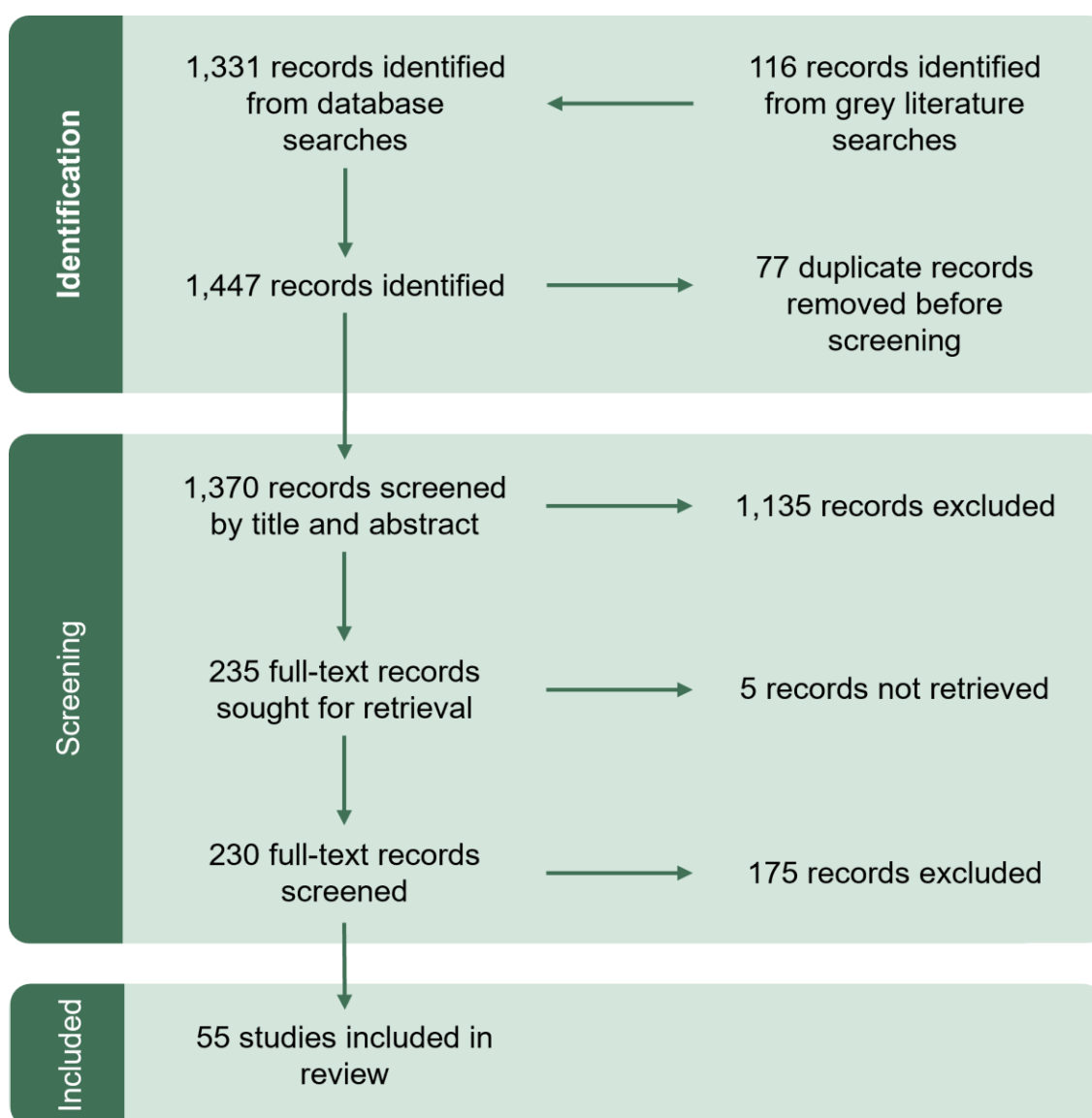


Figure 4.1. PRISMA flow diagram showing the study selection process for this systematic review. The diagram details the number of records identified, screened, excluded, and included at each stage of the review

4.2 The full list of articles assessed at the full-text stage, along with the reasons for their exclusion is provided in Appendix 3. The final 55 studies included in the review are listed in Appendix 4.

4.3 Of the 55 studies included in this review, 39 studies (71%) were conducted in the Mediterranean region, specifically from Italy (19, 35%), Spain (12, 24%), Portugal (2, 4%), France (1, 2%) Greece (1, 2%), and Monaco (1, 2%). This also includes three studies (5%) that were carried out across multiple Mediterranean countries, including Croatia, France, Greece, Italy, Morocco, Slovenia, Spain and Turkey. A further two studies (4%) were carried out in both Sweden and Denmark. The United Kingdom accounted for a substantial portion of the remaining studies, with 14 studies (25%) in total. Of these, seven were conducted in England (13%), three in Scotland (5%), and one each in Northern Ireland, Wales and Jersey (2% each). A detailed geographical breakdown of study origins is presented in Figure 4.2.

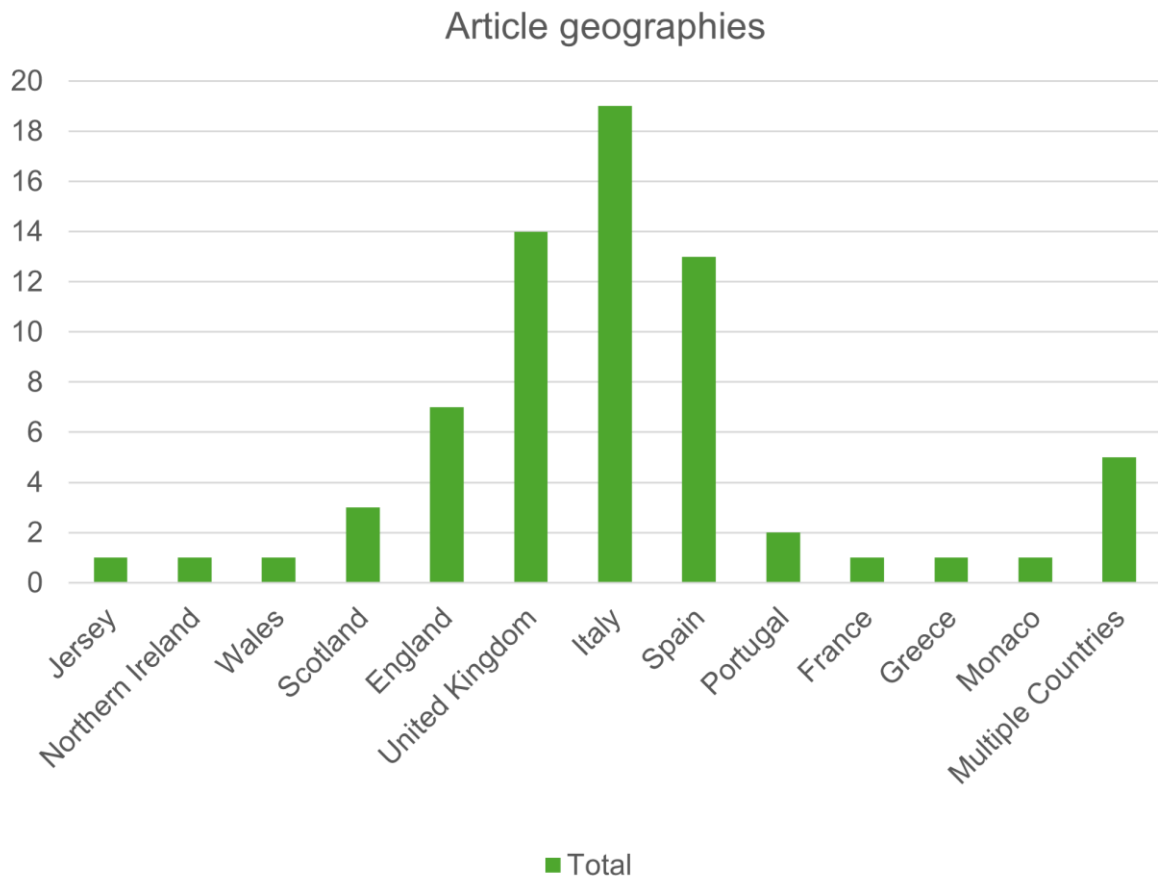


Figure 4.2. Geographic distribution of the 55 studies included in the review. Bars represent the number of studies conducted in each country. The "Multiple Countries" category includes studies conducted across multiple countries.

