SEAGRASS RESTORATION HANDBOOK

UK & IRELAND

NOVEMBER 2021

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This handbook supports the goals of the UN Decade on Ecosystem Restoration (2021-2030). Find out more about this UN Decade here: https://www.decadeonrestoration.org/

The ecological and societal benefits of restoring marine habitats has become more widely recognised over the past decade. This has meant that marine habitat restoration has become a priority for the general public and government agencies.

Seagrass beds in the Helford River, Cornwall. Photo: Lewis Jefferies.

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CONTENTS

EXECUTIVE SUMMARY

This *Seagrass Restoration Handbook* provides foundational and practical guidance on the restoration and conservation of seagrasses and seagrass beds in the UK and Ireland with a focus on the *Zostera* species: common eelgrass (*Zostera marina*) and dwarf eelgrass (*Zostera noltei*). The guidance outlined is also relevant to restoration projects across the biogeographic range of these seagrass species.

The handbook provides i) an introduction to seagrass beds, their ecological importance, the threats to existing seagrass and the concept of restoring resilient and well-functioning seagrass habitats (Chapter 1); ii) guidance on starting a restoration project including site selection, project planning and the licensing process, and key government, public bodies and agencies to contact (Chapter 2); iii) guidance on the different seagrass restoration approaches and methods (Chapter 3); iv) guidance on how to effectively monitor change following restoration (Chapter 4), and v) an outline of how to successfully communicate a seagrass restoration project during its planning and implementation (Chapter 5).

Seagrasses are called ecosystem engineers because they create a physical habitat that can alter hydrodynamic and biogeochemical processes, stabilise sediment and improve water quality. However, beds have declined by > 40% since the 1930s, and an estimated 92% from historic extent, due to decreasing water quality, physical disturbance of the seabed, coastal development, disease and increasing siltation. With this decline, we have also lost the vital ecological services that seagrass beds provide such as a habitat for fish and the uptake of carbon and nitrogen. By restoring seagrass habitats and reversing that trend, the UK and Ireland would reap a range of benefits in terms of climate change mitigation, biodiversity, fisheries, water quality and well-being.

In this UN Decade on Ecosystem Restoration and Ocean Science for Sustainable Development 2021-2030, we recognise humanity's dependence on healthy, robust and functioning marine ecosystems. More than ever, we need to protect and restore ecological systems that provide nature-based solutions and resilience to the challenges we face. The restoration of seagrass habitats, with the many ecosystem services they provide, will require a combination of approaches depending on the location, surrounding landscape and extent of degradation or loss. This handbook aims to shed light on these different approaches, and to support small-scale projects but, ultimately with an ambition to facilitate larger seagrass seascape restoration efforts.

HANDBOOK CONTEXT

Over the past decade, the field of marine habitat restoration in Europe has grown significantly. This is a result of both our increased awareness of the extent of the degradation of marine habitats – including native oyster reefs, saltmarshes, seagrasses and kelp – and our knowledge of just how valuable these habitats are.

The UK Government's 25 Year Environment Plan commits to 'securing clean, healthy, productive and biologically diverse seas and oceans', while European directives (for example, Natura 2000) recognise seagrass beds as a priority habitat. There are two different approaches to restoring marine habitats: reducing pressure on systems to enable natural recovery or taking positive action to restore marine habitats and species. This handbook provides practical guidance on the latter. Nevertheless, it recognises the importance of reducing human impacts to increase the likelihood of active restoration success.

The production of this handbook was commissioned by the Environment Agency, as part of the cross-agency Restoring Meadows, Marsh and Reef (ReMeMaRe) initiative. ReMeMaRe's vision is to restore estuarine and coastal habitats that benefit people and nature, and it aims to restore at least 15% of priority habitats along the English coast by 2043, in line with the timeframe of the 25 Year Environment Plan. This also supports the goals of the UN Decade on Ecosystem Restoration.

This handbook is part of a quartet of restoration guidelines consisting of those developed for saltmarsh and native oyster habitats, and for the restoration of coastal habitats using dredged sediments.

Foreword
by Tony Juniper CBE, Chair of Natural England.

Some 70 to 100 million years ago, flowering land plants colonised the ocean floor. This remarkable evolutionary event, which has never been repeated, led to the emergence of a remarkable and unique marine ecosystem: seagrass beds. This habitat is home to a wide range of other species, including a host of invertebrates and wonderful creatures such as seahorses.

Extensive seagrass beds once fringed shallow coastal waters across much of Europe, but over the course of the last century they have declined significantly, due to pressures that include coastal development, pollution, and damage caused by fishing gear and leisure boat use. Not only has this led to a loss of important wildlife habitat for protected creatures, but it has also reduced the benefits that people derive from seagrasses.

Seagrass beds hold significant quantities of carbon that would otherwise be in the atmosphere. They also help mitigate the impact of more extreme weather and sea-level rise while improving water quality and stabilising the seabed. In addition, lush, dense seagrass beds full of life show us what a healthy sea should look like and inspire us to protect our oceans.

Although many of our seagrass beds are now within Marine Protected Areas, it is important to increase our ambition and add restoration to protection efforts. This will require active intervention to re-establish natural systems which, once lost, struggle to recover on their own. Fortunately, restoration can be successful.

During the last five years or so, a small number of enthusiastic academics and conservationists, notably the teams at Project Seagrass, Swansea University and the Ocean Conservation Trust, have pioneered methods that are leading to impressive results. Through their hard work, seagrass restoration has been brought into the national spotlight and, by combining their collective knowledge in this handbook, many others will now be better placed to design, undertake and communicate their own seagrass restoration projects.

I would like to thank the many authors who have contributed their experiences to this handbook, and I look forward to seeing the recovery of this vital and important habitat across the UK and Ireland.

GLOSSARY

- **Abiotic (factors):** Non-biological (e.g. salinity, light, temperature, wind patterns, tides, currents and precipitation). As opposed to **biotic**.
- **Adaptive management:** A cyclical approach to conservation management. The outcomes of management actions are used to improve and refine future management activity.
- **Baseline:** The existing conditions of the physical, chemical, biological and human environment prior to the start of an activity.
- **Biotic (factors):** Belonging to, or caused by, living organisms (e.g. grazing). As opposed to **abiotic**.
- **Biosecurity:** Preventive measures to reduce the risk of the spread of infectious diseases, pathogens, pests, invasive non-native species, modified organisms, and sometimes toxins and pollutants.
- **Biodegradable ecosystem engineering elements (BESE) frames:** Biodegradable mesh frames used to plant seagrass.
- **Before-after-control-impact (BACI):** A survey design that monitors a control site (unrestored) and impact site (to be restored) both before and after the restoration of seagrass beds.
- **Blue carbon:** Carbon stored in coastal and marine ecosystems.
- **Buoy-deployed seed bags (BuDS):** A low-cost method for seed processing.
- **Bags of seagrass seeds (BOSS) line system:** A system in which seeds are deposited on the seabed using hessian bags.
- **Carbon sequestration:** A biochemical process by which atmospheric carbon is absorbed by living organisms, including seagrass, and involving the storage of carbon in sediments, with potential to reduce atmospheric carbon dioxide levels.
- **Carbon stock:** The quantity of organic carbon held within carbon pools, which are systems that can store or release carbon (e.g. below-ground biomass).
- **Coastal squeeze:** The loss of natural habitats or deterioration of their quality arising from anthropogenic structures or actions, preventing the landward transgression of those habitats that would otherwise naturally occur in response to sea level rise and other coastal processes. Coastal squeeze affects habitats on the seaward side of existing structures.
- **Conservation translocation:** The intentional movement of a living organism from one location to another that could be considered a different body of water, and its release, where the primary objective is a conservation benefit.
- **Disease:** A disorder of structure or function in an organism that produces specific signs that are not caused by physical injury alone.
- **Donor site:** The place from which translocated organisms are taken.
- **Focal species:** The seagrass species being used for restoration.
- **Ecosystem service:** The benefits provided by seagrass beds to humans.
- **Eutrophication:** The process of enrichment of waters with excess plant nutrients, primarily phosphorus and nitrogen, which enhances the growth of algae, periphyton or macrophytes.
- **Invasive non-native species (INNS):** Organisms that have been introduced by humans deliberately or accidentally across a biogeographic boundary, and which go on to have a negative ecological or economic impact in their new range.
- **Metapopulation:** A set of populations each existing on a patch of suitable habitat spatially separated from other occupied patches by unsuitable habitat, but connected by dispersal to different degrees. A metapopulation's long-term persistence and stability arises from a balance between population extinction and recolonisation.
- **Natural range:** The natural past or present geographical distribution of a species. This excludes areas where it has been deliberately or accidentally introduced by humans, if it never occurred there naturally and would not have done so naturally in the foreseeable future. Can also be defined as all locations where a species is or was indigenous.
- **Nature-based solutions (NbS):** Solutions that work with nature to address societal challenges, providing benefits for both human well-being and biodiversity.
- **Ocean literacy:** The understanding of our individual and collective impact on the ocean and its impact on our lives and well-being.
- **Pathogen:** The biological agent (especially microorganisms such as bacteria and viruses) that cause disease in their host.
- **Propagule:** A vegetative structure that can become detached from a plant and give rise to a new plant.
- **Realised niche:** The set of conditions or habitats currently inhabited by a population or species.
- **Self-sustaining:** A species or population of a species is self-sustaining if it can maintain itself without active and deliberate human intervention.
- **Source population:** The place from which translocated organisms are taken. Also called the **donor** population.
- **Sods:** Shoots with substrate still attached.
- **Transplanting eelgrass remotely with a frame system (TERFS):** A method of transplanting seagrass, by which common eelgrass shoots are tied with biodegradable plastic ties to a rubber-coated, weighted wire frame.

This publication is intended to provide foundational information, to serve as a useful starting point for seagrass habitat restoration.

Dotted sea hare *Aplysia punctata* within a seagrass bed at Gyllyngvase Beach, Falmouth, UK. Photo: Lewis Jefferies.

CHAPTER 1
SEAGRASS RESTORATION: AN INTRODUCTION

CHAPTER AUTHORS
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KEY SUMMARY POINTS:

- **Extensive seagrass loss has occurred in United Kingdom (UK) waters during the last 100 years, with recent research estimating that at least 44% of the UK's seagrass has been lost since 1936, of which 39% has been since the 1980s.**
- **The significant decline and lack of re-establishment of seagrass beds across Europe has highlighted that active intervention is required if these species are to recover.**
- **In a European context, a comprehensive definition of what constitutes a healthy seagrass bed is lacking. However, a definition of the habitat is critical to ensuring that the aims of habitat restoration are universally understood.**
- **The carbon sequestration potential of seagrass could incentivise its restoration, but this must be considered in addition to other co-benefits and ecosystem services provided by seagrass ecosystems.**

INTRODUCTION

There has been extensive seagrass loss in UK waters during the last 100 years which reflects the global loss recorded (Waycott *et al.* 2009). Recent research estimates UK seagrass habitat losses of at least 44% since 1936, with 39% of those losses occurring since the 1980s and some values reaching as high as 92% (Green *et al.* 2021). Active restoration and mapping of this important habitat are gaining momentum in the UK, following growing recognition that the ecosystem services provided by seagrass habitats are being lost. Over the last three decades, progress has been made throughout mainland Europe and globally in recovering these critical ecosystems. The well documented long-term restoration success in Chesapeake Bay in the United States showcases that large-scale seagrass restoration efforts can be successful, while important progress on the restoration of eelgrass (*Zostera* spp.) is also being made in China, Japan and South Korea.

This handbook seeks to facilitate information-sharing on seagrass habitat restoration to build upon pioneering efforts in the UK and beyond. This introductory chapter provides information about the ecology and biology of UK seagrass species, their current distribution and historical declines in their extent. It also summarises the reasons why seagrasses should be restored, the beneficiaries of seagrass restoration, and the main threats to seagrass ecosystems.

SEAGRASS ECOLOGY AND BIOLOGY

There are two recognised species of seagrass in the UK: **common eelgrass** (*Zostera marina*) and **dwarf eelgrass** (*Zostera noltei*), see Figure 1.1. Common eelgrass is an intertidal to sublittoral species found in shallow, fully marine conditions on muddy to relatively coarse sediment. When observed intertidally, it can sometimes be interspersed with dwarf eelgrass between the mid- and low-tide mark. Dwarf eelgrass occurs higher on the shore (up to the high-tide mark) on mud, sand and muddy sands and, being more tolerant of desiccation, inhabits areas that are entirely exposed at low tide (Natural Resources Wales 2019).

Widgeon grass (*Ruppia* sp.) is a genus of aquatic freshwater plants found in the UK that have similar environmental preferences to the *Zostera* spp., such as temporarily to permanently flooded mesohaline-hyperhaline estuarine wetlands, brackish waters of lagoonal habitats, lochs and estuaries. The two species of widgeon grass found in the UK, beaked tasselweed (*Ruppia maritima*) and spiral tasselweed (*Ruppia cirrhosa*), are not strictly considered as part of the traditional seagrass arrangement but are commonly grouped with *Zostera* spp. as they can occupy a similar niche due to their pronounced salinity tolerance. This handbook focuses on the two species of the *Zostera* genus: *Zostera marina* and *Zostera noltei*.

BOX 1.1: MARINE AND COASTAL HABITAT RESTORATION TERMS

Ecosystem resilience: The inherent ability to absorb various disturbances and reorganise while undergoing state changes to maintain critical functions.

Habitat enhancement: Any action that has a positive impact on habitat quality or extent.

Habitat recovery: Removing pressures to allow a habitat to recover naturally and become more resilient (e.g. reducing anchoring in seagrass areas).

Habitat regeneration: Low-level interventions that take place alongside the removal of a pressure and that improve habitat resilience (e.g. reseeding of mooring scars alongside the deployment of Advanced Mooring Systems).

Habitat restoration: High-level interventions aimed at returning a habitat to its pre-existing condition, including the same species composition, distribution, abundance and function (e.g. restoring seagrass to a site where seagrass was previously known to exist).

Habitat creation: Creating habitat where it was not historically present (e.g. planting seagrass at a site that is now suitable for seagrass growth following coastal modification).

Reinforcement: Translocation of an organism into an existing population of the same species.

Reintroduction: Translocation of an organism inside its natural range from where it has disappeared.

Rewilding: Helping large areas to return to their natural state.

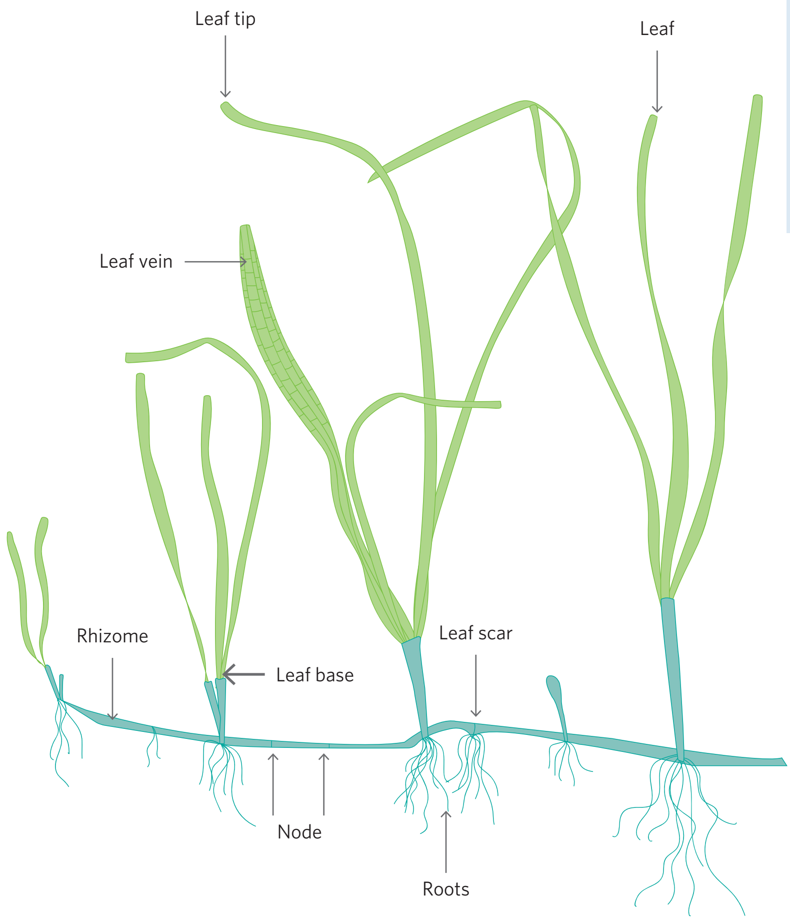

Figure 1.1: Generalised illustration of *Zostera* spp. showing plant structure and leaf morphology.

COLONISATION, GROWTH AND HEALTH OF SEAGRASSES

A variety of physical, chemical and biological factors regulate the colonisation, distribution, growth and health of seagrasses. The basic requirements for seagrass growth and distribution are similar to the needs of terrestrial plants, but life in the aquatic environment differs considerably and some resources may be limited in accessibility or quantity. Seagrasses require sufficient light, nutrients and inorganic carbon for photosynthesis, and a suitable substratum, moderate exposure and temperature. Besides physical and chemical factors, the growth and distribution of seagrasses are affected by other organisms, primarily through competition or herbivory. Biological factors include the associated grazing community and the connectivity with other seagrass meadows or beds (hereafter beds) within a wider seascape, or competition for the occupation of space with other organisms, such as macroalgal beds and mussels. It is the balance of these factors that governs the distribution of the seagrass bed and determines whether it comprises one or two species of seagrass.

Seagrass bed in St Michaels Mount, Cornwall.
Photo: Lewis Jefferies.

BOX 1.2: EUROPEAN NATURE INFORMATION SYSTEM (EUNIS) BIOTOPES AND EQUIVALENT MARINE HABITAT CLASSIFICATION (MHC) FOR UK SEAGRASS BEDS

The majority of seagrass beds around the UK are thought to be representative of two intertidal biotopes and two subtidal biotopes listed in the European Nature Information System (EUNIS) habitat classification system (**see table below**). These mostly occur on muddy sand sediments, but some beds have also been recorded on mixed sediments (e.g. the Welsh Grounds bed in the Severn Estuary) that may warrant addition of further mixed sediment biotopes. Biotope mosaics also exist where two or more of the listed biotopes occur over small spatial scales (< 25m^2). The most common seagrass mosaic biotope occurs on the lower shore where the lower portions of *Zostera noltei* beds merge with the upper portions of *Zostera marina* beds, or where semi-permanent channels run down the shore. This is represented as either A2.6111/A5.5331 or A5.5331/A2.6111 depending on the predominant biotope (Parry 2019). For Water Environment Regulations/ Water Framework Directive (WFD) monitoring purposes, intertidal seagrass beds are further subdivided into sub-habitats with > 5% cover and < 5% cover, the latter commonly associated with the periphery of the bed (Water Framework Directive – United Kingdom Technical Advisory Group [UKTAG] 2014).

EUNIS biotopes and the equivalent Joint Nature Conservation Committee (JNCC) Marine Habitat Classification (MHC) for UK seagrass beds. The biotope descriptions still include *Zostera angustifolia* but require revision to reflect its taxonomic status as an ecotype of *Zostera marina*.

EUNIS CODE	JNCC MHC V 15.03	BIOTOPE DESCRIPTION
A2.6	LS.LMp	**Littoral sediments dominated by aquatic angiosperms**
A2.61	LS.LMp.LSgr	**Seagrass beds on littoral sediments**
A2.611	–	**Mainland Atlantic [*Zostera noltei*] or [*Zostera angustifolia*] meadows**
A2.6111	LS.LMp.LSgr.Znol	**[*Zostera noltei*] beds in littoral muddy sand**
A2.614	–	**[*Ruppia maritima*] on lower shore sediment**
A5.53	SS.SMp.SSgr	**Sublittoral seagrass beds**
A5.533	–	**[*Zostera*] beds in full salinity infralittoral sediments**
A5.5331	SS.SMp.SSgr.Zmar	**[*Zostera marina*]/[*angustifolia*] beds on lower shore or infralittoral clean or muddy sand**
A5.5343	SS.SMp.SSgr.Rup	**[*Ruppia maritima*] in reduced salinity infralittoral muddy sand**

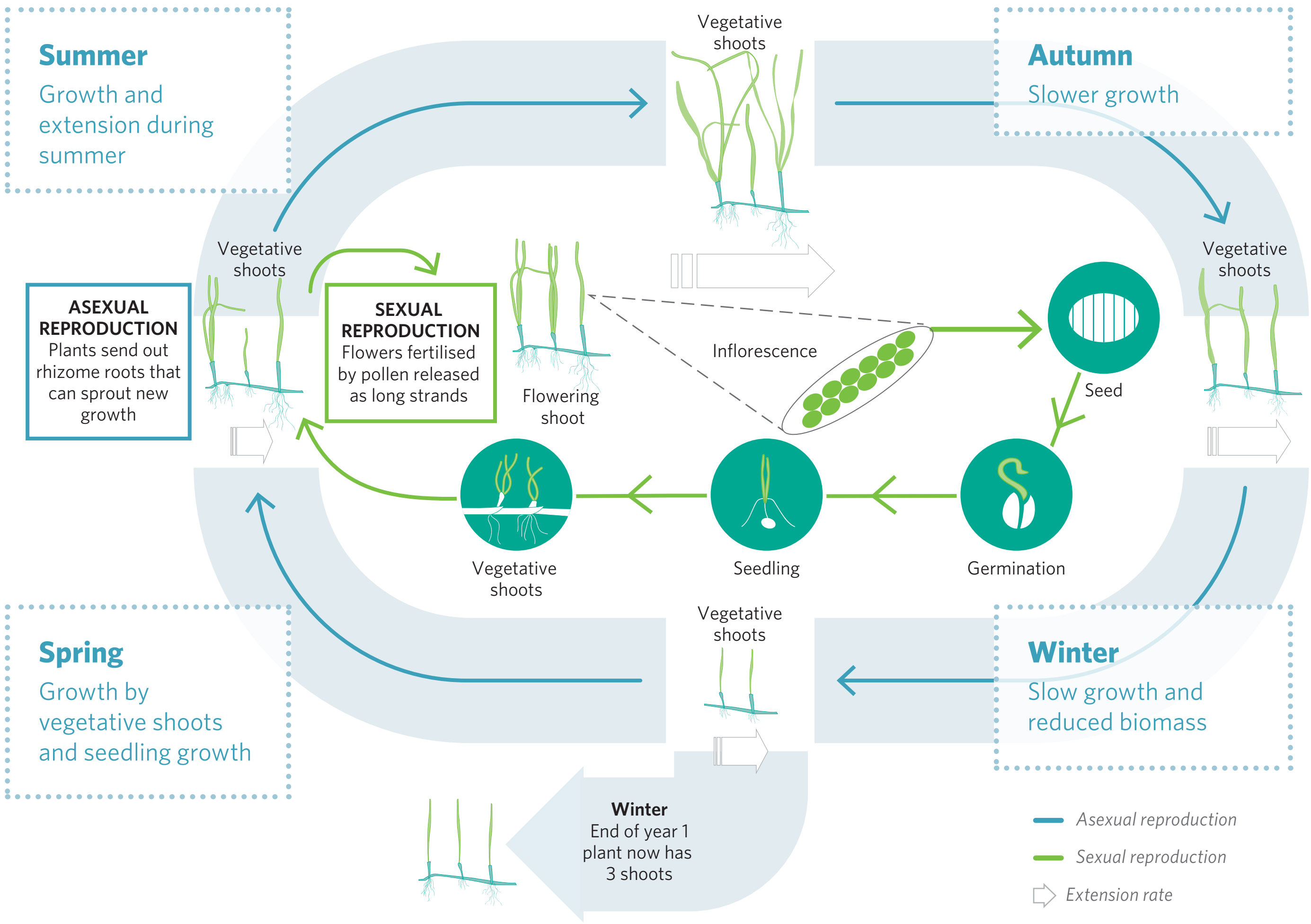

Figure 1.2: Generalised life history of *Zostera* spp. in North East Atlantic. The timings displayed are based on observations by restoration practitioners, and may vary depending on regional temperature and climate factors.

REPRODUCTION AND DISPERSAL MECHANISMS

Zostera spp. have two methods of reproduction: asexually, via the production of vegetative or clonal shoots from rhizomes; and sexually, via the production of flowers or inflorescences, which produce seeds that can grow into new shoots. Flowering shoots emerge in the late winter and develop until ambient water temperatures reach approximately 20°C in the summer, triggering the release of the seeds (see Figure 1.2). Flowering times in eelgrass differ depending on its depth. This may limit gene flow across seagrass beds, with the potential for repeated genetic divergence spanning a depth gradient, which suggests that eelgrass at different depths could have a different genetic structure (Ort *et al.* 2012). In the North Sea, passive rafting of flowering shoots along oceanographic currents is the main driver of gene flow. Identifying distinct clusters, connectivity hotspots or areas where connectivity has become limited over the last century can provide critical information for spatial management, conservation and restoration of seagrasses.

Dwarf eelgrass, the predominant seagrass of soft-bottom intertidal regions along the coasts of northern Europe, has high potential for self-fertilisation and inbreeding, especially if clone sizes exceed pollen dispersal distances. Multiple paternity is common and 20–30% of mature seeds originate from matings within the plot, with pollen dispersal distances sufficient to maintain outcrossing and high clonal diversity. A recent positive trajectory in dwarf eelgrass populations across mainland Europe is the result of a combination management actions (e.g. reduction of industrial sewage, removal of mechanical damage) and natural recovery due to improved environmental conditions, which may or may not be related to management actions (de los Santos *et al.* 2019). A variety of conservation approaches could therefore protect or enable the recovery of existing seagrass beds.

WHAT IS A HEALTHY SEAGRASS BED?

Seagrasses are foundation species that form productive habitats, primarily occurring in shallow, sheltered soft sedimentary environments. Seagrass habitats are known as seagrass beds (see Box 1.3) because of the complex three-dimensional structures formed by their shoots and leaves. Patches of seagrass may also occur within pebble and rubble environments (e.g. Strangford Lough in Northern Ireland), near other sensitive sedimentary habitats such as oyster reefs, maerl beds and mussel beds, and within other coastal habitats such as saltmarsh and mudflats. Seagrasses exhibit a high ability to change their physiology in response to environmental conditions, which enables them to adapt to changes and resist certain levels of disturbance.

BOX 1.3: DEFINITION OF *ZOSTERA* SPECIES HABITAT

Given the degraded status of seagrass beds throughout most of *Zostera* spp. range, and the lack of historical surveying prior to impacts from declining water quality in Europe, a comprehensive definition and historical distribution of seagrass beds is lacking. However, a definition of the habitat is critical in ensuring that there is universal understanding of the aims of habitat restoration and guiding principles. The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) has defined *Zostera* beds as plant densities that provide at least 5% cover, but with the caveat that when densities are as low as 5%, expert judgement should be sought.

