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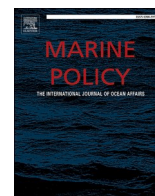
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A regional and international framework for evaluating seagrass management and conservation

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ABSTRACT

Seagrass meadows provide a range of key ecosystem services that are of high economic and societal value; seagrass meadows enhance biodiversity, provide food security through fisheries support, and are increasingly recognised for the role they play in mitigating climate change by the process of carbon sequestration. Whilst there is an increasing understanding of the global significance of seagrass habitats, the extent of these habitats is declining globally. The requirement to implement effective seagrass conservation and management strategies is thus becoming increasingly important. If the ambitions of the United Nations 2030 Agenda for Sustainable Development and the Sustainable Development Goals are to be achieved, then nations need ambitious and applicable marine conservation plans. This includes management and protection to vulnerable ecosystems such as seagrass meadows. This study aims to evaluate a range of seagrass management and conservation approaches identified in different geographic regions, using a critique framework developed from the United Nations Environment Programme 2020 report on seagrass ‘Out Of The Blue: The Value Of Seagrasses To The Environment And To People’. Using the framework, seagrass management in Scotland is used as a case study and compared nationally to the rest of the UK (England, Wales and Northern Ireland) and internationally, to Europe (Wadden Sea), Australia (Great Barrier Reef Marine Park) and West Africa (Senegal). The results identify potential areas of development in Scotland to enhance its seagrass conservation effort, including increased research in seagrass science, widespread mapping of seagrass, long-term monitoring programmes, improved marine protected areas, inclusion of seagrass protective measures into environmental laws and policies and the implementation of appropriate habitat restoration schemes. The results also identify the need for open data if effective knowledge sharing is to take place, and to ensure that ocean science can fully support countries to achieve the 2030 Agenda for Sustainable Development.

1. Introduction

Seagrass meadows are recognised as one of the most productive ecosystems in the coastal zone, present in both tropical and temperate waters, with an estimated global coverage of 160,387 km², and potentially as much as 266,562 km² [1]. Seagrass meadows provide important ecosystem services that contribute greatly to human wellbeing and the security of coastal communities through supporting fisheries, food security, cultural and recreational activities, habitat functioning and contributing significantly to global ‘blue carbon’ stores [2–4]. Over the last two decades, seagrass science has grown, notable by the surge in seagrass research publications, with over 70% of seagrass peer-reviewed literature generated since the start of the new millennium [5]. With a

transition to applied research focusing on management solutions [6], innovative technology and emerging methods has led to improved monitoring and estimations of seagrass coverage [1,7].

Despite its importance, seagrass habitats are declining globally, and seagrass ecosystems are increasingly under threat [8] as a result of anthropogenic pressures [9] including coastal development and land use changes, overexploitation and localised disturbances [10]. Climate change is predicted to further threaten seagrass [11]. Given the significance of this marine ecosystem, it is critical to understand and to develop more sustainable management approaches to preserve [12] and where necessary restore these important coastal habitats with the aim to ‘rebuild ocean life’ [13].

The UN, acknowledging the urgency of protecting these important

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environments, launched the UN Decade on Ecosystem Restoration (2021–2030); in addition to the UN's Decade of Ocean Science for Sustainable Development that provides a common framework to ensure ocean science can fully support countries' actions to sustainably manage the oceans and achieve the 2030 Agenda for Sustainable Development. The overarching goal of this decade is to stop and reverse the destruction and degradation of millions of hectares of ecosystems [14]. Governments are required to make progress on the commitments set, and the creation of large restored areas has been given heightened urgency by national and international policy targets. In line with the overarching goal, further research into seagrass areas and localities is required, with a need for successful conservation and management strategies that are multifaceted and interdisciplinary, and for these to be implemented into policy plans.

Scotland positions itself as a country looking to progress in marine ecosystem restoration and management; having recently announced the extension of their MPA network and the commitment to continue Scotland's 'Year of Coasts and Water' [15]. At Scotland's International Marine Conference (2019), Scotland's First Minister highlighted the importance of the ocean to Scotland, and the significance of Marine Protected Areas and of 'blue carbon' [16]; two areas in which Scotland is trying to show international leadership with ambitious targets including the Scottish Blue Carbon Forum research programme [17].

To identify potential areas of development in Scotland, Scotland was chosen as the main case study to compare nationally (with the rest of the UK), internationally; to potential exemplars in Europe (Wadden Sea region) and Australia (Great Barrier Reef Marine Park), and to Senegal in West Africa to understand approaches from the perspective of a Least Developed Country (LDC) as described by the United Nations [18].

This study provides a repeatable framework to critically evaluate different seagrass conservation and management strategies both regionally and internationally. The study is intended to provide a platform to facilitate communication and discussion across research and stakeholder communities through providing a benchmark assessment, whereby the implementation of management and conservation approaches can be tracked over time to identify priority areas for continued development and deliver more effective science-based marine management. The framework is used here with freely accessible data on seagrass ecosystems and management. While this framework can be refined by using regional non-publicly accessible data, the importance of freely accessible data allows comparisons to be made across scales, regionally, nationally and internationally. It is proposed in the spirit of the Ocean Decade that this framework be used as a tool 'across the science-policy interface to strengthen the management of our oceans and coasts for the benefit of humanity' [19].

2. Methods

A review was undertaken of existing seagrass research, using a critique framework to identify aspects of seagrass conservation and management within specific case study areas. The study's objective is to assess the transferability of the framework created, considering the different themes, rather than evaluating the efficacy of the evidence of seagrass management approaches. The literature search was conducted using Scopus to identify peer-reviewed literature searching by the specific region, while Google Scholar was used to identify grey literature. This requires relevant information from organisations and government to be readily available and accessible. Limited information being accessible and publicly available, from government and research programmes, can result in missing data and in this study could result in over or underestimated scoring for regions.

The study was considered and framed around Scotland, with England, Wales and Northern Ireland providing national comparisons, and three international case studies were considered for regional and global insight at different levels. These were the Wadden Sea in Europe, as an example of a large intertidal region managed in collaboration between

multiple countries, the Great Barrier Reef Marine Park in Australia, as an example of an early leader in the use of marine spatial zoning [20], and of Senegal in West Africa as an example of a Least Developed Country (LDC) but also as a country making progress in this area. Although there are many other examples of seagrass management approaches globally, including the United States, focus here was on Europe with common frameworks to the U.K. until recently, the GBR as an exemplar, and Senegal as an LDC [21].

Seagrass conservation and management approaches in the different geographical areas were evaluated using a critique framework developed from a policy and management report for seagrass ecosystems published by the United Nations Environment Programme [8]. UNEP's "Out of the Blue, The Value of Seagrasses to the Environment and to People" document [8] provides policy and management options for the conservation and management of seagrass habitats. UNEP propose ten key management measures and tools available for use at national, regional and global levels to ensure a sustainable future for seagrass ecosystems. UNEP's ten management measures that are suggested were used to develop a critique framework with a set of eight indicators and questions (Fig. 1) that closely align to UNEP's proposed measures and are presented under four overarching but interconnected themes: monitoring; management; protection and restoration; that enable the evaluation of conservation and management practices in each of the case study areas.