4.4 Of the 55 studies examined, 50 reported a change or difference in benthic habitat or associated assemblage within an MPA, including three studies that reported mixed outcomes, with both areas of change and no change. Among the 50 studies, 37 (74%) reported predominately positive changes, three (6%) reported negative changes, and 10 (20%) reported mixed positive and negative changes. Of the 50 studies that reported a change, 48 (96%) attributed the change to the MPA. This includes all studies that reported positive changes. One study reported no overall change in assemblage structure but attributed greater temporal stability of the assemblage to the MPA's influence. An additional three studies that reported mixed outcomes (i.e. change and no change) also attributed positive effects to the MPA (6%). The reported changes are summarised in Table 4-1

Table 4-1. Summary of reported changes in benthic habitat or associated assemblages across 55 studies evaluating MPA effectiveness. The table presents the direction of change, number of studies reporting each type of change, how many attributed the change to the MPA.

Change Reported	Direction of Change	Number of Studies	Attributed to MPA
Yes			
	Positive	34	34
	Negative	3	2
	Mixed	10	9
Mixed			
	Positive	3	3
No			
	-	5	
Total		55	48

5. Discussion

5.1 This review highlights that targeted scientific evidence from the last 25 years, which quantifies the effects of MPAs on the extent and condition of benthic habitats and their associated communities, is limited to relatively few studies. While MPAs are widely promoted as a tool for preserving and restoring marine ecosystems, much of the existing research has focused primarily on mobile or commercially valuable taxa, particularly fish. Indeed, 20% of the studies identified in this review are focused exclusively on fish assemblages associated with benthic habitats, with comparatively less attention paid to benthic systems such as seafloor invertebrate communities, macroalgae, and structural habitats like corals, sponges, or seagrasses. This taxonomic and thematic bias continues to constrain our understanding of how MPAs affect benthic habitats and their associated communities, especially those structured by slow-growing, habitat-forming organisms, such as maerl and horse mussels (*Modiolus modiolus*).

5.2 Nevertheless, most of the studies reviewed reported predominately positive ecological responses from benthic habitats and their associated biological communities, attributed to the implementation of MPAs. These benefits are reflected in multiple metrics, including increased species richness, shifts in community composition,[5-7] enhanced biomass of benthic organisms,[8-12] and improvements in habitat complexity,[6] alongside evidence of enhanced recovery from natural disturbance.[13] Although the evidence base remains limited, these findings collectively underscore the potential for MPAs to contribute meaningfully to the conservation and recovery of benthic ecosystems when appropriate conditions and management frameworks are in place.

Benthic community responses to protection

5.3 Changes in community composition, species richness, abundance, and biomass are among the most commonly reported ecological responses to MPAs. However, these changes are not uniform across all habitats or ecological contexts, and often vary depending on habitat type, assemblage structure, species-specific ecological traits, or a combination of these factors. Nevertheless, a recurring pattern observed across the literature is that MPAs tend to promote shifts in the structure of benthic communities, with assemblages in protected areas diverging over time from those in

adjacent areas without protection. The direction and magnitude of these changes, however, can vary considerably, with some communities showing pronounced recovery [6, 10] and restructuring while others remain stable and exhibit minimal change.[14]

5.4 Among the most consistent ecological responses to protection is the transformation of benthic community composition. Several studies reviewed reported an increase in biodiversity and species richness within MPAs in comparison to their unprotected counterparts,[5, 15-17] particularly among sessile and slow-growing organisms, such as sponges, corals and bryozoans. These changes are often characterised by a shift away from disturbance-tolerant or opportunistic species toward more structurally complex and ecologically functional assemblages [5, 15], indicating a broader move towards healthier and more stable benthic ecosystems.

5.5 The benthic community changes observed within the Lyme Bay MPA, located off the south coast of England, provide a compelling example of how spatial protection can influence benthic community composition over time.[6] Between 2008 and 2011, the structure of benthic assemblages shifted significantly, marked by substantial increases in the abundance of several habitat-forming and ecologically important taxa. The bryozoan *Pentapora fascialis*, a colony-forming invertebrate, increased by an average of 385%, while branching sponges rose by 414%. Hydroid abundance increased by 229%, although high spatial variability limited statistical confidence. Cold-water corals *Parerythropodium mammillatum* and *Alcyonium digitatum* exhibited increases of 467% and 2,541%, respectively. Meanwhile, the sea fan *Eunicella verrucosa*, a key structural species, showed a 636% rise in mean abundance.[6]

5.6 These patterns suggest the development of more mature and structurally diverse benthic communities, showing greater structural complexity and dominance of slower growing taxa over early colonising species. In turn, these compositional changes reflect improved habitat quality and enhanced ecological functioning, consistent with broader patterns of benthic recovery documented in effectively managed MPAs. Such findings highlight the potential for MPAs to enable community-level recovery following anthropogenic disturbance, especially where damaging activities like bottom-contact fishing have historically degraded habitat quality. Through protection,

MPAs can allow complex assemblages to re-establish over time, thereby enhancing ecosystem resilience, biodiversity, and habitat integrity.

5.7 Beyond changes in benthic community composition, numerous studies have documented increases in the biomass of marine species within MPAs [9, 12, 18], particularly among commercially targeted taxa such as fish and scallops.[19, 20] These increases are often attributed to the cessation or reduction of extractive activities under MPA protection, allowing populations to recover from prior exploitation. However, the response to protection is not universal, and outcomes can vary depending on a species' trophic role and its interactions with other species within the community, as well as the broader ecological context of the protected area.

5.8 Within commercially exploited species, there are consistent trends of increases in biomass, abundance, and body size within MPAs. For example, in the South Arran Marine Reserve (now designated as a NCMPA), scallop populations of *Aequipecten opercularis* and *Pecten maximus* were, on average, significantly larger and exhibited greater exploitable and reproductive biomass than those found outside the MPA.[20] Moreover, densities of these species were substantially higher within the reserve compared to adjacent, unprotected areas, with densities declining progressively with increasing distance from the MPA boundary, suggesting a potential spillover effect into surrounding fished areas.[19]

5.9 Similarly, commercially targeted sparid fish such as *Diplodus sargus* and *Diplodus vulgaris* have shown significant increases in both size and biomass within protected areas that restrict all fishing compared to adjacent fished sites, a trend that has been documented across several studies.[9, 12, 21, 22] However, it is important to note that increased biomass within MPAs can often reflect the presence of larger individuals rather than a higher density or abundance of individuals.[11] In these cases, the absence of fishing pressure enables fish to survive longer and grow into larger size classes, which ultimately enhances reproductive output and supports long-term population sustainability, even if overall abundance increases are not observed in short terms (~3-5 year) studies. These findings also reflect a broader bias in the literature, where monitoring and assessment efforts have disproportionately focused on commercially valuable species, potentially overlooking

responses among other benthic species that may not exhibit such conspicuous or economically relevant changes.

5.10 In contrast, species that are not strongly affected by fishing pressure often show inconsistent or negligible responses to protection within MPAs.[23]. This variability highlights the need to consider species-specific ecological characteristics when evaluating MPA effectiveness. For instance, sedentary or site-attached benthic species with long lifespans and slow maturation rates are more likely to benefit from reduced exploitation and disturbance within MPAs over time. In contrast, highly mobile or opportunistic species may move freely across MPA boundaries or recover quickly due to natural fluctuations, making their response to spatial protection less predictable.

5.11 The broader ecological context of spatial protection – such as habitat quality within the MPA, connectivity to surrounding habitats/populations, and the intensity of fishing pressure in adjacent areas - can significantly influence ecological outcomes. Importantly, the demographic changes induced by protection frequently extend beyond individual species, driving shifts in trophic interactions and broader community dynamics. As populations of predators recover within MPAs, they can exert increased top-down control on lower trophic levels, altering species abundances and interactions across the food web.

5.12 For example, in the Kattegat no take zone (NTZ), the recovery of predatory benthivore fish has been associated with notable declines in brittle star populations, specifically *Amphiura filiformis* and *Amphiura chiajei*, likely driven by increased predation pressure.[5] This negative correlation between benthivore fish biomass and brittle star biomass was observed within the NTZ, in contrast to the absence of such a relationship in adjacent trawled reference areas. These patterns are indicative of trophic restructuring, whereby the increase in benthivore flatfish following the cessation of fishing within the NTZ has likely contributed to the suppression of dominant brittle star populations through enhanced top-down control.

5.13 Similar patterns have been observed in sea urchin populations, which frequently decline within MPAs as predatory fish recover and recover their ecological roles.[10] As predator assemblages recover within MPAs, increased predation pressure can significantly reshape the size-frequency distribution of sea urchin populations, often leading to a notable reduction in intermediate size classes. This

pattern reflects size-selective predation and provides strong evidence of top-down control within benthic food webs.

5.14 In the case of the sea urchin species *Paracentrotus lividus*, predation risk was found to correlate positively with protection level and the biomass of predatory fish within a fully protected area.[22] Elevated predator densities within fully protected zones appeared to offset the expected positive demographic response of sea urchins to reduced harvesting. The resulting population structure was skewed, with a dominance of small and large individuals and a marked deficiency of medium-sized urchins. This bimodal distribution likely arose from the ability of juveniles to seek refuge in crevices and the reduced vulnerability of larger individuals due to predator handling limitations, thereby concentrating predation pressure on intermediate size classes. This demographic shift led to a reduction in overall grazing pressure, which in turn facilitated an increase in benthic primary producers. Within the MPA, this was reflected in a higher cover of turf-forming and erect branched algal species compared to adjacent unprotected areas.[22] This highlights the cascading ecological effects of predator recovery and the restoration of natural trophic interactions.