OSPAR considers two subtypes:

Z. marina forms dense beds, with trailing leaves up to 2m long in sheltered bays and lagoons from the lower shore to about 10m deep, occasionally down to 15m if water is very clear, typically on sand, mud or gravel.

Z. noltei forms dense beds, with leaves up to 20cm long, typically in the intertidal region (although it can occur in the very shallow subtidal), on mud and sand.

Where their geographical range overlaps, *Zostera noltei* is found higher on the intertidal zone than *Zostera marina*. *Zostera* beds support distinct associated communities that vary across the species' geographic range (from Morocco to Greenland), making it difficult to define the habitat based on the fauna that they support.

Tullrot (2009).

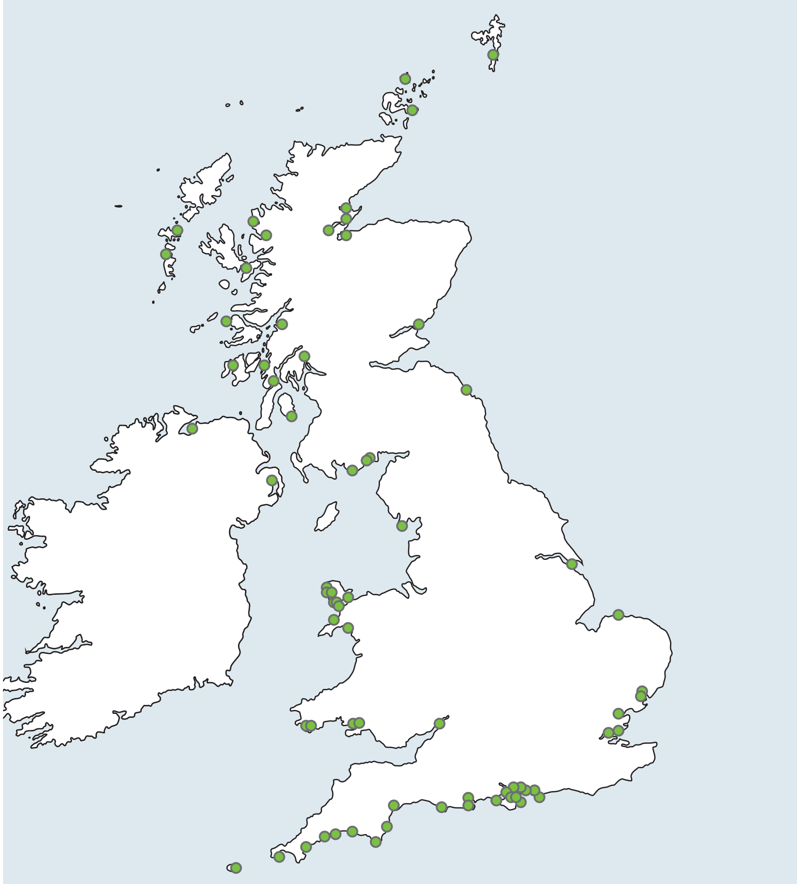

Figure 1.3: Distribution of areas of mapped seagrass beds using records from 1998 to present day, taken from the analysis of Green *et al.* (2021), Natural England and Yorkshire Wildlife Trust. Other records of seagrass exist but have not been mapped. Source: Rice, Unsworth, Green, 2021.

THE CURRENT DISTRIBUTION OF SEAGRASS BEDS IN THE UK

According to a recent estimate, the UK contains approximately 8,493ha of mapped seagrass (since 1998). This estimate is based on a re-analysis of the same spatial data that were available to the authors of that study through exhaustive networking and access to public data sources (Green *et al.* 2021, see Figure 1.3). Such estimates are fraught with errors and uncertainty due to the large variability in the methods used to quantify area and the definitions used to establish an area as a seagrass bed, the decreasing reliability of estimates in subtidal areas, and the lack of metadata contained within many spatial mapping data sources. Unfortunately, this is not just a UK problem but symptomatic of the wider global data on seagrass coverage (McKenzie *et al.* 2020). While we often know where seagrass is broadly present, with numerous data point observations collected (with programmes such as SeagrassSpotter.org and Seasearch), we often don't know how extensive those beds are as they've never been properly mapped. Although 8,493ha of seagrass has been mapped, many of these maps are grossly out of date and do not accurately reflect current distributions.

On a broad level, seagrass mapping in England, Northern Ireland and Wales is much more advanced than in Scotland, where seagrass is poorly mapped, principally due to the geographic challenges of the Western Isles' complex coastline. Rising to the challenge of mapping UK seagrass requires better technological assistance, investment in human capital as well as equipment, and a better, more coherent strategy to fill extensive gaps and improve current estimates. Teams around the UK are now advancing the use of drone mapping for determining seagrass cover, and using satellite remote sensing and acoustic mapping. However, challenges remain: deeper subtidal beds are difficult to map even with acoustic tools, particularly when cover is low or the canopy is short, and seagrass is mixed within algal assemblages. Simplistic drop-down video and camera tools continue to remain essential for seagrass mapping in many subtidal areas, and in locations where teams don't have access to equipment, seagrass is commonly mapped on foot using a basic Global Positing System (GPS).

Accurate knowledge of seagrass distribution helps us inform future restoration, not just in terms of local decision-making but also habitat suitability models, making them better and more reliable. The increasing interest in seagrass as a means of improving carbon sequestration of the natural environment has resulted in increasing emphasis and focus on seagrass mapping. Although many solutions remain limited by investment, interest in blue carbon is attracting new players to seagrass mapping. For example, Project Seagrass are running two initiatives with commercial enterprises, assisting with seagrass mapping using automated vessels and improved algorithms for assessing Sentinel-2 imagery.

THE DECLINE OF SEAGRASS BEDS IN THE UK

Seagrass extent in the UK has declined dramatically over the past century, with recent estimates indicating that at least 44% has been lost since 1936, of which 39% since the 1980s (Green *et al.* 2021). Previous estimates indicate that of Britain's 155 estuaries, only 20 possess eelgrass beds of more than 1ha – a decline of 85% since the 1920s (Hiscock *et al.* 2005). As an illustration, seagrass was once recorded at Tyne in Newcastle, at a site long since reclaimed from the sea which now exists as an industrial estate. Seagrass was once so prolific that there were industries based on the use of seagrass leaves washed up on beaches, as duvet and pillow stuffing and wall insulation. In the 1880s, seagrass was so plentiful in the UK that entrepreneurs discussed in *The Times* letters section its potential use as an alternative to cotton (September to November 1886). In addition, in 1861, an Ebenezer Hartnell obtained a patent to make paper from common eelgrass (Daily News Sept 1862). The Royal Botanic Gardens, Kew still holds an archive and artifact evidence of some of these historical uses.

The reliance on anecdotal descriptions and use of modelling to document seagrass change in the UK reflects a dearth of historic data beyond a series of key detailed examples, including for the Humber, Solent, Stour and Orwell, and the Cromarty Firth. The Humber has lost hundreds of hectares of seagrass that was intertidally extensive in the 1930s (Philip 1936). This loss extends throughout Wales (Kay 1998), Northern Ireland (Portig *et al.* 1994) and Scotland (Cleator 1993), and continues to this day (Bertelli *et al.* 2021).

This extensive seagrass loss is the result of a complex combination of factors that have fundamentally altered the UK coastline. Coastal development through physical removal of the habitat from activities such as fishing, and poor water quality which remains problematic for many seagrasses. Extensive outbreaks of the seagrass wasting disease, *Labyrinthula zosterae*, has been described as another cause of seagrass loss in Western Europe and the UK in the 1930s (den Hartog 1983), but this is likely the result of environmental degradation, the cumulative impacts of poor water quality, and the limited capacity of scientists to analyse the subtidal distribution of seagrass at that time.

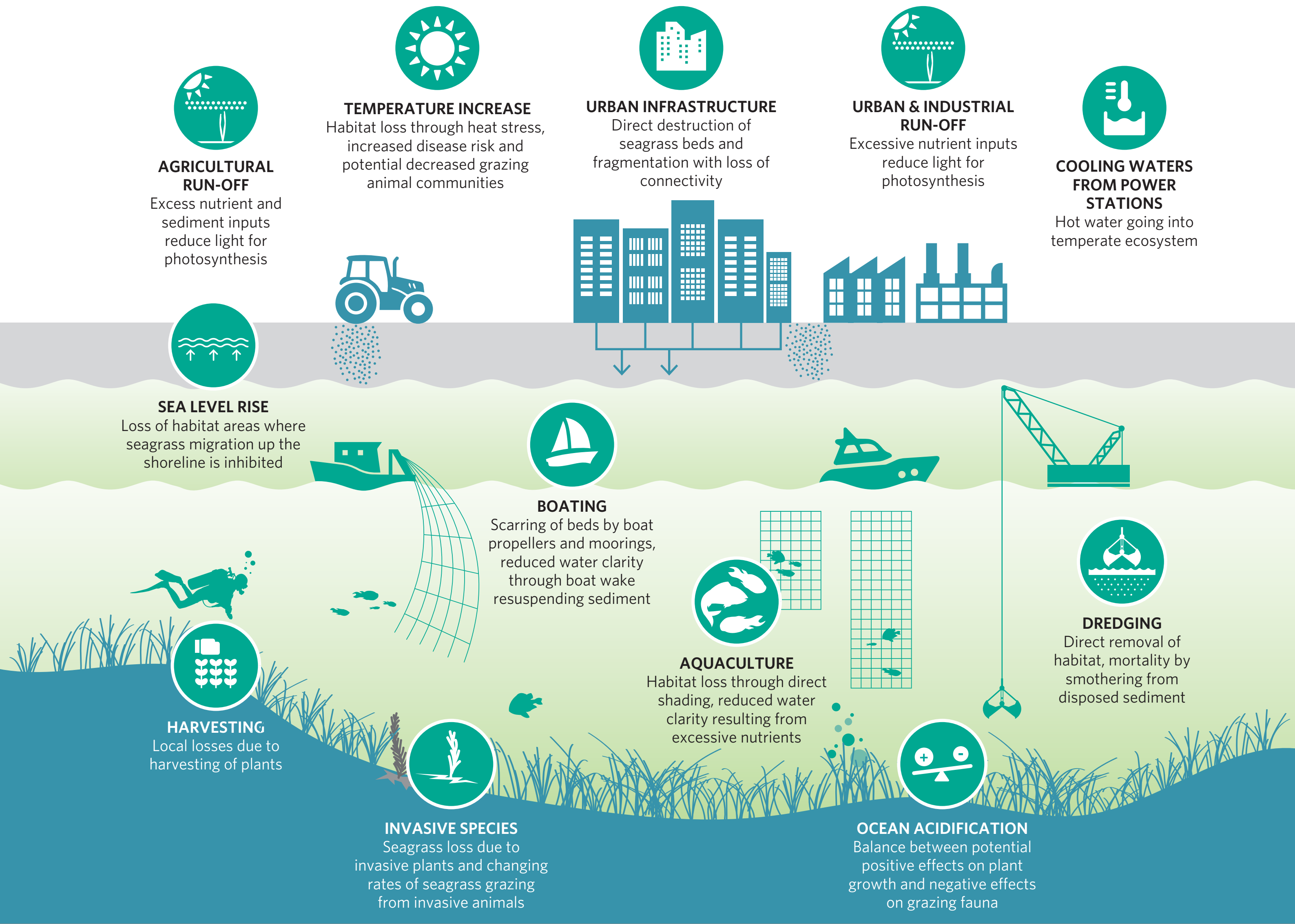

Figure 1.4: Threats to seagrass ecosystems. Figure modified from United Nations Environment Programme (UNEP) (2020).

WHAT ARE THE MAIN THREATS TO SEAGRASS ECOSYSTEMS?

Due to their shallow coastal location, seagrass beds often come into direct contact with humans, such as for anchoring of boats, fishing and recreational activities, and with coastal development areas, causing conflict between conservation interests and commercial or sustenance users. In addition, indirect impacts from land activities, including sedimentation, eutrophication and run-off of chemicals such as herbicides, further threaten seagrass health and survival (see Figure 1.4 and Table 1.1).

Direct pressures include mechanical damage as a result of coastal zone development, mobile fishing gear and recreational boating activities (anchoring and chain moorings), eutrophication, siltation from agriculture, urban waste, and aquaculture. *Zostera* is not physically robust; its root systems are typically located within the top 20cm of the sediment, meaning it is easily uprooted. Deposition of physical material leads to smothering via increased sedimentation or direct dumping of sediment onto the seagrass beds. These pressures are increasingly causing fragmentation and even loss of many beds.

Nutrient enrichment due to sewage, agricultural run-off and more localised inputs (for example, from boating and aquaculture) have all been correlated with increased growth of epiphytic algae (in particular filamentous), drift algae and phytoplankton. Each of these plant groups has the potential to compete with seagrass for nutrients and reduce the amount of light reaching it. Loss of seagrass exposes the seabed to wave action, causing resuspension, which further increases turbidity, creating one of several positive feedback loops of eutrophication.

Indirect pressures include climate-driven changes, changes in global sea levels, increases in both CO_2 and ultraviolet (UV) rays, and anthropogenic impacts on marine biodiversity, leading to changes in oceanic and coastal food webs (see Table 1.2).

Table 1.1: Summary of the impact of human pressures on seagrass. Source: Marine Climate Change Impacts Partnership (MCCIP) (2018).

HUMAN PRESSURE	EFFECT OF IMPACT ON SEAGRASS	
	POSITIVE	NEGATIVE
Eutrophication – nutrient loading from urbanisation, run-off from agricultural activities, sewage and aquaculture.	May lead to increased biomass and/or flowering and sexual reproduction.	Increased risk of disease, reduction in net growth and primary production. Increase in growth of epiphytes on subtidal seagrass and potential smothering by opportunistic algae on intertidal habitats.
Siltation – adjacent land management, shoreline erosion, dredging, dumping, mineral extraction, boating activities, fishing and aquaculture.	Nutrient inputs associated with a small increase in sedimentation may benefit seagrass growth. Sand accretion may make more areas available for seagrass colonisation in shallow areas.	Decrease in shoot density and productivity. Increase in mortality due to reduced light availability for photosynthesis. Risk of desiccation and dieback of seagrass due to overheating and increased exposure. Excess sand (e.g. from floods) may limit seagrass growth, causing mortality.
Physical disturbance of supporting sediment habitats – dredging, trawling, bait digging, hand gathering, anchoring, construction, land reclamation.	Some of these impacts may favour colonisation of seagrass pioneer species (such as *Halodule uninervis*).	Erosion of fine sediment, bed fragmentation and habitat loss. Plants uprooted by trawling gear and anchors. Compression of sediment and reduction in availability of oxygen to roots and rhizomes. Increased water turbidity prevents establishment and full development of seagrass beds.

Table 1.2: Climate change impacts and their effects on seagrass. Source: MCCIP (2018).

CLIMATE CHANGE IMPACT	EFFECTS ON SEAGRASS	
	POSITIVE	NEGATIVE
Increase in seawater temperature	Senescence (deterioration) in the winter may be reduced. Increased temperatures can increase seed germination. Potential for habitats to be more suitable at more northerly latitudes.	Respiration exceeds photosynthesis at high temperatures, resulting in a negative energy balance within the plant.
Rise in sea level	Potential for shift of beds inland if new habitat is created.	Coastal squeeze and loss of supporting habitat in correct tolerance range (depth, light levels, etc.). In restricted intertidal estuarine zones, populations may not be able to adapt quickly enough.
Increase in storminess	Sedimentation due to associated floods may make more areas available for seagrass colonisation.	Increase in mobilised sediment due to changes in hydrodynamics. Reduced light availability for photosynthesis. Risk of smothering from burial and erosion. Potential for physical disturbance.
Changes in rainfall regimes	A decrease in salinity below ~22 parts per thousand reduces wasting disease activity. Lower salinities increase *Zostera marina's* germination rates.	Higher light requirement due to impact from higher sediment loads and reduced light availability. In a field experiment, negative effects were visible even at the lowest burial level (5cm) and shortest duration (4 weeks), with effects increasing over time and burial level.
Ocean acidification	Raised aqueous CO_2 levels enhance seagrass survival, photosynthesis, growth and proliferation at warm temperatures. Seagrass growth may maintain a lower CO_2 concentration, reducing stress to calcifying organisms.	If calcifying organisms are stressed, there may be a reduction in epiphytic grazers which will lead to excess epiphytes, decreasing seagrass photosynthetic activity.

WHY RESTORE SEAGRASS BEDS?

Seagrasses are one of the most valuable coastal and marine ecosystems on the planet. They provide a wealth of highly valuable ecosystem services and benefits that greatly contribute to the health of our seas, our well-being and the security of coastal communities (see Figure 1.5).

Fisheries: Seagrasses are one of the most biodiverse subtidal habitats, with rich fish assemblages globally. Seagrass beds are important nursery and feeding habitats for invertebrates and fish which support fisheries and adjacent habitats. Fish density within temperate eelgrass beds is highly variable and abundant, with fish density 4.6 times higher than in nearby sand habitats. Studies have recorded 10 species of commercial importance for the UK. Economically important species, such as cod, spend critical periods of their lives in seagrass.

Climate regulation: Among the numerous important ecological services that seagrasses provide, their capacity to sequester CO_2 has generated considerable interest for its potential role in mitigating climate change. Seagrass beds are significant carbon sinks on a global scale, with high capacity for taking up and storing carbon in the sediment, also known as blue carbon (see Blue Carbon overview on page 12).

Biodiversity: Seagrasses are productive ecosystems supporting greater invertebrate, fish and bird diversity than adjacent sand and mud environments. This increased complexity provides shelter from predation, more ecological niches and a wide range of food resources that enriches faunal species, ensuring the ecosystem's resilience. Their capacity to oxygenate sediments also enhances infaunal communities.

Genetic diversity: Research has shown that genetic diversity has been lost in seagrass species in conjunction with their beds and their connectivity. This diversity and connectivity is crucial for building strong populations that can withstand and even adapt to changes in their environments, such as climate change, novel pests and diseases, and other changes in their immediate surroundings.

Habitat connectivity: Seagrass ecosystems do not occur in isolation and are instead interconnected across a continuous land–sea interface. Seagrasses typically exist near saltmarshes, kelp forests and bivalve reefs (e.g. mussel and oyster beds). This connectivity allows for a direct transfer of carbon and nutrients, and is also important for the ontogenetic and foraging movements of marine fauna across different habitats.

Ocean acidification buffer: Seagrass beds can alleviate low pH (more acidic) conditions for extended periods of time, sometimes by up to 30% (Ricart *et al.* 2021). Time of year is an important factor as are the local oceanographic conditions, with more buffering occurring in springtime when seagrasses are highly productive.

Disease control: Compared with non-vegetated areas, seagrass can reduce general bacteria (and more specifically, those belonging to the genus *Vibrio*) by 39% for all *Vibrio* species, and 63% for the potentially harmful *V. vulnificus/cholerae* subtype.

Tourism: Seagrasses provide habitats for wildlife watching (e.g. birdwatching, SCUBA diving) and recreational fishing; clearer, cleaner water for swimming, and stable beach.

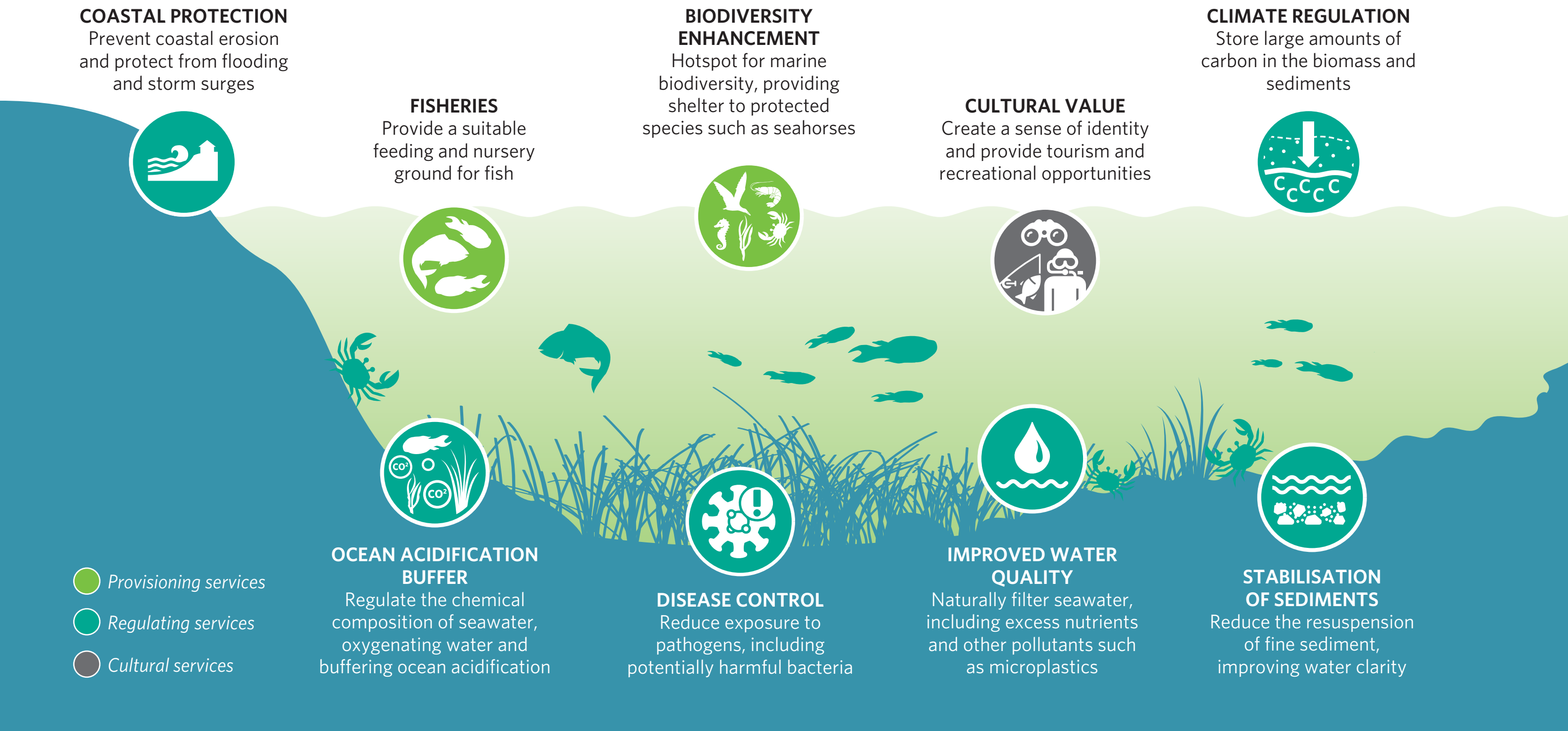

Figure 1.5: Ecosystem services provided by seagrass beds. Modified from UNEP (2020) and Potouroglou, M., Westerveld, L. and Fylakis, G. (2020).

Nutrient cycling/water filtration: Seagrasses help improve and maintain high water quality by contributing to the benthic-pelagic coupling, or the exchange of nutrients from the benthic to pelagic layer. Seagrass is known to play a crucial role in nutrient cycling by acting as both a sink and a source for nutrients in varying areas of nutrient availability. Nitrogen is assimilated in large quantities into the biomass of seagrass where it is temporarily retained for a period of between a few weeks to months. Unlike burying or denitrification, the nitrogen that is assimilated is only temporarily held within the seagrass and is released back into the surrounding environment via decomposition, leaching and grazing. As well as assimilating nitrogen in large quantities, seagrass also aids in the burial of nitrogen by increasing sedimentation as the seagrass canopy can attenuate the waves and current; by stabilising sediment with its roots and rhizomes, and via the build-up of recalcitrant seagrass tissue in the sediment.

Coastal protection: Coastal vegetation acts as a buffer, reducing wave and tidal energy. Seagrasses have a well developed network of rhizomes and roots that secure and consolidate sediment, while their canopies reduce current speeds, aiding the settlement of suspended material. Seagrasses trap sediment and raise the sediment profile, helping to protect the coast.

The benefits of seagrass restoration projects are expected to reach beyond the direct project footprint (see Figure 1.7). Seagrass beds are of fundamental importance to world fisheries production, providing valuable nursery habitat to over one fifth of the world's largest 25 fisheries, which contribute to food provision and job creation (Unsworth *et al.* 2018). For example, in the North Atlantic region, eelgrass beds contribute to Atlantic cod stocks by providing a safe nursery habitat for juveniles' growth and survival. This then also benefits countries that import part of the Atlantic cod landings, such as Brazil, China, the Netherlands, Portugal and Spain (UNEP 2020).

BOX 1.4: SEAGRASS BEDS PROTECT COASTLINES FROM EROSION AND FLOODING

***Zostera* spp. protect coastlines from erosion and flooding by decreasing the intensity of incoming coastal waters through three mechanisms:**

- In a unidirectional flow (e.g. tides, flooding events), *Zostera* spp. reduce the current's velocity as it passes through and over the canopy via frictional effects of the biomass, causing a loss of momentum.
- In an oscillatory flow (e.g. waves), the circular motion causes *Zostera* spp. leaves to move periodically, with amplitude strongly dependent on leaf stiffness. In flume studies, *Zostera marina* was shown to reduce wave energy by 40% per metre of seagrass when the blade length was approximately equal to the water depth (Fonseca and Cahalan 1992).
- *Zostera* spp. have an indirect coastal defence mechanism by stabilising and maintaining the sediment, increasing surface elevation. This reduces water currents and wave energy, increasing sedimentation rates within the beds and reducing potential for resuspension. The presence of *Zostera noltei* in the Firth of Forth, Scotland has been shown to result in an average difference in surface elevation rate of 9.01mm/year, compared to adjacent unvegetated areas (Potouroglou *et al.* 2017).

Figure 1.6: Eelgrass *Zostera Marina* meadow near Ord, Skye. Photo: Project Seagrass.