Within each theme, two questions were developed that encompass the key management and policy options identified in the UNEP report, and to function as indicators for assessing seagrass conservation and management practices (Fig. 1). Using this critique framework and a scoring system, an evaluation of conservation and management approaches in each of the case study areas were undertaken based on evidence from the available literature. The scoring system applied values from 1 to 5 for each of the questions, where 1 indicates no evidence and 5 indicates significant evidence with excellent examples of best practice (Table 1). The assessment scores are based upon the presence of management plans rather than upon their efficacy, which would be hard to assess based upon literature and lacking local expert knowledge.

For the successful transferability of the framework to different settings, both temporal and spatial scales, and what constitutes a 'place' for each of the case study areas needs to be considered [22], with clear boundaries articulated. The framework is designed to enable comparisons between regions over different spatial scales. Through establishing clear boundaries of 'place', the framework can facilitate discussion on national (i.e. Scotland vs England), regional (UK vs Wadden Sea) or subnational (e.g. Argyll vs Cornwall) scales. While the developed framework defines scoring characteristics, we recognise that there will

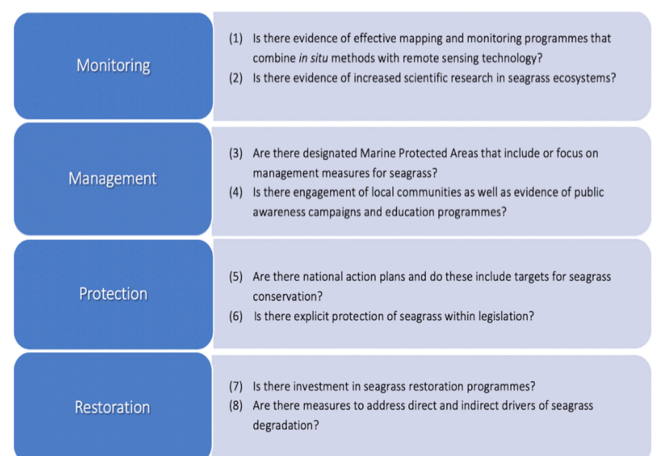


Fig. 1. Critique framework developed from the UNEP recommended management measures and tools.

Table 1
Criteria of the scoring system ranging from 1 to 5, with examples commensurate with the grading.

1	2	3	4	5
No Evidence	Limited evidence; major gaps	Moderate evidence; some gaps	Well evidenced	Significant evidence; excellent examples of best practice
Monitoring				
<ul style="list-style-type: none"> No monitoring programmes in place Extent of seagrass is not known No accurate or recent mapping of seagrass Limited research being carried out in this area; small number of publications 	<ul style="list-style-type: none"> Some monitoring for specific research studies, small scale or ad hoc surveys, may be reliant on short-term funding Relatively basic monitoring methods and techniques Extent of seagrass is not known with no accurate or recent mapping of seagrass Some research being conducted and number of publications varies between years, no clear trend 	<ul style="list-style-type: none"> More than one mapping and monitoring programme Evidence of monitoring but not sustained over long periods of time Monitoring methods of good standard Extent of seagrass is somewhat known with evidence of mapping Ongoing research, research base indicating a steady upward trend 	<ul style="list-style-type: none"> Various monitoring programmes and studies ongoing Up-to-date techniques to map and monitor, with a combination of methods (in situ and remote sensing) Significant ongoing research, research base indicating a clear upward trend 	<ul style="list-style-type: none"> Highly effective mapping and a long time series seagrass monitoring programme Consistent water quality monitoring Most up-to-date techniques to map and monitor that combine in situ methods with remote sensing technology Use of global seagrass monitoring networks Significant research, research base increasing exponentially
Management				
<ul style="list-style-type: none"> No management measures specific to seagrass habitats No public awareness campaigns and education programmes relating to seagrass 	<ul style="list-style-type: none"> Little evidence of management measures specific to seagrass habitats Limited public awareness campaigns and education programmes relating to seagrass 	<ul style="list-style-type: none"> Management measures in place relating to seagrass habitats A number of public awareness campaigns and education programmes 	<ul style="list-style-type: none"> Designated MPAs that include seagrass management measures Engagement of local communities Well-established public awareness campaigns and education programmes 	<ul style="list-style-type: none"> Designated MPAs that include seagrass management measures and include targets and actions for seagrass habitats Engagement of local communities Extensive and well-established public awareness campaigns and education programmes
Protection				
<ul style="list-style-type: none"> No national action plans or targets for marine habitats No seagrass protection in legislation or policy 	<ul style="list-style-type: none"> National action plan for marine habitats but no targets for seagrass Limited seagrass protection in legislation or policy 	<ul style="list-style-type: none"> National action plans for marine habitats: seagrass species listed in plans Seagrass protection through managed areas or legislation e.g. protection to benthic habitats 	<ul style="list-style-type: none"> National action plans for marine habitats: seagrass species listed with targets for conservation Seagrass protection through managed areas or legislation specifically relating to seagrass 	<ul style="list-style-type: none"> Well established national action plans for marine habitats: seagrass species listed and targets for seagrass conservation and management Explicit protection of seagrass within managed areas and legislation
Restoration				
<ul style="list-style-type: none"> No seagrass restoration programmes No evidence of plans or proposals for seagrass restoration No measures taken to address drivers of seagrass degradation, through international frameworks and directives 	<ul style="list-style-type: none"> Plans and proposed research looking into possibility of restoration of seagrass meadows with feasibility studies Some measures taken to address drivers of seagrass degradation, through international and national frameworks and directives 	<ul style="list-style-type: none"> Current research looking into ecosystem restoration of seagrass meadows Seagrass restoration trials and projects may have been undertaken in some cases with varying levels of success Measures in place to address drivers of seagrass degradation with local consideration as well as international and national frameworks and directives 	<ul style="list-style-type: none"> Some investment in seagrass restoration programmes Seagrass restoration trials and projects have been undertaken Measures in place to address drivers of seagrass degradation with local consideration as well as international and national frameworks and directives 	<ul style="list-style-type: none"> Large amount of investment in seagrass restoration programmes Multiple successful seagrass restoration projects have been undertaken Measures in place to address drivers of seagrass degradation explicitly considering seagrass habitats

exist some subjectivity between boundaries, and that temporal and spatial factors need to be considered when assessing the ‘place’. For example, long-term monitoring scores more highly than short-term monitoring, and national monitoring scores more highly than regional monitoring. Management approaches identified must also be at scales relevant to the specific place, with place-based solutions that address the challenges involved in integrating science and policy across multiple scales and respect social, economic and political circumstances [23]. While certain ‘places’ here are assessed broadly, future assessments could also break this down by country (e.g. the Wadden Sea) to see where national improvements can be made.