5.15 While such cascading ecological effects are often attributed to protection, it is also essential to recognise that natural ecological variability can sometimes mask or confound these patterns. For example, great scallops exhibited a marked increase in juvenile abundance within protected areas, with densities substantially higher than those in adjacent, unprotected areas[19, 20] While this trend aligns with expectations under reduced fishing pressure, it is important to note that the overall abundance of juvenile scallops in the region has been observed to fluctuate on a roughly biennial basis, alternating between low and high recruitment years.[19] Such natural variability in recruitment cycles complicates the attribution of observed changes solely to MPA protection. Short-term assessments that coincide with unusually high or low recruitment periods may overestimate or underestimate the true effects of protection. This highlights the critical importance of long-term monitoring and the inclusion of appropriate reference sites to disentangle protection effects from background ecological dynamics, ensuring that observed changes are interpreted within the correct temporal and environmental context.

5.16 In summary, the ecological responses of benthic species and communities to MPAs are diverse, complex, and strongly context dependent. While consistent trends such as increases in biomass, body size, and biodiversity are well documented, particularly among commercially targeted and structurally important benthic taxa, these outcomes are shaped by a range of interacting factors. Habitat type, assemblage composition, species-specific life-history traits, and broader ecological conditions all influence the direction and magnitude of community change. Importantly, MPAs can facilitate trophic restructuring through the recovery of predator populations, leading to cascading effects that alter benthic community composition, suppress grazer populations, and promote the proliferation of habitat-forming species. However, natural ecological variability, such as episodic recruitment and environmental fluctuations, can obscure or confound these effects, highlighting the importance of long-term, spatially replicated monitoring. A nuanced, ecosystem-based approach to MPA evaluation that accounts for both protection effects and background ecological dynamics is therefore essential for accurately assessing outcomes and guiding effective conservation management.

Recovery of benthic habitats within MPAs

5.17 The recovery of benthic habitats represents a key ecological outcome of effective implementation of MPAs. Beyond changes in species composition and biomass, improvements in habitat structure and integrity are critical indicators of ecosystem restoration. Within MPAs, the exclusion or reduction of damaging activities, particularly bottom-contact fishing, allows physically degraded habitats to begin a natural recovery process, often marked by increased complexity, stability, and biological productivity.

5.18 Structurally complex habitats such as biogenic reefs, sponge grounds, seagrass meadows, and maerl beds have shown strong potential for recovery under sustained protection. As previously discussed in paragraph 5.5, the cessation of mobile fishing in Lyme Bay MPA has led to the re-establishment of diverse epifaunal assemblages and the return of key habitat-forming species, including branching sponges and cold-water corals.[6] These organisms play a foundational role in creating three-dimension benthic habitat with vertical surfaces and increased surface area that provide shelter and substrate for a variety of associated fauna.

5.19 The trajectory, pace, and outcomes of benthic habitat recovery are influenced by multiple factors, including substrate type, the intensity and duration of historical disturbance, and the regenerative capacity of the species. Maerl beds, formed by slow-growing calcareous red algae, are particularly sensitive to physical disturbance, and their slow rates of recovery are widely recognised. Consistent with this, evidence suggests that maerl beds can exhibit marked differences in morphology and structural complexity depending on the duration of protection. For instance, maerl beds within an MPA, which had designated for six years, displayed significantly lower structural development, characterised by smaller size, less spheroidal shape, and lower morphological complexity when compared to those in a long-established MPA that had been designated for 25 years.[24] These findings suggest that while MPAs can promote the recovery of maerl habitats, extended periods of sustained protection are likely required for them to regain their full structural complexity and ecological function.

5.20 Environmental conditions can further influence recovery trajectories. For instance, within the same study, maerl morphology was compared across different depths in the long-established MPA, revealing significant variation. Regardless of growth strategy (ramified versus nucleated), maerl in shallow beds was generally larger, rounder, and more solid, meaning less branched and structurally complex, than maerl found in deeper areas.[24] These patterns underscore the influence of environmental gradients such as hydrodynamics, light availability, and sedimentation rates on habitat structure, suggesting that recovery potential is not uniform even under long-term protection.

5.21 While MPAs can facilitate the recovery of benthic habitats, protection does not always equate to ecological improvement or measurable recovery. In some cases, the absence of observed recovery, or even further degradation, reflects complex underlying pressures or historical impacts that are not easily reversed. A notable example is Strangford Lough, where benthic habitat condition has continued to decline despite protective measures. Between 2003 and 2010, mean densities of horse mussels (*M. modiolus*) in the north basin declined by approximately 83%, from 80 individuals per square metre to just 13.6 individuals per square metre.[7] This represents an average reduction of over 66 individuals per square metre, and a significant deterioration in condition within a relatively short timeframe, despite the area being designated for conservation.

5.22 Such trends highlight the importance of recognising that recovery is not guaranteed simply through spatial protection. In many nearshore environments, particularly those with a long history of anthropogenic disturbance, conservation efforts must contend with shifting baselines. This term refers to the gradual lowering of ecological reference points used in trend assessments over time, as each generation comes to accept a progressively degraded state as normal. The presence of shifting baselines complicates the assessment of MPA outcomes, since current conservation targets may be based on already altered or degraded benchmarks.

5.23 In some instances, habitat recovery may be further constrained by legacy impacts that have pushed ecosystems beyond critical thresholds, significantly reducing their capacity to regenerate without active intervention. This highlights the need for timely protection, ideally implemented before irreversible degradation occurs. It also underscores the potential necessity of active restoration measures, such as reseedling, artificial reef construction, or sediment remediation, particularly in severely impacted areas.

5.24 In addition to historical impacts and environmental conditions, the recovery of benthic habitats can also be influenced by interactions with other species within the community. As previously discussed, trophic dynamics and species-specific responses to protection can shape recovery trajectories in unexpected ways. For example, *Laminaria ochroleuca*, a habitat-forming kelp species, has been observed to fail to re-establish a canopy forest within an MPA, despite reductions in direct physical disturbance.[25] Instead, persistent grazing by recovering fish populations has limited the survival of juvenile kelp, thereby inhibiting the development of a mature *L. ochroleuca* canopy.

5.25 This example highlights how ecological interactions within protected areas can influence habitat recovery outcomes, even in the absence of direct anthropogenic disturbance. It demonstrates that protection alone does not guarantee the re-establishment of all habitat-forming species, particularly when biotic pressures such as herbivory remain high. Such outcomes underscore the complexity of benthic ecosystem dynamics and reinforce the need for holistic, community-level assessments when evaluating MPA effectiveness for achieving seafloor integrity targets. Assessing not only the responses of individual species, but also the

interactions among functional groups, is essential for anticipating potential trade-offs and managing ecosystems in a way that supports broader objectives for GES.

Role of disturbance and recovery support

5.26 Both natural and anthropogenic disturbances can significantly alter marine habitats and the composition of benthic assemblages, even within designated MPAs. Extreme weather events can induce rapid and profound alterations in benthic ecosystems, potentially offsetting ecological gains achieved through protection. A well-documented example of this comes from Lyme Bay (United Kingdom), where a severe storm event in 2013 caused widespread disruption to the benthic community.[13] The effects of the storm were more pronounced within the MPA than in adjacent unprotected sites, resulting in greater losses of species and individuals. This disturbance temporarily reversed the protective gains, with community composition within the MPA reverting to a state more closely resembling that of unprotected areas and effectively erasing the structural divergence that had previously developed through protection.

5.27 Despite this setback, post-disturbance monitoring revealed a markedly faster recovery trajectory within the Lyme Bay MPA relative to unprotected sites. Over time, the protected assemblages re-established greater ecological distinctiveness and structural complexity, whereas communities outside the MPA remained in a persistently degraded state. These findings suggest that although the MPA did not confer strong resistance to the acute impact of the storm, it enhanced ecological resilience by facilitating more rapid and complete recovery. This distinction is important as while resistance refers to the ability to withstand disturbance, resilience reflects the capacity to recover. The observed pattern was further supported by evidence showing that recovery from storm damage within the MPA outpaced previous recovery from chronic impacts such as bottom-towed fishing activities.[13] In contrast, benthic assemblages in unprotected areas remained impacted throughout the monitoring period, highlighting the long-term consequences of continued anthropogenic pressure.

5.28 This case illustrates that, although MPAs may not always buffer against the immediate effects of extreme events, they can play a critical role in promoting ecosystem resilience and long-term recovery. Protection appears to enhance recovery capacity by fostering more functionally diverse, structurally complex, and

interconnected communities, which are better equipped to rebound following disturbance events.

