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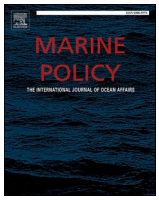

Full length article

Connecting governance and practice views on the barriers and solutions to scaled seagrass restoration in the UK

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ABSTRACT

Seagrass restoration is rapidly gaining popularity in the UK. Increased public and political awareness of historic and ongoing declines, along with its value to people and planet, have inspired several restoration projects. However, there remain key bottlenecks in the seagrass restoration process preventing success at scales required to halt declines, let alone to increase habitat coverage. To improve restoration success collaboratively, it is important that those involved in the governance and practice of restoration have shared understanding of what those bottlenecks are and what can be done to overcome them. Here we present insight gathered through semi-structured interviews with individuals working in the governance of seagrass restoration and with practitioners involved in active restoration projects. We highlight the key perceived barriers and discuss potential solutions proposed by those who know the sector best. Some solutions are already happening or emerging in practice, while others remain ambitious ideas that will require strong political and social will, robust funding and time to realise. Now is the time to act to capitalise on the current momentum in the sector and put UK seagrass on a trajectory of net gain, rather than net loss.

1. Introduction

Increased awareness of historic and ongoing declines of UK seagrass meadows [12], along with their high value to people and planet [4], has led to rapidly increasing interest in restoration initiatives. Seagrass is a protected habitat in the UK with two main species: *Zostera marina* and *Z. noltii*. It is protected as a habitat supporting high biodiversity as well as for providing multiple other ecosystem services. Subtidally, *Z. marina* provides nursery habitat for commercially important fishery species [2] and for charismatic endangered seahorses [10], which add to their recreation value to divers and tourism. Intertidally, both seagrass species form monospecific as well as mixed meadows, which provide a suitable habitat for diverse invertebrate communities, including commercially valuable bait species, and for internationally important populations of wading birds that graze on the plant [7,22]. Meadows provide a degree of coastal stabilisation against wave energy [16], while of highest political interest is their capacity to capture and store carbon [19].

Despite the protected status of seagrass in the UK and existence of numerous protected areas designating it as a feature (or designated site part-feature) of conservation interest, it remains in poor environmental condition nationwide [15]. Water quality is one of the main pressures driving declines, as seagrass relies on clear water with high light availability for photosynthesis and limited nutrient input that can cause eutrophication and smothering algal blooms [14]. Other localised pressures include scouring from anchor and mooring lines, abrasion from bottom-contact fishing gear, and trampling or vehicle damage from intertidal resource use such as bait digging and boat launching [6]. Larger-scale pressures come from seagrass wasting disease (the cause of which is unclear; [3]) and increasing coastal development, with built-up coastlines squeezing the available area of shallow and intertidal seabed suitable for seagrass growth [20]. Finally, increasing storminess and frequency of heatwaves driven by climate change will increase the vulnerability of meadows to natural disturbance and loss, while sea level rise may render entire areas of coastline unsuitable for seagrass in the long term [6].

The restoration movement has gained popularity in the UK, as scientists and conservationists are driven to take active measures to improve the natural environment. Seagrass restoration has received media attention, which has stirred interest among the public and policy-

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makers. In particular, the tantalising potential of meadows to help mitigate climate change by sinking carbon into sediments [13] has led to new policies regarding 'net gain' and 'compensation' in marine planning, plus growing interest from emerging carbon credit systems and natural capital markets [23]. Funders have stepped forward to support fledgling restoration projects with exciting publicity opportunities to fulfil and market their environmental commitments. As a result, several restoration projects have been initiated around UK coastlines in recent years, with some successes reported [9]. However, there remain key bottlenecks in the seagrass restoration process preventing success at scales required to halt ongoing declines, let alone to increase habitat coverage to replace recorded losses [24].

To overcome these bottlenecks collaboratively, it is crucial that those involved in the governance and practice of seagrass restoration have shared understanding of how the process does and should happen, and what the limiting factors are. We therefore set out to elucidate perceptions regarding the barriers and potential solutions to successful scaled seagrass restoration among these groups. We did this through semi-structured interviews with 15 individuals. Eight worked for organisations involved in the governance of seagrass restoration in the UK, with specific remit of such in their roles, while seven were practitioners involved in active seagrass restoration projects in the UK. Here we aim to highlight the key perceived barriers to successful scaled restoration and discuss potential solutions, with their wider implications.

2. Methods

Two researchers interviewed 15 individuals using qualitative semi-structured interviews during 2023–2024, under Swansea University ethics approval SU-Ethics-Staff-250822/518. A purposive sampling approach was used to select interviewees [21]. Eight individuals worked for organisations involved in the governance of seagrass restoration in the devolved UK nations of Wales, Scotland and England, with specific remit of such in their roles. The remaining seven were practitioners involved in active seagrass restoration projects in Wales, Scotland and England. Interviews were undertaken via recorded video conferencing on a one-to-one basis, apart from two governance interviews and one practitioner interview, in which two people from the same organisation or project were interviewed together (Table S1). Before the interviews, individuals signed a consent form and confirmed they had read a participant information sheet outlining the project.

Governance and practitioner interviews followed a different set of questions (Table S2–S3) since they were designed to cover a range of topics for the Restoration of Seagrass for Ocean Wealth (ReSOW; https://resow.uk/) project. But several common and complementary themes were discussed across the two types of respondent, which allowed us to draw out insight into the perceived barriers and proposed solutions to scaled seagrass restoration in the UK. Recordings were manually transcribed and thematically analysed over three rounds of coding: first to inductively code all content as it was encountered by the researcher; second to create a coding hierarchy summarising key themes; and third to deductively re-code interviews against the complete hierarchical codebook. All interviewees, organisations, projects and quotes were anonymised for reporting.

3. Barriers to seagrass restoration in the UK

Several key themes emerged regarding the perceived barriers to seagrass restoration in the UK (Box 1).