3. Results

3.1. Nationally

Different approaches to management and conservation are detailed in Table 2 and demonstrate the variability in approaches at a national level within the UK. The evaluation results (Table 3) demonstrate that in the UK, Wales was assessed to be more advanced in terms of conservation and management approaches compared to Scotland and the other countries. It can be observed that in all four countries, the rating varies from 2 to 3 for monitoring and management, and all were rated 3 for protection. There was a range of scores of between 1 and 3 for restoration efforts, with Scotland and N. Ireland assessed at the lowest level.

3.2. Internationally

The UK is found to be considerably further behind in terms of demonstrating examples of good practice compared the global case studies in GBRMP and Wadden Sea, supported by evidence in Table 3. The GBRMP was evaluated at either 4 or 5 in seven out of the eight areas being assessed, with a top rating of 5 given to three of the indicators relating to monitoring, management and restoration. Although not considered as advanced in terms of best practice compared to the GBRMP, the Wadden Sea was also evaluated as having a number of examples of good practice, and scored 4 or 5 in four of the eight areas, specifically monitoring, management and restoration. Senegal is at an early stage of developing strategies to support seagrass management and conservation, and this is reflected in evaluation scores of 1 and 2.

Fig. 2 displays the overall evaluation scores from Table 4. The GBRMP achieved 35 out of the potential 40, the Wadden Sea (30), the UK (20) and Senegal (11). The GBRMP shows relatively high values for all of the key indicators, with the Wadden Sea also scoring highly in restoration, but lower in the other three areas: monitoring, management and protection. Comparatively the UK scores lower on the rating scale, with moderate evidence for monitoring, management and protection in effective seagrass conservation approaches, and limited evidence for its restoration efforts (Table 3). Senegal scores lower in all areas but shows evidence of development in one of the areas of monitoring (scoring 2) and management (scoring 2).

To assess whether there has been an increased interest in seagrass as

Table 2

Highlights of UK case studies; Scotland, England, Wales and Northern Ireland, with regard to monitoring, management, protection and restoration efforts of seagrass (Full table in [supplementary material](#)).

	Scotland	England	Wales	Northern Ireland
Monitoring	<ul style="list-style-type: none"> • Scottish seagrass distribution maps indicate a high number of recorded seagrass compared to Western Europe[24] • Extent of seagrass meadows in Scotland is uncertain[25] • Monitoring generally been ad hoc surveys and as part of research and scientific studies[26–29] 	<ul style="list-style-type: none"> • Seagrass baseline monitoring in SACs and MCZs as part of contracted work [30–36] • Isles of Scilly only annual monitoring data over a long time period (1996-present)[33] • Cornwall and Devon Seagrass-Watch monitoring programmes[37] 	<ul style="list-style-type: none"> • Monitoring seagrass is a key part of the work of Project Seagrass (established in 2013)[38] • Monitoring programmes with use of volunteers and involvement of local organisations and universities[39] • Long-term monitoring programmes being conducted in the Skomer Marine Reserve[40] • Seasonal sampling taken place as part of monitoring programme for over 3 years[41] 	<ul style="list-style-type: none"> • Evidence of distribution mapping of seagrass[42–44] with few long-term monitoring programmes • Most extensive seagrass research at Strangford Lough [45] • Wilkes study (2017) collates for first time an inventory of N. I. intertidal seagrasses • Ad hoc surveys by Queens University Belfast[45] • Seagrass data collected by volunteer divers through Seasearch, a volunteer survey project for divers[46] • Engagement with local communities through the Wildlife Trust and citizen science programmes[49]
Management	<ul style="list-style-type: none"> • MPA network consists of 244 sites, with 230 for conservation purposes, providing protection to 37% of Scotland's seas [230] • Seagrass protected in 26 locations around Scotland (with 16 sites thought to be providing adequate protection[47]) 	<ul style="list-style-type: none"> • Seagrass Spotter app (citizen science programme) established in 2016, records submitted to CEDaR (Centre for Environmental Data and Recording) [38] 	<ul style="list-style-type: none"> • Engagement with local communities and stakeholders through restoration projects[48] 	
Protection	<ul style="list-style-type: none"> • Marine Scotland Act 2010[50] • Protection under International directives and conventions • Protection under European, national and regional regulations • All UK seagrass species included in UK Biodiversity Action Plan [51] 	<ul style="list-style-type: none"> • Protection under International directives and conventions • Protection under European, national and regional regulations • All UK seagrass species included in UK Biodiversity Action Plan[51] 	<ul style="list-style-type: none"> • Welsh Environment Act 2016 include policy for priority habitats (seagrass) [48] • Protection under International directives and conventions • Protection under European, national and regional regulations • All UK seagrass species included in UK Biodiversity Action Plan[51] 	<ul style="list-style-type: none"> • Seagrass habitat action plan identifies specific targets to deliver UK BAP[52] • Protection under International directives and conventions • Protection under European, national and regional regulations • All UK seagrass species included in UK Biodiversity Action Plan[51]
Restoration	<ul style="list-style-type: none"> • No active seagrass restoration work 	<ul style="list-style-type: none"> • LIFE Recreation ReMEDIES project is a four-year project, led by Natural England, to protect seagrass meadows[53] - first successful planting (April 2021) 	<ul style="list-style-type: none"> • First major UK seagrass restoration carried out with successful restoration in Dale, Pembrokeshire (2020) in which 1 million seeds were planted [50] 	<ul style="list-style-type: none"> • No active seagrass restoration work • Funding from DAERA to undertake feasibility studies of blue carbon habitat restoration including seagrass[54]

a research topic and the importance that is being placed on this subject area in the UK, peer-reviewed seagrass literature from 1985 to 2022 was considered. The peer-reviewed seagrass literature data was sourced using Scopus using the search term “seagrass”, which was selected to be the focus of the paper, and each of the relevant regions. The research was also selected to be open access and in English. The cumulative publications for the UK incorporate publications from Scotland, England, Wales and Northern Ireland, as it was not practical to separate by country within the UK.

The Wadden Sea region, incorporated publications from the Netherlands, Germany and Denmark, Australia encompasses those from north-eastern Australia and the Great Barrier Reef and Senegal includes papers from West Africa. Fig. 3 displays an upward trend in the research of the countries over the last 37 years. Seagrass is identified as an important research topic in Australia with 121 publications in 2018 and 134 in 2021. In the UK publications peaked at 77 in 2018, falling to 61 and 65 in consecutive years, and in Europe there has also been fluctuations in seagrass research over this period noting peaks in 2020 and 2021 with a number of 63 and 72 publications respectively. Research into seagrass in West Africa has remained at a relatively low level over the last decade with publication levels ranging from 0 to 7 papers per year. This method has limitations as only captures publications written in English, and the size and population of the region has not been taken into account. However, it provides an insight of the growing knowledge base of seagrass ecosystems, as well as potentially the interest in seagrass.