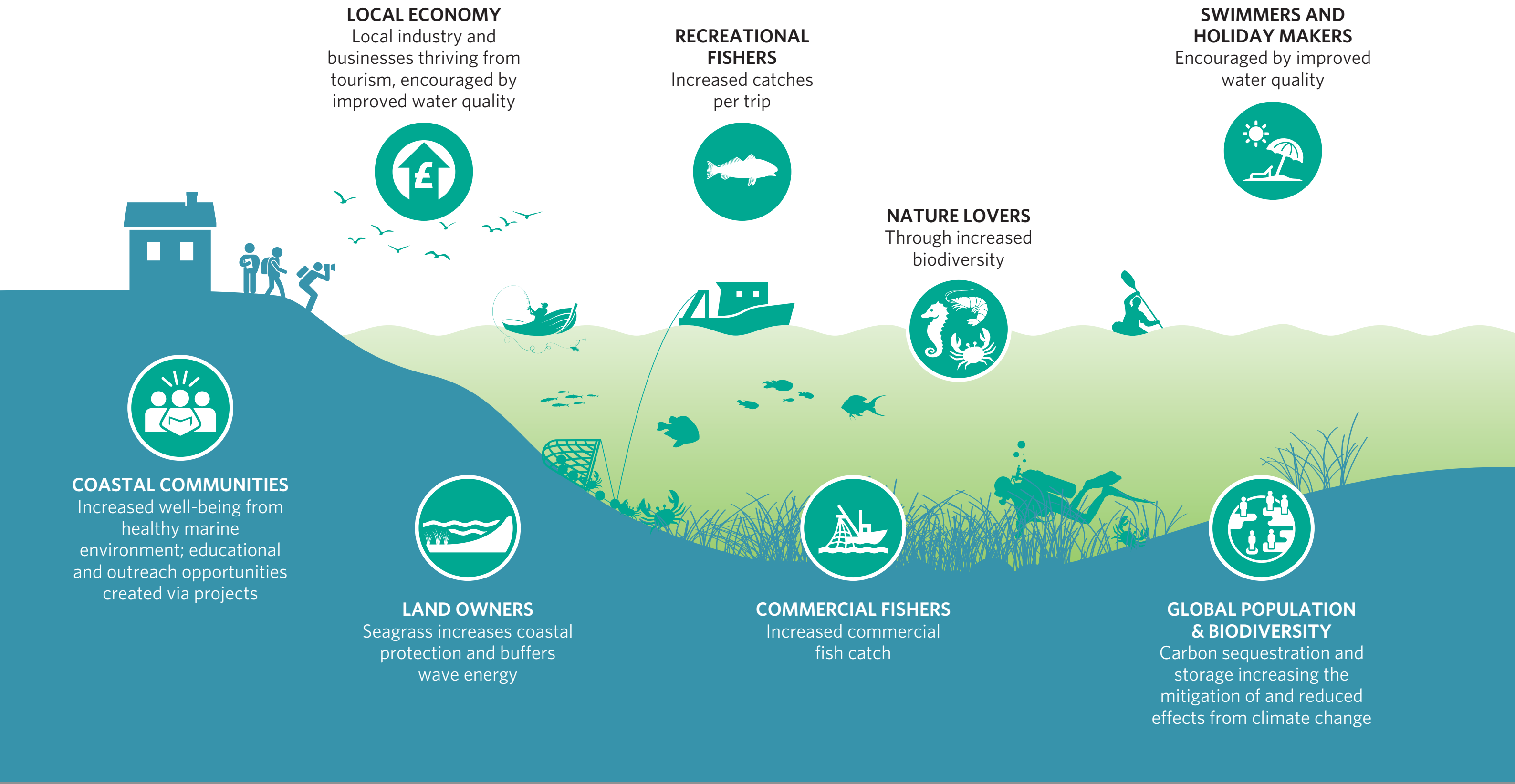

Figure 1.7: Beneficiaries of seagrass bed restoration.

BLUE CARBON OVERVIEW

Nature-based solutions to climate change are now being broadened beyond terrestrial forests that contain rich carbon reservoirs to reduce the potentially significant emissions from conversion and degradation. In particular, marine and coastal ecosystems, such as seagrasses, tidal marshes and mangroves, sequester and store large quantities of 'blue carbon' in both the plants and the sediment below them. Blue carbon strategies build on the opportunity to mitigate greenhouse gas emissions and to enhance organic carbon sequestration through the conservation and/or restoration of marine and coastal ecosystems. The loss or deterioration of seagrass beds would not only lead to the loss of their carbon sink capacity, but could potentially release the carbon already stored in their sediments.

The Intergovernmental Panel on Climate Change (IPCC) Wetland Supplement (IPCC, 2014) details expanded guidelines for the quantification and accounting of GHG emissions and removals associated with the management of different coastal wetland types, including seagrass beds.

In the UK, carbon stocks have been quantified for intertidal and subtidal seagrass, in both monospecific and multispecific beds comprising common eelgrass and dwarf eelgrass, with sites across England, Scotland and Wales (with average carbon stocks in the upper 100cm ranging from 78 to 141 tons [Mg C] per hectare; Potouroglou *et al.* 2021). Comparing UK seagrass sedimentary carbon stocks can distinguish 'carbon hotspots' – those beds with an overall high quantity of carbon stored in their sediments. However, assessing carbon stocks from a single time point only provides a 'snapshot', and does not reflect the active rate of carbon sequestration and accumulation, the external influences on that capacity, or the different sources of carbon. Data on carbon sequestration rates for UK seagrasses are still lacking. This information is critical for understanding how seagrass can be used as a nature-based solution for mitigating climate change. Studies on carbon sources within common eelgrass beds throughout the northern hemisphere found that seagrass contributes up to 50% of the carbon to seagrass sediments, with its trapping role leading to the sequestration of material from other species and environments. Comparison with non-vegetated areas is also of interest, since there may be large stocks of organic carbon in coastal sediments free of vegetation. In assessing the current and potential contribution of seagrass to carbon storage, their 'net impact' is most relevant. In Scottish intertidal seagrass beds, the organic carbon in seagrass sediments was on average 20% higher than those in reference unvegetated areas, supporting the idea that the presence of seagrass can enhance sediment carbon stocks. See further details in Chapter 4 page 63, "Carbon Stock Assessment".

BOX 1.5: CARBON SEQUESTRATION AND STORAGE BENEFITS

There are three key examples of carbon stock assessment post-seagrass restoration: *Zostera marina* beds in Virginia Coast, North America; *Posidonia australis* beds in Perth, Western Australia and *Thalassia testudinum* and *Halodule wrightii* beds in the Gulf of Mexico. While all sites showed an increase in sedimentary carbon stock post-restoration, the specific extent varies considerably and the data are limited. The effectiveness of seagrass restoration in enhancing carbon sequestration appears to be influenced by several factors in these cases, including the pressures to the seagrass prior to restoration, the local environmental conditions, the species of seagrass undergoing restoration and the level of protection post-restoration, suggesting that not all seagrass beds across the UK, and potential restoration efforts, are equal in terms of blue carbon potential. The Virginia Coast restoration project is a prime case study for the carbon storage capacity of restored seagrass beds in the UK given the use of *Zostera marina* as the target species and the general temperate climatic conditions.

The success of the wider Chesapeake Bay restoration programme hinged on the holistic nature of its vision: the bay was targeted as part of an integrated watershed approach led by several US environmental agencies that included specific objectives on improving water quality, such as reducing nitrogen and phosphorus inputs to the bay by 40%. Seagrass restoration was initiated as a means of reducing sedimentation and enhancing water quality, in combination with other activities under the programme. Enhancing water quality required seagrass restoration at both a large scale and over the long term (various methodologies since 1978). The restored seagrass beds are a result of over 70 million seeds planted since 1999, which, besides enhancing water quality, sequester carbon as an additional ecosystem service. The increase in shoot density and its subsequent influence on water flow enabled the restored seagrass to switch from erosional to depositional between 4 to 10 years post-restoration (Oreska *et al.* 2020).

Figure 1.8: Seagrass beds in Durgan, Helford River, Cornwall. Photo: Lewis Jefferies.

SEAGRASS BED CONSERVATION DESIGNATIONS

Table 1.3: Seagrass conservation designations.

SEAGRASS PROTECTION POLICY/LEGISLATION	DETAIL	REGION
UK Post-2010 Biodiversity Framework (2012)	The Framework supersedes the UK Biodiversity Action Plan (1994) which was the Government's response to the Convention on Biological Diversity, opened for signature at the Rio de Janeiro Earth Summit in 1992. The most threatened or rapidly declining species and habitats are listed with action plans for their conservation. Seagrass beds are a UK priority Biodiversity Action Plan Habitat.	UK
Natural Environment and Rural Communities (NERC) Act 2006	Section 40 requires public bodies to "have regard... to the purpose of conserving biodiversity". Section 41 (England) and Section 42 (Wales) list the species and habitats of "principal importance" for the purposes of conserving biodiversity (originating from the UK Biodiversity Action Plan).	England and Wales
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) 1992	Seagrass beds are categorised as a habitat in decline in OSPAR Region II (Greater North Sea) and under threat in all areas where they occur.	North-East Atlantic signatory countries
Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1979	The Bern Convention affords protection directly to seagrass species, listing seagrass beds on littoral sediments as an endangered natural habitat requiring specific conservation measures (Resolution No. 4, 1996, revised to be based on the EUNIS habitats classification) to be protected by the Emerald Network of Areas of Special Conservation Interest (ASCIs). The UK is a contracting party, and existing Special Protection Area (SPA) and Special Area of Conservation (SAC) sites are already recognised as a contribution to the Emerald Network.	Signatory countries (includes UK and Ireland)
Environment (Wales) Act 2016	Replaces the NERC Act 2006 and places the duty upon public authorities to "maintain and enhance biodiversity" and "promote the resilience of ecosystems" in the exercise of their functions. Seagrass beds are listed under Section 7 (Section 42 under NERC Act).	Wales
Scotland's National Marine Plan (2015)	Seagrass beds are listed as a Priority Marine Feature (PMF) in Scottish waters. Seagrass beds include the biotopes: *Zostera noltei* beds in littoral muddy sand (Biotope: LS.LMp.LSgr.Znol) *Zostera marina/angustifolia* beds on lower shore clean or muddy sand SS.SMp.SSgr.Zmar. *Zostera marina/angustifolia* beds on infralittoral clean or muddy sand SS.SMp.SSgr.Zmar. *Ruppia maritima* in reduced salinity infralittoral muddy sand SS.SMp.SSgr.Rup.	Scotland

CASE STUDY
A HELPING HAND: The case for policy aiding seagrass recovery across Europe

Seagrass beds can be restored through not only direct intervention by planting, but also indirect intervention by removing anthropogenic pressures. For example, focused management plans aimed at improving water quality for seagrass restoration, especially those that address nutrient sources and reduce input, have had considerable success in some areas.

In Europe, many seagrass beds declined between 1869 and 2016, while others have increased in extent since the 1990s. More specifically, a review on 107 *Zostera noltei* beds found that over half of them were either stable or increasing in extent (de los Santos *et al.* 2019). There is strong evidence that increases in seagrass extent observed in Portugal, Wales and the Wadden Sea were the direct result of management measures and practices established by the European Union in the early 1990s to 2000s (Cardoso *et al.* 2010; Dolch, Buschbaum and Reise 2013; Bertelli *et al.* 2018). These management measures notably included Council Directives aimed at improving water quality by regulating urban waste-water treatment and agricultural nitrate pollution (91/271/EEC; 91/676/EEC).

Seagrass recovery was also included in the WFD, with EU nations required to restore poor- and moderate-quality waters containing seagrass beds to good ecological status by 2015 or face financial penalties (WFD 2000/60/EC). These policy enforcements might have contributed to the recovery of some seagrass beds through nutrient-loading reduction (de los Santos *et al.* 2019). In this way, the development and successful implementation of policies can play an important role in not only seagrass recovery, but also restoration efforts (de los Santos *et al.* 2019).

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CHAPTER 2
GETTING STARTED: RESTORATION PROJECT DESIGN, PLANNING, PERMITTING, LICENSING AND FUNDING

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KEY SUMMARY POINTS

- **A well constructed restoration plan with clear goals and targets enables successful delivery. It allows the purpose of the project to be clearly communicated, funding to be secured and conservation outcomes to be measured.**
- **Potential sites for seagrass restoration should be surveyed as part of the feasibility study prior to selection. This will ensure that active restoration is the most suitable conservation strategy and ascertain baseline conditions, including presence of other features of conservation importance.**
- **To maximise restoration success, sites for seagrass restoration should demonstrate environmental and biological conditions within the suitable range for seagrass species.**
- **Logistics and licence requirements should be addressed early, as they may require considerable investments in time and resources, and may present significant barriers to progress. Consultation with the relevant authorities should take place at the earliest opportunity.**

INTRODUCTION

This chapter aims to provide information and guidance for restoration practitioners establishing a seagrass restoration project. The approach suggested here is based on international standards for ecological restoration. Experience from restoration projects in the United Kingdom (UK), Europe and beyond has informed the overview of a project's key stages. Taking time at this stage is important, as the success or failure of any restoration attempt will largely depend on the amount of effort devoted to developing a well planned approach.

Seagrass restoration planning should be undertaken with an understanding of the environmental conditions prevalent at a chosen site, with water quality, availability of suitable light levels and sediment type all being key considerations. The extent and condition of existing seagrass beds at proposed restoration sites and nearby should be understood in order to inform both site suitability and potential sources of seeds, as well as considerations of population genetics. Current pressures on the site must also be understood in order to establish whether active restoration is indeed the correct approach as opposed to, or as well as, pressure removal. It is also important to be aware that self-reinforcing ecological feedbacks can inhibit or undermine seagrass restoration efforts, see Maxwell *et al.* (2017) for an in-depth review of the impact of these.

Local, national and international policy and regulations will determine which permit, marine and/or wildlife licences must be obtained prior to physical restoration activity commencing. The preparation of a biosecurity plan to assess the risk of introducing diseases or invasive non-native species (INNS) will minimise or eliminate these risks. The biosecurity plan should be agreed with the relevant authorities.

Finally, a potential seagrass restoration project will need to have adequate funding in place, access to appropriate logistical support and an understanding of the wider social considerations of stakeholder perceptions and public support.

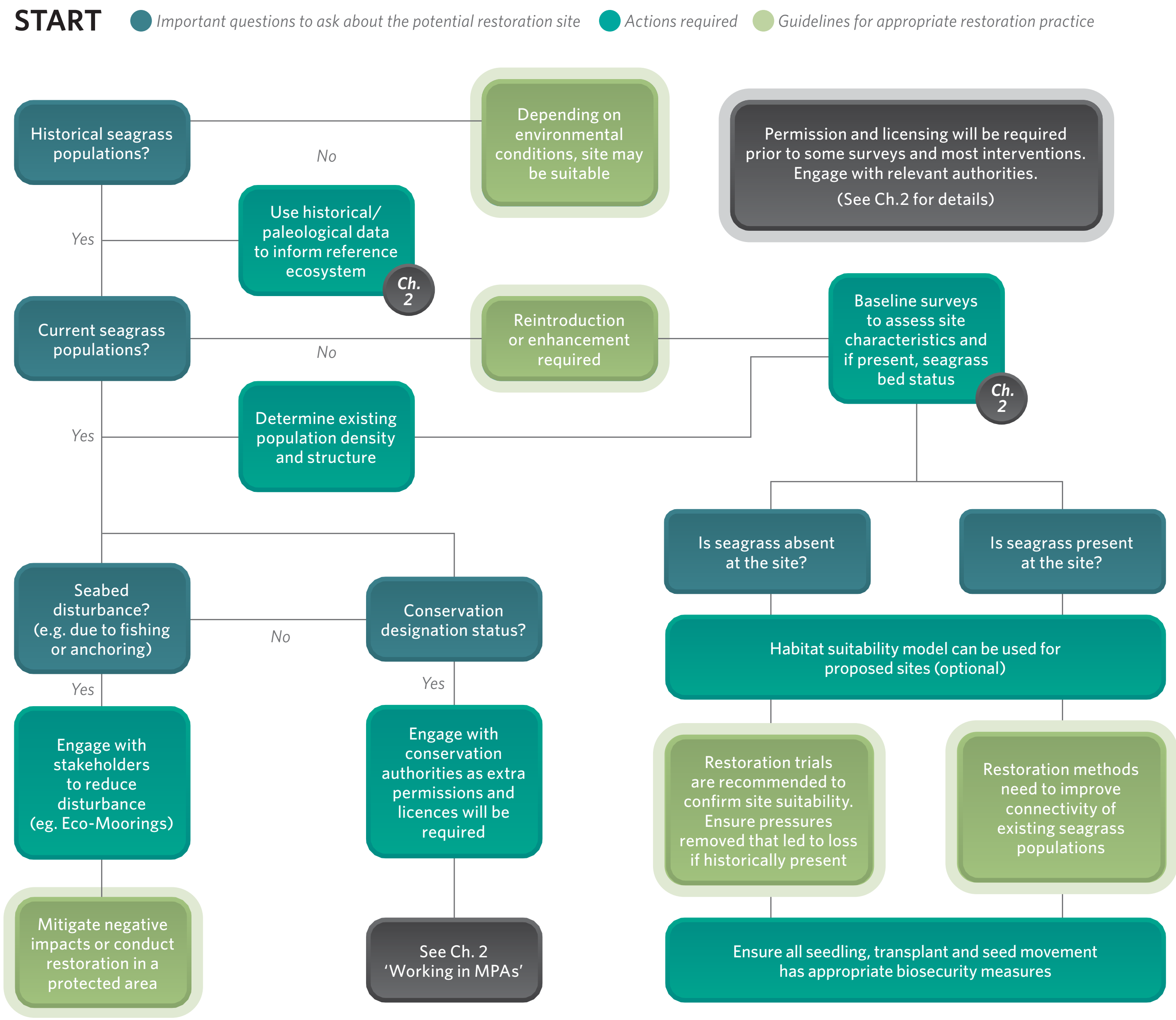


Figure 2.1: Getting started decision tree. This flow diagram is a decision making tool to help restoration practitioners consider some of the main factors regarding the feasibility and planning of a project. **Note:** Each project should conduct its own comprehensive study.

RESTORATION PROJECT PLANNING

It is important to identify the focus of a seagrass restoration project from the outset, in order to facilitate clear communication with funders, licensing and permitting authorities, resource users and community groups. **Goal-based** project planning is recommended to provide a framework while ensuring the best chance of achieving the highest level of recovery possible. A 'getting started' flow chart is provided to aid decision-making during the feasibility, site-selection and licensing phases of a restoration project (Figure 2.1). A typical project timeline provides an aid to project planning and setting out realistic deliverables and milestones (Figure 2.2). It is also vital to consult with key stakeholders early on to help ensure that projects access a wide range of knowledge and expertise, and generate the social licence needed to succeed.

TYPICAL PROJECT TIMELINE

A series of steps must be completed before active restoration can commence. Figure 2.2 sets out the approximate timeline, assuming that funding is in place. When planning and delivering the project, it is always sensible to think at least one year ahead, particularly as seed collection is seasonal and licences and permission can take months to be granted.

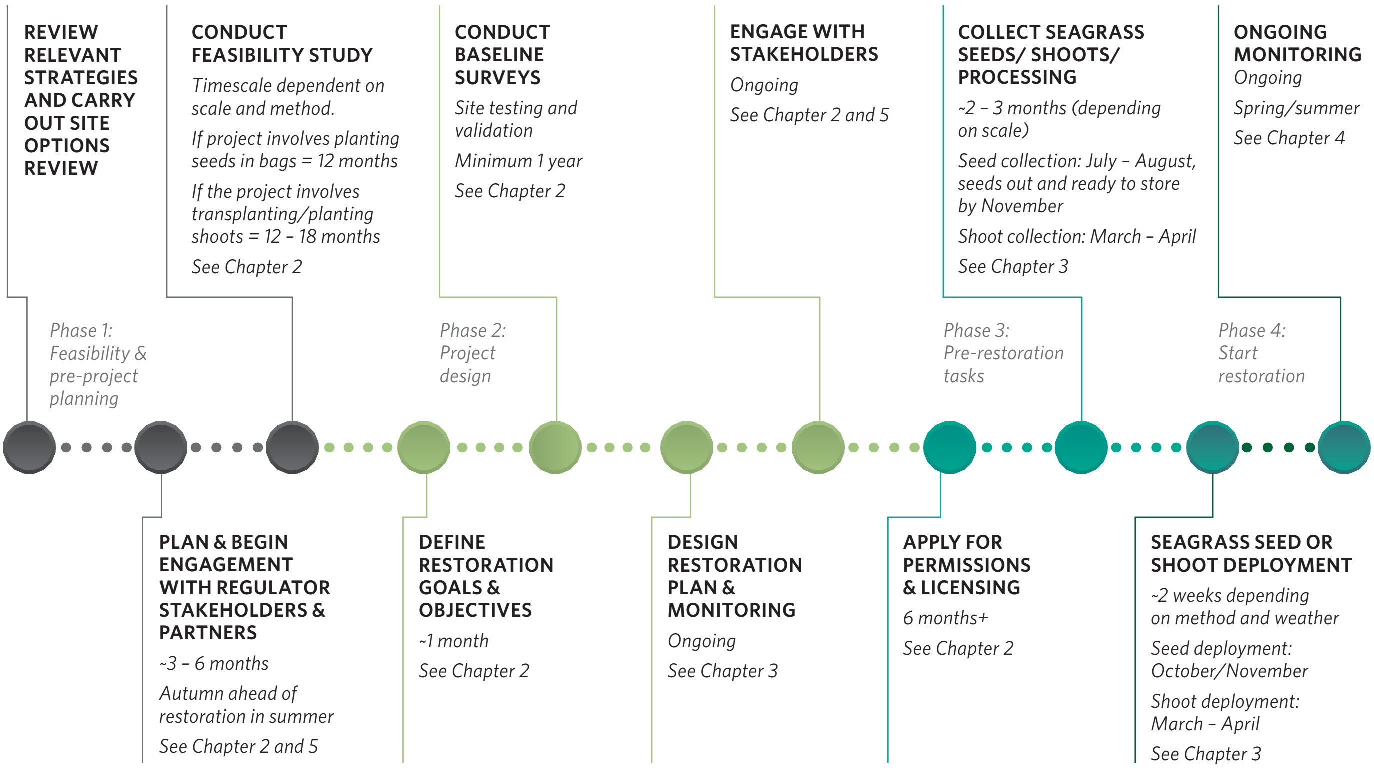


Figure 2.2: Generalised but typical, timeline of a seagrass restoration project.

SETTING RESTORATION GOALS AND OBJECTIVES

International standards of ecological restoration recognise the need for setting clear targets, goals and objectives by which success can be measured, and encourage the development of both **social** and **ecological** goals. These elements should be agreed on early, through both stakeholder and community engagement as well as expert consultation (see Box 2.1 and Table 2.1).

This approach also recognises that individual projects and practitioners will have different motivations. The project target is likely to be the recovery of healthy and resilient populations of seagrasses in a given area, but there are multiple reasons why this might want to be achieved, including:

- ecological outcomes
- meeting legislative commitments or outcomes
- stakeholders' and the community's expectations

BOX 2.1: DEFINING TARGET, GOALS AND OBJECTIVES

Project target: This describes the site and native ecosystem to be restored. It should be broad, general and inspiring.

Goals: A project will normally have several goals. They are open and describe the level of recovery and outcomes desired, both in social and ecological terms.

Objectives: Objectives translate goals into clear, distinct and measurable outcomes or changes. They can be helpful in determining the restoration strategies to implement, assessing progress and managing the project. Often relating to a site's distinct aspects or a project's timeframe, they are critical to allowing the project to meet expectations, operate within budget and deliver outcomes against performance criteria.

Table 2.1: Examples of how the restoration goals inform project planning and design.

PROJECT GOALS	PRE-DESIGN OBJECTIVES	DESIGN CONSIDERATIONS
Offset seagrass loss at a specific site by introducing seagrass at alternative locations.	• Have the environmental pressures that caused the loss been removed from the alternative site? • Consider the pre-disturbance conditions of the lost seagrass bed to inform reference or target ecosystem. • Is enhancement required?	• Monitor the site to assess environmental conditions for sustaining target species of seagrass. • Enhance site if needed. • Trial methods. • Undertake restoration. • Monitor restoration success against previous state. • Adapt methodologies if required.
Promote wider seagrass population resilience.	• Assess connectivity between beds in the wider population, to identify sinks and sources of seagrass propagules (parts of the plant that become detached and go on to create new plants, such as seeds). • Identify suitable habitat and past and current distribution to ascertain fundamental and realised niches. • Map anthropogenic and natural disturbance.	• Prioritise sites for restoration, habitat creation and enhancement, based on their position within the wider population (e.g. an important source of propagules). • Assess the frequency of interventions required (e.g. maintaining an important meadow with high disturbance and poor propagule retention may require frequent facilitated dispersal, i.e. seeding).
Create seagrass beds for carbon sequestration.	• Which conditions would provide highest carbon sequestration (mud, low current velocity, large dense beds, supply of organic matter)? • Which locations are available? • Can beds be maintained and protected in the long term?	• Select habitat sites. • Select species (perennial versus annual). • Establish protection mechanisms. • Monitor carbon sequestration, including seasonal variations.
Restore fish and shellfish nurseries and foraging habitat.	• Subtidal versus intertidal? • Is there a supply of larval recruits? • Is there good connectivity with spawning habitats? • Create a continuous meadow? • Distance from other habitats? • Increased edge to core (reticulated meadow design)?	• Introduce regular sampling to monitor fish and shellfish populations. • Adjust site locations as necessary to promote connectivity.
Enhance feeding habitat for birds.	• Identify the target bird species and their prey. • Does their prey utilise seagrass? • Is the target species' use of seagrass impacted by water level? • How might seagrass restoration impact other bird species that prefer to forage in unvegetated areas?	• Monitor target bird species' populations. • Monitor other non-target bird species' populations, to ensure against unintended consequences.

FEASIBILITY STUDY

Before progressing to practical considerations of restoration practice, it is important to take time to assess a project's feasibility, determining whether restoration targets and goals can be achieved in the proposed restoration location.

This includes four broad steps that this chapter aims to support:

1. Establish whether ecosystem restoration is possible within the desired location(s). This step involves feasibility studies, site selection processes and determining whether there are significant ecological, logistical, legislative or financial barriers to restoration.
2. Decide on an appropriate method and establish its feasibility for achieving project aims. This step may require extensive field testing of the method's effectiveness in light of the site conditions.
3. Understand the local reference ecosystem or the ecological target that will be used to guide the restoration process.
4. Understand who should be involved in the project, in what context and at which stage.

It is advisable to conduct a review of recent advances in seagrass restoration and of the local information to understand historic and current seagrass distribution and establish likely causes of loss or degradation, alongside future risks.

At this stage, it is also recommended to collate spatial and temporal data sets (either by conducting baseline surveys or from existing data) to facilitate the construction of **habitat suitability models** to guide decision-making (see Box 2.3). These help predict where seagrass could potentially grow, based on factors such as shear bed stress, slope, depth, hydrodynamic connectivity data (e.g. identification of propagule sinks), photosynthetically active radiation (PAR), and sedimentation/erosion rates. Such information can also be utilised to assess the likely potential for successful seagrass beds and the status of existing nearby beds (e.g. species, form and dynamics), which represent potential donor sites and dispersal source sites.