Effectiveness and limitations of MPAs: implications for management

5.29 MPAs represent a widely used tool for marine conservation and habitat recovery, yet their effectiveness is neither universal nor guaranteed. As this review has shown, MPAs can facilitate the restoration of benthic habitats and communities, enhance biodiversity, and improve ecological resilience. However, these outcomes are contingent on a range of ecological and managerial factors, and protection alone is not always sufficient to ensure recovery and/or progress towards seafloor integrity targets for GES.

5.30 The ecological success of an MPA depends critically on its design, implementation, and enforcement. Key attributes such as size, age, level of protection, spatial configuration, and placement relative to key habitats and ecological corridors collectively influence the extent to which an MPA can mitigate anthropogenic impacts and support ecological recovery. Older, well-enforced MPAs are consistently associated with more pronounced ecological benefits. In contrast, smaller MPAs, those with limited enforcement, or those incorporating partially protected zones (where some human activities remain) tend to show more variable or limited ecological outcomes. Evidence increasingly suggests that fully protected areas, where extractive activities are entirely prohibited across the site, are more effective than partially protected zones in achieving meaningful conservation gains, particularly for benthic habitats and associated communities.

5.31 While MPAs offer localised protection, they are not insulated from broader environmental pressures. Disturbances originating beyond their boundaries, including increased sedimentation, nutrient loading, invasive species, ocean warming, and extreme storm events, can reduce their ecological effectiveness. These external stressors have the potential to degrade habitat condition and alter community structure, even in well-managed protected areas. Nevertheless, as noted in paragraph 5.25, MPAs can increase the resilience of benthic habitats and communities, supporting more rapid and complete recovery following such disturbances. This highlights the importance of integrating MPAs with wider marine

management measures that address both local and regional drivers of ecological change.

5.32 Slow ecological response times and historically degraded baseline conditions further complicate assessments of effectiveness. In some cases, benthic habitats may require extended periods to respond to protection due to slow growth rates or limited larval supply. Recovery may also be masked by shifting baselines, where the full extent of historical degradation is poorly understood, and modern reference conditions already reflect diminished ecological states.

5.33 Importantly, the absence of measurable ecological change should not automatically be interpreted as evidence of MPA failure or that spatial protection is an ineffective measure for achieving seafloor integrity targets. In some cases, limited or no apparent response may reflect complex ecological constraints, insufficient time since designation, or misalignment between management measures and the ecological characteristics or recovery timescales of the targeted habitats and communities. In addition, sampling at insufficient time intervals may fail to capture natural seasonal or interannual variability, potentially obscuring underlying trends. Such outcomes do not definitively indicate that an MPA is ineffective but rather highlight the need for careful interpretation and long-term, ecologically informed monitoring. The most effective way to minimise the likelihood of ambiguous or limited outcomes is to carefully plan and design MPAs around the specific ecological characteristics and recovery dynamics of benthic habitats. Aligning spatial protection with habitat-specific needs increases the likelihood of achieving conservation objectives, such as GES, and delivering measurable ecological benefits.

5.34 Given this complexity, robust and habitat-specific monitoring strategies are essential. Benthic communities are often highly variable and tend to respond slowly and non-linearly to management interventions. Effective monitoring must be capable of capturing both annual and seasonal variation across the entire benthic community, including habitat features, sessile and mobile invertebrates, structural taxa, and associated fish assemblages. The reviewed literature demonstrate that where possible, it is critical to gather baseline data prior to MPA designation to establish ecological reference points and enable meaningful assessment of change over time. In addition, monitoring programmes should include sampling at appropriately matched reference sites located in ecologically similar, unprotected areas. This

spatial replication allows for better attribution of observed changes to protection effects, helping to distinguish them from broader environmental variation. Long-term, spatially explicit programmes should incorporate benthic indicators, such as habitat extent and structural complexity, to detect ecologically meaningful trends and assess recovery trajectories in systems where responses may be subtle, lagged, or spatially heterogeneous.

5.35 In conclusion, the reviewed literature demonstrates that MPAs can be effective in improving the extent and condition of benthic habitats and their associated assemblages. However, their success depends on careful design, consistent enforcement, and long-term management. Protection measures must be ecologically tailored, adequately resourced, and embedded within broader management strategies that address both local and regional pressures. To restore and sustain healthy benthic ecosystems and their associated assemblages, MPAs must be supported by scientific understanding, adaptive management, and targeted monitoring. Only through this integrated approach can they be full effective for delivering targets for GES under the UKMS.

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7. Appendices

Appendix 1. List of population and search terms

Population Search Terms				
Benthic habitat*	Benthic reef*	Biogenic habitat*	Biogenic bed*	Biogenic reef*
Blue mussel bed*	Blue mussel communit*	Blue mussel habitat*	Blue mussel reef*	Burrowed mud
Burrowing megafauna	Carbonate mound	Cold-water coral colon*	Cold-water coral communit*	Cold-water coral garden*
Cold-water coral habitat*	Cold-water coral mound*	Cold-water coral reef*	Deep-sea sponge aggregation*	Deep-sea sponge communit*
Deep-sea sponge ground*	Flame shell*	<i>Funiculina quadrangularis</i>	Horse mussel bed*	Horse mussel communit*
Horse mussel habitat*	Horse mussel reef*	Kelp bed*	Kelp communit*	Kelp forest*
Kelp habitat*	<i>Lima* hians</i>	<i>Lophelia pertusa</i> colon*	<i>Lophelia pertusa</i> habitat*	<i>Lophelia pertusa</i> reef*
Maerl bed*	Maerl communit*	Maerl habitat*	<i>Modiolus modiolus</i> aggregation*	<i>Modiolus modiolus</i> bed*
<i>Modiolus modiolus</i> communit*	<i>Modiolus modiolus</i> reef*	Mussel aggregation*	Mussel bed*	Mussel communit*
Mussel habitat*	Mussel reef*	<i>Mytilus edulis</i> aggregation*	<i>Mytilus edulis</i> bed*	<i>Mytilus edulis</i> communit*
<i>Mytilus edulis</i> reef*	Native oyster bed*	Native oyster habitat*	Native oyster reef*	Northern sea fan
<i>Ostrea edulis</i> bed*	<i>Ostrea edulis</i> habitat*	<i>Ostrea edulis</i> reef*	Rock* reef*	<i>Sabellaria spinulosa</i> reef*
Sea pen	Seabed habitat*	Seamount	Seapen	<i>Serpula vermicularis</i> aggregation*
<i>Serpula vermicularis</i> reef*	Serpulid aggregation*	Serpulid reef*	Serpulidae aggregation*	Serpulidae reef*

Population Search Terms				
<i>Zostera marina</i> AND eelgrass bed*	<i>Zostera marina</i> AND eelgrass habitat*	<i>Zostera marina</i> AND eelgrass meadow*	<i>Zostera marina</i> AND seagrass bed*	<i>Zostera marina</i> AND seagrass habitat*
<i>Zostera marina</i> AND seagrass meadow*				
Intervention Search Terms				
Marine protected area*	Marine reserve*	Marine sanctuary*	Marine refuge*	No-take zone*
Special Area of Conservation*	Site* of Special Scientific Interest*			