4. Discussion

4.1. Nationally

4.1.1. Monitoring

4.1.1.1. *Is there evidence of effective mapping and monitoring programmes that combine in situ methods with remote sensing technology?* In the UK, there is evidence of seagrass monitoring, mapping and data collection in support of scientific research [26–28], and as part of validation surveys on multiple marine features or for MPA monitoring purposes or development. This includes surveys commissioned in Scotland by NatureScot, in Northern Ireland by Department of the Environment, in England by Natural England and in Wales by Natural Resources Wales; the data of which is available on the data.gov.uk website [47]. These surveys are distinct and for a specific purpose, and for Scotland and Northern Ireland are not provided as part of a national co-ordinated approach or any long-term monitoring measure. There is evidence of a more co-ordinated approach in England and Wales, with long-term monitoring programmes being conducted in the Isles of Scilly [31], and in the Skomer Marine Reserve, Wales [40]. Seagrass-Watch monitoring methods are also being used and developed in the UK. Project Seagrass, working in partnership with other organisations, is playing an important role in monitoring seagrass in Wales, notably at Porthdinllaen within the Pen Llŷn a'r Sarnau Special Area of Conservation, and at Dale in the Pembrokeshire Marine Special Area of Conservation [37].

Table 3

Highlights of international case studies, UK, Wadden Sea, Europe and Great Barrier Reef Marine Park, Australia and Senegal, West Africa, with regard to monitoring strategies, management, protection and restoration efforts of seagrass (Full table in [supplementary material](#)).

	United Kingdom	Wadden Sea, Europe	Great Barrier Reef Marine Park, Australia	Senegal, West Africa
Monitoring	<ul style="list-style-type: none"> Evidence of monitoring and mapping throughout the UK, in Scotland[26] and N.I.[42] but only a few long-term programmes in England[33,37] and Wales[39,40] 	<ul style="list-style-type: none"> Trilateral Monitoring and Assessment Programme[55] Surveys contain seasonal component and repeat sampling[56] 	<ul style="list-style-type: none"> Significant number of seagrass mapping and monitoring programmes sponsored by the Australian and Queensland Government[57,58] Large-scale seagrass monitoring project; Seagrass-Watch[59,60] 	<ul style="list-style-type: none"> Has been no assessment of seagrass ecosystem services off the west coast of Africa (until ResilienSEA project 2018–2021)[61] Focus of ResilienSEA project to strengthen knowledge on seagrass meadows in West Africa; conduct pilot actions on selected sites; develop new management tools and help governments in protecting seagrasses[61]
Management	<ul style="list-style-type: none"> Public awareness increasing with the use of novel approaches such as crowdsourcing with smartphone apps including SeagrassSpotter[40] 	<ul style="list-style-type: none"> Management shared by Denmark, Germany and the Netherlands through Trilateral Wadden Sea Cooperation[62] Wadden Sea Plan (WSP) is the management plan of the Wadden Sea based on the ecosystem[63,64] Engagement with local communities and stakeholders through the ‘Wadden Sea Forum’, and by use of education and outreach programmes to citizens, politicians and managers and local NGO’s[65] 	<ul style="list-style-type: none"> Multiple-use zoning approach is in place which provides high levels of protection for specific areas[66] Zones with highest level of protection equating to 5.4% of estimated seagrass area and Habitat Protection Zones free from benthic disturbance[67,68] Seagrass-Watch citizen science program originated in Queensland and has expanded globally to reach 408 sites across 21 countries[69] 	<ul style="list-style-type: none"> WWF’s West African Marine Ecoregion (WAMER) programme started in 2000[70] Creation of four MPAs in Senegal of 960km² as part of WAMER programme[71] ResilienSEA project established community-based marine protected area including participatory seagrass beds mapped by local fisherman[61] ResilienSEA project is helping to address limited awareness of the existence and importance of seagrass meadows with workshops, training activities[61]
Protection	<ul style="list-style-type: none"> Seagrass included in UK’s Biodiversity Action Plan as a priority habitat[51] Protection under international directives and conventions Protection under European, national and regional regulations 	<ul style="list-style-type: none"> Wadden Sea has had the status of a protected area for more than 20 years[56] Protection under international directives and conventions Protection under European, national and regional regulations 	<ul style="list-style-type: none"> 40 Acts, policies and plans relevant to management of the marine park[57] Direct legislative management in place with permission for plant removal under the Queensland Fisheries Act 1994 Protection under international directives and conventions 	<ul style="list-style-type: none"> WWF working with West African governments to improve fisheries management, conserve coastal habitats and species, and support establishment of MPAs[70] Protection under national regulations[71] Protection under international directives and conventions
Restoration	<ul style="list-style-type: none"> Seagrass restoration project at Dale Bay, Pembrokeshire, Wales is the first and only of its scale in the UK, completed 2020[38] LIFE Recreation ReMEDIES project in England over 4 years that involves seagrass restoration and first planting completed (2021)[53] 	<ul style="list-style-type: none"> Restoration projects carried out in Dutch Wadden Sea[72–74] Many restoration efforts yet to prove long-term success have generated valuable information regarding habitat suitability for future efforts [73–77] 	<ul style="list-style-type: none"> Several recent restoration successes in Australia[78] Rehabilitation efforts undertaken in Queensland[79–83] mostly focused on small scale experimental tests Large seagrass restoration project currently underway in South Australia with a \$1 million project fund[84] 	<ul style="list-style-type: none"> No specific targets in national action plans to address seagrass degradation No seagrass restoration work

4.1.1.2. *Is there evidence of increased scientific research in seagrass ecosystems?* To assess whether there has been an increased interest in seagrass as a research topic and the importance that is being placed on this subject area in the UK, peer-reviewed seagrass literature from 1985 to 2022 for Scotland, England, Wales and Northern Ireland was considered (Fig. 3). An overall upward trend can be observed in seagrass research across the UK over the last 37 years. Considering the evidence of individual scientific papers and monitoring programmes for each of the countries; England and Wales were observed to have more research behind them than in Scotland and Northern Ireland.

4.1.2. Management

4.1.2.1. *Are there designated Marine Protected Areas that include or focus on management measures for seagrass?* In the UK, there is a focus on management measures for seagrass ecosystems, and seagrass meadows are included in a number of designated marine protected areas. This is considered a positive step towards protecting the biodiversity of this environment, and seagrass meadows are a Priority Habitat designated under the UK Biodiversity Action Plan. Seagrass is currently protected and managed in 26 locations around Scotland by a suite of Marine Protected Areas (MPAs) [85], and in other parts of the UK by a network

of protected areas including Marine Conservation Zones (MCZs) and Special Area of Conservation (SACs). Over the last decade the Scottish MPA network has expanded in size, with designations in 2020 adding a further 16 sites to the Scottish MPA network, including four new inshore MPAs and 12 Special Protection Areas (SPAs). This currently covers 37% of Scotland’s seas with 244 sites. In England, there are 178 marine protected sites covering 40% of English inshore and offshore waters combined. Of these, 91 are MCZs, with several authorities responsible for managing the MCZs including Natural England and the Environmental Agency (EA). In Wales, there are 139 protected sites made up of 13 Special Protection Areas (SPAs), 15 Special Areas of Conservation (SACs), 1 Marine Conservation Zone (MCZs), 107 Sites of Special Scientific Interest (SSSIs) and 3 Ramsar sites. In Northern Ireland, the current MPA network is made up of 48 protected sites with 17 MCZs, in total covering 38% of the inshore region, with further efforts being made towards establishing an ecologically coherent network [54]. The establishment and the expansion of the current networks of marine protected areas in Scotland, England, Wales and Northern Ireland to specifically protect seagrass ecosystems demonstrates a continued commitment to protect the biodiversity of this habitat. However, with the inclusion of new marine protected zones creating a large network of MPAs, the ineffectiveness of MPAs should be acknowledged. The overall