3.1. Barrier 1 seagrass restoration in the UK is difficult

3.1.1. Barrier 1.1 evidence, knowledge and success rates

All seven practitioners reported low certainty and success in their planting-based seagrass restoration activities. Seagrass restoration is in its infancy in the UK, with only a handful of *Zostera marina* projects to draw from, and the first *Z. noltii* trials begun. Methods that have been successful elsewhere (e.g. [17]) do not translate well to the locations, populations and environmental contexts targeted in the UK to date. This is likely because at site level, prevailing environmental conditions (e.g. wave intensity, climatic conditions, nutrient levels) and ecological feedbacks (e.g. seed predation, rhizome–sediment stability) determine methodological success [24]. There is no specific formula to guarantee seagrass restoration success. In the words of one practitioner "*you can't go to the seagrass restoration suppliers' depot and pick up the kit you need. … Everyone is having to find their own way and try different things to suit their circumstances.*" It is, therefore, necessary for projects to include a development phase to identify relevant site parameters and trial different methods. This is good practice to reduce high risk investment at scale [25]. However, some practitioners reported challenges for this crucial preliminary phase in terms of project timeframes and funder expectations (see *Barriers 2.2–2.3*).

All governance interviewees commented on low or varying success in UK planting trials. A lack of published results from trials – especially those reporting failures – result in limited supporting information available for decision-making. It was suggested by one interviewee that competition amongst practitioners causes a reluctance to share findings. This view was not shared by other interviewees, who all described

BOX 1

PERCEIVED BARRIERS TO SEAGRASS RESTORATION IN THE UK

1. **Seagrass restoration in the UK is difficult:**
   - 1.1. *Evidence, knowledge & success rates*
   - 1.2. *Site selection & suitability*
   - 1.3. *Seed/transplant/sediment supply, collection & storage*
   - 1.4. *Skills, expertise & labour*
2. **Seagrass restoration in the UK is expensive and time-consuming, with funding often misaligned:**
   - 2.1. *Costs of restoration*
   - 2.2. *Time for restoration*
   - 2.3. *Funder perceptions & priorities*
3. **The licensing system governing seagrass restoration in the UK is onerous:**
   - 3.1. *Complexity, cost & time*
   - 3.2. *Inconsistencies*

diverse and wholehearted collaboration within the field (see *Solution 1*). The bias towards significant *positive* outcomes is however, a well-recognised problem in scientific publishing [8] (see *Solution 3*). Meanwhile, several practitioners commented that the long-term monitoring and reporting needed to generate useful transferrable data is not always possible within funding timeframes (*Barriers 2.2–2.3*), and that accessing and publishing in scientific journals without a university affiliation is difficult.

3.1.2. Barrier 1.2 site selection and suitability

There is no national or regional plan for where active seagrass restoration should be targeted. Practitioners described using several approaches to select sites for projects. They used habitat suitability models (HSMs) [1] to identify theoretically-suitable areas. But since model data are incomplete and of low spatial resolution, on-the-ground surveys are essential to ground-truth models and assess local environmental conditions. Some practitioners also leaned on local knowledge and insight, followed by small-scale experiments to test the suitability of sites and methods (see *Barrier 1.1*). They spoke of needing to consider societal factors such as potential conflict between site users, local stakeholder support and an available volunteer pool to support project implementation (*Barrier 1.4*). One practitioner indicated that funding availability and funder priorities sometimes dictated restoration efforts. Others described how land ownership and licensing limited options. Several expressed that these constraints impact the likelihood of success.

Governance interviewees recognised that HSMs are a work-in-progress and not yet suitable alone, to identify appropriate restoration sites. Some highlighted that there is not an abundance of suitable sites where seagrass can be restored through planting, without first implementing broader-scale interventions. For example, where the causes of historic decline are unclear or pressures persist, there are often no mechanisms or funds to remediate sites to facilitate seagrass growth (*Barrier 2.1*). "*If you try and do seagrass restoration where there's eutrophication, for instance, or some other pollution or pressures, then it's just not going to work.*" It was suggested that sites within existing protected areas may provide mechanisms for management during and post planting restoration. However, it was also reported that protected sites sometimes present perceived conflict between planting activity and other designated features, such as seahorses, over-wintering birds or archaeological relics.

3.1.3. Barrier 1.3 supply, collection and storage of seeds, transplants, and sediment

Site selection also featured in discussions around sourcing seeds, transplants and associated planting media (i.e. sediment) for planting-based restoration. Most seagrass meadows in the UK – particularly those that are dense and productive enough to be suitable donor meadows – are protected under conservation designations. Legal permissions are required for activities that may disturb or damage the habitat or other listed features. Interviewees governing extractive activities shared that decisions are made based on the condition of the meadow, number or intensity of collection proposals, proposed methods and timing of extraction, biosecurity risk (i.e. introduction of non-native species and transmission of disease) and genetic matching with recipient sites. One interviewee noted "*there isn't an agreed set of wisdom about what genetics [are] appropriate where*". Other site users and their perceptions are also considered, with seed collection discouraged, for example, to preserve relations with boat users observing voluntary no-anchor zones designed to protect a meadow.

These decisions based on poorly defined criteria create additional challenges for practitioners. In one location, for example, practitioners were only permitted to use one specific seed-planting method (direct injection seeding (DIS)) [11]. DIS requires a specific consistency of mud as a planting media but practitioners were only permitted to use sediment from the local area, which was not the required consistency for the method to work. Practitioners also described unforeseen challenges such as donor meadows failing to produce seeds at the anticipated volume and time following extreme weather events. Cross-border politics further restrict seed access. Practitioners described the seed collection process as "*incredibly labour-intensive*", often relying on a force of volunteers. Mechanised processes are in development to streamline seed collection, but these require further testing to demonstrate no detrimental impact on donor meadows (*Barrier 2.1*). One governance interviewee was concerned about the supply of seeds or transplants to restore seagrass at the scale required in the UK: "*you can't just raid donor beds …* ad nauseum *because you'll have no beds left, … especially if you've got more and more projects [at] bigger and bigger scales*". Emerging evidence suggests high capacity for reproductively healthy donor meadows to supply seeds or transplants for restoration (Project Seagrass unpublished data; [26,28]. However, it may be beneficial to supplement seed or transplant supply with nursery-reared stock. Seagrass nursery and aquaria facilities are currently required for seed processing and storage under controlled conditions before planting. These facilities are technical, expensive to set-up and run (*Barrier 2.1*), and require skilled husbandry (*Barrier 1.4*), but may be a necessary contribution to best practice for generating a sustainable, robust and safe supply of plant material.