Taking this a step further, restoration suitability models could be developed, which not only look at habitat suitability but also consider logistical and social factors. Restoration suitability models consider areas where it would either be suitable or not suitable to undertake restoration for reasons other than ecological. Social or logistical considerations could include avoiding shipping channels, fishing areas, staging/loading areas and culturally significant sites.

Where knowledge gaps remain, attempts should be made to build the knowledge base through a combination of field observations and surveys, experiments and modelling. For example, if elevated levels of turbidity are suspected to cause seagrass failure, laboratory and/or field experiments can be useful to test the sensitivity of local species to various light and turbidity levels. Results from such experiments can then be used to model the probability of particular field sites sustaining seagrass and to validate potential restoration site selection.

BOX 2.2: IDENTIFYING RISKS

A key part of any planned project is the identification of risks and mitigation planning. For example, although sites subject to active anchoring are likely to be avoided, unexpected intense vessel activity could occur. Mitigation of potential disturbances can be encouraged through, for example, the use of physical buffers in the sea to protect newly restored seagrass habitat.

Images demonstrating the damage to seagrass beds caused by mooring chains in the Helford River. Photos: Lewis Jefferies.

HOW TO CARRY OUT A BASELINE SURVEY

Baseline surveys should provide robust information that helps inform site location and suitability and determine whether the aim is to restore seagrass in an area where it is absent, or to enhance an existing seagrass bed. A baseline survey provides the critical information necessary to determine whether the physical, biological and ecological conditions at a proposed location lie within the range likely to support seagrass species' establishment and growth. Establishing baseline conditions also provides an all-important benchmark against which progress of seagrass restoration can be monitored, which may be important for reporting to marine managers and regulators, funders and stakeholders and for maintaining public engagement.

A first step is to establish whether current or historic extent or mapping data already exist. Such data may reside with biological records centres such as NBN Atlas (nbnatlas.org/), non-governmental organisation (NGO) databases (e.g. seagrassspotter.org) and statutory nature conservation agencies such as NatureScot, Natural England, Natural Resource Wales or the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland. Local authorities, environmental regulators (e.g. the Environment Agency, the Scottish Environment Protection Agency (SEPA) and Natural Resources Wales (NRW)), local inshore fisheries and conservation authorities (IFCAs) and local NGOs such as wildlife trusts may also hold relevant records, which may be supplemented through information from stakeholders and the public. There are several online portals that may provide information on seagrass locations, such as MAGiC in England (magic.defra.gov.uk/magicmap.aspx), Marine Scotland Maps (marinescotland.atkinsgeospatial.com/nmpi/), Data Map Wales (e.g. datamap.gov.wales/), the NBN Atlases (e.g. wales.nbnatlas.org/ for Wales) or the SeagrassSpotter app (seagrassspotter.org/).

Where seagrass beds are present, they should be surveyed to establish their current extent, health, growth and reproductive status. The level of survey undertaken may be limited by resources and/or expertise and it may be useful to form partnerships with other groups (such as universities) in order to expand the range of survey methods that can be deployed. See Chapter 4 for an outline of survey methods.

Baseline surveys can include a number of parameters, all of which help create an understanding of the status of a seagrass bed and its suitability as either a donor site, a site for enhancement or extension, or a site likely to support local restoration. Where possible, it is advised to use biochemical indicators of seagrass environmental health. Typical parameters include the following (but for reference the reader is directed to Bertelli *et al.* 2021):

- bed extent
- shoot density/percentage cover
- leaf length
- reproduction (flowing and seed production, seed banks)
- epifaunal growth density
- biochemical parameters (e.g. plant tissue carbon (C), nitrogen (N) and phosphorus (P))

Additional baseline information is required to identify and assess sites for seagrass restoration where no seagrass is currently present or to gain a more complete understanding of the conditions within existing seagrass beds. In locations where seagrass was formerly present, it is vital to attempt to understand the reasons that led to its disappearance as a successful restoration attempt may be highly unlikely if those conditions still prevail. These baseline studies should typically focus on key abiotic parameters as well as some biotic factors that may influence feedbacks such as:

- water quality (nutrients and other pollutants)
- light levels and penetration (relative to healthy seagrass)
- sedimentation and sediment characteristics
- salinity
- currents and wave action
- suspended materials and sedimentation
- other targeted pollutants of concern (e.g. heavy metal or herbicide contamination)

Note: These baseline surveys should help inform the final design and method selection, and in part the target used to inform these.

The results of a well executed baseline survey enable a potential restoration site to be selected with increased confidence and provide relevant information to support applications for appropriate licences and permits. If a restoration proposal is in development, the information can be used to support funding applications.

IDENTIFYING SUITABLE RESTORATION SITE LOCATIONS

Selecting appropriate sites is critically important in restoration. In practice, potential sites are often broadly identified during the early planning phase, through general indications of possible locations. Figure 2.4 sets out the key factors to consider when defining the precise locations and extent of sites. This process builds on information gathered during the feasibility study and baseline surveys.

Figure 2.3: Project Seagrass carrying out boat surveys in Porthdinllaen. Photo: Jake Davies.

Donor sites: Locate and assess suitability of existing seagrass beds for harvesting plant material (seeds or shoots) for use in restoration.

Transplant sites: Locate and assess suitability (e.g. biotic and abiotic characteristics). Establish why seagrass does not currently grow at site.

Costs: Where possible, reduce project costs by planting in intertidal and shallow subtidal areas. Seagrass can subsequently grow in subtidal zone.

Designated status: Consider protected conservation features of both donor and restoration sites.

Reference beds: Identify control sites against which to gauge performance of restored areas.

Seagrass survival and persistence: Consider potential for persistent seagrass bed development by comparing nearby sites similar to proposed restoration site. Consider most suitable location within larger restoration sites for persistent seagrass growth.

Present and historic distribution: This gives an indication of likely success in seagrass growth and persistence.

Logistical, social and cultural considerations.

Figure 2.4: Practical considerations for seagrass restoration site selection.

BOX 2.3: HABITAT SUITABILITY MODELLING (HSM)

To keep HSM considerations up to date, it is advisable to partner with university researchers, and consult statutory nature conservation bodies and other local authorities that have publicly available data. Data quantity and quality continues to advance in this area through remote sensing and high-performance computing. Next-generation habitat suitability models are being developed that link presence with the environment through biological mechanisms (e.g. based around long-term population growth rate or fitness), rather than simple correlation. Where these take a life cycle approach (e.g. linking environment with flowering, germination, seedling development, or over-winter survival), this should allow restoration practitioners to link their restoration method with habitat suitability. Ultimately, using the research to develop decision tools will involve trial and error, making it imperative that long-term monitoring be included in restoration projects and reported openly, regardless of success.

Habitat suitability modelling considerations and challenges:

Data quality and gaps	It is important to obtain recent data at sufficiently high spatial resolution for all relevant parameters including light, current and wave energy, sea temperature, salinity, and organic matter. This probably needs to be at least 50m resolution.
Ecological validity	Both species distributions and environmental parameters are dynamic in nature. Species may be absent from highly suitable habitat through historical loss, or present in unsuitable habitat, for example through rafting of plant material or through recent degradation of local conditions, and thus destined to fail.
Connectivity	Current emphasis is on modelling local environmental conditions. However, geographic parameters (e.g. connectivity with other seagrass populations) are generally not included in any robust and quantitative way. These conditions should ideally also be considered from an ecosystem perspective (e.g. understanding links between seagrass and other marine ecosystems such as saltmarsh).
Inferring restoration suitability	Current habitat suitability models for seagrass are based on identifying environmental and geographical parameters associated with well established seagrass. Particularly since seagrass acts as an ecosystem engineer and creates habitat that enhances its own success (self-facilitation), conditions suitable for maintaining established beds may not indicate suitability for establishing a new population.
Decision tools	A final challenge, once an effective habitat suitability model has been developed, is in translating statistical outputs into effective decision(-making) tools for practitioners. This often relies on layering quite arbitrary suitability thresholds on the probabilistic maps produced by the model.

The decision to restore at a specific site is usually made based on the past occurrence of a specific seagrass species at the site, based on robust historical data. In areas where the natural environment has been significantly modified, some areas of seagrass may be lost permanently (e.g. through land claim) or may have become unsuitable for growth. Equally, areas may exist where seagrass has not previously been recorded but where habitat may, nonetheless, be suitable.

From the identified potential restoration, creation or enhancement sites, information on connectivity and seagrass propagule (seagrass propagules are seagrass material that helps it grow to its next life stage) sources and sinks is used to ascertain locations where the probability of long-term persistence is highest, where transplanting seagrass may contribute to wider metapopulation persistence and resilience, or where natural recovery may be limited due to poor connectivity with other beds despite high habitat suitability. Population connectivity considerations are especially important for seagrass restoration efforts, given the desire to prioritise resources for beds that are well connected within the existing meadow matrix.

HABITAT SUITABILITY MODELLING

When generating new habitat rather than supporting a poor existing site, it is important to assess the suitability of the recipient environment. The standard approach is habitat suitability modelling (HSM), also known as species distribution modelling, which provides a tool and starting point for discussions with stakeholders to help rule out unsuitable areas by drawing statistical associations between presence or absence of the focal species and candidate environmental variables. The models are only as accurate as the resolution and accuracy of the variables underpinning them. Current approaches are often largely based on expert opinion, although there are many challenges to this approach (see Box 2.3). Box 2.4 provides an example of the output (potential seagrass restoration sites identified for England) that can be achieved through HSM.

Using information on connectivity, habitat suitability and historical data, it is possible to create a decision framework to identify locations that could be considered for restoration. The information and potential locations can then be presented to stakeholders, who decide on final locations. The following questions can aid in spatial prioritisation of seagrass restoration, creation or enhancement sites:

- Where is seagrass restoration likely to result in sustainable populations, given the environmental conditions and the connectivity to other populations?
- Where would habitats require enhancement, or for pressures to be negated prior to restoration interventions?
- Where would natural recovery be most likely to occur, and therefore the requirement for restoration interventions lower?
- Where would seagrass restoration be a feasible option as part of a carbon-offsetting strategy?

The final locations should ideally be selected based on the combined input of all stakeholders and regulators.

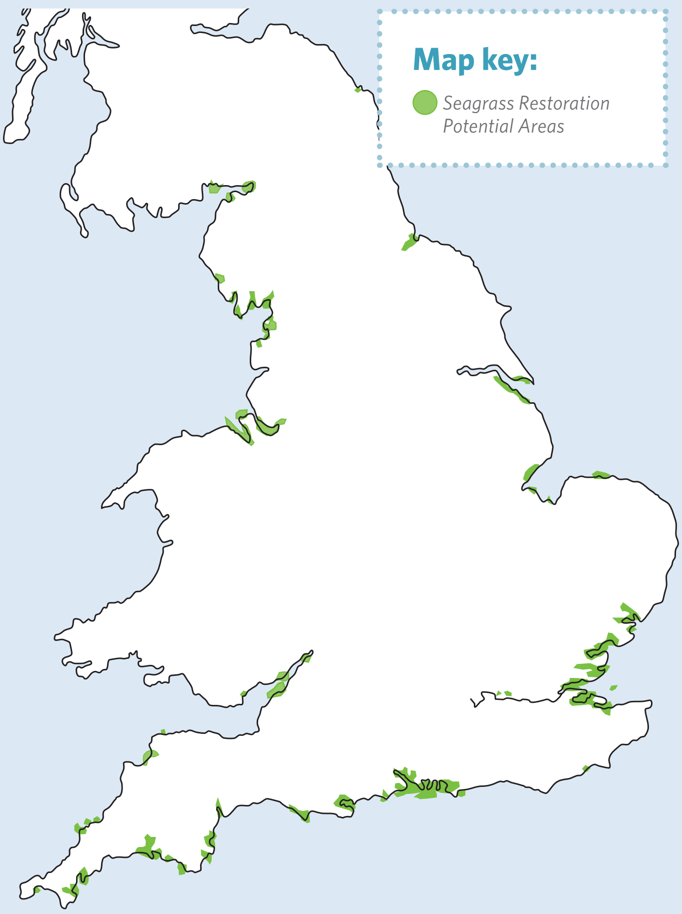
BOX 2.4: NATIONAL SCALES OF SITE SELECTION: A CASE STUDY FROM ENGLAND

The Environment Agency has developed a geographic information system (GIS) layer identifying areas with seagrass restoration potential in England, which provides a national 'high-level' indication of where seagrass beds could potentially be restored based on four key environmental variables: current speed (low energy sites, < 130nm^{-2}), wave energy (< 11.41nm^{-2}), bathymetry and turbidity (low turbidity waterbodies between -10 and +5m depth range, medium-high turbidity between -5 and +5m depth range) and salinity (see below).

Note: The map derived by the Environment Agency should be considered only as an initial aid to identifying sites, as it is based on large-scale modelled data and may not be accurate at the local level. The modelling went one nautical mile (nm) from the coast and the location of significant activities (such as dredging), marine assets (such as submarine cables) and ecological risks (such as non-native species), which could restrain a location's potential, have not been considered. Areas not identified on the seagrass restoration potential map may also be suitable for restoration.

The seagrass restoration potential layer is also now available to download from: data.gov.uk/dataset/5b943c08-288f-4d47-a924-a51adda6d288/seagrass-potential

Large-scale national restoration site selection for England: Potential seagrass restoration sites.



SPECIES SELECTION

Species selection will depend on the environmental, biological and physical conditions typical at potential restoration site(s). Consideration should be given to habitat-forming traits and life forms, and matching the tolerance of species with conditions at potential transplant sites. Dwarf eelgrass (*Zostera noltei*) will be suitable for intertidal habitat and common eelgrass (*Zostera marina*) for subtidal habitat.

Regardless of whether the project will be sourcing transplant material or seeds, adequate genetic diversity must be considered in order to support the resilience of restored populations (see "Genetic considerations" section on page 30). However, it is recommended that when restoring mixed intertidal beds, seeds/transplants of common eelgrass are taken from the existing intertidal common eelgrass stock.

BIOTIC AND ABIOTIC CHARACTERISTICS OF SEAGRASS BEDS

The establishment of healthy seagrass habitat depends on the likelihood of seagrass survival, the capacity for growth, and recruitment within the meadow. These processes are influenced by a range of abiotic (e.g. salinity, water temperature, light, water depth, seabed dynamics, substrate) and biotic (e.g. diseases, competition, grazing) factors (see Table 2.2). The optimum conditions for seagrass bed health will be a balance of the suitable conditions across all life stages. Further to this, the conditions at a site will change seasonally, but if these seasonal patterns remain consistent year to year, it can still act as a stable and suitable site.

Large variation exists between the seagrass habitat found across the UK, demonstrating the plasticity of seagrass to respond to a wide range of conditions. The morphological and physiological characteristics of seagrass that vary in response to site conditions on a very localised scale are called bioindicators. For example, high shoot density and cover combined with leaf nutrient bioindicators can indicate that seagrass live in a high-light environment with low nutrient loading. Short, narrow leaves and low shoot densities in shallow seagrass habitat are a possible response to increased wave motion. If measured over time, seagrass bioindicators and site conditions can be used to assess whether local sites will remain a stable, suitable site for seagrass.

One approach to identifying suitable seagrass habitat for restoration is to integrate multiple types and sources of data, such as coupling key large-scale patterns (e.g. hydrodynamic modelling) with a locally derived seagrass physiological model. However, data sets on key conditions known to locally control seagrass survival and growth are often lacking. Field visits, data collection and small-scale pilot studies can therefore help inform on local site conditions and the local seagrass population's suitability for proposed restoration sites.

Table 2.2: Biotic and abiotic parameters of *Zostera marina*. The data provided in this table are sourced from studies across the range of *Zostera marina* but provide a useful starting point. Further information is required from the UK and Ireland to fully understand the environmental parameters for successful seagrass restoration at the local and regional scales.

ABIOTIC AND BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT
Sediment composition	*Zostera marina* can found in a range of sediment EUNIS habitats: • A2.2/5.2 intertidal/subtidal sand, 63μm–0.5mm. > 80% sand (MarLIN). • A2.3/5.3 intertidal/ subtidal mud, < 63μm (silt/ clay fraction). > 80% mud (MarLIN). • A2.4/5.4 intertidal/ subtidal mixed sediments. • 15–90% of silt, particles < 63μm (Zhou *et al.* 2016).	Optimum suggested to be 60–80% (% of silt, particles < 63μm) (Zhou *et al.* 2016). Nitrogen rich sediment can increase vegetative growth while phosphorus enriched sediment can slightly improve vegetative growth (Qin *et al.* 2021).	Optimum likely to be the same as growth. Nitrogen enriched sediment can help stimulate sexual reproduction (Qin *et al.* 2021).	The optimum seed germination sediment is a 2:1 mixture of sand: silt (Wang *et al.* 2016). Anoxic sediment environment increases the likelihood of germination; this is created by finer sediment, as it is less porous (Cumming *et al.* 2017).
Light (% surface irradiance SI mol photons $m^{-2} s^{-1}$)	Minimum light requirements estimated to be 18% surface irradiance (SI); or > 20μmol photons $m^{-2} s^{-1}$ (Lee *et al.* 2007; Erftemeijer and Lewis 2006; Bertelli and Unsworth 2018). Underwater min values of 10.3 ± 7.4μmol photons $m^{-2} s^{-1}$ have been observed in Irish seagrass beds (Beca-Carretero *et al.* 2019).	Between 12% and 37% of SI to survive in the long-term; maximum growth rates of 100–150μmol photons $\mu m^{-2} s^{-1}$ (Dennison and Alberte 1985; Olesen and Sand-Jensen 1993; Lee *et al.* 2007; Erftemeijer and Lewis 2006; Bertelli and Unsworth 2018).	Likely the same as growth, although data unavailable.	Research on light and dark exposure has shown no consistent effect on seed germination (Moore *et al.* 1993).

ABIOTIC AND BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT
Temperature winter, Tmin (°C)	0°C (Zimmerman *et al.* 2017).	13 and 24°C (Lee *et al.* 2007). Stop growing at 20°C and start to die off at 25°C (Reusch *et al.* 2005).	Optimum suggested to be between 15 and 20°C (Nejrup and Pedersen 2008).	Optimum seedling development for North Sea populations of *Zostera marina* occurs at 10°C (Hootsmans *et al.* 1987). In populations at the southern tip of their global distribution, germination occurs at 18–20°C (McMillan 1983), which suggests that this species can tolerate and adapt to a wide range of temperatures.
Temperature summer, Tmax (°C)	30°C-45°C (Zimmerman *et al.* 2017).	13 and 24°C (Lee *et al.* 2007). Stop growing at 20°C and start to die off at 25°C (Reusch *et al.* 2005).	Optimum suggested to be between 15 and 20°C (Nejrup and Pedersen 2008).	Seedlings are unable to survive at higher temperatures (Abe *et al.* 2008) and if summer temperatures exceed 28°C for long periods of time, the species may not recover from seasonal die-offs (Shields *et al.* 2018). Maximum seed germination was recorded in freshwater at 15°C (Xu *et al.* 2016).
Predation	Green shore crabs *Carcinus maenas* have been responsible for a large proportion of seagrass seed depletion as they can consume 10 seagrass seeds a day, with each seed being consumed whole (Infantes *et al.* 2016).	Several different species of herbivorous water birds feed on *Zostera marina* blades: Eurasian coot *Fulica atra*, Swans *Cygnus* spp., Dabbling ducks *Anas* spp. and Brent Geese *Branta bernicula* in intertidal or shallow water areas (Ganter 2000).		
Water depth (m)	Exists in intertidal (up to 4m above chart datum) (Environment Agency 2020), and as low as 10m in clear waters. Will depend upon conditions such as light availability and wave action. Depth limits in turbid estuarine conditions can be < 2m. Around the UK, maximal depth limit is typically between 0.5 and 4m (Davison and Hughes 1998; Jackson *et al.* 2013).	Optimum growth will depend on other conditions, predominantly light availability, but studies suggest most extensive seagrass growth/densities at ~ 2m (Hannam *et al.* 2015; Xu *et al.* 2020) or at 1–6m (Zhou *et al.* 2016).	Some studies show higher numbers of flowering shoots in deeper seagrass bed areas (~ 5.5m, Kim *et al.* 2014) or at deeper seagrass bed edges (Olesen *et al.* 2017).	Seedling recruitment can occur throughout the whole seagrass bed range, although it may be higher at deeper seagrass bed edges where there is a higher proportion of bare area and lower competition (Kim *et al.* 2014; Olesen *et al.* 2017).

ABIOTIC AND BIOTIC CHARACTERISTIC	SURVIVAL	GROWTH	REPRODUCTION	RECRUITMENT
Salinity (PSU or ppt)	10–39 PSU (Davison and Hughes 1998).	15–20 PSU for optimal growth (Zhou *et al.* 2016).	Data unavailable.	Optimum salinity for *Zostera marina* seedling establishment and colonisation appears to be above 20 PSU in natural beds (Xu *et al.* 2016). Rapid near-complete germination found at full salinity (30 ppt) under anaerobic conditions, or at lower salinity (15 ppt) under aerobic conditions (Probert and Brenchley 1999).
Oxygen conditions (mg l^{-1})	Not reported in the literature. Believed to be tolerant of low oxygen in the short-term but long periods of low oxygen may have an impact (MarLIN).	Data unavailable.	Data unavailable.	Moore *et al.* (1993) found that *Zostera marina* seeds needed to be buried in at least 0.5cm of anoxic sediment to germinate. Anaerobic conditions are preferred for higher germination rates but dependent on salinity (see above, Probert and Brenchley 1999).
Current velocity (ms^{-1})	5–180 $cm.s^{-1}$ (Koch 2001).	Optimal velocity $\leq 0.5 ms^{-1}$ (Tyler-Walters 2008; Zhou *et al.* 2016).	Data unavailable.	Data unavailable.

ESTABLISH A REFERENCE OR TARGET ECOSYSTEM

Reference ecosystems are existing seagrass sites with available data that can guide seagrass restoration planning. They also provide a foundation for identifying indicators of resilience and success in a project's later stages. It is recommended to use a composite reference that incorporates several different sites in order to incorporate a variety of factors that may impact seagrass growth.

Ecosystems with long-term data can be especially helpful as references, because they represent the system in a range of states, and at different stages of development (see Isles of Scilly case study in Box 2.6). Unfortunately, most seagrass restoration projects do not have long-term data available, because they are newly established or have only recently begun monitoring. Practitioners need to be mindful of sliding baseline syndrome when selecting reference sites, and the target ecosystem should be resilient to environmentally driven ecological shifts (see Box 2.5).

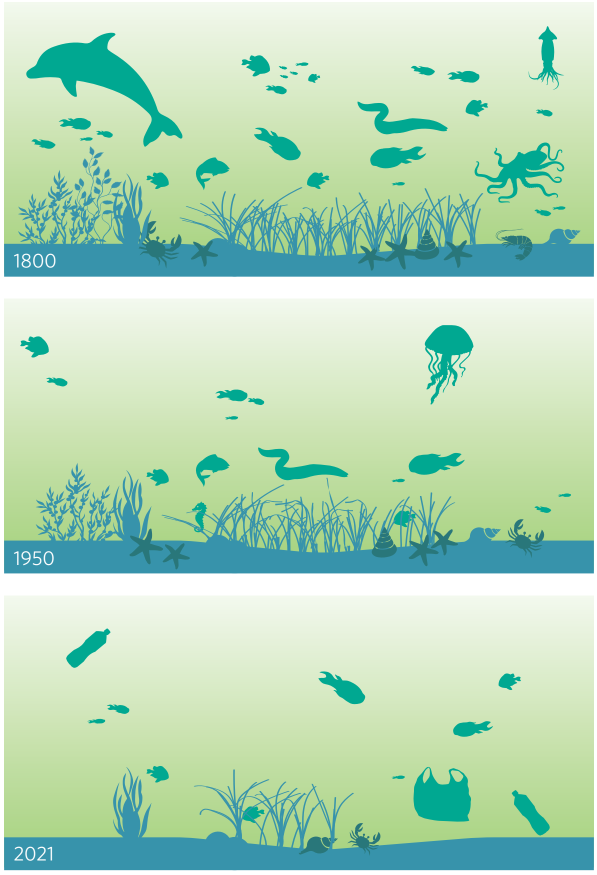
BOX 2.5: SHIFTING BASELINE SYNDROME AND ECOSYSTEM SHIFT CONSIDERATIONS IN RESTORATION

Shifting baseline syndrome describes the gradual decline in the threshold of environmental conditions or states that are considered 'normal' or 'healthy', due to the loss of memory or knowledge of previous historic ecosystem states (Soga and Gaston 2018). Therefore, given recent decades of decline and often poorly quantified recording, particularly pre-1980s, current seagrass state may not represent a stable or desirable reference ecosystem. This syndrome is common in conservation and restoration interventions and highlights the value of using historical information to help define a healthy and resilient reference ecosystem.

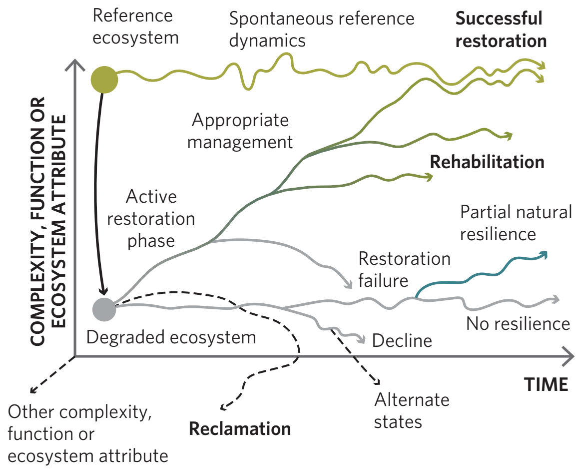
More recently, it has been recognised that ecosystems can shift from one state to another ('ecosystem shift'). This can create challenges when a relatively small environmental perturbation causes a transition to a degraded, less biodiverse and complex alternative state, but a much larger environmental change is needed to transition the habitat back again (see conceptual framework). For example, healthy seagrass has a positive effect on the habitat, yet transition to a poorer state can occur rapidly once initiated, due to the resulting loss of sediment stabilisation and water clarity. To reverse this degradation, a critical threshold density or area must be achieved that enables positive feedback. This is essential to successful seagrass restoration.