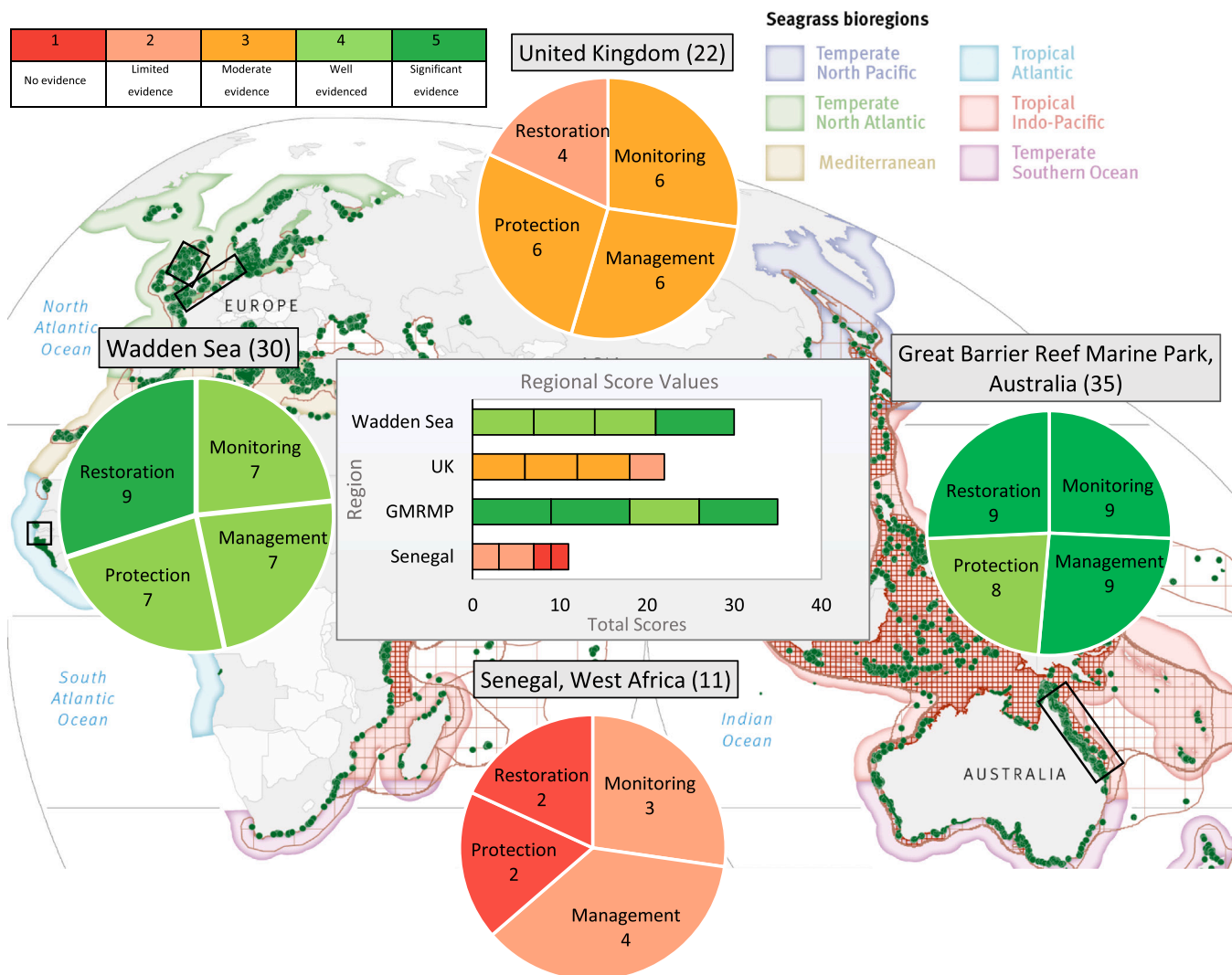


Fig. 2. Bar graph displaying overall score. Pie-charts for case studies detail the combined indicator scoring for monitoring, management, protection and restoration. Colours show the scoring 1–5, red: no evidence, pink: limited evidence; major gaps, orange: moderate evidence; some gaps, light green: well evidenced and dark green: significant evidence; excellent examples of best practice. Map behind shows green dots as seagrass locations from a seagrass distribution study (UNEP, 2020). Using map produced by Levi Westerveld/GRID-Arendal (2019).

‘success’ of marine protection zones depends on the implementation and management specific to the region and in order to know if the efforts are conducive, monitoring over a period of time will establish the status and conditions of seagrass meadows, that will provide further insight into the longevity and effects of the measures in place. Therefore, when ‘marine protection zones’ are designated and not monitored and managed correctly, the MPA may be conceptual rather than environmentally beneficial.

4.1.2.2. *Is there engagement of local communities as well as evidence of public awareness campaigns and education programmes?* It is recognised that community engagement and effective awareness campaigns and education programmes can support seagrass management interventions. SeagrassSpotter was created in Wales as part of Project Seagrass, as a conservation, education, and research tool to help the public engage and better understand seagrass meadows and provides a means to facilitate rapid field data collection aligned to public communication of the findings [86]. In Wales there are significant public engagement and ongoing citizen science projects. In the UK, awareness of the importance of seagrass is increasing, with the use of novel approaches such as crowdsourcing with smartphone apps including SeagrassSpotter, and technology and social media increasingly being used to communicate

and engage with the public about the value of seagrass ecosystems. There is however the opportunity for considerably more engagement and awareness activities in this area to enhance current understanding.

4.1.3. *Protection*

4.1.3.1. *Are there national action plans and do these include targets for seagrass conservation?* In Scotland and the UK, national action plans with targets specifically for seagrass conservation relate to the Marine Strategy Framework Directive (MSFD). The MSFD is a European Directive which was developed to protect, preserve and restore the quality of the marine environment across Europe [87], and provides protection for benthic habitats. Although not specifically targeted at seagrass, Member states are required to take the necessary measures to achieve or maintain Good Environmental status (GES), based on 11 qualitative descriptors of the marine environment by the year 2020. In the UK, there is explicit protection of seagrass within legislation and seagrass habitats are subjected to differing levels of protection, ranging from international directives and conventions to national and regional regulations. The compiled legislative tools that apply are: the *Habitats Directive (92/43/EEC)*, the OSPAR Convention (protection of 3 of the European seagrasses in Atlantic coasts), the Bern Convention (protection of

Table 4

Case studies scoring results, within countries; Scotland; England; Wales; Northern Ireland and Regions; the United Kingdom; the Wadden Sea, the Great Barrier Reef Marine Park and Senegal, West Africa. Colours show the scoring 1–5, red: no evidence, pink: limited evidence; major gaps, orange: moderate evidence; some gaps, light green: well evidenced and dark green; significant evidence; excellent examples of best practice.