3.1.4. Barrier 1.4 skills, expertise and labour

The success of large-scale seagrass restoration requires significant human capital (discussed [25]. Roles include advocacy with politicians and investors, community engagement, fundraising and licencing applications, planning and delivering restoration activity, design and manufacture of equipment, systems and materials to support restoration, and monitoring, reporting and evaluation of projects. A broad range of specialist skills is required to support restoration activities, and with the field in its infancy in the UK practitioners are "*still finding their way*". Interviewees commented that the broad range of skills required is a considerable barrier to smaller-scale and community-led projects without access to highly skilled teams with varied expertise. Experience and capacity to navigate the licensing system was repeatedly raised as a limitation (*Barrier 3*). Another key skills gap, even in larger more experienced projects, was perceived by one governance interviewee to be business development and large-scale project management: "*restoration practitioners, for the most part, are not project managers … especially large-scale £25million project managers. That's quite a different skillset.*" They saw this as a key barrier to scaling the sector in terms of forecasting and instilling confidence in large-scale funders (see *Solution 4.2*).

Practitioners described a boom-and-bust workload, with labour intensive periods, e.g. for seed collection, processing and planting. Projects, therefore, frequently relied on volunteers who must be recruited, trained and continually supported [5]. Practitioners also described challenging working conditions, including cold water, poor visibility, storms, and even heatwaves affecting their work. Intertidal work is often in muddy substrate that is difficult to traverse, and subtidal work requires boats with appropriately qualified and insured crew, snorkellers or divers. Both rely on limited working windows.

3.2. Barrier 2 seagrass restoration in the UK is expensive and time-consuming, with funding often misaligned

3.2.1. Barrier 2.1 costs of restoration

As described above (*Barrier 1.4*), seagrass restoration requires a diversity of highly skilled personnel, with associated costs, so projects often rely on large volunteer input to undertake labour-intensive tasks. "*We don't have an army of people to go out and plant … We can't afford to pay [an] army for the whole year.*" Mechanisation of parts of the restoration process are forthcoming but not yet widely applicable. Interviewees discussed development of a seed-collecting "*underwater lawnmower*", a Dispenser Injection Seeding (DIS) "*wheelbarrow*", a seed bag planting "*sled*", in addition to various underwater remotely operated vehicles ("*ROVs*"). This technology – like the sector as a whole – is still in an embryonic phase, drawing on other sectors to aid progress. One

practitioner explained their innovation work has roots in agriculture. They pointed out "*It's taken thousands of years to come to the point where we can just hop in the Massey Ferguson* {a brand of agricultural machinery} *and plant tens of thousands of potatoes in a morning. But taking those concepts and ideas and applying them to seagrass … there's a lot of taking it and seeing what sticks [because] we have no idea what works.*" New technologies and methods are subject to rigorous testing of their efficacy and potential to impact the natural environment. These research and development activities require significant staff time and capital investment, with potential cost-savings deferred to future projects.

Expensive equipment and facilities are required for restoration, including boats, SCUBA equipment, specialised safety and personal protective equipment (PPE), specialised aquaria and nursery facilities, laboratory space and equipment, and transport. Some projects also had to pay for permissions and governance advice (by the hour), depending on where they worked and the methods they wanted to use (*Barrier 3*). One practitioner commented that recent inflation had seen costs *skyrocket*, making it difficult to budget for new projects based on previous spend.

As noted above (*Barrier 1.2*), interviewees – particularly those involved in governance – spoke about the importance of wider site remediation for meadow recovery. Whether as an alternative management approach to planting-based interventions, or alongside and post-planting, the cost of required interventions was raised as a considerable barrier to restoration success "*you've got complexities of land management, wastewater management, surface water drainage, … it's a big challenge … and who pays [the] cost … for massive changes and who's going to enforce it?*"

3.2.2. Barrier 2.2 time for restoration

It is difficult to summarise how long it takes to restore seagrass, since many variables contribute and there are few examples of successful meadow-scale restoration to draw from. However, most practitioners expressed that their projects were not afforded adequate time to set up, deliver and evaluate success. As noted above (*Barrier 1.1*), projects normally require a development phase to assess the social and ecological conditions of sites, test the site-suitability of methods, acquire permissions, and build capacity in the team and local area. This can take several years, yet many projects are only funded for two or three years in total, often with ambitious planting goals to fulfil. Similarly, at the end of projects, monitoring timeframes were rarely considered long enough to assess and report meaningful outcomes. One practitioner noted that because the seagrass life cycle dictates the timing of planting and monitoring "*one of the biggest difficulties of choosing [the] appropriate method is [that] you plant but you're waiting at least a year before you get results … So, you've already planned and planted your next experiment before you know if your first has worked.*" Furthermore, several practitioners commented that restoration should be an iterative process, with repeat interventions over time until a meadow becomes self-facilitating. There are sometimes options to apply for follow-on funding to continue projects, but this carries uncertainty for planning and administrative inefficiency.