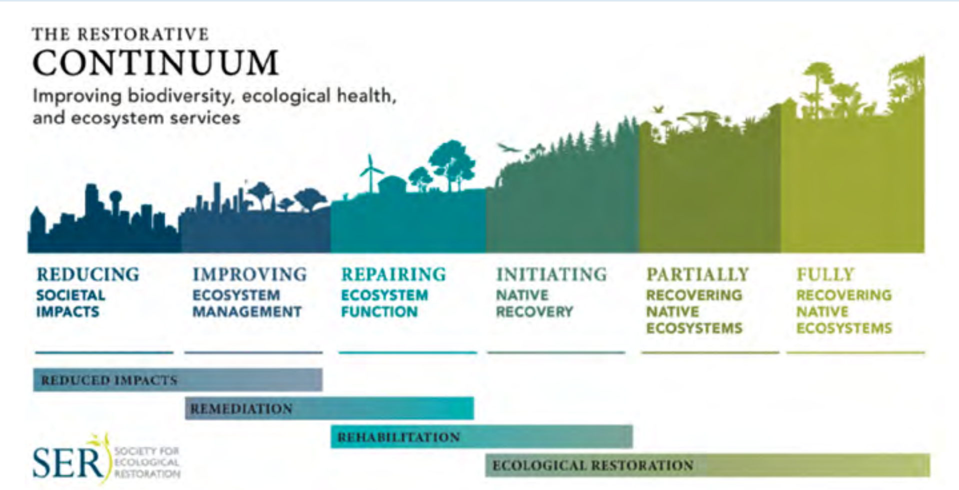
Marine habitat restoration can play a key role in overcoming challenges associated with global environmental change. It is hoped that this recognition will lead to larger-scale efforts to restore the ecosystem functions and services upon which humans depend.

Conceptual infographic to illustrate shifting baseline syndrome



Conceptual framework for restoration and the role of ecosystem resilience





KEY ECOSYSTEM ATTRIBUTES OF A REFERENCE ECOSYSTEM

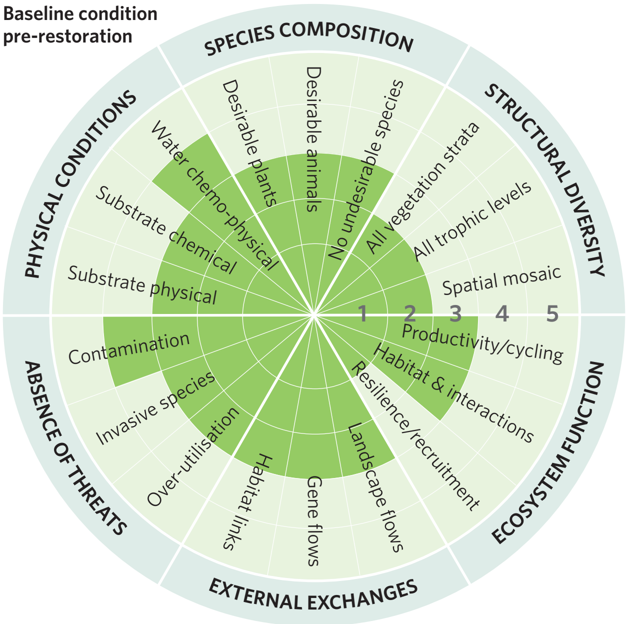
To help formulate a reference ecosystem, the ecosystem attributes desired as an outcome of a restoration project must be clearly defined. See Figure 2.5 for a description of these attributes used to characterise a reference ecosystem and an example of how a recovery wheel can be used as a tool to map ecosystem restoration progress.

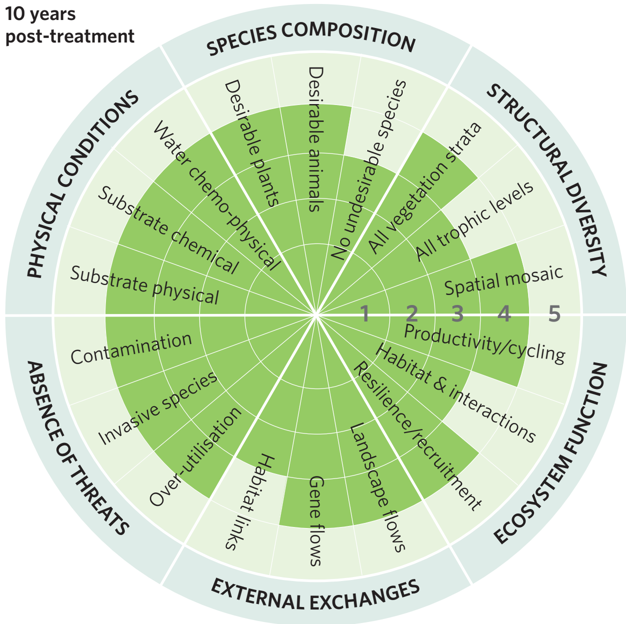
Templates are available at seraustralasia.com/standards/appendix5.html or as an online tool seraustralasia.com/wheel/wheel.html.

The recovery wheel is designed to work with a five-star system that denotes the level or recovery across the ecosystem attributes. See Gann *et al.* (2019) for further details. It is important that practitioners adapt the five-star ratings to be site- and scale-specific.

ATTRIBUTE	DESCRIPTION
Absence of threats	Direct threats to the ecosystem such as overutilisation, contamination, or invasive species are absent.
Physical conditions	Environmental conditions (including the physical and chemical conditions of soil and water, and topography) required to sustain the target ecosystem are present.
Species composition	Native species characteristic of the appropriate reference ecosystem are present, whereas undesirable species are absent.
Structural diversity	Appropriate diversity of key structural components, including demographic stages, trophic levels, vegetation strata and spacial habitat diversity are present.
Ecosystem function	Appropriate levels of growth and productivity, nutrient cycling, decomposition, species interactions, and rates of disturbance.
External exchanges	The ecosystem is appropriately integrated into its larger landscape or aquatic context through abiotic and biotic flows and exchanges.

a) Key ecosystem attributes table: Description of the key ecosystem attributes used to characterise the reference ecosystem, as well as to evaluate baseline condition, set project goals, and monitor degree of recovery at a restoration site.





b) Recovery Wheel: The ecological recovery wheel is a tool for conveying progress of recovery of ecosystem attributes compared to those of a reference model. In this example, the first wheel represents the condition of each attribute assessed during the baseline inventory stage of the project. The second wheel depicts a 10-year-old restoration project, where over half its attributes have attained a four-star condition.

Figure 2.5: a) Key ecosystem attributes table and b) recovery wheel for monitoring restoration projects against a reference ecosystem. Recovery wheel kindly provided by the Society for Ecological Restoration. Blank recovery wheel templates available to download from: cdn.ymaws.com/www.ser.org/resource/resmgr/custompages/publications/ser_publications/recovery_wheel.pdf.

BOX 2.6: THE ISLES OF SCILLY SPECIAL AREA OF CONSERVATION – A CASE STUDY OF LONG-TERM SEAGRASS MONITORING

Long-term monitoring is essential to understanding seagrass ecology and restoration success. It allows for the measurement of long-term trends and establishes an understanding of processes supporting resilience.

The Isles of Scilly archipelago incorporates a Special Area of Conservation, including one of the largest seagrass bed complexes in the UK. Following concerns about recurrence of wasting disease, annual monitoring of the seagrass was established in the mid-1990s. Specific objectives included measuring key above-ground seagrass metrics, including shoot density, shoot morphology and flowering prevalence, as well as percentage cover estimates of wasting disease and epiphytes. Using this 25-year-old data set, transient dips in seagrass can be separated from longer-term trajectories, allowing a focus on genuine threats. Spatial replication of quadrats assessed within each location also allows a focus on multiple scales of above-ground growth.

Robust baseline data provide a foundation for identifying indicators of resilience and success. Environmental data including currents, bathymetry, light levels, and temperature are available from databases such as the European Marine Observation and Data Network (EMODnet, see emodnet.eu/en). This multivariate approach is necessary to understand changes in ecological processes, such as metapopulation rescue effects and gene flow. Similarly, this long-term approach to annual data collection is necessary to understand the processes and mechanisms responsible for persistence and resilience in a natural seagrass ecosystem.


Seagrass survey taking place on the Isles of Scilly. Photos: Chiara Bertelli.

KEY STAKEHOLDERS TO INVOLVE IN A PROJECT

Identifying key stakeholders and engaging with them in the early stages of project development is vital to establishing a successful project (see Figure 2.6 and Chapter 5 for more detail). Engagement with stakeholders can reduce conflict and promote project success through increased understanding and support, access to local ecological knowledge and increased opportunities to engage with local natural resources management strategies. Early engagement can also increase a sense of ownership in the community, hence resulting in greater voluntary protection and compliance with management of the restoration site(s).

The first stage in a stakeholder engagement process is to identify key stakeholder groups and put in place mechanisms to promote diversity, equality and inclusivity. This can be achieved through a rapid stakeholder assessment conducted as follows:

1. Convene an interdisciplinary work group that represents a variety of areas of expertise, such as ecology, fisheries management, maritime, regulation, hydrology, economics, political science and engineering.
2. Define the geographic boundaries and scale of interest. These will vary depending upon biophysical aspects of the restoration project, hydrology, jurisdiction, and location of stakeholders who are benefiting from or impacted by the project. It may be worth considering a scale larger than the project site itself, as restoration may impact ecosystem service values at a larger scale.
3. List the ecosystem service/ecological benefits that will result from the upcoming restoration/protection project(s). Consult with the interdisciplinary work group to determine which benefits are most likely.
4. List all relevant stakeholders in the project, including beneficiaries and those who may be impacted negatively, and those who have the power to influence the success or failure of the project.
5. Determine the relative importance of each ecosystem service benefit, based upon expected number of beneficiaries and magnitude of benefit.
6. Understand and be able to effectively communicate potential trade-offs in ecosystem service delivery.

Note: While steps one to six are listed sequentially, the process is iterative and may involve circling back to previous steps as additional information is gained.

It is recommended that approximately two to three months be assigned to complete a rapid stakeholder assessment. This can run concurrently with exploration of logistical considerations.

Figure 2.6: Potential stakeholders to consider involving in the design and delivery of a seagrass bed restoration project.

GENETIC CONSIDERATIONS

Seagrass populations must be able to adapt to environmental change, such as climate change or the outbreak of new pests and diseases. As genetic diversity provides the building blocks that lead to adaptation, restoration projects should aim to maximise genetic diversity in new populations to increase long-term success. Globally, plant restoration success is rather limited, including for eelgrass: on average only 50% of reintroduced plants survive, < 20% produce flowers or fruits and further declines beyond monitoring periods are likely (Van Katwijk *et al.* 2009). Increasing restoration success by introducing the best possible genetic mix of individuals is therefore of utmost importance.

The three major genetic considerations when restoring populations are:

- maximising genetic diversity
- avoiding inbreeding
- enabling or maintaining gene flow

Genetic diversity is the sum of all genetic variations found in a plant or population, or loosely the genetic variety of plants. Genetic diversity found in wild populations will determine the diversity that is available for restoration of a given species. A restoration site should aim to have a genetic diversity as high as a healthy, large natural population. Information on such populations can be helpful in guiding the definition of restoration success.

Inbreeding is the mating between close relatives (also ‘selfing’ in plants). It results in offspring that are likely to inherit more harmful genetic information compared to outbred individuals. This is because the parents have a similar genetic make-up and similar harmful alleles which are more likely to be expressed in their offspring. In plants, the fitness decrease caused by inbreeding (called **inbreeding depression**) can, for example, lead to reduced seed set, germination, or survival rates. While eelgrass is self-compatible, the species has been shown to be negatively affected by inbreeding depression, by producing smaller seeds and having a reduced gamete (plant) size (Hämmerli and Reusch 2003). In wild, widespread and connected populations, mixing of unrelated individuals happens naturally through the exchange of pollen or seed between populations (called **gene flow**). Small and isolated populations generally have a lower fitness due to genetic issues caused by inbreeding. The remedy for such populations is gene flow.

Gene flow is the exchange of genes between populations. For seagrass, gene flow generally happens through pollen or seed dispersal in the water and/or parts of rhizomes breaking off and being transported to new locations through currents. Gene flow helps keep genetic diversity high and inbreeding levels low. It can also reverse negative genetic effects caused by inbreeding depression.

Warning: Mixing populations may also have adverse consequences, such as introducing maladapted genes, or negative allelic combinations that cause outbreeding depression (reduced fitness caused by outbreeding). While the likelihood of outbreeding depression is low in largely connected habitats such as marine environments, it is advisable to refrain from mixing populations that are genetically very distinct or geographically very distant. In the long term, natural selection will favour the best adapted genotypes and outbreeding depression, if present, will be only a short-term issue.

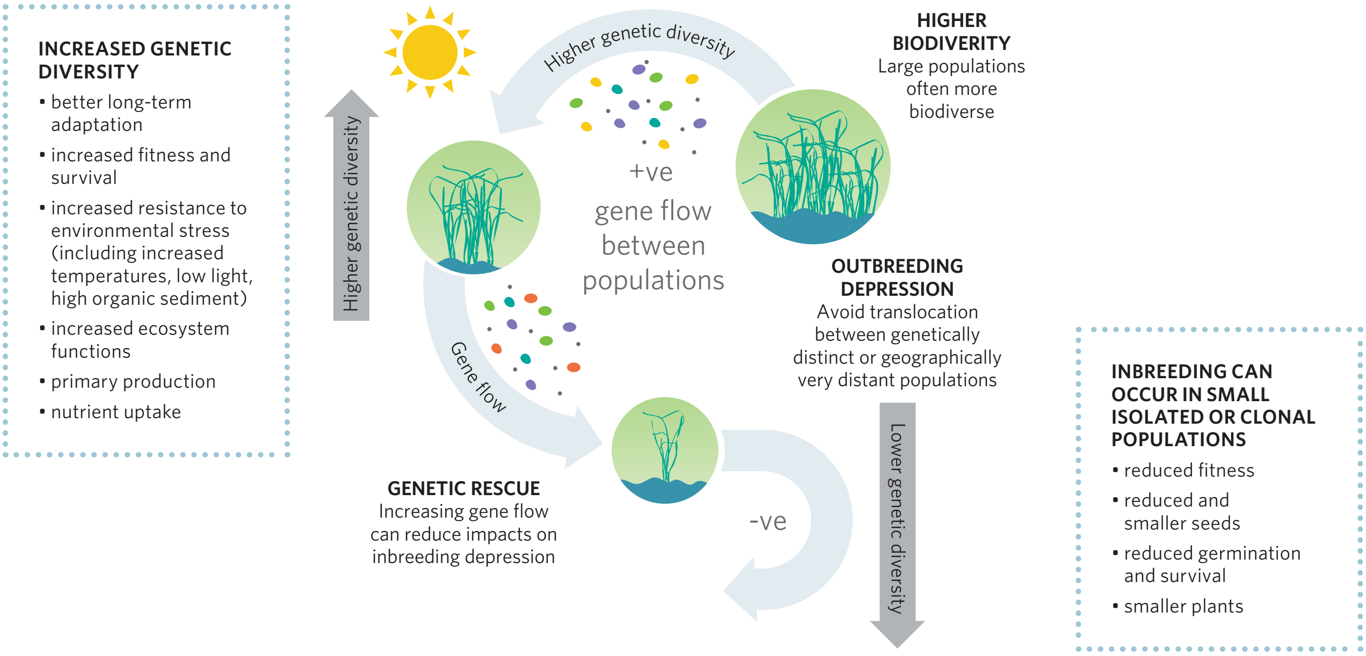


Figure 2.7: Genetic considerations and impacts on seagrass health and restoration success.

BOX 2.7: RECOMMENDATIONS FOR RESTORATION PRACTICE TO MAXIMISE GENETIC DIVERSITY AND GENETICALLY HEALTHY SEAGRASS POPULATIONS

Maximise genetic diversity:

- *Mix plant material from different source populations.* This has been shown to have positive effects on the survival and reproductive success of reintroduced plants.
- *Avoid sampling clones* (genetically identical rhizomal growth) *from the source population.* Clonal growth is common in eelgrass and varies significantly between different populations. Some (even large) populations consist of only one clone/individual and are therefore less suited to being a source population for restoration projects.
- Collect source material from large populations.

Reduce inbreeding (inbreeding values):

- *Mix plant material from different source populations.*
- *Use root stock/plant source material if inbreeding values are high*, as eelgrass is self-compatible and there is a risk of collecting selfed seeds.

Enable or maintain gene flow:

- *Facilitate genetic rescue.* Ensure there is gene flow between restoration sites, either by placing sites in close proximity to each other, or by artificial gene flow.
- *Select restoration sites to ensure gene flow between nearby natural sites.* How close sites need to be to ensure gene flow depends on currents and the dispersal abilities of the species, which for seagrasses can be up to several hundred metres.

Avoid outbreeding depression:

- *Avoid mixing genetically distinct populations.* The risks of outbreeding depression are low if habitats of mixed populations are similar and populations have not been (genetically) isolated from each other for more than 500 years.
- *Avoid using geographically distant source populations.* Exact distances depend on a species' dispersal abilities. Common eelgrass has dispersal distances of up to hundreds of kilometres (McMahon *et al*. 2014; Kendrick *et al.* 2012; 2017) and genetic studies suggest that this is also likely the case for dwarf eelgrass (Kendrick *et al*. 2012).
- *Test for outbreeding depression in a controlled environment prior to project start.* Hand-pollinating individuals from different populations as well as individuals within populations in an experimental set-up will reveal fitness effects on seed viability, germination, plant size and survival (Ruckelshaus 1995).

ASSESSING GENETIC DIVERSITY OF SEAGRASS POPULATIONS

When planning a restoration project, it is recommended to consider genetic information on the seagrass sites. This will provide insight into how depleted natural populations are. Secondly, it will allow for the identification of high-diversity sites that can be used as source populations (e.g. for seed collections) or to determine a range of sites that can be mixed to achieve high diversity.

For some species (e.g. common eelgrass), data on diversity and inbreeding are already available for many populations, in which case they can be sourced via a literature review. If no such data are available, projects are advised to collaborate with universities or bioinformatic companies early on as they will advise on sampling. Genetic studies are highly technical, can be costly (depending on the number of species and populations) and need to be undertaken by specialist laboratories. It is advisable to collect source material from large populations, as they are more likely to be highly diverse. Sampling within populations should avoid collecting clones by collecting plants that are several metres apart.

BOX 2.8: RECOMMENDATIONS FOR PLANT TRANSLOCATIONS

The best practices for plant translocations consider both the extent of local adaptation and the amount of genetic diversity. To account for local adaptation, most current reintroduction projects delineate suitable seed source zones in geographically nearby or environmentally similar areas to the target site. The underlying assumption is that these source populations will contain locally adapted alleles that confer survivorship to the environment of the threatened target population (due to a distance decay relationship of genetic similarity) and will be most suitable in terms of local adaptation because they come from similar environments (‘**local provenancing**’).

Another approach is simply to mix populations of local provenances while also including a few more distant provenances (‘**composite provenancing**’), which should not only avoid outbreeding depression but also increase genetic diversity and build a pool of standing genetic variation on which natural selection may act. This will potentially make the population more resilient to a changing environment. Identify key sites as suggested in the Science for Environment Policy seascape management issue.

For more information, see the Scottish and English guidelines for conservation translocations.

BIOSECURITY CONSIDERATIONS IN SEAGRASS RESTORATION

INVASIVE NON-NATIVE SPECIES

In the UK, some 90 non-native species have been identified in marine and brackish environments, of which 58 have established (Minchin *et al.* 2013). Although some seagrass species are significant INNS (e.g. the Tropical seagrass (*Halophila stipulacea*) in the Mediterranean and Caribbean), there is no specific evidence of UK native seagrass species as significant INNS vectors. However, restoration and enhancement projects may pose additional risk due to the possible movement of people, plants, substrate, vessels and seawater.

It is considered that translocation of native seagrass seeds alone would present a low risk. However, translocation of whole plants or plant structures may represent a risk as they are often colonised with epiflora and fauna which could include hard-to-detect species or juvenile life stages. Seagrass plants and beds are used as breeding grounds for many species, meaning that translocation of eggs could present an additional risk. These risks are amplified if seagrass plants are translocated with associated sediment and seawater.

Therefore, it is important that any seagrass restoration project involving the translocation of biological material between different localities adopts a precautionary approach to biosecurity. Some areas, particularly those with significant international shipping routes (such as The Solent), are hotspots for marine INNS. An awareness of the INNS present should inform appropriate efforts to screen material and restrict the transfer of any unnecessary materials, seawater and so on.

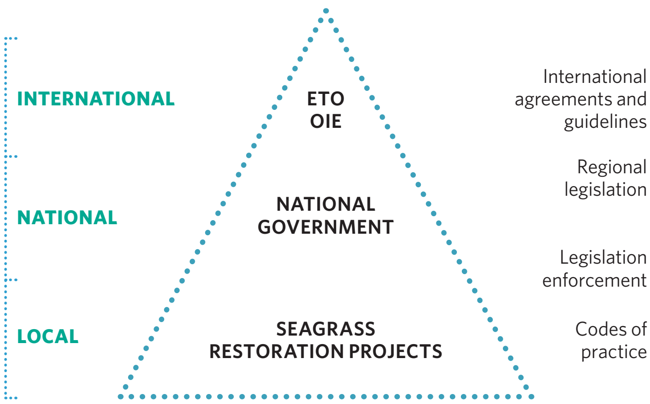


Figure 2.8: Legislation and policy regarding biosecurity function at a variety of scales, all of which projects should be aware of and seek advice on.

Note: OIE = World Organisation for Animal Health. ETO= Extraterritorial obligations.

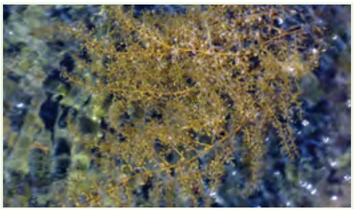
SPECIES:		IMPACT:
Japanese wire weed (*Sargassum muticum*) Photo: Rosser1954, (some rights reserved) CC BY-SA-4.0 via Wikimedia Commons		Changes the physical /chemical characteristics of the local environment and creates the potential for changes in the epibionts associated with the seagrass blades (DeAmicis and Foggo, 2015).
Common cordgrass (*Spartina anglica*) Photo: Stock photo ID: 1215958798		*Spartina anglica* can encroach on intertidal seagrass beds from the upper shore, displacing seagrass which can reduce its availability as food to overwintering birds such as Brent Geese and widgeon (Percival *et al*. 1998).
Slipper limpet (*Crepidula fornicata*) Photo: Joanne Preston		Stops seagrass from reestablishing in areas as dead shells prevent propagule growth.
Harris mud crab (*Rhithropanopeus harrisii*) Photo: Majk90 (own work) CC-BY-SA-3.0 via Wikimedia Commons		Mud crab burrowing behaviour could disturb seagrass, especially transplanted shoots that are not stabilised by complex root and rhizome structures (Engström and Linn, 2020).
Asian shore crab (*Hemigrapus takanoi*) Photo: John Bishop © MBA		This species has only recently been discovered in the UK, so the potential impacts are unknown. Direct impacts to seagrasses are likely to be low unless they also predate upon seagrass seeds.
Wakame (*Undaria pinnatifida*) Photo: CSIRO (http://www.scienceimage.csiro.au/pages/about/)		Wakame is a non-native species of kelp that is able to outcompete native kelp species. Its ability to colonise a variety of substrates and conditions (marine and estuarine) raises concerns for its potential to outcompete seagrasses.

Figure 2.9: Examples of UK INNS of relevance to seagrass restoration projects.

DISEASE

The best-known infectious disease affecting seagrass is known as wasting disease. Historically, huge dieback of seagrass has been attributed to this disease, with very substantial losses reported in the 1930s. Sometimes records are of variable quality, but wasting disease undoubtedly contributed to major losses across the North Atlantic during the 20th century.

The causative agent of wasting disease is identified as *Labyrinthula zosterae*, a single-celled organism of the superphylum Heterokonta. *L. zosterae* spreads through host plant tissues, causing cell death and eventually resulting in the death of infected leaves and shoots. Transmission is often by direct contact between leaves but there are also likely to be longer-range mechanisms, by rafting of infected plant material, and pathogen DNA has even been identified on waterfowl associated with seagrass. However, pathogenicity and transmission seem to be low in the absence of environmental stressors.

In addition to wasting disease, other fungal pathogens have been reported in seagrasses. For example, marine *Phytophthora* fungi can cause bed degradation and reduce germination success. Prior to planting seeds or plants, they should be soaked in a 2ppm copper solution to sterilise the seed from pathogens and encourage germination.

In the short-term and as a precaution, rigorous hygiene is strongly advised when translocating seagrass for planting. In the longer term, research into genetic susceptibility of certain seagrass genotypes may help reduce the likelihood of adverse environmental events triggering disease outbreaks.

Table 2.3: Overview of known seagrass pathogens and hosts. Table modified from Sullivan *et al.* (2018).

AGENT OF DISEASE	HOST SPECIES	TYPE	SYMPTOMS	REFERENCES
Halophytophthora sp. zostera	*Zostera marina*	Oomycetes, Heterokonta	Reduced seed germination, impaired seedling development	Govers *et al.* 2016; Govers *et al.* 2017
Labyrinthula sp. including *L. zosterae*	*Zostera marina* *Zostera caulescens* *Zostera japonica* *Zostera noltei* *Zostera pacifica* *Cymodocea nodosa* *Posidonia oceanica* *Ruppia cirrhosa* *Ruppia maritima* *Syringodium isoetifolium* *Thalassia testudinum*	Labyrinthulomycete, Heterokonta	Leaf lesions, mortality if lesion advancement out-grows new leaf growth	Garcias-Bonet *et al.* 2011; Martin *et al.* 2016; Muehlstein *et al.* 1991
Phytophthora gemini	*Zostera marina*	Oomycetes, Heterokonta	Reduced seed germination (seed pathogen)	Govers *et al.* 2016; Govers *et al.* 2017
Plasmodiophora bicaudata	*Zostera noltei* *Zostera capensis* *Zostera muelleri* *Zostera japonica*	Phytomyxea, Rhizaria	Shoot galls	Den Hartog 1989

WORKING IN MARINE PROTECTED AREAS

Marine Protected Areas (MPAs) are designated to protect marine features of nature conservation importance. See Table 2.4 for a summary of MPAs in the UK. Most seagrass restoration in MPAs is likely to take place on the seabed in one of the habitat biotopes listed in Box 1.2, Chapter 1.

Seagrass beds can be named features of Sites/Areas of Special Scientific Interest (SSSIs/ASSIs), Nature Conservation Marine Protected Areas (NCMPAs) and Marine Conservation Zones (MCZs). Within Special Areas of Conservation (SACs), seagrass beds can be component parts of the Annex I features: estuaries, large shallow inlets and bays, intertidal mudflats and sandflats, and sandbanks.