Appendix 2. Web of Science Search String

(TS=("Benthic habitat*") OR TS=("Benthic reef*") OR TS=("Biogenic habitat*") OR TS=("Biogenic bed*") OR TS=("Biogenic reef*") OR TS=("Seabed habitat*") OR TS=("rock* reef*") OR TS=("flame shell") OR TS=("Lima* hians") OR TS=("Horse mussel bed*") OR TS=("Horse mussel communit*") OR TS=("Horse mussel habitat*") OR TS=("Horse mussel reef*") OR TS=("Modiolus modiolus aggregation*") OR TS=("Modiolus modiolus bed*") OR TS=("Modiolus modiolus communit*") OR TS=("Modiolus modiolus reef*") OR TS=("Blue mussel bed*") OR TS=("Blue mussel communit*") OR TS=("Blue mussel habitat*") OR TS=("Blue mussel reef*") OR TS=("Mytilus edulis aggregation*") OR TS=("Mytilus edulis bed*") OR TS=("Mytilus edulis communit*") OR TS=("Mytilus edulis reef*") OR TS=("mussel aggregation*") OR TS=("mussel bed*") OR TS=("mussel communit*") OR TS=("mussel habitat*") OR TS=("mussel reef*") OR TS=("Native oyster bed*") OR TS=("Native oyster habitat*") OR TS=("Native oyster reef*") OR TS=("Ostrea edulis bed*") OR TS=("Ostrea edulis habitat*") OR TS=("Ostrea edulis reef*") OR TS=("Maerl bed*") OR TS=("Maerl communit*") OR TS=("Maerl habitat*") OR TS=("Sabellaria spinulosa reef*") OR TS=("Serpulid aggregation*") OR TS=("Serpulid reef*") OR TS=("Serpulidae aggregation*") OR TS=("Serpulidae reef*") OR TS=("Serpula vermicularis aggregation*") OR TS=("Serpula vermicularis reef*") OR TS=("Kelp bed*") OR TS=("Kelp communit*") OR TS=("Kelp forest*") OR TS=("Kelp habitat*") OR (TS=("Zostera marina") AND TS=("Seagrass bed*")) OR (TS=("Zostera marina") AND TS=("Seagrass habitat*")) OR (TS=("Zostera marina") AND TS=("Seagrass meadow*")) OR (TS=("Zostera marina") AND TS=("Eelgrass bed*")) OR (TS=("Zostera marina") AND TS=("Eelgrass habitat*")) OR (TS=("Zostera marina") AND TS=("Eelgrass meadow*")) OR TS=("Cold-water coral colon*") OR TS=("Cold-water coral communit*") OR TS=("Cold-water coral garden*") OR TS=("cold-water coral habitat*") OR TS=("cold-water coral mound*") OR TS=("cold-water coral reef*") OR TS=("Iophelia pertusa colon*") OR TS=("Iophelia pertusa habitat*") OR TS=("Iophelia pertusa reef*") OR TS=("carbonate mound*") OR TS=("Deep-sea sponge aggregation*") OR TS=("Deep-sea sponge communit*") OR TS=("Deep-sea sponge ground*") OR TS=("northern sea fan*") OR TS=("burrowed mud") OR TS=("burrowing megafauna") OR TS=("seapen") OR TS=("sea pen") OR TS=("Funiculina quadrangularis") OR TS=("seamount")) AND (TS=("marine protected area*") OR TS=("marine reserve*") OR TS=("marine sanctuary*") OR TS=("marine refuge*") OR TS=("no take zone*") OR TS=("Special Area of Conservation*") OR TS=("Site* of Special Scientific Interest"))

Appendix 3. Summary of all studies **excluded** during full-text screening. Screening outcomes are coded as follows: E = Exclude, study does not meet inclusion criteria; E - B = Exclude – Baseline data, study does not meet inclusion criteria but provides useful baseline data; E - R = Exclude – Related information, study does not meet inclusion criteria but provides relevant contextual or supplementary information; U = Unavailable, study could not be accessed due to inaccessible full text

Author(s)	Year	Title	Decision
NatureScot	2025	Conservation and Management Advice - Firth of Lorn SAC	E - B
NatureScot	2025	Conservation and Management Advice - Clyde Sea Sill MPA	E - B
NatureScot	2025	Conservation and Management Advice - Loch Creran SAC and MPA	E - B
Rizzo et al.	2025	Subtidal benthic assemblages in a mediterranean bank along a depth gradient: Conservation perspectives of a vulnerable marine ecosystem	E - B
Canessa, Bavestrello & Giorgio	2024	Intense bioturbation by the irregular sea urchin <i>Spatangus purpureus</i> in a Mediterranean maerl bed.	E
Costa et al.	2024	The grim fate of a <i>Paramuricea clavata</i> (Risso, 1827) forest off Asinara Island (northwest Sardinia, Italy).	E
Gogina et al.	2024	Baseline Inventory of Benthic Macrofauna in German Marine Protected Areas (2020-2022) before Closure for Bottom-Contact Fishing.	E - B
Hall-Spencer & Rasmuson	2024	The importance of public engagement for maerl conservation: Insights from Scotland	E
Heres et al.	2024	Characterization of deep-sea sponge ground (<i>Asconema setubalense</i>) using structure from motion methodology.	E - R
Honeyman et al.	2024	Correspondence among multiple methods provides confidence when measuring marine protected area effects for species and assemblages	E
Jacob et al.	2024	Understanding the ecosystem quality of Mediterranean shallow rocky reefs: Insights from the application of ecosystem-based indices	E
NatureScot	2024	Conservation and Management Advice - Loch Laxford SAC	E - B

Author(s)	Year	Title	Decision
NatureScot	2024	Conservation and Management Advice - Sanday SAC	E - B
NatureScot	2024	Conservation and Management Advice - Dornoch Firth and Morrich More SAC	E - B
NatureScot	2024	Conservation and Management Advice - Firth of Tay and Eden Estuary SAC	E - B
NatureScot	2024	Conservation and Management Advice - Loch Sween MPA	E - B
NatureScot	2024	Conservation and Management Advice - Wyre and Rousay Sounds MPA	E - B
NatureScot	2024	Conservation and Management Advice - St Kilda SAC	E - B
NatureScot	2024	Conservation and Management Advice - Sea of the Hebrides MPA	E - B
NatureScot	2024	Conservation and Management Advice - Southern Trench MPA	E - B
NatureScot	2024	Conservation and Management Advice - Fetlar to Haroldswick MPA	E - B
NatureScot	2024	Conservation and Management Advice - Loch Carron MPA	E - B
NatureScot	2024	Conservation and Management Advice - Small Isles MPA	E - B
NatureScot	2024	Conservation and Management Advice - Upper Loch Fyne and Loch Goil MPA	E - B
NatureScot	2024	Conservation and Management Advice - Mousa SAC	E - B

Author(s)	Year	Title	Decision
NatureScot	2024	Conservation and Management Advice - South Arran MPA	E - B
NatureScot	2024	Conservation and Management Advice - Sullom Voe SAC	E - B
NatureScot	2024	Conservation and Management Advice - Papa Stour SAC	E - B
NatureScot	2024	Conservation and Management Advice - Lochs Duich, Long and Aish Reefs SAC and Lochs Duich, Long and Aish MPA	E - B
NatureScot	2024	Conservation and Management Advice - Moray Firth SAC	E - B
NatureScot	2024	Conservation and Management Advice - Loch Nam Madadh SAC	E - B
NatureScot	2024	Conservation and Management Advice - Isle of May SAC	E - B
NatureScot	2024	Conservation and Management Advice - Monach Islands SAC and Monach Isles MPA	E - B
NatureScot	2024	Conservation Objectives and Advice to Support Management - Noss Head MPA	E - B
NatureScot	2024	Conservation and Management Advice - Treshnish Isles SAC	E - B
NatureScot	2024	Conservation and Management Advice - Yell Sound Coast SAC	E - B
Ingrassia et al.	2023	A Review of Rhodolith/Maerl Beds of the Italian Seas	E
Langton, Stirling & Boulcott	2023	Using regional-scale predictive habitat models to assess protection and identify potential locations for additional management or monitoring for a species of conservation interest	E

Author(s)	Year	Title	Decision
NatureScot	2023	Conservation and Management Advice - Ythan Estuary, Sands of Forvie & Meikle Loch SPA	E - B
NatureScot	2023	Conservation and Management Advice - Solway Firth SPA	E - B
Nenciu et al.	2023	An Assessment of Potential Beam Trawling Impact on North-Western Black Sea Benthic Habitats Aiming at a Sustainable Fisheries Management	E
Podda & Porporato	2023	Marine spatial planning for connectivity and conservation through ecological corridors between marine protected areas and other effective area-based conservation measures.	E
Savin et al.	2023	Assessment of macroalgal communities on shallow rocky reefs in the Aegean Sea indicates an impoverished ecological status	E
Azzola et al.	2022	Variability between observers does not hamper detecting change over time in a temperate reef	U
Begun et al.	2022	Habitat and Macrozoobenthic Diversity in Marine Protected Areas of the Southern Romanian Black Sea Coast	E - B
Boutahar, Espinosa & Bazairi	2022	Reconstruction of <i>Cymodocea nodosa</i> 's dynamics as a tool to examine the conservation status of a Mediterranean declared marine protected area	E - B
Bracchi et al.	2022	Morphostructural Characterization of the Heterogeneous Rhodolith Bed at the Marine Protected Area "Capo Carbonara" (Italy) and Hydrodynamics	E - B
Hopf et al.	2022	No-take marine protected areas enhance the benefits of kelp-forest restoration for fish but not fisheries	E
Laffoley & Baxter	2022	Blue Carbon in Marine Protected Areas - Progress Review.	E - R
Massuti et al.	2022	Improving Scientific Knowledge of Mallorca Channel Seamounts (Western Mediterranean) within the Framework of Natura 2000 Network	E - B
Mogstad et al.	2022	Remote Sensing of the Tautra Ridge: An Overview of the World's Shallowest Cold-Water Coral Reefs	E