3.2.3. Barrier 2.3 funder perceptions and priorities

Funding available for seagrass restoration is increasing, but both governance and practitioner interviewees suggested that funder perceptions and priorities were often misaligned with project realities and needs. One of the key problems raised was funding timeframes: "*Funding is … quite short-term at the moment. You're looking at one, two, three years, which isn't sufficient*". As well as limiting project capabilities (discussed in *Barrier 2.2*), short project funding means short-term staff contracts, causing a skills and experience 'drain' in the sector (see *Barrier 1.4*). "*Every single time I talk to a grantee, they say 'any chance you could just fund [staff] and I could stop chasing staff costs for five minutes and get on with planting … seagrass.'*"

Interviewees suggested that messaging on the potential and success of restoration projects could be over-optimistic, even verging on "*greenwashing … with the best intentions*". One practitioner said "*I think the expectations of a lot of funders are riding far ahead of reality*." One governance interviewee added "*when you create a habitat, it can take years, decades for that habitat to start delivering the same level of [ecosystem] services [as a mature meadow] … [while] there seems to be an inference that you put the habitat in and it's just away and doing it.*" There is clearly appeal to funders in marketing that their investment is going to create specified hectares of seagrass, for example, but the reality is that much of the funding required is needed for advocacy, planning, capacity-building, research and development, permissions, and monitoring (see *Barriers 1.1, 2.1, 3*) – all crucial activities to facilitate scaled restoration, but not measurable by the hectare. One practitioner reported they had to "*hide the science*" they were doing because their funding was focused only on community outcomes. But they pointed out that without the science they would have to report that, "*it didn't work and I don't know why*". Another told us they suspected the money a funder had spent on marketing their investment in restoration probably "*dwarfed*" the amount directed towards restoration activity.

3.3. Barrier 3 the licensing system governing seagrass restoration in the UK is onerous

3.3.1. Barrier 3.1 complexity, cost and time

All interviewees agreed that the process of securing permissions for seagrass restoration in the UK is a barrier for projects. Different permissions are required for different activities, methods and locations, and the requirements frequently change [27].

Practitioners reported needing marine licences, Site of Special Scientific Interest (SSSI) consents, European Marine Site (EMS) permissions (via habitats regulations assessments), wildlife licences, water abstraction or release licences, landowner permissions and seabed leases. These were for a range of activities including seed, transplant, sediment and water collection (see *Barrier 1.3*), planting, and in case of accidental disturbance to endangered species. Although recognising that regulation of seagrass restoration is important, practitioners felt the process was disproportionate for projects aiming to enhance the natural environment. They reported it taking several months and hundreds-to-thousands of pounds (not including staff time) to secure appropriate licenses. Quotes from practitioners ranged from "*we're trying to restore nature, we're not trying to damage it.*" to "*it's frustrating mentally … but it's also a financial drain both in your resource time and the money it costs to get all the licences … we're treated as if we want to build an oil rig!*"

Some governance interviewees told us they were responsible for issuing and advising on permissions, in addition to adhering to the same requirements for site management. There was general awareness of the "*huge challenges*" faced by practitioners, and it was recognised that practitioners "*are very frustrated*". One governance interviewee explained that "*overlapping jurisdictions [of] different regulatory bodies … creates complexity and drives a timeframe challenge that can be unhelpful*". Decisions involve multiple people often from different organisations as well as from different and disconnected teams within organisations. For projects covering multiple sites (e.g. collecting seeds from one and planting at another), the permissions, paperwork and people involved is multiplied.

Much of the seabed around the UK is owned by The Crown Estate (TCE), but practitioners reported specific difficulties and delays when ownership was unclear, either because of private ownership or because a TCE area had been leased to third parties. Locating responsible persons for permissions to be sought can drain project timelines. Marine licence applications also undergo stakeholder consultation, adding additional time, extended further if concerns are raised. When permissions are issued, they can mandate restrictions on sites, methods and timings of project activities. Restrictions are further complicated by proposed mechanisation steps, with additional licensing restrictions for activities involving vehicles or vessels, compared with by-hand and on-foot

activities. "*You need to be flexible and creative to work around the hurdles … But this is only possible because we work with such a big project and we have the budget … for a small community it might just be too high a barrier.*"

3.3.2. Barrier 3.2 inconsistencies

Several practitioners reported inconsistencies and confusion while securing restoration permissions, this included changeable requirements, advice and decisions, and varying response times from different organisations and different people within organisations – either from different teams or where handling officers changed during the process. One practitioner stated "*you really have to adapt to whoever you speak to, which makes the process difficult.*" Others said they discovered similar projects had received different advice or decisions to theirs, or that advice varied over time. Differences were magnified between devolved nations. Whilst inconsistencies do not necessarily indicate a breakdown in process, they do reflect that seagrass restoration is an emerging and rapidly evolving practice in the UK; every project presents a different scenario in terms of location and methods as well as ecological or stakeholder conflicts. Some practitioners commented on unclear rationale for some advice or decisions, which several governance interviewees acknowledged as a barrier (*Barriers 1.1–1.3*). "*Within every project there have been different barriers and difficulties, so each project lead has their own very niche knowledge of how to complete the licensing process for that area … it's not particularly transferrable. … You have to go through the process yourself to discover what the drawbacks are going to be and what is going to be the problem you're going to have to overcome.*" Practitioners suggested that incremental advances would help "*pave the way for others*" as seagrass restoration becomes more common and experience is built on both sides of the process.

4. Potential solutions to scaled seagrass restoration in the UK

Several suggestions were made regarding potential solutions to the perceived barriers to seagrass restoration in the UK (Box 2).

4.1. Solution 1 more collaboration

Practitioners expressed that the field of seagrass restoration in the UK (and internationally) is highly collaborative and mutually supportive. Practitioners collaborate with each other, academics, NGOs, communities and volunteer groups involved in or affected by projects. There is also collaboration outside of the seagrass sector, drawing on, for example, horticulture, botany, zoology, other habitat restoration projects, engineering startups, and industry. There are formal and informal networks to steer progress and share knowledge. Collaboration extends beyond funding agreements and statutory engagement, with proactive teamwork and knowledge exchange. However, some key collaborations were flagged as missing, with their development considered part of the solution for increased success.