Figure 2.10: Seagrass bed beneath the Helford River SAC in Cornwall, providing crucial habitat to (left) a small-spotted catshark and (right) a shoal of juvenile pollock. Photos: Lewis Jefferies.

To determine how best to work within the MPA and avoid detrimentally impacting its designated features, it is suggested to have early contact with the statutory nature conservation body (SNCB) as well as the appropriate regulator. All protected sites will have information about the features that are protected and the aims for their conservation. This information can be found in various formats, depending on the type of site and SNCB. Information on protected sites can be found on the relevant SNCB websites. For example, data and maps from the Welsh public sector can be found on DataMapWales, Natural England's Designated Sites View provides further information on inshore site designations, while the Joint Nature Conservation Committee's Site Information Centres provide further details on offshore sites.

Any activity that involves the removal or placement on the seabed below mean high water springs (MHWS) requires a marine licence. It is important to note that any project in an MPA will need to undergo some form of assessment, depending on the designation, to identify any adverse impacts of the project, which will require mitigation over its course. Further details on this can be found in the section on licensing and permit requirements.

Table 2.4: Marine Protected Areas in the UK.

DESIGNATION	ABBREVIATION	JURISDICTION	LEGISLATION
Marine Conservation Zone	MCZ	England, Wales Northern Ireland	Marine and Coastal Access Act 2009 Marine Act (NI) 2013
Nature Conservation Marine Protected Area	NCMPA	Scotland	Marine (Scotland) Act 2010; Marine and Coastal Access Act 2009
Site of Special Scientific Interest (England, Scotland, Wales)	SSSI	England, Wales Scotland	Wildlife and Countryside Act 1981 as amended (primarily by the Countryside and Rights of Way Act 2000) Nature Conservation (Scotland) Act 2004
Area of Special Scientific Interest (N. Ireland)	ASSI	Northern Ireland	Environment (Northern Ireland) Order 2002
Natural Heritage Area	NHA	Ireland	The Wildlife (Amendment) Act, 2000
Special Area of Conservation and Special Protection Area	SAC/SPA	England, Wales Scotland Northern Ireland Ireland EU	The Conservation of Habitats and Species Regulations 2017, as amended The Conservation (Natural Habitats, &c.) Regulations 1994, as amended The Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1994 (as amended) The Wildlife (Amendment) Act, 2000 and the Birds and Natural Habitats Regulations 2011 EC Habitats Directive 92/43/EEC and EC Birds Directive 2009/147/EC
Ramsar Site		International	Ramsar Convention 1976

PERMITTING AND LICENSING REQUIREMENTS

Seeking early engagement with key government agencies early in a project is of utmost importance for any proposed restoration project. While some policy, governance and legal aspects are common to all UK administrations, there are also differences and it is the responsibility of the restoration practitioner to ensure that they seek advice and follow due procedure for all restoration projects. Additionally, the use of seagrass nursery ponds or aquaculture facilities that discharge water into the environment will require a permit from the body that regulates water quality.

It is advisable that licence and permissions requirements be researched in detail and the competent authorities relevant to the restoration locality be consulted early on in project planning. An overview of the competent authorities and advisory agencies for nations across the UK and the Republic of Ireland is given in Table 2.5. The underpinning legislations and inshore relevant authorities are provided in Figure 2.11.

There are broad areas of jurisdiction, which include:

- **Marine licensing and marine planning** – for activity in the sea and on the seabed.
- **Protected species licence** – for activity that may kill, take, disturb or possess a protected species for survey, research or conservation work.
- **Seabed owner** – permissions or licences will be needed from the seabed owner e.g. the Crown Estate or harbour authority.
- **Habitat regulation assessment** – Conservation advice should be reviewed for proposed activities that take place within a MPA, or adjacent to it, and which could potentially affect the habitats and species within.
- **Water quality** – relates to activities that impact or are impacted by water quality.

Further to this are considerations about safe navigation at sea and protection of assets of historic importance.

A marine licence constitutes a statutory consent. The named licence holder is responsible for ensuring its conditions are complied with in full and will be binding upon any agent or contractor who undertakes any activity of the project on their behalf.

The applicant should bear in mind that it may take several months to get a licence. Once issued, the licence will likely have conditions to be discharged before the project can commence, e.g. issuing Notices to Mariners. These considerations need to be factored to project planning. Engaging with the regulator would ideally start 12 months before restoration activity to start in the field.

The cost of a licence is set by each nation's body that regulates marine activities. Costs to budget for may include 1) seeking pre-application advice to inform the application e.g. method statement, 2) the cost of the permit, 3) post-licensing work associated with the licence, including discharge of conditions.

Table 2.5: Competent inshore authorities and advisory agencies for areas requiring licensing and permissions in the UK and the Republic of Ireland.

	ENGLAND	WALES	N. IRELAND	SCOTLAND	IRELAND
Marine licences	Marine Management Organisation (MMO)	Natural Resources Wales	Department of Agriculture, Environment and Rural Affairs (DAERA)	Marine Scotland	Aquaculture and Foreshore Management Division
Foreshore and seabed leases	Crown Estate	Crown Estate	Crown Estate	Crown Estate Scotland	Department of Housing, Local Government and Heritage
Assessing impacts in MPAs	Natural England	Natural Resources Wales	DAERA, Marine and Fisheries Division	NatureScot	National Parks & Wildlife Service (NPWS), Marine Institute and Bord Iascaigh Mhara (BIM)
Inshore fisheries	Inshore fisheries and conservation authorities (IFCAs)	Welsh Government	Inshore and Environment Branch of DAERA	Marine Scotland	BIM and Marine Institute
Water environment & quality	Environment Agency	Natural Resources Wales	Northern Ireland Environment Agency (NIEA)	Scottish Environment Protection Agency (SEPA)	EPA (Environmental Protection Agency)

MARINE MANAGEMENT, LICENSING, NATURE CONSERVATION AND FISHERIES AUTHORITIES

ENGLAND

Marine licences:
The Marine Management Organisation (MMO) delivers planning, licensing activities and enforcement functions in English waters from mean high water springs.

Nature conservation:
Natural England (from 0 to 12nm, territorial waters) advises on the designation and management of Marine Protected Areas (MPAs) in inshore waters.

Foreshore and seabed leases:
The Crown Estate manages and leases the seabed and half of the foreshore (under the Crown Estate Act 1961).

Water quality:
The Environment Agency monitors and works to protect the quality of estuaries and coastal waters. Relevant legislation includes the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017.

NORTHERN IRELAND

The Northern Ireland Executive has executive competence over:

- marine conservation
- marine planning
- marine licensing
- fisheries and aquaculture

Marine licensing:
The Department of Agriculture, Environment and Rural Affairs (DAERA) regulates marine licensing under the Marine and Coastal Access Act 2009.

Nature conservation:
DAERA designates and advises on the management of MPAs in inshore waters.

Foreshore and seabed leases:
The Crown Estate manages and leases the seabed and half of the foreshore under the Crown Estate Act 1961.

Water quality:
DAERA Marine and Fisheries Division monitors and works to protect the quality of estuaries and coastal waters. Relevant legislation includes the Water Environment (Water Framework Directive) Regulations (Northern Ireland).

SCOTLAND

The Scottish Parliament has devolved competence over:

- marine conservation
- marine planning
- marine licensing
- fisheries and aquaculture

Marine licensing:
Marine Scotland regulates marine licensing, on behalf of the Scottish Parliament, under the Marine (Scotland) Act 2010.

For more information on planning restoration activities in Scotland, Seagrass restoration in Scotland – Handbook and Guidance (Kent *et al.* 2021).

Nature conservation:
NatureScot advises on the designation and management of MPAs in inshore waters.

Foreshore and seabed leases:
The Crown Estate Scotland manages and leases the seabed and half of the foreshore under the Crown Estate Act 1961 and the Scotland Act 2016.

Water quality:
The Scottish Environment Protection Agency monitors and works to protect the quality of estuaries and coastal waters. Relevant legislation includes the Water Environment (Controlled Activities) (Scotland) Regulations 2011.

REPUBLIC OF IRELAND

Marine licensing:
Dredging and dumping-at-sea licences are regulated by the Environmental Protection Agency. Aquaculture and sea fisheries are regulated by the Aquaculture and Foreshore Management Division of the Department of Agriculture, Food and the Marine.

Nature conservation:
The National Parks & Wildlife Service is the competent authority for conservation of MPAs.

Foreshore:
The Department of Housing, Local Government and Heritage regulates the use of the foreshore through a system of leasing and licensing under the Foreshore Act 1933.

Water quality:
The Environmental Protection Agency monitors and works to protect the quality of estuaries and coastal waters. Relevant legislation includes the European Communities (Water Policy) Regulations 2003.

WALES

The Welsh Government has devolved competence over:

- marine conservation
- marine planning
- marine licensing
- fisheries and aquaculture

Marine licensing:
Natural Resources Wales regulates marine licensing, on behalf of the Welsh Government, under the Marine and Coastal Access Act 2009.

Nature conservation:
Welsh ministers designate MCZs under the UK Marine and Coastal Access Act. Natural Resources Wales advises on the designation and management of MPAs in inshore waters.

Foreshore and seabed leases:
The Crown Estate manages and leases the seabed and half of the foreshore under the Crown Estate Act 1961.

Water quality:
Natural Resources Wales monitors and works to protect the quality of estuaries and coastal waters. Relevant legislation includes the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017.

Note
The Northern Ireland and Welsh Governments can ask MMO to undertake functions on their behalf.

Source: Adapted from SPICe Briefing (2009) comparison of UK and Scottish Marine Bills, using additional data and updated information.

Maps not to scale.

Figure 2.11: Marine management, licensing and nature conservation authorities for coastal waters across the UK and the Republic of Ireland, with the underpinning legislation highlighted.

FUNDING OF RESTORATION PROJECTS

To successfully secure funding, it is important to have a clear project goal at the outset and to define the outcomes that the project will achieve. To achieve these outcomes, defined outputs that the donor would like to see will be listed alongside who will deliver them. Successful restoration can take several years and a range of funders may be required throughout the project life cycle. A project can be divided into work packages to help target different funders. Similarly, funders may only partially fund project costs and prefer to co-fund to reduce their risk. Match funding from other stakeholders, in-kind funding (e.g. staff time or facilities) and/or volunteer time is often required.

Although blue carbon is a growing area of interest and a potential source of funding for blue carbon habitats such as seagrass, there are many complexities to consider (see Box 2.9). Other ecosystem services that seagrasses provide will likely be attractive to funders looking to invest in either nutrient trading, biodiversity offsets or biodiversity net gain. Other drivers of funding include mitigation of coastal erosion and supporting habitats that support and sustain fish stocks. Increasingly, achieving the United Nations' Sustainable Development Goals is a driver of funding for marine habitat restoration.

Examples of the types of existing funding streams available to a marine habitat restoration include:

Government/public funding

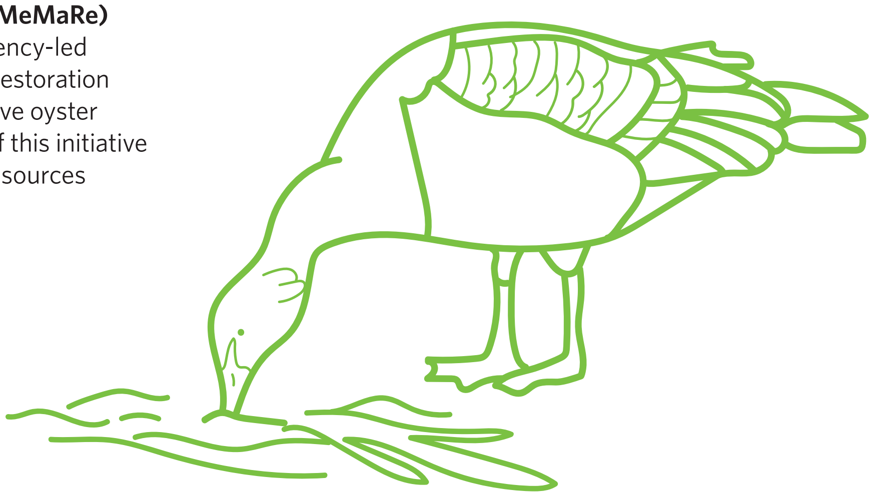
- **European funding bodies** e.g. LIFE Programme of the European Union.
- **UK Government** e.g. Natural England, NatureScot, Natural Resources Wales, Marine Institute Ireland
- **Water Environment Improvement Fund (WEIF, England):** The WEIF scheme provides funding to improve the water environment in rural England, including by enhancing protected areas and achieving Water Environment Regulations objectives.
- **Flood and coastal erosion protection funding (grant-in-aid):** If a scheme has flood defence potential, it may be eligible for funding through Flood and Coastal Erosion Risk Management Grant-in-Aid partnership funding.
- **Restoring Meadows, Marsh and Reef (ReMeMaRe) (England):** This (English) Environment Agency-led initiative aims to facilitate the coordinated restoration of 15% of England's priority saltmarsh, native oyster reef and seagrass habitats by 2043. Part of this initiative involves exploring different and innovative sources of funding for restoration.

Community/developer funding

- **Philanthropic organisations:** Private foundations or trusts may finance nature restoration projects for charitable reasons. They generally fund registered charities or organisations only.
- **Lottery funding** e.g. National Lottery Heritage Fund: Supports a range of projects, including nature conservation initiatives that protect and preserve historic and rural landscapes. Applicants must ensure they have a clear plan and fulfil as many predefined 'outcomes' as possible.
- **Corporate (social responsibility) funding:** A means for businesses to contribute to societal goals, including net zero and nature recovery (e.g. Sky Ocean Rescue).
- **Individual giving:** Whereby a person provides funds in the form of a gift to a charity.
- **Crowdfunding, via websites such as JustGiving:** A way of raising finance online by asking a large number of individuals and organisations for small amounts of money. Tends to lead to some active involvement of/ engagement with the local community.
- **Nature conservation charities:** Often drawing on member contributions, as well as various external funding sources, charities such as the Royal Society for the Protection of Birds (RSPB), The Wildlife Trusts and the Wildfowl and Wetlands Trust, have been instrumental in implementing many existing saltmarsh restoration projects.

Tips:

- Identify and align funder priorities e.g. education, community project, heritage assets.
- Research previous grantees and award amounts.



BOX 2.9: BLUE CARBON FINANCE AND CREDIT

Blue carbon finance has generated interest for its potential to incentivise private investment into the restoration of blue carbon habitats to offset greenhouse gas emissions. It follows a payment-for-ecosystem-services model, whereby the ecosystem services provided from restored seagrass can be viewed as a product. In this case, the reduction in greenhouse gas emissions generated from restoration activities can be traded as offset credits through carbon markets.

There are two types of carbon markets for offset credits: regulatory and voluntary. Regulatory markets consist of buyers whose emission reduction targets are enforced through regulation, while voluntary markets typically consist of buyers supporting wider strategic priorities, such as corporate social responsibility. Of the two, the voluntary carbon market has been the primary source of funding for blue carbon habitat restoration.

Blue carbon finance is a rapidly evolving field in the UK and marine restoration projects are yet to attract funding from this source. International projects can be used as case studies. Restoration of *Zostera marina* in Virginia Coast is expected to achieve accreditation within the voluntary carbon market under the Verified Carbon Standard (VCS) programme in early 2022. This will likely be the first stand-alone seagrass restoration project to achieve carbon accreditation, calculated from seagrass-derived offsets, and will certainly be the first temperate seagrass example to do so, which is important in a UK seagrass restoration context.

The only other project to date to include seagrass under a carbon accreditation scheme is the Plan Vivo Mikoko Pamoja project in Gazi Bay, Kenya. However, here seagrass bed protection is included under a 'carbon-plus' approach as it represents an additive benefit to the project's mangrove carbon credits. In this instance, the seagrass is ineligible for stand-alone accreditation due to technical and financial challenges in monitoring. Instead, it is included as an additional donation to fund seagrass management measures (calculated assuming seagrass burial: 1.38 tC ha^{-2} $year^{1}$), with wider ecosystem services (coastal protection, fisheries enhancement and biodiversity) emphasised.

For future seagrass restoration projects to achieve similar accreditation, certain requirements must be met. The VCS programme, for example, set out an offset-credit accounting framework for seagrass restoration: VM0033. Based on the greenhouse gas offsets achieved by restored seagrass in South Bay, Virginia Coast, the VCS methodology forecast offset credits to achieve \$87 K at \$10 $MtCO_2e^{-1}$, nearly 10% of the seagrass project's restoration costs.

For all blue carbon projects, it is vital that carbon accounting is based on robust evidence to quantify the carbon emissions saved, that these are additional savings, and that the carbon is stored permanently to ensure environmental integrity

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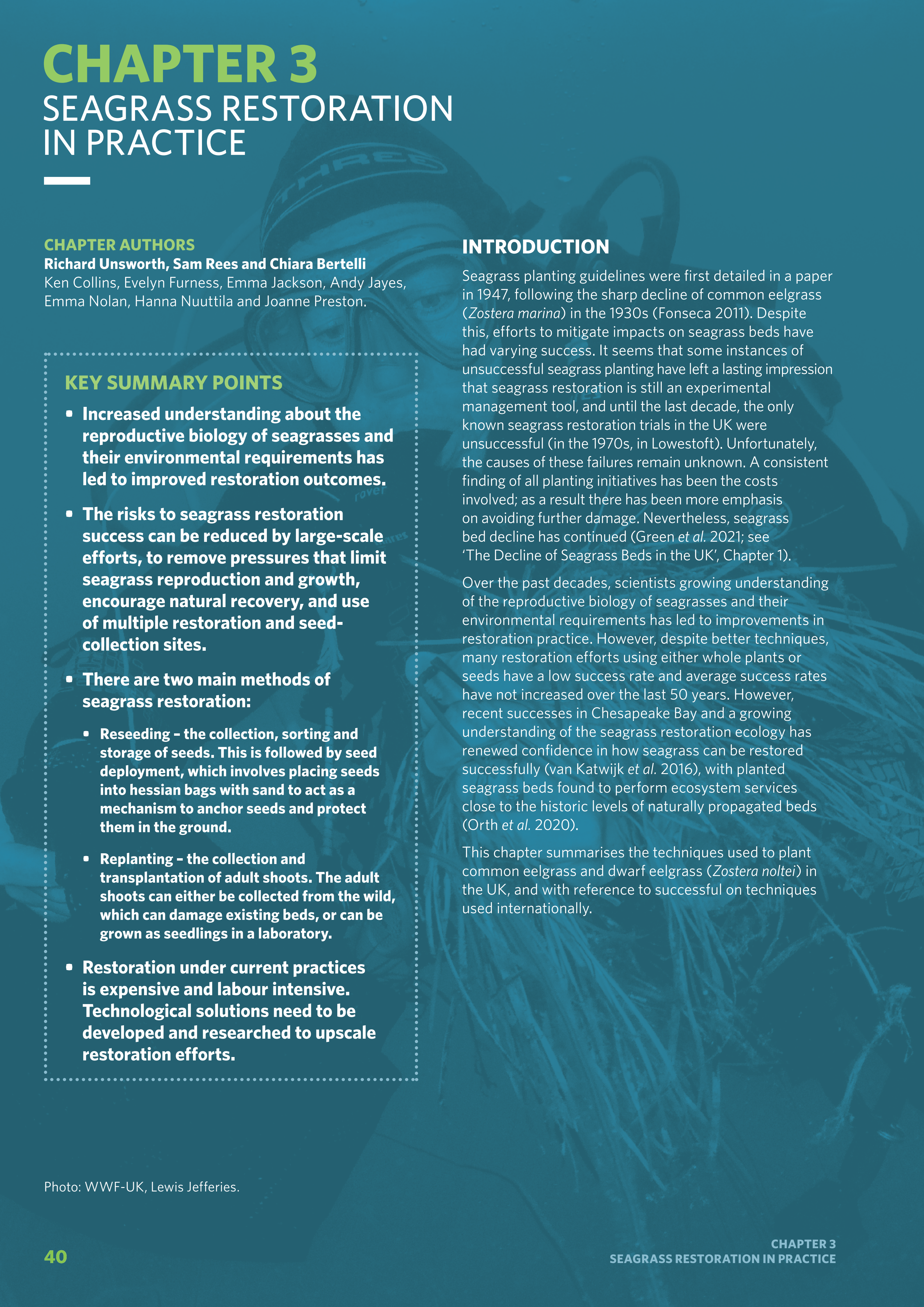

CHAPTER 3
SEAGRASS RESTORATION IN PRACTICE

CHAPTER AUTHORS

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KEY SUMMARY POINTS

- **Increased understanding about the reproductive biology of seagrasses and their environmental requirements has led to improved restoration outcomes.**
- **The risks to seagrass restoration success can be reduced by large-scale efforts, to remove pressures that limit seagrass reproduction and growth, encourage natural recovery, and use of multiple restoration and seed-collection sites.**
- **There are two main methods of seagrass restoration:**
  - **Reseeding – the collection, sorting and storage of seeds. This is followed by seed deployment, which involves placing seeds into hessian bags with sand to act as a mechanism to anchor seeds and protect them in the ground.**
  - **Replanting – the collection and transplantation of adult shoots. The adult shoots can either be collected from the wild, which can damage existing beds, or can be grown as seedlings in a laboratory.**
- **Restoration under current practices is expensive and labour intensive. Technological solutions need to be developed and researched to upscale restoration efforts.**

Photo: WWF-UK, Lewis Jefferies.

INTRODUCTION

Seagrass planting guidelines were first detailed in a paper in 1947, following the sharp decline of common eelgrass (*Zostera marina*) in the 1930s (Fonseca 2011). Despite this, efforts to mitigate impacts on seagrass beds have had varying success. It seems that some instances of unsuccessful seagrass planting have left a lasting impression that seagrass restoration is still an experimental management tool, and until the last decade, the only known seagrass restoration trials in the UK were unsuccessful (in the 1970s, in Lowestoft). Unfortunately, the causes of these failures remain unknown. A consistent finding of all planting initiatives has been the costs involved; as a result there has been more emphasis on avoiding further damage. Nevertheless, seagrass bed decline has continued (Green *et al.* 2021; see 'The Decline of Seagrass Beds in the UK', Chapter 1).

Over the past decades, scientists growing understanding of the reproductive biology of seagrasses and their environmental requirements has led to improvements in restoration practice. However, despite better techniques, many restoration efforts using either whole plants or seeds have a low success rate and average success rates have not increased over the last 50 years. However, recent successes in Chesapeake Bay and a growing understanding of the seagrass restoration ecology has renewed confidence in how seagrass can be restored successfully (van Katwijk *et al.* 2016), with planted seagrass beds found to perform ecosystem services close to the historic levels of naturally propagated beds (Orth *et al.* 2020).

This chapter summarises the techniques used to plant common eelgrass and dwarf eelgrass (*Zostera noltei*) in the UK, and with reference to successful on techniques used internationally.

SEAGRASS RESTORATION TECHNIQUES

This section provides an overview of the main two seagrass restoration techniques that have already been developed and trialed: **replanting** of adult shoots, and **reseeding**. Both techniques have merits and have had varying success. Reseeding generally involves the collection and targeted redistribution (and sometimes processing) of wild seed. Meanwhile, replanting normally involves harvesting plants from an existing bed and transplanting them to the restoration site, where in most instances, there is no readily available source of nursery-grown plants or seeds.

The shoots and/or seeds generally need to be anchored to the bottom in some way until the roots can take hold (root into the seabed). Replanting uses either labour-intensive hand-planting techniques, requiring self-contained underwater breathing apparatus (SCUBA) for subtidal species, or various mechanistic approaches to planting various sizes and ages of seagrass plants into new localities. In the US, reseeding and replanting techniques have sometimes been combined. This may, in some instances, prove to be more effective.

Seagrass restoration projects can fail if insufficient consideration is given to the species' habitat requirements and the continued presence of the stressor that caused the seagrass loss. Restoration projects success has been found to be related to the severity and cause of the habitat degradation. For example, restoration was less successful in locations where seagrass loss was caused by water quality issues (usually eutrophication) than in those with threats from dredging and construction activities (van Katwijk *et al.* 2016). Little difference was seen in success between methods using seeds, adult plants and 'sods' (large seagrass cores including sediment), but seedlings had lower survival rates. A shorter distance between the restoration site and the donor site improves restoration success. Although transplantations (replanting) have been found to have a high failure rate (60%) or limited success, there are also a substantial number of instances of transplantation that have shown high rates of expansion (van Katwijk *et al.* 2016).

A study in the Wadden Zee (van Katwijk *et al.* 2009) incorporated a series of guiding principles for maximising success rates:

- Ensure long-term survival by promoting self-facilitation through implementation at a large enough scale (hectares).
- Focus on facilitating natural recovery by alleviating recruitment limitations ('let nature work for you').
- Spread risks through space and time by restoring multiple sites on multiple occasions.
- Keep the costs of restoration (per hectare) as low as possible to maximise the scale of success.
- Minimise impacts on source beds and avoid introducing invasive species at restoration sites.

In addition to these guiding principles, it may be prudent to ensure that the restored seagrass will not be resubjected to the stressors that caused their loss (depending on the type of stressor).

METHOD SELECTION

The most suitable method will be different for each location and species. That said, understanding the advantages and disadvantages of each method enables practitioners to select the method best suited to their specific project needs in a local setting. When selecting a method, the following should be considered:

- cost, potential risks and seagrass species;
- previous outcomes in similar environments and for similar species;
- results of small-scale feasibility trials.

Only after completing all these planning steps should on-the-ground restoration activities begin.

RESTORATION FEEDBACKS

Both environmental and biological factors are major drivers of change in seagrass systems. It is therefore no surprise that such factors have been identified as reducing transplant or seedling survival. These include seasonal turbidity pulses, bioturbation by animals such as crabs and polychaetes, exposure to strong wave dynamics, and deposition of sediment on the seagrass bed (see Figure 3.1). Planting success has been found to be influenced by other factors, including season and reduced sediment mobility (Park and Lee 2007; Paulo *et al.* 2019).