Author(s)	Year	Title	Decision
NatureScot	2022	Conservation and Management Advice - Moray Firth SPA	E
NatureScot	2022	Conservation and Management Advice - Scapa Flow SAC	E - B
NatureScot	2022	Conservation and Management Advice - Coll and Tiree SPA	E - B
NatureScot	2022	Conservation and Management Advice - Outer Firth of Forth and St Andrews Bay Complex SPA	E - B
NatureScot	2022	Conservation and Management Advice - Sound of Gigha SPA	E - B
NatureScot	2022	Conservation and Management Advice - Sound of Barra SAC	E - B
NatureScot	2022	Conservation and Management Advice - North Orkney SPA	E - B
NatureScot	2022	Conservation and Management Advice - East Mainland Coast, Shetland SPA	E - B
NatureScot	2022	Conservation and Management Advice - West Coast of the Outer Hebrides SPA	E - B
Angiolillo et al.	2021	New records of scleractinian cold-water coral (CWC) assemblages in the southern Tyrrhenian Sea (western Mediterranean Sea): Human impacts and conservation prospects	E - B
Bo et al.	2021	The high biodiversity and vulnerability of two Mediterranean bathyal seamounts support the need for creating offshore protected areas	E - B
Felix et al.	2021	Modelling the Distribution of a Commercial NE-Atlantic Sea Cucumber, <i>Holothuria mammata</i> : Demographic and Abundance Spatio-Temporal Patterns	E
Hinchen et al.	2021	Detecting the impacts on UK sublittoral rock communities of resuspended sediments from fishing activity	E

Author(s)	Year	Title	Decision
NatureScot	2021	Conservation and Management Advice - The Vadills SAC	E - B
NatureScot	2021	Conservation and Management Advice - Obain Loch Euphoirt SAC	E - B
NatureScot	2021	Conservation and Management Advice - Sound of Arisaig (Loch Ailort to Loch Ceann Traigh) SAC	E - B
NatureScot	2021	Conservation and Management Advice - Loch Road Lagoons SAC	E - B
NatureScot	2021	Conservation and Management Advice - Loch of Stenness SAC	E - B
NatureScot	2021	Scottish MPA Programme Data Confidence Assessment - Red Rocks and Longay Possible MPA	E - B
O'Dell et al.	2021	Biological analyses of seabed imagery from within and around Loch Alsh, Loch Carron, Wester Ross, Small Isles and South Arran Marine Protected Areas in 2018.	E - B
Eerkes-Medrano et al.	2020	A community assessment of the demersal fish and benthic invertebrates of the Rosemary Bank Seamount marine protected area (NE Atlantic)	E
Langton et al.	2020	Are MPAs effective in removing fishing pressure from benthic species and habitats?	E - R
Leon et al.	2020	Assessing the Repeatability of Automated Seafloor Classification Algorithms, with Application in Marine Protected Area Monitoring	E
McLaverly et al.	2020	High-resolution fisheries data reveal effects of bivalve dredging on benthic communities in stressed coastal systems	E
Moore	2020	Biological analyses of underwater video from monitoring and research cruises carried out from 2017 to 2019 in the Sounds of Barra and Mull, Lochs Sunart, Alsh and Carron, the Inner Sound, and off the Small Isles and east of Shetland	E - B
Moore et al.	2020	The current status of serpulid reefs, horse mussel beds and flame shell beds in Loch Creran SAC and MPA	E - R

Author(s)	Year	Title	Decision
Munoz, Buckel & Fangman	2020	Project 5. Benthic fish communities and structural habitat measurements from Gray's Reef National Marine Sanctuary, 2010-2016.	E
Pearce & Kimber	2020	The Status of <i>Sabellaria spinulosa</i> Reef off the Moray Firth and Aberdeenshire Coasts and Guidance for Conservation of the Species off the Scottish East Coast	E - R
Scottish Government	2020	Biogenic Habitats	E - R
Turrel	2020	A Compendium of Marine Related Carbon Stores, Sequestration and Emmissions	E - R
Werner et al.	2020	Density-driven habitat use differences across fishing zones by predator fishes (Serranidae) in south-western Mediterranean rocky reefs	E - R
Allen	2019	Infaunal and PSA analyses of benthic samples collected from Loch Carron, Wester Ross, Moray Firth and the Sound of Barra in 2017	E - B
de la Torriente et al.	2019	Benthic habitat modelling and mapping as a conservation tool for marine protected areas: A seamount in the western Mediterranean	E - B
Innangi et al.	2019	Seabed classification around Lampione islet, Pelagie Islands Marine Protected area, Sicily Channel, Mediterranean Sea	E - B
Moore	2019	Biological analyses of underwater video from monitoring and research cruises in Lochs Ailort and Fyne, the Sounds of Barra and Mull, inner Moray Firth, off Wester Ross, Noss Head and Rattray Head, and around the Southern Trench in outer Moray Firth	E - R
NatureScot	2019	Conservation Objectives and Advice to Support - East Mingulay SAC	E - B
NatureScot	2019	Conservation and Management Advice - Southern Trench Possible MPA	E - B
NatureScot	2019	Conservation and Management Advice - Sea of The Hebrides Possible MPA	E - B
NatureScot	2019	Scottish MPA Programme Data Confidence Assessment - Loch Carron MPA	E - B

Author(s)	Year	Title	Decision
NatureScot	2019	Scottish MPA Programme Data confidence assessment - Shiant East Bank Possible MPA	E - B
NatureScot	2019	Scottish MPA Programme Data confidence assessment - North-East Lewis Possible MPA	E - B
NatureScot	2019	Conservation and Management Advice - Shiant East Bank Possible MPA	E - B
Rogers	2019	Threats to Seamount Ecosystems and Their Management	E
Allen	2018	Infaunal and PSA analyses of benthic samples collected from the South of Skye, Southannan Sands SSSI and Mousa SAC / MPA in 2016	E - B
Boswarva et al.	2018	Improving marine habitat mapping using high-resolution acoustic data; a predictive habitat map for the Firth of Lorn, Scotland	E
Bunker et al.	2018	Site condition monitoring of maerl beds and seagrass beds in the Sound of Barra SAC 2015 – diving survey	E - B
Farinas-Franco et al.	2018	Missing native oyster (<i>Ostrea edulis L.</i>) beds in a European Marine Protected Area: Should there be widespread restorative management?	E - R
Harries et al.	2018	The establishment of site condition monitoring of the sea caves of the St Kilda and North Rona Special Areas of Conservation with supplementary data from Loch Eriboll	E - B
Jenkins et al.	2018	Advances in assessing Sabellaria spinulosa reefs for ongoing monitoring	E
Kolyuchkina et al.	2018	Presentability of the Utrish Nature Reserve's benthic communities for the north Caucasian Black Sea coast	E
Mercer et al.	2018	South Arran MPA diver survey of maerl beds, kelp and seaweed communities on sublittoral sediment, and seagrass beds 2014	E - B
Moore et al.	2018	The distribution and condition of flame shell beds and other Priority Marine Features in Loch Carron Marine Protected Area and adjacent waters	E - R

Author(s)	Year	Title	Decision
NatureScot	2018	Conservation Objectives and Management Advice - Loch Carron Possible MPA	E - B
NatureScot	2018	Scottish MPA Project Data confidence assessment - Small Isles Possible Nature Conservation MPA	E - B
Santin et al.	2018	Sponge assemblages on the deep Mediterranean continental shelf and slope (Menorca Channel, Western Mediterranean Sea)	E - B
Vassallo et al.	2018	A predictive approach to benthic marine habitat mapping: Efficacy and management implications	E
Axelsson, O'Dell & Dewey	2017	Infaunal and PSA analyses of benthic samples collected from South Arran MPA, Lochs Duich, Long and Alsh MPA and Southern Trench MPA proposal	E - B
Buhl-Mortensen	2017	Coral reefs in the Southern Barents Sea: habitat description and the effects of bottom fishing	E
De Leij et al.	2017	The influence of native macroalgal canopies on the distribution and abundance of the non-native kelp <i>Undaria pinnatifida</i> in natural reef habitats	E
Franco et al.	2017	Infaunal and PSA analysis of grab samples collected from the Sound of Barra area, 2016.	E - B
Franzese et al.	2017	Natural capital accounting in marine protected areas: The case of the Islands of Ventotene and S. Stefano (Central Italy)	E
Kent et al.	2017	Commercially important species associated with horse mussel (<i>Modiolus modiolus</i>) biogenic reefs: A priority habitat for nature conservation and fisheries benefits	E
Moore	2017	Biological analyses of underwater video from ongoing monitoring and research cruises in Lochs Sunart, Etive and Alsh, sea lochs off South Skye, the Sounds of Barra and Arisaig, and around the Southern Trench.	E - B
Tarsitano et al.	2017	A preliminary assessment of marine biodiversity to support the establishment of a marine protected area along the coast of Manduria (southeastern Italy, Ionian Sea).	E - B
Brennan et al.	2016	Quantification of bottom trawl fishing damage to ancient shipwreck sites	E