One governance interviewee made a strong argument for practitioners building more links with high-value project managers and finance or business developers, i.e. "*people who know how to run big projects*" (see *Barrier 1.4*). They saw this as "*important to scale [the sector] and for confidence for the kind of people who are putting money in to know the project's going to be run efficiently.*" "*When you're looking to bring in private investment, for the most part, the lowest ticket price they're interested in is … ten million, twenty million pounds, but you need to be able to tell them what you're going to do with that money.*" (see *Solution 4.2*). It was felt that improved collaboration between restoration projects working in the same area would reduce perceived conflict and improve seascape-scale outcomes (*Solution 7.2*). "*I often connect up projects focusing on a single habitat in the same geography, … [saying] 'you guys need to work together because we need to think carefully about sequencing activities.'*" "*If you've just worked really hard to restore a seagrass bed and somebody brings in a digger [for] managed realignment for saltmarsh, that's likely to be a problem.*"

Practitioners identified key groups missing from the marine restoration conversation, for example the agriculture and wastewater sectors. There are statutory instruments to enforce and incentivise improved land management practice (see *Solution 4.1*), but catchment scale engagement and collaboration would benefit projects (*Solution 8*).

4.2. Solution 2 upskilling and capacity-building

In addition to extending collaborations (*Solution 1*), suggestions were made for other ways of upskilling the sector to meet the highly variable

Box 2

SOLUTIONS TO SUPPORT SCALED SEAGRASS RESTORATION IN THE UK

1. More collaboration:
Missing skills & groups
2. Upskilling and capacity-building:
Project staff & local communities
3. Improve evidence & knowledge:
R&D, monitoring & reporting
4. Improve funding streams & fundability:
4.1 Funding streams
4.2 Fundability
5. Streamline the licensing system:
Rigorous but fit-for-purpose
6. Establish a national strategic plan & restoration authority:
6.1 Strategic plan
6.2 Restoration authority
7. Improve catchment-wide & seascape-scale management:
7.1 Catchment-wide management
7.2 Seascape-scale restoration
8. More public engagement:
Foster long-term protection

demands of restoration (see *Barrier 1.4*). Funding long-term staff is "*absolutely crucial*" for retaining skills and experience in the sector (discussed further in *Solution 4.2*). Conversely, some practitioners told us their longer-term aim was to gradually handover project managemet to local custodians, to have *"in the end, community-led seagrass restoration"* (see *Solution 8*). But given the current challenges of undertaking restoration projects (*Barriers 1–3*), both practitioner and governance interviewees were clear that considerable skills- and capacity-building was needed before ownership could be responsibly and successfully transferred.

Governance interviewees reported several restoration "*guidance*", "*handbooks*", "*toolkits*" and "*frameworks*" in production, aimed at guiding practitioners through the restoration process. Given that seagrass restoration is a rapidly developing field it was acknowledged that "*they're living documents, so they will adapt and change over time as things develop*". Capacity building through "*Events designed specifically to help communities upskill and lesson-learn"* was suggested as beneficial (see *Solution 4.2*).

Given the challenges practitioners raised regarding the costly infrastructure, resource and skill requirements for restoration (*Barriers 1.3, 1.4, 2.1*), the sector would benefit from strategic capacity-building investment in these areas. A strategic national plan or authority could help drive and facilitate this (*Solution 6*).

4.3. Solution 3 improve evidence and knowledge

Governance interviewees recognised the need to increase evidence, knowledge, certainty and success in seagrass restoration. They suggested: improving the evidence base for the impacts of different pressures on seagrass and for the value of seagrass ecosystem services (for existing and restored meadows); developing an agreed spatial dataset of "*the best restoration sites*"; and developing and trialling new seed germination and planting methods (including mechanised methods for scaling up). So, while they were aware of some of the evidence and knowledge gaps that need addressing (*Barriers 1.1–1.3*), they were not able to propose tangible solutions for doing so. Some suggested doing the research alongside restoration projects. Practitioners, however, reported the challenges of this approach: "*it's hard to restore two hectares of seagrass while you're actually trying to figure out how [to] do it*". They instead stressed the value of dedicated research and development funding allowing them to focus on innovation and rigorous experimental design, removed from ambitious restoration targets. Most practitioners incorporate the best available science into projects, from methods and site selection (*Barriers 1.1–1.3*) to collaborating with other experts (*Solution 1*) to developing and trialling new technologies with innovation startups (*Barrier 2.1*, *Solution 4.2*). Practitioners are studying genetic connectivity, working on improved HSMs, trialling novel methods and adapting existing ones– all while aiming to meet the requirements of their restoration funding (*Barrier 2.3*). One practitioner noted that the recent development of specialised nursery facilities made rigorous controlled experiments easier, removed from the environmental variability and uncertainty of field experiments. But with regard to field trials, they felt "*we need to stop doing little experiments and do big experiments*" to increase the likelihood of finding useful results at ecologically-meaningful scales.

Governance interviewees also recommended practitioners monitor more and report more failures. "*We need people to say what doesn't work as much as they do what does. People are very good at publicising success but not failures, but it's the failures you learn from.*" Reporting of failures would benefit the sector [25]. It is more difficult to publish negative outcomes in peer-reviewed literature which remains a barrier. The Conservation Evidence journal (https://conservationevidencejournal.com/), however, is a free-to-publish open-access journal reporting outcomes of conservation actions. Funding priorities and timeframes (*Barriers 2.2–2.3*) often don't allow practitioners adequate time for long-term monitoring and reporting. Practitioners need to respond to ecologically appropriate timescales, with trials monitored for long enough to measure reliable (and publishable) outcomes. Funding streams therefore need to adapt to reflect this (*Solution 4.1*).

4.4. Solution 4 improve funding streams and fundability

4.4.1. Solution 4.1 funding streams

As noted above (*Barrier 2.3*), funding for seagrass restoration in the UK has increased, but is often misaligned with project needs, which require funding guaranteed over extended timeframes. Practitioners suggested that funding should come from ethical sources with realistic expectations, priorities and publicity. Some interviewees suggested governmental wastewater and agricultural schemes that provide financial incentives for improved watershed management. For example, "*payments are allocated … to improve farming so there is less run-off, which over time should improve water clarity.*" However, the extent to which these schemes connect with marine restoration was unclear (see *Solution 7.1*). Part of the solution to reduce pressures on seagrass might be to maximise the benefits of existing statutory mechanisms. Interviewees felt that strengthened government ambitions and targets would stimulate such mechanisms, funding and action. Currently, governance organisations must focus all resources on their statutory priorities, with "*no money to do the rest*".