Environmental and biological drivers can act as feedbacks in both a positive and negative manner, leading to seagrass beds existing in alternate states maintained by these feedbacks. The lack of recovery of many seagrass beds largely results from systems becoming locked in one of these negative feedbacks, see Figure 3.1 and Maxwell *et al.* 2017 for further detail. For example, loss of seagrass allows sediment to remobilise; this sediment is then readily resuspended, preventing seagrass seedlings from taking root and growing due to the physical instability of the seabed, and smothering and loss of light. As seagrass loss increases recovery becomes increasingly difficult. At this point, active, specific intervention is required to overcome this negative feedback and establish a suitable environment for seagrass restoration. For example, "sand capping" has been trialed in Sweden whereby coarse sediment is used to 'cap' fine sediment and prevent resuspension, facilitating restoration. The results of this first-of-its-kind trial are not yet available at the time of writing. To overcome negative feedback created by a site's physical conditions, use of BESE (biodegradable ecosystem engineering elements) matrix structures were found to be a success in Sweden, facilitating the development of mature plants in locations previously too exposed for plants to colonise or take root due to high levels of hydrodynamic stress. have. High densities of green crabs, which consume seagrass seeds, and high sulphide levels in sediments, which prevent plant rhizome establishment, are two other key examples of negative feedbacks that require consideration.

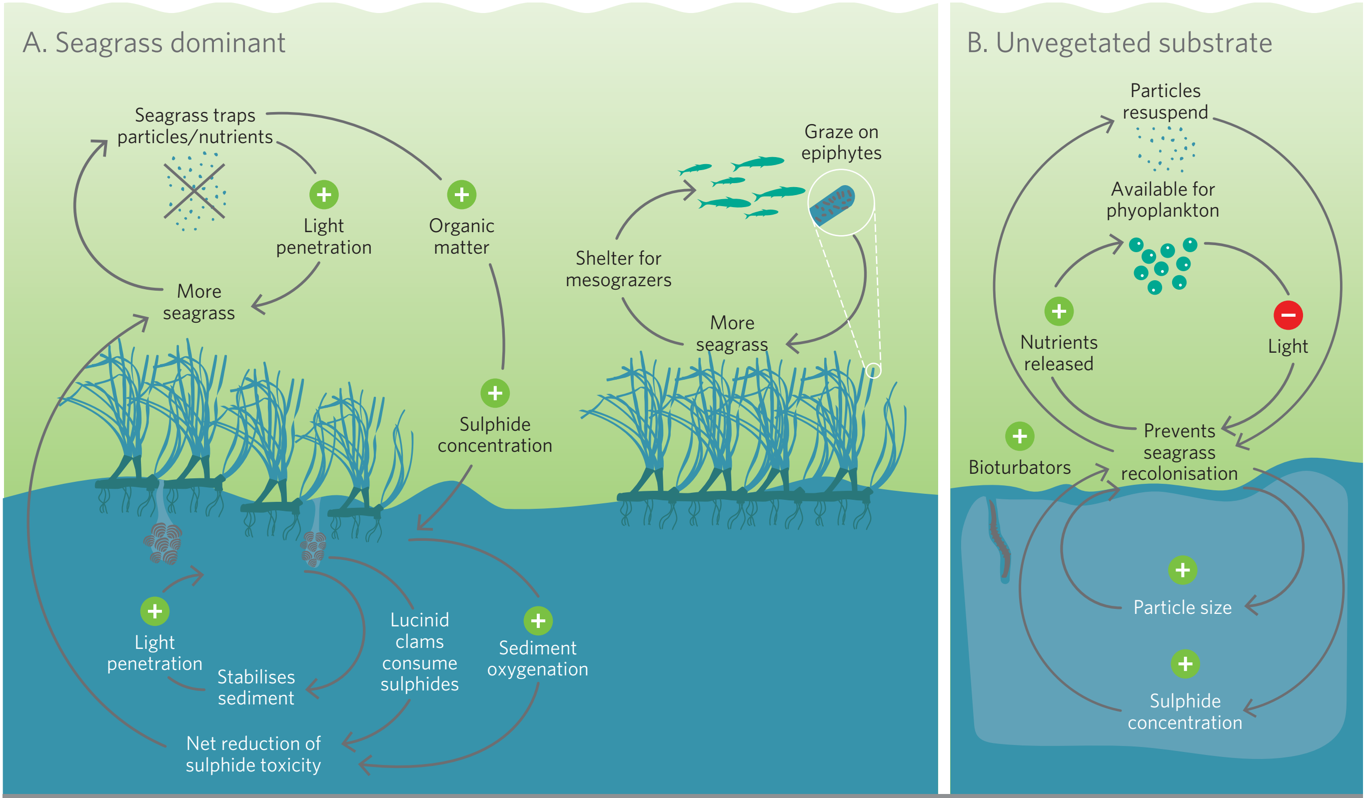

Figure 3.1: Feedback loops in seagrass ecosystems that control the stability of alternate regimes. (A) Seagrass dominant; (B) Unvegetated. Green + symbols indicate an increase in levels and red − symbols indicate a decrease. Infographic modified from Maxwell *et al.* (2017).

RESTORATION TIMING

Timing of restoration activities is one of the most important elements for project success. Identifying whether the project goal is habitat restoration (planting seagrass where it was historically present), creation (planting seagrass where it was not historically present) or enhancement (planting seagrass where it is currently present but degraded) (see definitions in Box 1.1) will inform not only the restoration site, but also the methodologies and timings of interventions. For example, beds with poor resilience due to poor connectivity with other beds may require subsequent interventions (e.g. regular reseeding) if they are to be maintained.

Timing should be based on factors such as:

- maximal light availability (i.e. summer months);
- avoidance of seasonal pulses in turbidity (i.e. avoid restoration after high rainfall or winter storms in areas close to estuaries);
- freshwater run-off (unless the aim is to facilitate natural germination);
- avoidance of peak times of human disturbance and interference (i.e. summer months in intertidal beds);
- natural growth cycles and natural environmental triggers in the system (e.g. winter freshwater and temperature triggers, and winter seed scarification);
- occurrence of fruit and flowers (or incorporating trigger factors for these);
- utilization of any predictable longer-term climate patterns (e.g. El Niño events).

RESEEDING METHODS

Seagrasses can produce vast quantities of seeds annually; beds in the UK can produce in excess of 10 million per hectare, although in some locations this can be orders of magnitude less. The drivers of such variability are poorly understood, but disturbance is a likely positive influence. Despite the potential for high loss rates, seeds can play an important role in the natural expansion of common eelgrass beds following disturbance events. However, their role in bed maintenance in stable beds is likely limited as seedlings are rapidly outcompeted by mature plants, particularly within continuous beds where the footprint of the existing meadow has filled the available niche. Rapid expansion of some common eelgrass beds (e.g. Chesapeake) has occurred at rates far exceeding the possible growth rate from vegetative propagation alone (at over 80ha/year) (Orth *et al.* 2006), illustrating the great potential for the use of seeds in restoration attempts (Marion and Orth 2010).

Reproduction in seagrasses is characterised by low investment cost per potential offspring. Seeds are generally found in late summer to autumn (in the flowering shoots, known as spadices), indicating a large capacity for bed enhancement and growth. Common eelgrass can produce over 30 seeds per specialist shoot, and it is therefore common for whole seagrass beds to produce hundreds of millions of seeds. However, most do not end up as successful germinated shoots, mostly due to their ineffective distribution into potential habitats determined by local oceanographic circulation patterns. This over-production of seeds creates an opportunity for their use in restoration programmes.

Prior to the late 1990s, seeds were not widely used in seagrass restoration projects. Seeds have since been used successfully to re-establish large areas of seagrass coverage. The scale of seed-based common eelgrass restoration attempts was limited by three factors: acquisition and processing of seeds, maintenance of viable seed supplies, and low initial seedling establishment rates. These limitations have now largely been overcome by locating beds of high seed productivity, using mechanised methods to collect the seeds, and using seed planting methods that bury or protect the seed.

SEED COLLECTIONS

All seeding methods require collection of seeds from natural beds. The seeds that common eelgrass and dwarf eelgrass produce are contained within the spadices, which require harvesting. These are typically collected in immature fruiting shoots using SCUBA or snorkelling, and by grasping and picking the shoot to detach it from the rest of the plant, which has relied heavily on volunteers. Projects in the UK have done this extensively, with beds where seagrass has been collected regularly continuing to harbour high seed densities the following year and remaining healthy and abundant. In some locations in the US, large machinery has been used to harvest seagrass seeds (see Figure 3.11), and Swansea University is currently trialling the construction and use of such machinery. This typically results in a much higher number of seeds – for example, the use of a mechanical harvesting boat in Chesapeake Bay allowed for an annual collection of over 30 million seeds. Only a small portion of the seeds are removed from each healthy bed, allowing them to reproduce and persist at healthy levels.

Seed supply is a key limiting factor in restoration from seeds. Therefore, it is important to identify suitable sites for seed harvest early in the planning process (or see section on nurseries). Donor bed selection should not only consider the impact on, or risk to, the health of the donor bed, if any, but also the potential for seed survival and growth in the environmental conditions of the restoration area. Preliminary site assessments of the donor site's condition are recommended to gauge its suitability for seed harvesting. These will likely be a requirement of key regulators so that licences or permissions for seed collection can be granted (see Chapter 2).

To maximise the potential of seed survival and growth, it is preferable to source seeds from donor sites of similar environmental conditions to the restoration site, if possible, especially in terms of depth, exposure rate and nutrient availability. The closer the donor site is to the restoration site, the better, as this can reduce biosecurity and genetic concerns (see Chapter 2) while also increasing restoration potential. Restoration trials where > 100,000 seeds were planted had the most success (van Katwijk *et al.* 2016).

In the UK, seeds are solely sourced from native beds and are collected either intertidally, or subtidally by SCUBA diving (see Figure 3.2). Once a suitable donor bed has been selected, it is useful to monitor seed development, as flowering is a temperature-dependent process and will therefore happen at different times in different locations. Sites on the south coast of England have been observed to mature from late July, and seeds in Scotland from late August to September, with central beds maturing in gradient to this.

The method of seed collection is the same for both common eelgrass and dwarf eelgrass. Immature seeds are longer and more slender, pointed and green, while mature seeds are wider (around twice as long as they are wide) and brown, with rounded tips. Identifying the seeds in a bed is simple: the seeds from a spathe, which is taller than the average canopy (see Figure 3.2), have a rounded 'stem' shape (as opposed to a flat leaf) and are typically a more yellow colour than the leaves. They are easily broken off using a thumbnail or scissors below the seeds, without disrupting the rhizomes (note: do not pull). A drawstring mesh bag is useful for storing the collected seeds. Table 3.1 compares the collection methods (for seeds and plants) used to date.

Figure 3.2: *Zostera marina* seed spathes floating above normal canopy (left) and spathes being identified and collected by SCUBA (right). Photo: Chiara Bertelli and Max Robinson.

Table 3.1: Overview of the methods used to collect seagrass propagules for restoration (seeds and plants) around the world.

METHOD	BENEFITS	CONSIDERATIONS	LOCATION	REFERENCE
Hand collection of adult shoots with intact rhizomes	Enables careful handling and selection of donor shoots for replanting.	Impacts donor bed. Labour intensive – requires SCUBA for subtidal species. Shoots were planted within 24 hours. Planted as bundles of 3 – 4 shoots.	Chesapeake Bay, US	Fishman *et al.* (2004)
Hand collection of seeds direct from spadices	Limits impact on donor beds.	Labour intensive – requires SCUBA if hundreds of thousands of seeds needed. If fewer, can be done by snorkelling/wading if site is shallow.	Chesapeake Bay, US Wadden Zee, Netherlands	Granger *et al.* (2002) van Katwijk and Wijgergangs (2004)
Mechanized shoot harvesting	Less labour intensive than hand collection. Suitable for large-scale restoration.	Greater impact on donor beds. Requires specialist equipment.	Chesapeake Bay, US	Orth *et al.* (2008)
Mechanized seed harvesting, from spadices	Less labour intensive than hand collection. Suitable for large-scale restoration. Low impact on donor site.	Suited to collection from large donor seagrass sites with numerous spadices available. Requires specialist equipment. Still requires separation of flowers and seeds.	Chesapeake Bay, US	Marion and Orth (2010)
Collection of sods (shoots with substrate still attached) using corer	Allows whole sections of seagrass and sediment to be transplanted.	Impacts donor bed. Labour intensive – requires SCUBA/ snorkelling depending on site.	Venice, Italy	Curiel, Scarton and Marzocchi (2003)
Collection of rhizomes (average length of 30 – 50 cm) using a water jet to minimise plant damage	Enables careful handling and selection of donor shoots for replanting.	Impacts donor bed. Labour-intensive – requires SCUBA/ snorkelling depending on site.	Venice, Italy	Curiel, Scarton and Marzocchi (2003)

Figure 3.3: Freshly collected *Zostera marina* seed spathes from Porthdinllaen, North Wales. Photo: WWF-UK/Nina Constable.

SEED PROCESSING

Once collected (see Figure 3.4), seeds need to be stored, transported and processed. When stored and transported, they need to be kept cool and wet at all times. Large fluctuations in temperature or use of fresh water can cause the seeds to germinate. In addition, frequent water changes and, if possible, a constant flow can reduce the chance of mould growth. When draining tanks and tubs, it is advisable to do so through a net to reduce any loss of seed.Seed processing can be based on either low-tech techniques or use of laboratory-based aquaria. A popular low-tech technique is to place the shoots (unprocessed) into buoy-deployed seed bags (BuDS). This avoids the time- and space-consuming seed processing method (Pickerell, Schott and Wyllie-Echeverria 2006). The BuDS system enables spadices to be taken directly from the field to the restoration site. It consists of an anchor line to a small buoy above the desired site with an attached aquaculture pearl net (6 – 9mm diameter mesh). The pearl nets are filled with the desired number of spadices. This system allows the spadices to naturally drop seeds over time as they develop. The length of the line depends on the desired area of seeding and multiple BuDS can be used for larger sites. BuDS have been used successfully in a number of locations; one example is a recent project in the Wadden Zee (Netherlands) where a first batch of 180 BuDS per site (3ha each) were deployed in summer 2011 with the help of volunteers. At low tide, volunteers collected shoots into bin bags and then placed them in mesh bags on the shore. Despite limited training, the volunteers managed to collect reproductive shoots whilst causing limited damage to the seagrass. Results suggest that these BuDS have been successful, with beds rapidly expanding.

An alternative way of processing the reproductive shoots is to take them back to the laboratory, allow the seeds to develop fully and release them from the remaining flower (see Granger *et al.* 2002 for detail). This is the method that Swansea University and Project Seagrass have used to date (see Figure 3.5). Once seeds are released, the spadices die and begin to decay, allowing for recovery of the seeds. This technique involves storing the seagrass in large, covered tanks with flowing seawater at ambient temperature and salinity. The shape and size of the tanks are not important as long as the plants can be kept fully submerged, cool (< 25°C) and well flushed with seawater (Granger *et al.* 2002). To separate the seeds from the large amounts of mulch, sieves are used, and then separation tubes with running water are used to float off the remaining matter. The remaining mulch can be used as a fertiliser if not disposed of. The seed-sorting process is labour intensive since it relies almost entirely on separation by hand, and there is the added challenge of loose and rotting seagrass rapidly blocking filters, pipework, and wrapping around moving parts.

See Project Seagrass YouTube video on how to collect seagrass seeds:

https://www.youtube.com/watch?v=6QQOMe9EZG8

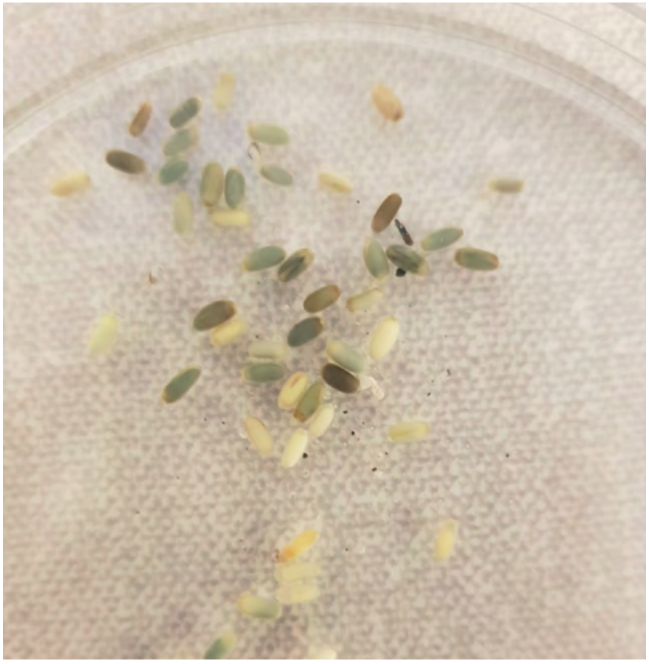

Figure 3.4: *Zostera marina* (top) and *Zostera noltei* (bottom) seeds once fully extracted from the spathe. Photos: Evie Furness (top) and Andy Jayes (bottom).

Figure 3.5: Manually processing *Zostera marina* seeds during the Seagrass Ocean Rescue Project. Photo: Sam Rees.

SEED STORAGE

Where seeds are not directly transported to the restoration site (see BuDS method), seeds need to be kept ex situ before planting, presenting a number of challenges. In the early stages of processing, the aim is to maintain seeds in near in-situ conditions (temperature, salinity and nutrients (ammonia/nitrates)). Once the seeds have been extracted, the three main risks are premature germination, seed death and mould growth. To prevent early germination, practitioners need to oppose the triggers of germination; previously identified triggers include temperature spikes (cold or hot), sulphide presence and low salinity (see Table 2.2 in Chapter 2).

Xu *et al.* (2020) demonstrated successful storage of common eelgrass seeds at a temperature near 0°C with a salinity of 40 – 50 practical salinity units (PSU). Furthermore, the addition of a 2ppm copper sulphate solution reduces the likelihood of premature germination, mould growth and maintains seed viability over a storage period of 17 months (Xu *et al.* 2020). It is also important to store the seeds in darkness.

The extraction of seed material is not perfect when dealing with bulk quantities. A small amount of rotting material will inevitably remain with the seeds, which encourages sulphuric/anoxic conditions. Anoxic conditions are an additional germination trigger and can encourage mould. To reduce this, practitioners should try to keep the seeds stored in a high-flow aquarium with sufficient filtration. If an aquarium set up is not possible, they should ensure regular (daily if possible) water changes and spread the seeds as thinly as possible.

Sink rate can be used to determine the viability of seeds so that those with a higher capability to germinate can be separated. Seeds must sink at a rate greater than 5cm per second in a 20 PSU water solution. Seeds that sink slower or float are not viable. Seed colour has not yet been proven to indicate viability.

Table 3.2: Overview of the different methods used to store seagrass seeds.

METHOD	BENEFITS	CONSIDERATIONS	LOCATION	REFERENCE
Indoors in clean, re-circulating, temperature-controlled water without aeration or disturbance.	Produced highest mean seed survival.	Facilities needed for large-scale storage.	Virginia, US	Marion and Orth (2010)
Bleach-rinse to remove microbes.	No significant impacts on seed survival. Sterilises to ensure biosecurity.	Correct concentration and timings necessary to avoid damage to seeds.	Virginia, US	Marion and Orth (2010)
Large, aerated tanks with flowing estuarine water (flow rate approximately 15L/min). Very-high-output fluorescent bulbs used, then replaced with 1000-watt metal halide lights.	89% of seeds fall faster than 5.5cm/second or faster-produced seedlings.	High electrical costs for pumps and lamps. Labour intensive.	Maryland, US	Tanner and Parham (2010)
Aerated seawater tanks for 2 – 3 weeks. Collect manually from debris in tanks. During winter, maintain in sea water at a salinity of 30 PSU and 4°C in the dark.	Successful enough to be used in restoration projects.	Labour intensive.	Netherlands	van Katwijk and Wijgergangs (2004)
Tanks of 30 PSU salinity.	Found to be optimum salinity at all temperatures.	May differ between seagrass species and different locations.	Virginia, US	Marion and Orth (2010)
Seed bags, 1mm mesh sized burlap (hessian) bags of 5 x 5cm, each containing 10 seeds.	50% viable seedlings developed in greenhouse tank experiments and 49% in field experiments.	Require labour for filling hessian bags.	Chesapeake Bay, US	Harwell and Orth (1999)

SEED PLANTING

When seagrass seeds have matured and dropped out of the shoot, they can then be stored, grown into young seedlings or taken straight out for distribution across restoration sites. The methods described in this section concern separated seeds and do not include the previously described BuDS method, which uses unprocessed seed spathes. There are a range of seed planting and distribution methods, including simple placement in the sediment (using SCUBA), attachment of seeds to biodegradable tape, deployment using seed bags and a range of injecting methods (see Table 3.3). Scattering of seeds from the boat surface has been a widely used method in Chesapeake Bay in the US, and while this has been found to be highly effective, trials in Sweden indicate that seed loss due to consumption by European green crabs (*Carcinus maenus*) can hinder success. Available evidence indicates that the germination and emergence of seedlings is enhanced if they are placed 2cm below the sediment surface (Infantes, Crouzy and Moksnes 2016).

In the US, the use of 'burlap' (hessian) bags has been shown to improve seedling germination and survival in field sites when compared with seeds distributed without protection (Harwell and Orth 1999). In the UK, the majority of projects to date (those in West Wales and Plymouth) have used an adapted version of this method, which was first tested at Swansea University, whereby seeds are deposited on the seabed using hessian bags (see Figure 3.6). The full method has been termed the bags of seagrass seeds line (BoSSLine) system. The system was scaled up for the 'Seagrass Ocean Rescue' project. Fifty-metre-long lines were made up with a large sandbag at each end (12.5kg), and a hessian seed bag tied at 1m intervals. Construction of the lines was time consuming; 10,000 hessian bags had to be filled with sand and seeds, tied to 10km of rope, and packed into boxes to ensure a knot-free delivery. Small-scale use of this method on initial trial sites in West Wales has proved to be very effective, with seed bags planted in 2018 having germinated and spread out to form large patches by 2021.

As an alternative to using lines to string out hessian bags, scientists at the Yorkshire Wildlife Trust used mechanical planters to push the bags into the sediment (Yorkshire Wildlife Trust 2021) to a depth of 3 inches, for planting dwarf eelgrass seeds in the intertidal (see Figure 3.8). The Natural England reducing and mitigating erosion and disturbance impacts affecting the seabed (ReMEDIES) project used a further variation, planting bags on the seabed in a vertical position directly from the boat via a 4m long tube to the seabed, at a spacing of approximately 50cm (LIFE Recreation ReMEDIES n.d.). No data from these projects are available yet.

An analysis of the effectiveness of burying hessian bags (by hand) of seagrass seeds compared with planting then on the surface, conducted by Project Seagrass and Swansea University, indicated that burying is more effective.

Alternative seed planting methods have been used in a number of locations around the world. These involve injecting seeds into the sediment using different pumping methods and associated media. Scientists at the University of Rhode Island developed a boat-pulled sled that deposits seeds below the sediment surface. Further developments of this include a procedure to encase seeds in a Knox gelatin matrix, preventing seed predation and loss of seeds from waves and currents. Gelatin-encased seeds are injected into the sediment from the sled using a food-processing pump similar to that used to make jelly donuts. This planting sled has been used to plant subtidal common eelgrass seeds in an area where seagrass presence was historically recorded, but the use of the gel and its effectiveness remain inconclusive (Orth *et al.* 2009). There has also been considerable success with silicon guns for planting common eelgrass seeds, both intertidally and subtidally, using SCUBA. Seeds are mixed into a semi-liquid mud and clay matrix before being injected at a depth of 2cm (Laura Govers 2021, personal communication).

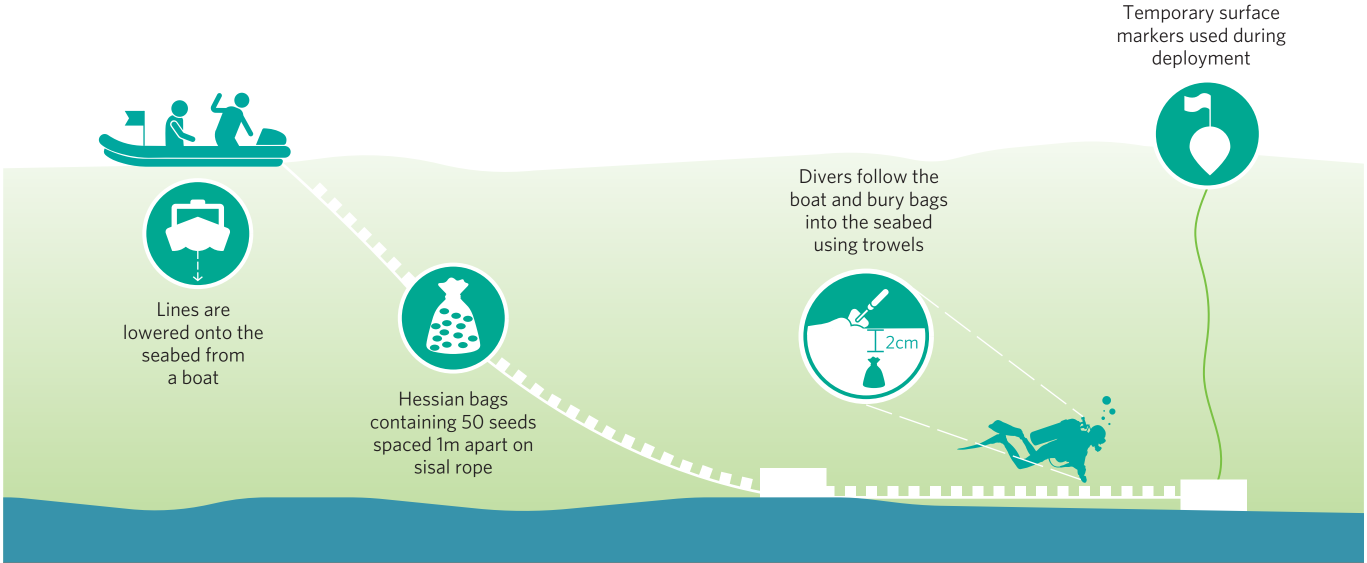

Figure 3.6: How seagrass seeds are planted using the hessian bag BoSSLines method.

Table 3.3: Overview of the different methods used to plant seagrass seeds.

METHOD	BENEFITS/SUCCESS	CONSIDERATIONS	LOCATION	REFERENCE
Seed buoys. Reproductive shoots harvested by SCUBA, then put into pearl nets (mesh 9mm) attached to buoys to aid seed dispersal.	Efficient and effective over a defined area.	Longer timescale for plants to establish/ mature. Risk of predators.	Sag Harbour Point, NY, US	Pickerell *et al.* 2005
Seed bags, 1mm mesh sized burlap (hessian) bags of 5 x 5cm, each containing 10 seeds.	50% viable seedlings developed in greenhouse tank experiments and 49% in field experiments. Mitigates predators.	Longer timescale for plants to establish/ mature.	Chesapeake Bay, US	Harwell and Orth 1999
Hand broadcast directly onto sediment surface.	5-10%	Longer timescale for plants to establish/ mature. Risk of predators.	Chesapeake Bay, US	Orth *et al.* 2008
Mechanical seed planter, using seed and suspension gel mix.	5-10% similar success to hand broadcast. Mitigates predators.	Need for specialist equipment.	Chesapeake Bay, US	Orth *et al.* 2008

Figure 3.7: Bags of seagrass seed lines (BoSSLines) ready in plastic crates and deployed over the side of a rib, with a 12.5kg sandbag used to anchor the 50m line, for the Sky and WWF-UK (World Wide Fund for Nature) Ocean Rescue restoration trials in West Wales conducted by Swansea University. Photos: Joseph Gray.