Author(s)	Year	Title	Decision
Carr & Reed	2016	Shallow Rocky Reefs and Kelp Forests	E
Hammar, Perry & Gullstorm	2016	Offshore Wind Power for Marine Conservation.	E - R
Jackson et al.	2016	Conservation inaction in action for Essex seagrass meadows?	E
Moore et al.	2016	2015 site condition monitoring and site check surveys of marine sedimentary and reef habitats in the Loch nam Madadh SAC, Loch nam Madadh SSSI and Loch an Duin SSSI	E - R
Strong, Service & Moore	2016	Estimating the historical distribution, abundance and ecological contribution of <i>Modiolus modiolus</i> in Strangford Lough, Northern Ireland	E - R
Tonielli et al.	2016	Distribution of <i>Posidonia oceanica</i> (L.) Delile meadows around Lampedusa Island (Strait of Sicily, Italy)	E
Trowbridge et al.	2016	Shallow subtidal octocorals in an Irish marine reserve	E
Allen	2015	Analyses of benthic samples collected from Wester Ross, Mousa to Boddam and Fetlar to Haroldswick MPAs in August 2014.	E - B
Colloca et al.	2015	The Seascape of Demersal Fish Nursery Areas in the North Mediterranean Sea, a First Step Towards the Implementation of Spatial Planning for Trawl Fisheries	E
Greathead et al.	2015	Environmental requirements for three sea pen species: relevance to distribution and conservation	E - B
Moore	2015	Biological analyses of underwater video from research cruises in marine protected areas and renewable energy locations around Scotland in 2014.	E - B
Moore et al.	2015	2014 site condition monitoring survey of marine sedimentary habitats in the Sound of Arisaig SAC	E - B
Morris-Webb & Stamp	2015	Biological analyses of underwater video footage from Arran, Loch Linnhe, Loch Shell and Loch Seaforth	E - B

Author(s)	Year	Title	Decision
Allen	2014	Infaunal and PSA analyses of benthic samples collected from Loch Alsh, in March 2014.	E
Gilby & Stevens	2014	Meta-analysis indicates habitat-specific alterations to primary producer and herbivore communities in marine protected areas	E
Guizien et al.	2014	Vulnerability of marine benthic metapopulations: implications of spatially structured connectivity for conservation practice in the Gulf of Lions (NW Mediterranean Sea)	E
Howson & Steel	2014	Validation of seabed habitat MPA search feature records relating to the South Arran Nature Conservation MPA.	E - B
Hughes	2014	Benthic habitat and megafaunal zonation across the Hebridean Slope, western Scotland, analysed from archived seabed photographs	E
Jackson et al.	2014	Future-proofing marine protected area networks for cold water coral reefs	E
Kelaher et al.	2014	Changes in Fish Assemblages following the Establishment of a Network of No-Take Marine Reserves and Partially-Protected Areas	E
NatureScot	2014	Scottish MPA Project Data Confidence Assessment - Loch Sunart to the Sound of Jura Nature Conservation MPA	E - B
NatureScot	2014	Scottish MPA Project Data Confidence Assessment - Monach Isles Nature Conservation MPA	E - B
NatureScot	2014	Scottish MPA Project Data Confidence Assessment - Loch Creran Nature Conservation MPA	E - B
Rees et al.	2014	Abiotic surrogates for temperate rocky reef biodiversity: implications for marine protected areas	E
Sotheran & Crawford-Avis	2014	Mapping habitats and biotopes to strengthen the information base of Marine Protected Areas in Scottish waters - Phase 2.	E
Sotheran & Crawford-Avis	2014	Mapping habitats and biotopes from acoustic datasets to strengthen the information base of Marine Protected Areas in Scottish waters.	E - B

Author(s)	Year	Title	Decision
Sotheran, Benson & Crawford	2014	Mapping habitats and biotopes from acoustic datasets to strengthen the information base of Marine Protected Areas in Scottish waters - Phase 2 (Barra Fan and Hebrides Terrace Seamount Area).	E
Werner et al.	2014	Response of Rocky Reef Top Predators (Serranidae: Epinephelinae) in and Around Marine Protected Areas in the Western Mediterranean Sea	E - R
Williamson et al.	2014	Habitat dynamics, marine reserve status, and the decline and recovery of coral reef fish communities	E
Coll et al.	2013	Using no-take marine reserves as a tool for evaluating rocky-reef fish resources in the western Mediterranean	E
Curley et al.	2013	Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion	E
Elsaesser et al.	2013	Identifying optimal sites for natural recovery and restoration of impacted biogenic habitats in a special area of conservation using hydrodynamic and habitat suitability modelling	E
Gianguzza & Bonaviri	2013	Arbacia	E
JNCC	2013	Offshore and inshore Special Area of Conservation Solan Bank Reef	E
JNCC	2013	Offshore and inshore Special Area of Conservation Pobie Bank Reef	E
La Mesa et al.	2013	Rocky reef fish assemblages at six Mediterranean marine protected areas: broad-scale patterns in assemblage structure, species richness and composition	E
Moore et al.	2013	The distribution and condition of proposed protected features within the Loch Sween possible Nature Conservation MPA	E - B
NatureScot	2013	Scottish MPA Project Data confidence assessment - Lochs Duich, Long and Alsh Possible Nature Conservation MPA	E - B
Rogers-Bennett	2013	Strongylocentrotus franciscanus and Strongylocentrotus purpuratus	E

Author(s)	Year	Title	Decision
Allan et al	2012	Data Mining of the Nephrops Survey Database to Support the Scottish MPA Project.	E
Hirst, Clark & Sanderson	2012	The distribution of selected MPA search features and Priority Marine Features off the NE coast of Scotland	E - B
Howson et al.	2012	Marine biological survey to establish the distribution and status of fan mussels <i>Atrina fragilis</i> and other Marine Protected Area (MPA) search features within the Sound of Canna, Inner Hebrides.	E - B
Moore, Harries & Trigg	2012	The distribution of selected MPA search features within Lochs Linnhe, Etive, Leven and Eil: a broadscale validation survey (Part B)	E - R
Seiler et al.	2012	Image-based continental shelf habitat mapping using novel automated data extraction techniques	E
Cole, McQuaid & Nakin	2011	Marine protected areas export larvae of infauna, but not of bioengineering mussels to adjacent areas	E
Greathead et al.	2011	Quantitative assessment of the distribution and abundance of the burrowing megafauna and large epifauna community in the Fladen fishing ground in the Northern North Sea.	E
Moore et al.	2011	The distribution of Priority Marine Features and MPA search features within the Ullapool Approaches: a broadscale validation survey	E - B
Moore et al.	2010	The establishment of site condition monitoring of the marine features of Loch Laxford Special Area of Conservation	E - B
Ayata et al.	2009	Modelling larval dispersal and settlement of the reef-building polychaete <i>Sabellaria alveolata</i> : Role of hydroclimatic processes on the sustainability of biogenic reefs	E
Gianguzza et al.	2009	A preliminary study on temporal and spatial patterns of variability in <i>Paracentrotus lividus</i> in the "Capo Gallo - Isola delle Femmine" MPA (Western mediterranean, Italy).	U
Gjerde	2007	High seas marine protected areas and deep-sea fishing.	E
Mercer, Howson & Moore	2007	Site Condition Monitoring: survey of marine features within the Sunart Special Area of Conservation (SAC) and Site of Special Scientific Interest	E - B

Author(s)	Year	Title	Decision
Pais, Azzurro & Guidetti	2007	Spatial variability of fish fauna in sheltered and exposed shallow rocky reefs from a recently established Mediterranean Marine Protected Area	E
Axelsson et al.	2006	Site condition monitoring – the sublittoral sandbanks of the Solway Firth	E - R
ERT (Scotland) Ltd.	2006	Site Condition Monitoring: Surveys of lagoons in the Vadills Lagoon Special Area of Conservation, July - August 2003.	E - B
Moore et al.	2006	The establishment of site condition monitoring of the subtidal reefs of Loch Creran Special Area of Conservation	E - B
Guidetti	2005	Reserve effect and trophic cascades in Mediterranean sublittoral rocky habitats: a case study at the Marine Protected Area of Torre Guaceto (southern Adriatic Sea).	U
Ordines et al.	2005	Variations in a shallow rocky reef fish community at different spatial scales in the western Mediterranean Sea	E - R
Santillo & Johnston	2005	Marine protected areas (MPAs) as management tools to conserve seamount ecosystems.	E
Bates et al.	2004	Broad scale mapping of habitats in the Firth of Tay and Eden Estuary, Scotland	E
Johnston & Santillo	2004	Conservation of seamount ecosystems: Application of a marine protected areas	E
Moreno & Guirado	2003	New data on the seagrasses distribution in Almeria and Granada (SE Spain).	U
Gimenez-Casaldueiro	2001	Variation in the structural parameters of the Polychaeta community of maerl beds from the Alicante littoral (southeast Iberian Peninsula)	U
Mair et al.	2000	A review of the status, ecology and conservation of horse mussel <i>Modiols modiolus</i> beds in Scotland	E - R

Appendix 4. Summary of the 55 studies included in this review following full-text screening