Case Study	Countries				Regions			
	Scotland	England	Wales	N. Ireland	UK	Wadden Sea	GBRMP	Senegal
Monitoring								
(1) Is there evidence of effective mapping and monitoring programmes that combine in situ methods with remote sensing technology?	2	3	3	2	3	4	5	2
(2) Is there evidence of increased scientific research in seagrass ecosystems?	2	3	3	2	3	3	4	1
Management								
(3) Are there designated Marine Protected Areas that include or focus on management measures for seagrass?	3	3	3	3	3	3	4	2
(4) Is there engagement of local communities as well as evidence of public awareness campaigns and education programmes?	2	3	3	2	3	4	5	2
Protection								
(5) Are there national action plans and do these include targets for seagrass conservation?	3	3	3	3	3	4	4	1
(6) Is there explicit protection of seagrass within legislation?	3	3	3	3	3	3	4	1
Restoration								
(7) Is there investment in seagrass restoration programmes?	1	2	3	1	2	5	5	1
(8) Are there measures to address direct and indirect drivers of seagrass degradation?	2	2	2	2	2	4	4	1
Total scores	18 / 40	22 / 40	23 / 40	18 / 40	22 / 40	30 / 40	35 / 40	11/40

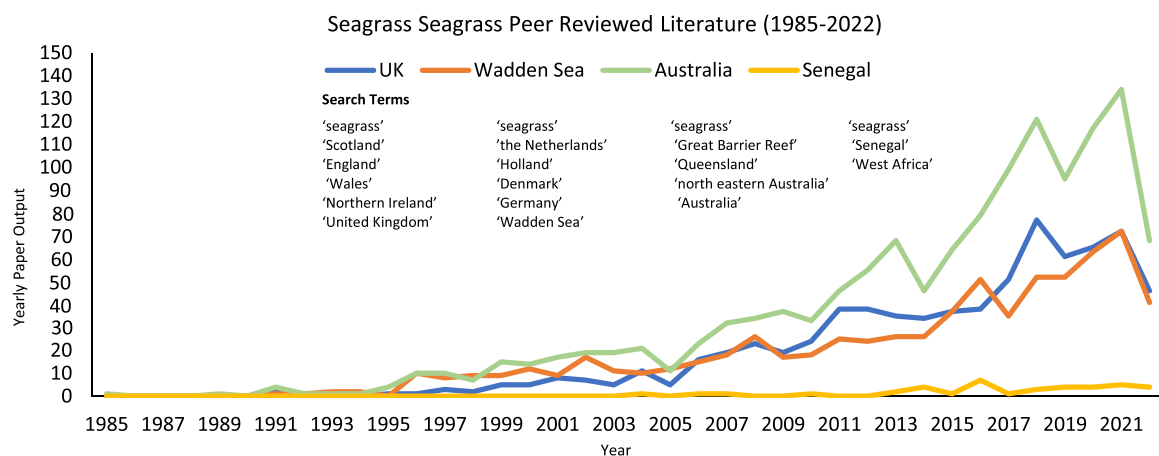


Fig. 3. Cumulative seagrass peer-reviewed literature (1985–2022) for the United Kingdom, the Wadden Sea (Europe), the Great Barrier Reef (Australia) and Senegal (West Africa). Data Source: Scopus.

seagrass species), the Barcelona Convention (indirect protection of Mediterranean seagrass habitats), the Ramsar Convention (indirect protection of seagrass habitats) and IUCN International Red List (considering European seagrass species as “Least Concern” although some species are locally threatened) [87]. At this time, after the UK left the European Union, the European legislation tools remains in place and current, however changes in environmental legislation, could result in differing levels of protection and will impact the efficacy of efforts for

ecosystem protection and restoration [88].

4.1.3.2. Is there explicit protection of seagrass within legislation?. Within the UK, seagrass meadows are a conservation management priority, and these habitats are included in a variety of conservation legislation including the UK’s Biodiversity Action Plan list of priority habitats, and in the designation of Marine Conservation Zones (MCZs) [51]. There is also specific legislation in place supporting an ecosystem-based

management approach. Europe's Integrated Maritime Policy has made ecosystem-based fisheries management obligatory with development of the Common Fisheries Policy and cross-sector policies and through the Marine and Coastal Access Act 2009 [89]. However, the European Common Fisheries policy is recognised to be lacking specific protection including protection of seagrass. Many issues faced need to be addressed regionally rather than at a European level, which could be regulated accordingly over the Brexit transition period as the UK move away from European environmental rules and legislation [88].

In Scotland, fisheries management measures help to conserve the range of biodiversity, with 50–60% of known seagrass meadows managed within protected or managed fisheries areas [90]. In England and Wales, fisheries management is heavily influenced by European legislation and international agreements, policies such as the Common Fisheries Policy (CFP) and national policy such as the Marine Strategy Framework Directive (MSFD). Welsh Government's commitment to implementing an ecosystem-based approach is through the Wales Marine and Fisheries Strategic Action Plan (2013) [91]. While in Northern Ireland, Irish policy for the development of fisheries explicitly includes environmental principles including prioritising environmental protection and conserving biodiversity [92]. There is an opportunity as the UK moves away from European laws for all these countries to develop legislation and laws reflecting the specific environmental protection needed in each of the different regions.

4.1.4. Restoration

4.1.4.1. *Is there investment in seagrass restoration programmes?* In Scotland and Northern Ireland there are currently no restoration projects taking place. However, there are projects taking place in other parts of the UK, in England and Wales. This includes the seagrass restoration project with the Ocean Rescue Project at Dale Bay, Pembrokeshire, which was successfully completed in 2020, planting 1 million seeds to restore 2 ha of seagrass meadows [93]. The project demonstrates a partnership approach with community and site users, with extensive work conducted with local stakeholders and communities to identify restoration locations. In England, the seagrass restoration LIFE Recreation ReMEDIES project, led by Natural England, is planning to improve the condition of threatened seagrass habitats and restore 8 ha of seagrass bed over the next three years, by reducing the negative impacts from recreational boating and through habitat restoration to provide model recovery systems to be replicated across Europe [93]. This will be the first at this scale in England [94]. Currently in Scotland and Wales, there are no seagrass restoration targets in place from the government. However, NGOs are working towards setting restoration targets with projects underway and investment from partnerships [38] and the ongoing projects in England and Wales could provide a model that could be initiated in locations across the UK.