Government policies on "*net gain*" and "*compensation*" can channel funding to restoration on a "*polluter pays*" basis. One interviewee highlighted the Scottish Marine Environmental Enhancement Fund (SMEEF) as a successful blueprint for administering large-scale private sector funding "*with due diligence and ethics*". It combines core government funding with private donor contributions (both voluntary and via 'net gain' obligations) to fund restoration projects. "*It's been welcomed by industry and by government*" as it provides a vehicle by which both sides can meet targets and policy requirements. The interviewee suggested the scheme could be extended to include land-based industry donors as well as marine, while another interviewee indicated similar schemes could work in other parts of the UK. One interviewee warned, however, that private funding raises concerns regarding subsequent rights over restored habitats. For example, if an industry needs to damage habitat to continue operations, "*does it mean because you planted it, you can dig it up? I don't think so, but we don't have any legislation that actually covers that as far as I know*" (see *Solution 7.1*).

Several interviewees commented on growing interest in carbon credit markets for seagrass restoration. Although acknowledging the potential income that could be generated, they had reservations. One governance interviewee said "*we are not comfortable with the idea of seagrass carbon credits at the moment.*" "*If you had more certainty over the methods for restoration and long-term protection, you could say 'ok we can start with some carbon credits'. But I think those credits would get swallowed up pretty quickly. It's a great habitat, supports many biodiversity benefits, but in terms of carbon – relative to everything we churn out, it's quite a small proportion.*" One practitioner added that in terrestrial systems "*you build your forest and then in five years, once it's established, you get credits from it … but we've not got a five-year-old [restored seagrass] meadow to even conceptualise that [yet].*"

There are several issues regarding misaligned funder perceptions, priorities and timeframes (*Barrier 2.3*). One governance interviewee felt the solution to overcoming these lies in changing funders' understanding of project realities: "*for the donor to be open and accepting that the science is not certain. The science in one area may be certain, but then you try six miles up the coast and it might be different … Donor openness to that kind of thing is really important. Likewise, donor openness to funding long-term staff posts to support these things is absolutely crucial.*" Supporting this statement, some of the best examples of long-term restoration funding come from academic sources (e.g. the British Ecological Society's 10-year research grants), where the challenges of ecological and scientific timeframes (*Barrier 2.2*) are well understood. Other interviewees suggested encouraging the same level of enthusiasm for funding removal of

pressures to allow existing seagrass to recover naturally might be more cost-effective and successful, "*but it's just not as exciting, the interest is in doing the active restoration stuff*".

4.4.2. Solution 4.2 fundability

Governance interviewees made two suggestions to make seagrass restoration more fundable at scale: improving cost-benefit forecasting (including the time required to deliver benefits) and professionalisation of the sector. One felt current cost predictions for scaled-up restoration are "*probably unrealistic*", since they are based on extrapolating costs of many small-scale projects – all done in different ways and involving lots of volunteer time, which is hard to cost. They suggested that we are "*not yet in a place where we can say 'okay, here's how we do five hectares or here's how we do 10 ha – how do we get to 200 ha? These are the steps we will go through, these are the gateways we will pass, this is the expertise we need, this is the time it will take.*'" They felt experts in the field are "*reluctant to put that down in writing because they're really concerned about it being correct … that then becomes a massive barrier to getting funding and private investment … if you can't articulate certainty of outcome, you do need to be able to articulate how much you do know and then what you would like to do next, 'if all these things were true'*." They felt the solution was for practitioners to collaborate more with "*people who know how to run big projects*" (*Solution 1*). For benefit predictions, another governance interviewee commented that what we need is "*those facts and figures about what seagrass can do for us in terms of nursery habitats, carbon sequestration and water quality…*", i.e. the natural capital of healthy, degraded and restored meadows. Valuation of these services is at the cutting edge of environmental economics, with work currently underway on the first attempt at ocean accounting (https://www.oceanaccounts.org/) for UK seagrass through the ReSOW project (https://resow.uk/).

One governance interviewee reported that the seagrass restoration sector had professionalised over recent years. "*It's gone from [a] hemp skirt/knitted hat kind of thing to a much more dynamic, dare I say it, sexy/glamorous/intriguing science-based systematic approach … I don't think it's lost its heart … it's really positive in terms of that.*" They hoped this professionalisation would continue – "*not exclusively, not to become boring, just to become more effective and mainstream, more fundable.*" Ultimately, they wanted to see it become "*something people can make a living out of … [so] people are being paid to restore in a meaningful way.*" Some practitioners also discussed the potential value of some elements of the sector becoming commercialised. This would reduce skill or labour demands (*Barrier 1.4*) and help improve cost predictions for scaled-up efforts (see above). For example, one described a future "*where local communities pick and process seeds and then … sell them to other seagrass restoration projects, so they have the power over their own resource*". Another talked about their experience collaborating with startup companies on new restoration technologies. They said while "*there is a healthy product to be produced, it's not going to make people millions"* but *"we might even be their customer in time.*" They described some teething problems of partnering with business. "*We always get NDAs* {non-disclosure agreements} *… They [say] 'Don't tell people about this project because we're going to make millions on it'*". This conflicts with the need for new methods and results to be widely shared for improved collective success (*Solutions 1, 3*). They felt they could overcome this, however, through gentle persuasion of the scientific and commercial benefits of sharing and promoting innovation.

4.5. Solution 5 streamline the licensing system

Practitioners told us they had seen minor improvements in the process of securing permissions for some activities. One said they are no longer required to pay to lease the seabed. Another described a new "*self-service*" marine licence for small-scale low-risk projects in England. However, the system as a whole remains extremely onerous and a key barrier for projects (*Barrier 3*). Without exception, interviewees supported action to streamline the process "*to make restoration easier and more straightforward, particularly for smaller-scale projects*".