Author	Year	Title
Skold et al.	2025	Long-term recovery and food web response of benthic macrofauna following cessation of bottom trawling in a marine protected area
Sanabria-Fernandez & Alday	2024	Marine protection enhances the resilience of biological communities on temperate rocky reefs
Ventura et al.	2024	Habitat-specific response of fish assemblages in a small fully protected urban MPA
Barrientos, Barreiro & Pineiro-Corbeira	2023	Paradoxical failure of <i>Laminaria ochroleuca</i> (Laminariales, Phaeophyceae) to consolidate a kelp forest inside a Marine National Park
Bevilacqua	2022	Multidecadal monitoring highlighted long-term stability of protected assemblages within a Mediterranean marine reserve
Blampied et al.	2022	Removal of bottom-towed fishing from whole-site Marine Protected Areas promotes mobile species biodiversity
Davies et al.	2022	A decade implementing ecosystem approach to fisheries management improves diversity of taxa and traits within a marine protected area in the UK
Farine et al.	2022	Protection effectiveness and sea urchin predation risk: The role of roving predators beyond the boundaries of a marine protected area in the Western Mediterranean Sea
Farriols et al.	2022	Recovery Signals of Rhodoliths Beds since Bottom Trawling Ban in the SCI Menorca Channel (Western Mediterranean)

Davies et al.	2021	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
Di Franco et al.	2021	Inconsistent relationships among protection, benthic assemblage, habitat complexity and fish biomass in Mediterranean temperate rocky reefs
Musco, Licciano & Giangrande	2021	Diversity and Distribution of Sabellida (Annelida) under Protection Regimes
Sheehan et al.	2021	Rewilding of Protected Areas Enhances Resilience of Marine Ecosystems to Extreme Climatic Events
Davies et al.	2020	Acoustic Complexity Index to assess benthic biodiversity of a partially protected area in the southwest of the UK
Medrano et al.	2020	From marine deserts to algal beds: <i>Treptacantha elegans</i> revegetation to reverse stable degraded ecosystems inside and outside a No-Take marine reserve
Medrano et al.	2020	Long-term monitoring of temperate macroalgal assemblages inside and outside a No take marine reserve
Moore et al.	2020	The current status of serpulid reefs, horse mussel beds and flame shell beds in Loch Creran SAC and MPA
Guidetti et al.	2019	Assessing the potential of marine Natura 2000 sites to produce ecosystem-wide effects in rocky reefs: A case study from Sardinia Island (Italy)
Harries et al.	2019	2016 site condition monitoring of the rocky reefs and sea caves of Mousa SAC and survey of sedimentary habitats of the Mousa to Boddam MPA.
Moore	2019	Biological analyses of underwater video from monitoring and research cruises in Lochs Ailort and Fyne, the Sounds of Barra and Mull, inner Moray Firth, off Wester

		Ross, Noss Head and Rattray Head, and around the Southern Trench in outer Moray Firth
Bianchi et al.	2018	The park never born: Outcome of a quarter of a century of inaction on the sea-floor integrity of a proposed but not established Marine Protected Area
Cabanellas-Reboredo et al.	2018	Morpho-demographic traits of two maerl-forming algae in beds with different depths and fishing histories
Dimitriadis et al.	2018	Assessment of fish communities in a Mediterranean MPA: Can a seasonal no-take zone provide effective protection?
Farinas-Franco, Allcock & Roberts	2018	Protection alone may not promote natural recovery of biogenic habitats of high biodiversity damaged by mobile fishing gears
Kaiser et al.	2018	Recovery linked to life history of sessile epifauna following exclusion of towed mobile fishing gear
Skold et al.	2018	Effects of chronic bottom trawling on soft-seafloor macrofauna in the Kattegat
Appolloni et al.	2017	Does full protection count for the maintenance of β -diversity patterns in marine communities? Evidence from Mediterranean fish assemblages
Barbera et al.	2017	Maerl beds inside and outside a 25-year-old no-take area
Betti et al.	2017	Over 10years of variation in Mediterranean reef benthic communities
Huvenne et al.	2016	Effectiveness of a deep-sea cold-water coral Marine Protected Area, following eight years of fisheries closure
Marra et al.	2016	Recovery Trends of Commercial Fish: The Case of an Underperforming Mediterranean Marine Protected Area

Moore et al.	2016	2015 site condition monitoring and site check surveys of marine sedimentary and reef habitats in the Loch nam Madadh SAC, Loch nam Madadh SSSI and Loch an Duin SSSI
Howarth et al.	2015	Effects of ecosystem protection on scallop populations within a community-led temperate marine reserve
Moore et al.	2015	2014 site condition monitoring survey of marine sedimentary habitats in the Sound of Arisaig SAC
Cunha et al.	2014	Biomares, a LIFE project to restore and manage the biodiversity of Prof. Luiz Saldanha Marine Park
Seytre & Francour	2014	A long-term survey of <i>Posidonia oceanica</i> fish assemblages in a Mediterranean Marine Protected Area: emphasis on stability and no-take area effectiveness
Werner et al.	2014	Response of Rocky Reef Top Predators (Serranidae: Epinephelinae) in and Around Marine Protected Areas in the Western Mediterranean Sea
Coll et al.	2013	Using no-take marine reserves as a tool for evaluating rocky-reef fish resources in the western Mediterranean
Curley et al.	2013	Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion
Henriques et al.	2013	Seasonal variability of rocky reef fish assemblages: Detecting functional and structural changes due to fishing effects
Sahyoun et al.	2013	Protection effects on Mediterranean fish assemblages associated with different rocky habitats
Sciberras et al.	2013	Benthic community response to a scallop dredging closure within a dynamic seabed habitat

Sheehan et al.	2013	Recovery of a Temperate Reef Assemblage in a Marine Protected Area following the Exclusion of Towed Demersal Fishing
Sheehan et al.	2013	Drawing lines at the sand: Evidence for functional vs. visual reef boundaries in temperate Marine Protected Areas
Hereu et al.	2012	Multiple Processes Regulate Long-Term Population Dynamics of Sea Urchins on Mediterranean Rocky Reefs
Moore, Harries & Trigg	2012	The distribution of selected MPA search features within Lochs Linnhe, Etive, Leven and Eil: a broadscale validation survey (Part B)
Pais et al.	2012	Harvesting Effects on <i>Paracentrotus lividus</i> Population Structure: A Case Study from Northwestern Sardinia, Italy, before and after the Fishing Season
Sala et al.	2012	The Structure of Mediterranean Rocky Reef Ecosystems across Environmental and Human Gradients, and Conservation Implications
Ceccherelli, Pinna & Sechi	2011	Evaluating the effects of protection on <i>Paracentrotus lividus</i> distribution in two contrasting habitats
Cole, McQuaid & Nakin	2011	Marine protected areas export larvae of infauna, but not of bioengineering mussels to adjacent areas
Howarth et al.	2011	Complex habitat boosts scallop recruitment in a fully protected marine reserve
Moore et al.	2010	The establishment of site condition monitoring of the marine features of Loch Laxford Special Area of Conservation Special Area of Conservation
Bonaviri et al.	2009	Fish versus starfish predation in controlling sea urchin populations in Mediterranean rocky shores

Di Franco et al.	2009	Evaluating effects of total and partial restrictions to fishing on Mediterranean rocky-reef fish assemblages
Ruis & Zabala	2008	Are marine protected areas useful for the recovery of the Mediterranean mussel populations?
Guidetti	2007	Potential of marine reserves to cause community-wide changes beyond their boundaries
Guidetti & Sala	2007	Community-wide effects of marine reserves in the Mediterranean Sea
Pais et al.	2007	The impact of commercial and recreational harvesting for <i>Paracentrotus lividus</i> on shallow rocky reef sea urchin communities in North-western Sardinia, Italy
Axelsson et al.	2006	Site condition monitoring – the sublittoral sandbanks of the Solway Firth
Bevilacqua et al.	2006	Mitigating human disturbance: can protection influence trajectories of recovery in benthic assemblages?
Ceccherelli et al.	2006	Evaluating the effects of protection on two benthic habitats at Tavolara-Punta Coda Cavallo MPA (North-East Sardinia, Italy)
Guidetti	2006	Marine reserves reestablish lost predatory interactions and cause community changes in rocky reefs
Moore et al.	2006	The establishment of site condition monitoring of the subtidal reefs of Loch Creran Special Area of Conservation
Hereu et al.	2005	The effects of predator abundance and habitat structural complexity on survival of juvenile sea urchins
Micheli et al.	2005	Cascading human impacts, marine protected areas, and the structure of Mediterranean reef assemblages

García-Charton	2004	Multi-scale spatial heterogeneity, habitat structure, and the effect of marine reserves on Western Mediterranean rocky reef fish assemblages
Bordehore, Ramos-Esplá & Riosmena-Rodríguez	2003	Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula

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