4.1.4.2. *Are there measures to address direct and indirect drivers of seagrass degradation?* There was limited evidence of measures to address direct and indirect drivers of seagrass degradation in Scotland, England, Wales and Northern Ireland, although under the EU Water Framework Directive (WFD). However, there are obligations to improve habitat quality and to implement measures that increase seagrass populations [72], with seagrasses listed as biological indicators of coastal water quality.

4.2. Internationally

4.2.1. Monitoring

4.2.1.1. *Is there evidence of effective mapping and monitoring programmes that combine in situ methods with remote sensing technology?* Within the Wadden Sea and the Great Barrier Reef Marine Park (GBRMP) there is

significantly more evidence of effective mapping and monitoring programmes compared to the UK. In the Wadden Sea, there is investment in long term monitoring measures of seagrass, and a co-ordinated programme takes place through the Trilateral Monitoring and Assessment programme (TMAP) between the three countries comprising the Trilateral Wadden Sea Cooperation (Denmark, Germany and the Netherlands). The TMAP provides regular reports on the progress of the targets of the Wadden Sea Plan (WSP) and a scientific assessment of the ecological status [55]. At the GBRMP there is also long-term investment in seagrass mapping and monitoring with a considerable number of programmes in the GBRMP sponsored by the Australian Government, Queensland Government, and Queensland Port Authorities [57], with over 54 monitoring programmes in place [58]. Since 2005, the GBRMP inshore seagrasses have been monitored as part of the Reef Rescue Marine Monitoring Programme (MMP). The GBRMP seagrass programme aims to collect an extensive range of data about the seagrass ecosystem, including light, temperature and seagrass tissue nutrient concentrations [60,95]. In contrast, there has been little evidence of mapping and monitoring programmes in Senegal until the ResilienSEA project in 2018–2021 which involved training the local communities in mapping and monitoring techniques [61].

4.2.1.2. *Is there evidence of increased scientific research in seagrass ecosystems?* There is an overall upward trend in the countries' seagrass research of the countries over the last 37 years, as displayed in Fig. 3. Seagrass is identified as a particularly important research topic in Australia, with over a hundred papers produced consecutively over the last few years. In the UK and Europe there have been fluctuations in publications in recent years, while published research into seagrass in West Africa has remained at a relatively low level over the last decade.

4.2.2. Management

4.2.2.1. *Are there designated Marine Protected Areas that include or focus on management measures for seagrass?* In the UK, although there is a focus on management measures for seagrass ecosystems, and seagrass meadows are included in a number of designated marine protected areas, this was not at the high level as seen in the Wadden Sea and the GBRMP. The Wadden Sea is an example of a large protected marine area with management protocols in place supported by good co-operation between member states [62]. The Wadden Sea Plan (WSP) presents an integrated approach in a transboundary context, based on the ecosystem approach [64]. In the GBRMP, continued expansion of MPAs across Australian government, state and territory jurisdictions have led to an increased proportion of the marine environment placed under active conservation management plans. Strategies focusing on biodiversity protection and sustainable development of Australia's environment have been released providing frameworks for co-ordinated management [68,96]. Management tools in this location include Marine Park Zoning, which involves the use of no take zones (NTZs) designated as "Green Zones", along with six other protective zones, general use zones and Estuarine conservation zones. Other multi-layered management tools overlay the zoning, and have a statutory basis so are legally binding on specific users [68]. About one-third of the GBRMP is "no-take" (IUCN Category II) with some small areas requiring a special permit [62]. Various types of fishing are permitted in two-thirds of the GBRMP, but the Habitat Protection Zone ensures a large area is free from benthic disturbance [68]. A targeted education and compliance strategy has been implemented to help give effect to the zoning plans, with focus on high-risk threats, as well as zoning maps and educational material to raise awareness and encourage visitors to follow regulations. In Senegal, although there is no specific focus on management measures for seagrass meadows, the West African Marine Ecoregion (WAMER) programme, which started in 2000, was designed to address critical marine biodiversity and fisheries issues in the region. Four MPAs of 960 km², were

created as part of the WAMER programme and seagrass meadows are included in these designated areas [70,71].

4.2.2.2. Is there engagement of local communities as well as evidence of public awareness campaigns and education programmes? Public awareness of seagrass and engagement with the community is more evident in the Wadden Sea and the Great Barrier Reef Marine Park, compared to the UK and Senegal. Seagrass management and conservation objectives in the Wadden Sea are communicated to target groups including the general public, press and media, schools and universities, interest groups and international organisations however this could be on a local scale rather than at a national level. This supports increased public awareness and appreciation of seagrasses throughout Europe, by use of education and outreach programmes to citizens, politicians and managers, with the cooperation and assistance of local NGO's [73]. In Australia, there has been a strong track record of engaging local communities in conservation issues relating to marine ecosystems, especially coral reefs, and this has provided an opportunity to also promote awareness of seagrass. The Seagrass-Watch monitoring programme was established in 1998, and the programme partners scientists with citizens to monitor the status and trends in seagrass condition [97,98]. Seagrass-Watch has expanded its reach globally, conducting over 5000 assessments from 396 sites across 19 countries and involving thousands of community volunteers who are trained to monitor intertidal seagrass habitats. With the citizen-science programme Seagrass-Watch, methods are designed to be rapid and completed with simple technology, ideal for local schools and community groups [99], with the purpose of developing the approach to bring local citizens into a discussion of managing habitat protection [41]. Public awareness of seagrass and engagement with the community in Senegal has been limited however the ResilienSEA project is helping seven West African countries, including Senegal, to address this with a programme of workshops, training activities and funding scholarships [61].

4.2.3. Protection

4.2.3.1. Are there national action plans and do these include targets for seagrass conservation? The development of action plans at a national level with targets for seagrass conservation are in place for the Wadden Sea, through the Wadden Sea Plan and the Wadden Sea Quality Status Report. These produced recommendations that included further consideration for the reduction and removal of threats, protection of areas larger than the present seagrass beds to allow a buffer zone for expansion, critical review of dredging and dumping activities of sediments, and consideration of restoration activities [56]. However, the report could also be considered to refer to developing strategies and management plans rather than an actual management plan in place. Similarly, in Australia, the development of action plans at a national level with targets for seagrass conservation are in place, and the management of the GBRMP is supported by various policies and programmes including the Reef 2050 Long-Term Sustainability Plan [100]. The UK, like Europe, has complied with the Marine Strategy Framework Directive (MSFD), to protect, preserve and restore the quality of the marine environment, although the protection relates to benthic habitats as opposed to seagrass specifically. In Senegal, there is a lack of conservation measures and currently no action plans for seagrass exist, although the ResilienSEA project was set up in 2018 to help governments in protecting seagrass and to develop new management tools [61].