Governance interviewees told us early discussions about this were underway. However, they stressed it is not a trivial task and would require changes in law. One flagged the need for caution in reducing obligations: "*not all restoration projects are just going to restore – some might also do damage*". This was echoed by others, explaining the need to ensure restoration actions "*fit the conservation objectives of sites*"; for example, "*to ensure people weren't trying to turn an important bird feeding site into a seagrass bed*". Another felt that with ongoing professionalisation of the sector (*Solution 4*) "*as we go through into compensation measures, net gain and so on, big businesses are going to start putting a lot of money behind this and they'll need proper robust consenting regimes they can work through*". They suggested one option was to introduce parallel systems: one for community groups and one for big business. They felt a better approach, however, would be to keep the process the same, but establish an organisation or authority whose role it is to support people through that process (*Solution 6.2*).

Practitioners agreed with the need for caution in streamlining the system. One said "*it would be a disaster if we introduced, for example, [a non-native species] into the environment.*" Another agreed "*if everyone goes out willy-nilly doing what they want, it's going to cause carnage.*" They added the process also avoids conflict in terms of land use. For example, at one site, there was an underwater cable running under the seabed. *"If we'd … planted seagrass there and then somebody said 'Oh we need to do some maintenance on the cable' and ripped it all up, that would have been a pain.*" While recognising the need for a rigorous process, they suggested restoration should be treated differently to large-scale commercial infrastructure projects, with reduced cost and time burdens and more consistency. One felt there should be a specific person in each governance organisation "*that already knows the process, is responsible and gives out a plan [of] how to [do it] and what requirements need to be fulfilled.*" This person should then provide more support than they themselves had experienced: "*instead of getting instructions on how they wanted us to do something, they only said 'this is not sufficient' … instead they could have said 'no we want you to do it like this' – that would have made it much easier … and faster.*"

4.6. Solution 6 establish a national strategic plan and restoration authority

4.6.1. Solution 6.1 strategic plan

Site selection for planting-based seagrass restoration in the UK is currently steered by a combination of funding availability, HSM and local assessments of the social-ecological site-suitability (see *Barrier 1.2*). There is no national or regional plan for where and how to restore seagrass, as there is for land-based reforestation [25]. Marine planning has introduced tools for identifying 'strategic resource areas' (so-called in Wales) to support siting for blue economy sectors (e.g. aquaculture, renewables) – but plans do not currently extend to restoration. Several governance interviewees commented on the value of having a more strategic high-level plan of where they would look favourably on restoration, informed by improved evidence (*Solution 3*) and backed by stronger targets or ambitions. Although not removing the need for site-level investigation and stakeholder support, they described situations where this could improve restoration planning, facilitate licensing and steer projects. For example, one said it was difficult to manage expectations of local communities who want to restore seagrass "*on their doorstep. Obviously, they've got the right idea but whether that site is actually going to work…*". They had also "*seen things where people have proposed seagrass for offshore*", where "*clearly that doesn't work*". Another said there is a desire to "*always have restoration projects where there's absolutely no other … disturbance on infrastructure. As an island, that's quite tricky … I'd love us to not see other sea-users as so much of a barrier.*" A third said "*there needs to be planning nationally about where the priority areas for seagrass restoration are … you need that strategic view … and there needs to be an overarching body assigned to it.*"

4.6.2. Solution 6.2 restoration authority

Others echoed the idea of a central authority or person whose role it is to support seagrass (and other) restoration projects, including helping them secure permissions, especially "*taking that burden off communities*" (see *Barrier 3*). One governance interviewee had reservations from a regulatory point of view, however, if it "*adds another layer of complexity and bureaucracy*". While one practitioner felt the solution was to have a responsible and experienced officer within each existing governance organisation (see *Solution 5*), another condoned the idea of a separate national organisation for oversight and support. They felt this was particularly important in light of predicted climate change and government plans for future managed realignment of coasts. "*We're restoring them* in situ *now but in 100 years it's quite possible none of those locations will be suitable anymore.*" While no interviewees raised it, a national authority could additionally help ready the UK for seagrass restoration at scale by supporting strategic capacity-building for infrastructure and resource needs (including seed/transplant supply) and skills gaps in the employment market (see *Barriers 1.3, 1.4, 2.1, Solution 2*).

4.7. Solution 7 improve catchment-wide and seascape-scale management

4.7.1. Solution 7.1 catchment-wide management

As highlighted above (*Barriers 1.2, 2.1, Solution 4.1*), some interviewees spoke about the importance of removing ongoing pressures for successful seagrass restoration. One governance interviewee said "*our view, which I'm pretty sure is shared with most government agencies … is that pressure removal is the fundamental thing for restoring nature. You can do as much active restoration as you like, but if the pressures are still there it's probably going to get damaged again.*" Another agreed "*we need to stop looking at individual habitats and start thinking about how they link to the wider catchment and ecosystem and … have a more holistic approach.*" Especially with regard to water quality, they felt "*there's no point doing all that restoration if we're not … targeting those issues on land as well.*" This supports suggestions for projects to collaborate more with land-based sectors (*Solution 1*) and for maximising statutory funding mechanisms that incentivise land management to benefit marine restoration (*Solution 4.1*). We heard there are already projects working successfully to reduce marine-based pressures, such as negotiating voluntary no-anchor zones and replacing swinging moorings with lower-impact Advanced Mooring Systems (AMS) (e.g. [18]).

Regardless of the specific pressures involved, governance interviewees expressed a need for robust post-restoration management for long-term meadow recovery. One felt this was critical before they could support a seagrass carbon credit system, to ensure carbon is sequestered and not re-released through disturbance (see *Solution 4.1*). Another noted certain legislation does "*kick-in*" once a restored area becomes an established seagrass bed, but a third felt that following many restoration projects, "*the then level of protection needed if it is not within an MPA is quite limited.*" They called for clearer strategies for how to manage restored habitats and who is responsible (see *Solution 6*). This links to concern raised about post-restoration rights following privately-funded restoration (discussed in *Solution 4.1*). They suggested restoration sites could become *de facto* protected areas, but this could cause greater conflict with marine users and undermine local trust and support. Practitioners felt local people hold the key to long-term restoration success if they are empowered and engaged in projects and able to benefit from restored ecosystem services (*Solutions 4.2, 8*). This is particularly in areas where formal regulation and enforcement of potentially damaging activities is not possible or appropriate (e.g. see comments on bait digging, *Solutions 1, 8*). For example, one said that in their view, following restoration "*it's ultimately [the community's] decision if they want to put moorings there one day … We always said we'd rather see seagrass with holes in it than no seagrass at all.*" Although sharing the sentiment, a governance interviewee flagged that communities should be made aware certain legislation automatically applies to established seagrass beds, even if there are no intentions to restrict activities at the time of restoration.

4.7.2. Solution 7.2 seascape-scale restoration

Several interviewees told us about emerging "*seascape-scale*" restoration projects, where multiple connecting habitats are restored to support one another. One governance interviewee noted the evidence suggests "*recovery of habitat mosaics delivers wider biodiversity and … societal benefits*". They felt seascape-scale projects present "*efficiencies of delivery … driving costs down*" and "*bring more collaborators to the table*" (*Solution 1*). They felt projects focusing on a single habitat were less effective "*because you don't necessarily get those boundary or transitional benefits.*" However, they recognised that understanding of how to restore different habitats varies in maturity and that single-habitat projects remain valid, as long as there is effective communication with other projects in the area (*Solution 1*). Again, this could be facilitated by an effective overarching national restoration plan or authority (*Solution 6*).

4.7.3. Solution 8 more public engagement

Interviewees told us their projects already involve considerable public outreach. They engage people via social media, tv, local papers, formal consultations, community events, and opportunistic on-site conversation. They maximise their reach through existing groups and organisations, such as local councils, NGOs, schools, yacht clubs and dive clubs. Practitioners value the local knowledge and experience they gain through this, learning about historic and current seagrass extent, seagrass biodiversity, site characteristics and suitability, and activities happening in the area. They also feel this engagement has helped minimise local concerns and increase project support.

Several interviewees told us they think awareness of and concern for seagrass has increased, probably because of project outreach and recent high-profile media coverage. Others felt there was a need for more effort in this area. "*Many people don't even know what seagrass is. They have never seen it, they can't relate to it, therefore they can't protect it.*" One suggested it was impossible for those immersed in the sector to really know the level of wider public awareness/concern from the outside. Regardless, one governance interviewee made a strong case for maximising the power of public pressure on industries causing environmental harm and their "*social licence to operate*". "*You've got a community, an entire ecosystem of humans, who are saying 'this is important to us, we're out there making headlines…'*". We also heard how community concern can lead to "*self-policing*" of potentially damaging activities. For example, "*people talk to others about using [eco-moorings], then they see them anchoring elsewhere.*" Community understanding of the potential benefits of healthy seagrass can similarly encourage self-regulation, e.g. if bait diggers recognise and benefit from increased bait abundance following restoration (see discussion in *Solutions 1, 7.1*).

Above all, practitioners told us of the positive impacts of engaging people through volunteering – on projects and on volunteers themselves. One said "*Whenever we ask for volunteers, a whole army shows up … kids, elderly, adults from different walks of life, they show up, they help, they're keen and interested.*" Another felt volunteers benefit through "*feeling like part of a bigger cause … it gives people hope, inspires and fuels people to do more rather than [the] doom and gloom we often hear … as well as wellbeing, being out in nature and feeling good.*" A third felt that even if mechanisation removes the need for human labour (see *Barrier 1.4*), projects should still involve volunteers "*to get that engagement and understanding … we'd rather people know about it and know it's there than not at all, because that's how we lost it in the first place*." One told us how this has fostered local buy-in and ownership in their community: "*there was a lady from the next village saying 'When your project is over … we will take this on, this is our spot. I remember which square I planted, I will come back and see if it worked.'*" As explained above (*Solution 2*), the long-term aim of some projects is to transfer ownership to local guardians: "*the more we can give the project away the better.*" "*[It] is scientifically interesting for sure. But that's all it will be if we don't involve volunteers. Because if nobody cares and nobody knows … and if people don't have those skills … it could be that*

we plant 10 ha but then after five years it's all gone." Fully engaged and informed communities are more likely to be concerned over long-term protection and sustainability, including if they become involved in potential future commercialisation activities (see *Solution 4.2*). They would also have more capacity for "*community-to-community*" teaching and upskilling (*Solution 2*).

One governance interviewee felt "*wherever there is appetite, people should be enabled to participate – there is plenty to go around.*" However, two practitioners reported having to close volunteer opportunities due to over-subscription and project limitations, e.g. seed shortages (*Barrier 1.3*). Addressing barriers such as this (see also *Barriers 1.4, 3*) and strategic capacity-building (*Solutions 2, 6.2*) would open more opportunities for community-led restoration.

5. Conclusion

Many of the solutions proposed here are already happening or emerging in practice, while others remain ambitious ideas that will require strong political and social will, robust funding and time to realise. There is clearly a momentum in the UK seagrass restoration sector, with political and public support, funder interest, and a growing community of skilled and experienced practitioners. There is a perceived risk amongst practitioners, however, that this time may soon pass and enthusiasm move onto "*the next big thing*". Although care needs to be taken not to rush in with under-informed and under-resourced action before rigorous evidence, knowledge and capacity is built, there is no reason to delay acting on the solutions proposed here by the people who know the sector best. Then, hopefully, by the time momentum does move on, we will have collectively restored enough seagrass to put the UK on a trajectory of seagrass net gain, rather than net loss.

Author statement

EF, LCU conceived and designed the study; EF, AE carried out the study; AE, EF analysed the data; AE wrote the first draft of the manuscript; all authors read and edited the final version of the first draft. LCU prepared the revised submission.

CRediT authorship contribution statement

Evans Alison Jane: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Ford Eleanor:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Leanne Cullen-Unsworth:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Data availability

Data will be made available on request.

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