4.2.3.2. Is there explicit protection of seagrass within legislation? In the UK and the Wadden Sea, seagrass meadows have been protected under the same EU legislation and the same international directives and conventions apply, specifically the Convention of Biological Diversity and the Ramsar Convention (Convention on Wetlands 1976). Other

protective measures operating in the Wadden Sea include a zoning system which regulates access, with closures of very sensitive areas at certain times of the year, such as breeding and resting stages for birds and seals. Australia is recognised as having well-developed legal and institutional mechanisms to guide the management of marine protected areas at the Commonwealth and state level, and the same international directives and conventions operating in the UK and Europe also apply. In addition, the GBRMP is governed by its own legislation, *the Great Barrier Reef Marine Park Act*, with the region added as a matter of national environmental significance under the *EPBC Act* [57]. Since 1975, the GBRMP has been protected by pioneering federal legislation which enables the 'reasonable use' of natural resources to co-exist with conservation, consequently introducing the concept of a multiple-use marine park. In Senegal, there is no explicit protection of seagrass within legislation however the Abidjan Convention provides the overarching legal framework for all marine-related programmes in West Africa [101].

4.2.4. Restoration

4.2.4.1. Is there investment in seagrass restoration programmes? In the UK there are limited seagrass restoration projects taking place and in Senegal there are none, and this contrasts to restoration programmes taking place in the Wadden Sea and the GBRMP. In the Wadden Sea, seagrass transplantation programmes with over 20 years' experience of seagrass research include a number of large-scale projects that have allowed evaluation of seagrass restoration programmes. Although not completely successful, these programmes have allowed seagrass restoration strategies to be assessed and have generated valuable information regarding habitat suitability for future efforts and allowed insight in the cause of failure and underlying mechanisms [72,77,97,98]. In Australia, seagrass transplantation programmes have also been taking places for years [78] with major rehabilitation programmes in Australia [79–83] with larger scale projects underway [83].

4.2.4.2. Are there measures to address direct and indirect drivers of seagrass degradation? Both the UK and the Wadden Sea region are impacted and must act under the EU Water Framework Directive (WFD), with obligations to improve habitat quality and to implement measures that increase seagrass populations [72]. Within the Wadden Sea, there have been restoration efforts that have addressed both indirect and indirect factors to seagrass decline; in mitigating the adverse effects of sediment-related processes, either by reducing hydrodynamic forces [102], increasing planting density [103], reducing effects of bio-turbating infauna [103–105], and enhancing sediment stabilisation [36]. This was also well evidenced in the GBRMP, where issues regarding water quality from catchment run off have been addressed through coastal watershed management and the *Great Barrier Reef Protection Amendment Act 2009 (Queensland)* and the *Reef Rescue and Reef Water Quality Protection Plan* and restoration efforts addressing other indirect pressures include sediment stabilising [102], and significant efforts to overcome problems associated with site specific stressors such as surge and wave exposure [106–108]. In Senegal, there are currently no measures in place to address direct and indirect drivers of seagrass degradation, although the Abidjan Convention lists sources of marine pollution that require control and identifies environmental management issues [101]. Of note is that water quality here has been assessed with regard to restoration efforts and habitat conservation, which may underestimate other applicable national and international plans that do not have such criteria named.

4.3. Opportunities for a framework for seagrass management and conservation

Overall, assessment of seagrass management through the critique

framework allowed the identification and consideration of management based on research data and monitoring programmes, targeted legislation and policies, and the impact of public engagement with key stakeholders. The framework in place allowed for comparison of these themes at different scales, providing valuable insight into the opportunities for seagrass conservation as well as the areas it is lacking. The framework provide an extremely useful tool that could facilitate important discussions to further develop environmental strategies. An expansion of seagrass research and communication of up-to-date information on seagrass status across sectors and with key stakeholders would support conservation to ensure decisions are met with public support and help influence government policy. The framework demonstrated the critical importance of data being widely available to guide further research, conservation and management. For example, monitoring the seagrass status creates a baseline to compare future efforts to, thereby creating a long-term assessment tool to track seagrass management. The framework created could be revisited in more depth with the additions of local knowledge, however the value of the approach here allows assessment from open access data.

4.4. Opportunities and challenges for seagrass management and conservation in Scotland

The UN Decade on Ecosystem Restoration and Decade on Ocean Science for Sustainable Development is recognised as a major opportunity for a phase shift in marine restoration [18] and a vehicle to catalyse action to meet the Sustainable Development Goals that are not yet advancing at the speed or scale required. Success requires the establishment of a committed and resilient global partnership of governments and societies aligned with coastal ecosystem restoration to coordinate and accelerate research and education. These need to be supported by coordinated policies, adequate financial backing, and evolving scientific and technological advances that allow a fast-learning curve of rebuilding interventions within ocean and coastal management [13]. Changes and uncertainties in environmental legislation will impact the efficacy of efforts for ecosystem protection and restoration. For example, to the UK, the impacts of Brexit pose a challenge to maintain standards and regulations while no new environmental legislation is in place [88]. A framework such as that outlined here provides a baseline for future efforts to be compared to. Within Scotland in particular, the framework has identified an opportunity to implement a more targeted and co-ordinated approach, with conservation that focuses on preventative measures to seagrass decline and tackle cumulative stressors. The challenge for Scotland and the rest of the UK is to effectively co-ordinate seagrass conservation that includes the integration of coastal management approaches to reduce multiple pressures on these valuable ecosystems and the strengthening of the marine strategy on seagrass through: further integration into policy plans; completion of the MPA network; developing marine plans and management measures that proactively drive improvement of marine ecosystems; investment in marine science, planning and governance; as well as fisheries management and ecosystem monitoring.

5. Conclusion

The evaluation of seagrass management through the application of a common methodology and a critique framework highlighted exemplars of good practice, and allowed for valuable insight into opportunities for seagrass conservation. The framework itself allows the examination, assessment and comparison to areas at different scales, providing an extremely useful tool for practitioners with a means to facilitate important discussions over how countries can improve their seagrass conservation management. These discussions could assist policy makers and environmental managers to develop and implement effective seagrass conservation and management strategies and support engagement with key stakeholders on environmental policy. The study also identifies

the critical importance of data being widely available to guide further research, conservation efforts and management strategies, and to enable accurate comparisons to be made and effective knowledge transfer from more developed management regimes to those that are less developed.

The study identified important management techniques and strategies including: the consideration of effective management based on research data; monitoring and review for adaptive management; targeted policies, governance with consultation of key stakeholders; and awareness raising tools. Engaging with local communities and developing public awareness campaigns and educational programmes was identified as playing an important role in raising the profile of seagrass and its significance in respect of the ecosystem services it provides. An expansion of seagrass research and communication of up-to-date information on seagrass status across sectors and with key stakeholders would support conservation to ensure decisions are met with public support and help influence government policy. As a threatened and depleting ecosystem, it is critical that proactive resource management approaches are considered for the long-term resilience and sustainability of seagrass meadows. The framework demonstrated here highlights the status and efficacy of current efforts, and creates a baseline to compare future efforts to, thereby creating a long-term assessment tool to track improvements in seagrass management.

Data availability

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2022.105306](https://doi.org/10.1016/j.marpol.2022.105306).

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