REPLANTING METHODS

The majority of seagrass restoration efforts so far have involved transplanting adult shoots (replanting). Transplants are either collected from the wild or seedlings grown in the laboratory/aquaria (see Table 3.1). Seagrass can be collected from the wild as small fragments broken off from live plants, as whole seagrass 'sods' (cores of seagrass including sediment), or fragments collected on the shore (typically after a storm). Collecting samples straight from the wild usually involves damaging an existing bed, so it can only be considered if healthy, suitable donor seagrass beds are available nearby, and permissions/licences have been granted from the relevant regulatory bodies (see Chapter 2). Studies from China indicate that when targeted at healthy beds and at low density, this is sustainable (Zhang *et al.* 2020). The collection of beach-cast fragments can also be considered sustainable, but supply and health of fragments are highly variable. Scientists in Europe and North America have tried a range of methods, including mechanised plant collection, and the available evidence suggests that these mechanised methods are in some way destructive towards the donor bed (see Table 3.1).

Figure 3.8: Hessian bags containing a single *Zostera noltei* seed deployed using a Pottiputki bulb planter as part of the Yorkshire Wildlife Trust *Zostera noltei* restoration trials in 2021. Photo: Andy Jayes.

Table 3.4: Overview of the different methods used to replant seagrass seeds.

METHOD	BENEFITS/SUCCESS	CONSIDERATIONS	LOCATION	REFERENCE
Single shoots with bare roots, planted by SCUBA.	Various levels of success – 73% after one month. Ensures shoots are anchored in substrate.	Very labour intensive – requires SCUBA, high costs.	Chesapeake Bay, US	Orth *et al.* (1999) Tanner and Parham (2010) Fishman *et al.* (2004)
Sods (shoots with substrate still attached).	Successful, planting sites increased in density after 2 growing seasons.	Labour intensive.	Venice, Italy	Curiel, Scarton and Marzocchi (2003)
Horizontal rhizome method. Planting unit of overlapping rhizomes in opposite directions, secured in sediment with a bamboo staple (SCUBA).	71% (1 – 99%) survival after 1 year.	Labour intensive – requires SCUBA for securing staples.	New England, US	Davis and Short (1997)
Use of shells for planting – shoots attached to shell which is then dropped off boat.	78% (73 – 83%) successful after 2 – 3 months. Helps anchoring without use of SCUBA or need for planting.	Labour intensive – attaching shoots to shells. Potential implications for upscaling.	South Korea	Lee, Park and Kim (2008)
'Planting boat' (mechanised planting)	40% initial survival rate. Less labour intensive – more shoots planted per unit time.	Specialist equipment needed.	Chesapeake Bay	Fishman *et al.* (2004)

A range of methods have been used to transplant seagrass plants into new habitats (see Table 3.4). One method is the transplantation of common eelgrass shoots secured horizontally onto sediment with a bamboo staple. One year after transplanting, survival rates were variable, but between 75-99% and the shoot densities of transplanted sites were equivalent to those at the control sites within two years. Good survival was also reported with the transplantation of single unanchored shoots of common eelgrass that were planted with their rhizomes placed into the sediment at an angle (i.e. the unanchored shoot method). Other methods have been used to anchor seagrass shoots, including oyster shells in muddy and silty sediments.

Seagrass may be replanted for a number of reasons, and either separately or in tandem to reseeding. Replanting mature seagrass may help to overcome negative feedbacks in the system (such as sediment stability) that seedlings alone may not. Where transplanting can be used, it has the potential to result in quicker establishment of healthy plants than reseeding. Transplanting is carried out using SCUBA diving, making it labour intensive, which therefore limits the scale of restoration. In instances of translocation, shoots (or sods) are dug up from the seabed, using trowels or cores. Translocation is far more specialised than replanting since extreme care is required to minimise disturbance to the rhizome and meristems. A range of methods for planting these shoots have been trialled to improve effectiveness across a variety of conditions. Replanting has long been the most commonly used method for common eelgrass restoration in some areas, such as Puget Sound, US, where it has been highly effective. Recent trials in Sweden and Wadden Zee have had equally positive results.

The need to replant can sometimes be driven by development needs. For example, seagrass was successfully relocated in Falmouth Harbour (UK) using sods to mitigate the impacts of a dredging programme (see Figure 3.9). In the UK, seed-based programmes have generally been favoured over replanting due to their lower impact on donor beds. That said, the collection of shoots at low density ($\leq 0.25m^2$) has been demonstrated in China and the US to have no negative impacts on healthy common eelgrass beds, with removal patches recovering to their previous condition or better (density and morphology) after several months (Zhang *et al.* 2020).

In an effort to improve the cost-effectiveness of seagrass transplanting, the transplanting eelgrass remotely with frame systems (TERFS) method was developed. This involves tying common eelgrass shoots to a rubber-coated weighted wire frame with biodegradable plastic ties. The frame is then dropped into position from a boat. The frame is removed once the ties have degraded after three to five weeks and the shoots have anchored into the sediment. A trial of this method showed an increase in common eelgrass shoot abundance at three out of four 1ac sites. In Korea, sites have achieved survival rates of 47 – 86% after one month and 58.7 – 69.0% after 14 months. Comparative studies have found the TERFS method to be more successful than directly transplanting rhizomes, known as the horizontal rhizome method, developed by Davis and Short (1997) (Park and Lee 2007).

Replanting trials were conducted by Swansea University in West Wales in 2017. These used a combination of shoots, sods and seagrass using BESE frames. Although all methods showed an initial high survival rate, all died within a year. Yet, seeds planted at the same location in the same year are now proliferating in 2021. High density of European green crabs was thought to create a negative feedback, with the crabs sometimes digging up plants fairly soon after planting and using the frame as habitat. Some experiments have used cages and nets to keep out predators of Mediterranean tapeweed (*Posidonia oceanica*) seedlings (Balestri *et al.* 1998); this could be considered where herbivore presence is high.

Intertidal and shallow sublittoral beds are subject to damage by winter storms, with loose drift shoots often found along the shoreline. Some of these loose shoots naturally take root higher up the beach, but they rarely survive because of prolonged aerial exposure. Loose shoots can be collected for replanting but need to be rapidly transferred and planted in a safe submerged environment for storage, such as open-air tanks or a more sheltered marine location. They can then be replanted in a donor site. This method has been commonly used to replant Posidonia beds in the Mediterranean (Ward *et al.* 2020) and in Australia (Ferretto *et al.* 2021), but has not been widely used for *Zostera* beds. It could be used in the UK after easterly storms, which are more likely to impact *Zostera* beds.

Figure 3.9: *Zostera marina* sods collected and replanted by SCUBA using coir pots in Falmouth. Photos: Matt Doggert.

BIOSECURITY AS AN INTEGRATED PART OF RESTORATION PRACTICE

Invasive non-native species and diseases can be moved between sites whenever people and equipment are moved. It is therefore important that all people participating in restoration activities, including science and monitoring, refer to the recommendations of the GB Non-Native Species Secretariat (nonnativespecies.org/) and comply with the Check, Clean, Dry protocol (see Figure 3.10):

Check all equipment before you leave a site, including wetsuits, vessels, boots and buckets. Remove all visible hitchhikers, sediment and debris. If this occurs away from the site, ensure that all material is at least disposed of in a bin, not near a watercourse. In high-risk situations, dispose of material into a specified biological waste disposal route (possibly including incineration).

Clean all equipment, including the vessel and bilge tank, with fresh water. Do not let water drain back into the sea, as spores and eggs can persist for some time.

Dry all equipment thoroughly, ideally in sunlight and for as long as possible, before moving to a new marine location. Biosecurity should be a central theme in all restoration project activities. All activities should be subject to a biosecurity plan and have specific protocols in place. The biosecurity plan should be agreed with relevant authorities. This can also function as a useful biosecurity awareness-raising and learning exercise. A biosecurity plan will ensure that a precautionary approach is adopted when planning project activities.

UPSCALING SEAGRASS RESTORATION

For many years, scientists from countries such as Australia, the Netherlands and the US have led the way in restoration. Consequently, the notion of upscaling has been commonplace, leading to the development of a whole series of tools and methods that allow for cheaper, more efficient restoration at a larger scale. The need to upscale seagrass restoration often stems from the desire to revitalise degraded coastal ecosystems. Large-scale seagrass restoration can help stimulate food webs, improve fisheries and make coastlines more stable. To date, UK seagrass restoration has been limited to hectares or less, and while these projects are useful demonstrations of restoration potential, ultimately, they do not lead to fundamental change. Thousands of hectares of seagrass need to be restored to support significant positive change, and projects in the US have already risen to this challenge. That said, more research and technological advances are required to ensure that upscaling methods (e.g. mechanised approaches) do not impact natural marine habitats and the wider environment in UK waters. In the meantime, it is important to engage coastal communities and volunteers – the contribution they can make to upscaling seagrass restoration should not be underestimated, and this can yield wider benefits for communities (see Chapter 5).

Stop the spread

The success and reputation of a restoration project can be negatively impacted by accidental introductions of invasive species and pathogens. Project equipment such as vans, boats and field kit can all be vectors for their transmission, which will ultimately damage the marine environment and wildlife.

CHECK

Check your equipment, clothing and boats after carrying out fieldwork for fouling material. Ensure that you remove anythingthat you find and dispose of it in the appropriate manner.

CLEAN

Clean all fieldwork items thoroughly with fresh water as soon as possible. Ensure that you pay attention to items such as fieldwork clothing, restoration equipment, trailer wheels and areas that are damp or hard to reach.

DRY

Dry Ensure that you drain water from any water remaining on fieldwork items, and equipment such as a trailer and boat. Try to dry all equipment for as long as possible before next usage.

WATCH OUT FOR

American slipper limpet
Crepidula fornicata

Japanese wireweed
Sargassum muticum

Harris mud crab
Rhithropanopeus harrisii

Wakame
Undaria pinnatifida

Figure 3.10: Check, Clean, Dry protocol to prevent transmission of INNS and diseases during restoration practice and fieldwork, and areas to be vigilant about when cleaning after carrying out fieldwork.

MECHANISED SEAGRASS SEED COLLECTION

In the US, scientists have been collecting seagrass using mechanised sleds for over a decade. The sleds are run over targeted areas of high seed density and give the seagrass a form of 'haircut'. The system collected 2.5 million seeds annually (Orth and Marion 2007). There were no short-term impacts observed from aerial photography assessments and no significant differences found in canopy cover from diver surveys. Although maximum leaf lengths were reduced within harvested areas (on average by 8%), impacts on donor beds were deemed to be low, indicating that this is a sustainable method for seed collection (Marion and Orth 2010). These sleds are a necessity for large scale restoration efforts, as seagrass seed collections by hand are time consuming, expensive and difficult, particularly for deeper subtidal beds, which restricts the scale of seed collection.

The sled used in Chesapeake Bay for cutting common eelgrass is approximately 1.5m wide and uses a mechanised cutter blade to cut the seagrass to a height of approximately 20cm. This is an adaptation of the type of blade used to cut fresh-water aquatic vegetation. The blade cuts in front of a towed sled with a net behind it (see Figure 3.11), catching material and sucking it onto the boat. Swansea University and Project Seagrass launched a study in Wales in summer 2021 to examine the sustainability of this method where seagrass has been cut along transects, with and without a mechanised cutter. A before-after-control-impact (BACI)-designed experiment will quantify its impact over time compared with untouched 'control' plots. It is anticipated that such a system could transform the capacity of seagrass restoration UK-wide.

Figure 3.12: Fifty seeds were placed by hand into 20,000 hessian bags to plant seagrass over a 2ha area.
Photo: Evie Furness.

Figure 3.11: Towed sled with cutting device for mechanised collection of seagrass seed.
Photo: Scott Marion, VIMS.

LARGE-SCALE PLANTING

Currently, seagrass seeds or shoots are largely planted by hand. In countries where seeds are not rapidly consumed by predators (e.g. European green crabs), seagrass seeds can spread over vast areas very rapidly without any mechanised planting. Where predators could be problematic (as studies in Sweden have found; see Infantes, Eriander and Moksnes 2016), seeds need to have some level of protection, such as hessian bags (see Figure 3.12). The BoSSLine technique is relatively quick and easy during the deployment stage, but it involves a long material building process (tying rope, adding sand and adding seeds): a 50m BoSSLine takes three people approximately one hour to build. Similarly, the use of hessian bags, though useful for expanding the planting area, is potentially too time-consuming a method to expand over multiple hectares. Therefore, large-scale restoration requires its own specific planting methods. A number of institutes in the US have used sleds that pump seeds into the sediment (Orth *et al.* 2008). This has been trialled in the Netherlands but was unsuccessful; it is not clear why (Laura Govers 2021, personal communication). In intertidal areas in Wadden Zee, volunteers have planted seeds across large areas using silicon guns, but this is less viable in deeper waters. Combining methods offers potential options, as does the use of nursery-grown plants (see following section). It is clear that to upscale seagrass planting in the UK, better understanding of more innovative/technological solutions is required.

For extra reading on mechanisation and novel techniques, see: www.vims.edu/research/units/programs/sav1/restoration/index.php.

NURSERIES AS AN ALTERNATIVE

Terrestrial native plant nurseries are well established. They supply seeds and propagate plants from specific provenances for revegetation projects, and play a vital role in furthering research on propagation of land grasses. As seagrass restoration matures in the UK, increased demand for seeds and plants may become a limiting factor, particularly as project scale increases. As a result, a marine plant equivalent of these nurseries will be necessary to supply marine conservation projects.

The basic set-up for a seagrass nursery involves an aquaria system with optimal conditions for the growth of the species of interest. For seagrass, this primarily relates to light, water flow, nutrients and salinity. As with terrestrial nurseries, restoration plant material can be propagated and cultivated in nurseries as either container plants, seedlings or seeds. Container seagrass plants are grown in aquaria propagation environments designed to minimise factors that potentially limit growth, and when harvested, have a root system and growing media, forming a "plug". Plugs grown out in containers in nurseries can produce healthy rhizomes and produce new growing shoots. Nursery-grown plants can also be 'hardened' to the conditions of the restoration site and have been found to have better survival than plants transplanted from natural beds (Tanner and Parham 2010). It is also possible for one donor plant to be vegetatively propagated into multiple plugs, minimising the burden on donor beds.

Dedicated seagrass nursery facilities can not only provide research infrastructure to develop seed and plant handling protocols, but also work with industry to develop mariculture technologies in a land-based plant nursery setting, which could be reliably achieved at an industrial scale. For seed nurseries to be successful, industrial operations should be established – mass production can facilitate a dependable supply of seeds and seedlings for applied coastal restoration and habitat creation projects through industry, community and research pathways.

The use of seagrass nurseries as a restoration tool is expanding globally, with sites being developed in Australia (see Figure 3.13), Mexico and the Netherlands. However, knowledge on marine mariculture techniques needs to be shared to maximise their effectiveness. Aquaculture operations in Spain claim to have achieved high seagrass seed yields from commercial collection for food (Kassam 2021). In the UK, Swansea University and Project Seagrass, the Ocean Conservation Trust, and the Yorkshire Wildlife Trust are all developing nurseries. A seagrass aquaria network was set up by Swansea University in collaboration with the British and Irish Association of Zoos and Aquariums (BIAZA) to provide a forum for knowledge-sharing, and it is expected that this will trigger improved open-access shared knowledge development both in the UK and globally.

Figure 3.13: A working seagrass nursery in Central Queensland (top) for growing out and establishing container plants (bottom left), cultivating flowering for seed production (bottom middle) and seedling propagation (bottom right). Photos: Emma Jackson.

RESTORATION FOR THE FUTURE

SEASCAPE-SCALE RESTORATION

Marine conservation practitioners increasingly recognise the interconnectedness of habitats throughout the coastal seascape, such as coral reefs, seagrass beds and mangrove forests. This recognition has been built on a range of academic studies examining the benefits of maintaining habitat connectivity, not only to enhance fisheries, but also to benefit other physical processes and bolster system-wide productivity. Although the scientific literature on these concepts is less advanced in the temperate environment, there is good evidence of the temperate seascape's interconnectedness: fish migrate between habitats, carbon produced in one habitat can be sequestered in another, and one habitat can provide physical and environmental benefits to another. This interconnectedness has not been researched to the same degree in the UK, but there is now increasing interest within universities, conservation charities and donors, including the Environment Agency, to pursue a more integrated restoration approach.

van der Heide *et al.* (2012) published a seminal paper that provided compelling evidence of a three-stage symbiosis between seagrass, lucinid bivalve, and their sulphide-oxidizing gill bacteria that reduces sulphide stress for seagrass. This bivalve–sulphide-oxidizer symbiosis was found to reduce sulphide levels and enhance seagrass biomass. In turn, the bivalves and their endosymbionts benefit from organic matter accumulation and radial oxygen release from the seagrass roots. It is primarily for this reason that there is increasing interest in investigating the restoration of seagrass in tandem to a range of bivalves. The use of oyster restoration structures in proximity to seagrass and saltmarsh restoration has been proven successful in several sites across Chesapeake Bay, Virginia, US. While a number of studies have examined such co-restoration, there remains much to learn about how this could benefit seagrass, and consequently, the role these bivalves could play in seagrass restoration.

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Seagrass bed transect being completed in the River Helford, Cornwall. Photo: Lewis Jefferies.

CHAPTER 4
MONITORING A SEAGRASS RESTORATION PROJECT

CHAPTER AUTHORS

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KEY SUMMARY POINTS

- **A monitoring strategy needs to planned before the start of the restoration project.**
- **A long-term monitoring strategy (longer than five years) is fundamental to determine whether a restoration project has been successful.**
- **To assess the status of a seagrass bed, both structural and functional metrics need to be taken into consideration:**
  - **Functional metrics (e.g. biodiversity, carbon stock) should be measured after five years.**
  - **Structural metrics (e.g. seagrass extent) should be measured annually.**
  - **Genetic monitoring will determine whether translocations or restoration action have led to genetically viable and self-sustaining populations.**

INTRODUCTION

Monitoring is a powerful tool which can enable restoration practitioners to draw conclusions on the state of seagrass health and changes over time in restoration sites. It provides evidence and data for changes in a range of bed characteristics such as shoot displacement, surface area cover (area and density), signs of epiphytic algal overgrowth on the leaves, and changes in associated biodiversity.

Monitoring may be required as part of an HRA/MPA assessment if restoring in a marine protected area, or as part of a condition assessment if restoring as part of a Biodiversity Net Gain project in England.

Monitoring programmes are used to measure changes in a restoration site over time and determine whether a restoration project has been successful. This involves comparing baseline information with healthy natural seagrass beds with similar physical and environmental characteristics, known as reference sites, preferably nearby. If, in the long term, the seagrass beds at the restoration site meet or exceed the structural, functional and genetic indicators of those at the reference sites, the restoration project can be considered a success. Each restoration site should also be measured before the project starts and at different intervals once the seagrass has been planted. This is called a before-after, control-impact (BACI) study. BACI studies provide information about ecosystem resilience, mainly recording how individuals, populations, and ecosystems respond to ecological restoration. The key metrics need to be measured at both the reference sites and the restoration site for comparison. If no reference sites are available, a BACI will not be needed.

For a restoration project to be successful, the restored beds need first and foremost to persist in their new site, be self-sustaining, and reproduce sexually to ensure long-term survival and ecosystem resilience.

MONITORING METRICS

To assess the status of a seagrass bed, there are several relatively low-cost monitoring metrics that indicate seagrass health and function (Table 4.1). These metrics are categorised into structural and functional metrics. Structural metrics concern the plants' morphology, density and cover; functional metrics concern the ecosystem services that the bed provides. Ecosystem services benefit local communities, the environment and the ecology of the area (e.g. climate change mitigation, nursery function and improved water quality). Functional metrics are used in year zero (before the project starts) and then from year five. This is to allow enough time for the ecological interactions needed for habitat development (ecosystem services).

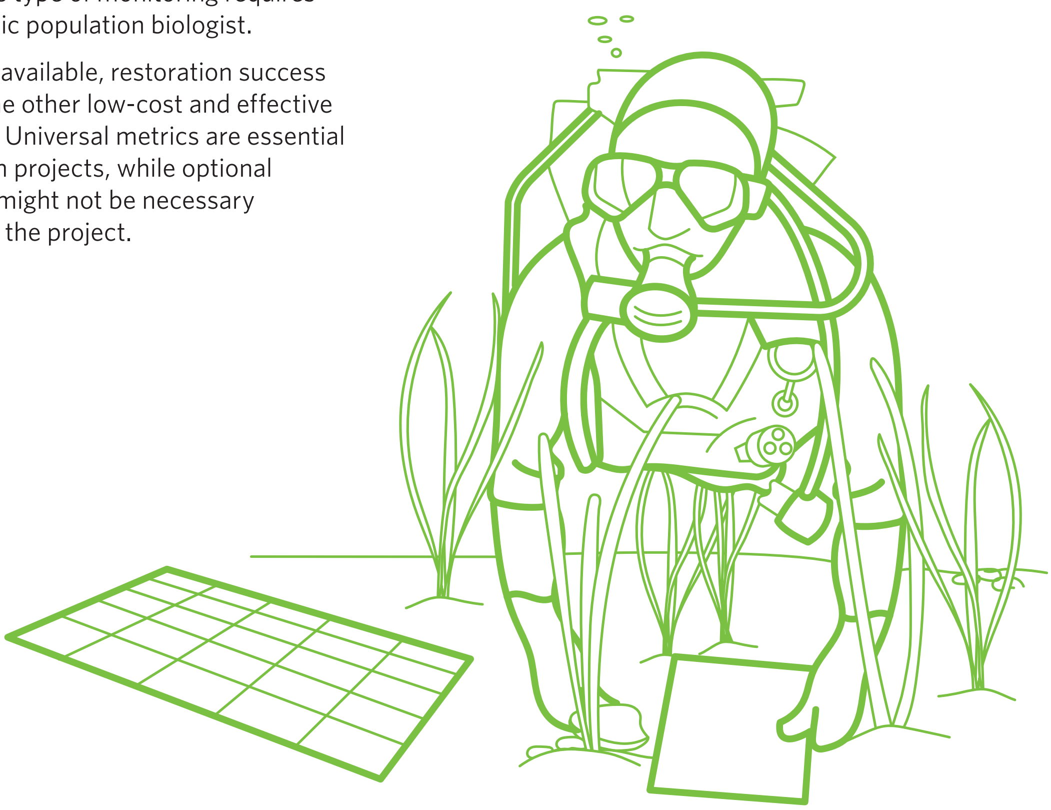
The development of the seagrass habitat will improve the structure and the functioning of the area. Over time, the seagrass beds will grow in extent and density, which will improve the structure of the habitat. This improved habitat structure will, in turn, improve ecosystem function – for example, a greater amount of atmospheric CO_2 will be sequestered, increasing below-ground carbon stock. This new ecosystem structure will increase the survivability of juvenile and vulnerable fauna. Fauna communities recruiting to the new beds will occupy different trophic (energy) levels, enhancing energy flow within and between ecosystems.

Although not a low-cost metric, genetic monitoring can provide important information about the seagrass population structure at restoration sites, such as inbreeding depression (lowered fitness due to inbreeding with close relatives), outbreeding, gene flow, adaptation and clonality (see Chapter 2). This information can be useful for evaluating the success of a site and for characterising genetically viable and dynamic populations. However, this type of monitoring requires collaboration with a genetic population biologist.

If these resources are not available, restoration success can be monitored using the other low-cost and effective metrics listed in Table 4.1. Universal metrics are essential for all seagrass restoration projects, while optional metrics are desirable but might not be necessary depending on the goals of the project.

Table 4.1: Structural and functional metrics (* = optional indicators to assess seagrass status; † = leaf length and width, from which canopy height and/or leaf area index is derived).

MONITORING METRICS
STRUCTURAL METRICS
Universal:
Cover/extent
Shoot density, leaves per shoot, leaf morphology†
Epiphyte cover and disease assessment
Optional:
Biomass*
FUNCTIONAL METRICS:
Universal:
Biodiversity
Water quality
Carbon stock assessment
Optional:
Sediment structure*,
Genetic monitoring*



MONITORING STRATEGY

Once the relevant metrics have been chosen, the next step is to define a monitoring strategy. A monitoring strategy is a carefully planned data-collection method, bespoke to the field site (e.g. how often should it be monitored? What level of replication is required? Transects or quadrats?). Transects are advised where the bed spans an environmental gradient (e.g. temperature, light, salinity and water depth (tidal height)). A number of national and international sampling strategies exist, which should be consulted for guidance (e.g. Water Framework Directive assessment methods) to allow comparison.

Long-term monitoring should be planned at the beginning of the project for year five onwards, and the challenges of securing sustained funding considered. However, it is important to gauge short-term success (up to year five, e.g. any increases in seagrass density, extent and biodiversity) so that restoration adjustments can be made if the project is not going to plan (adaptive management). Monitoring of newly restored beds or new beds begins with structural metrics indicators (shoot density, area cover, leaf morphology and growth, and seed production) and water quality. In year zero, structural indicators should be measured several times one, three and six months after planting the new bed, when the risk of loss is greatest. Frequent sampling will also help to identify any problems early on, so that those problems can be corrected with appropriate consultation (e.g. local university, agency). Functional metrics should be assessed after five years for comparison with the baseline surveys. See Table 4.2 for a timeline and suggested frequency for seagrass monitoring metrics.

Globally, lack of long-term monitoring (under five years) has been identified as a critical source of uncertainty in understanding seagrass restoration success (Rezek *et al.* 2019). Lack of long-term genetic monitoring has also been highlighted as a major gap in understanding restoration success (Van Rossum and Hardy 2021). Inter-annual survival is a useful measure of success while monitoring, but not for longer-term outcomes. Ideally, average annual change (in shoot density or percentage cover) should be measured over more than five years to estimate long-term success independent of inter-annual variability.

For monitoring to be efficient in detecting possible changes in seagrass distribution and abundance, it is important that variability in estimates is kept as low as possible. Monitoring should be carried out in the growth season (May to August) and at the same time of year in multi-year comparisons.

Table 4.2: Suggestion for a restoration monitoring programme (£ = cheap, ££ = medium expense, and £££ = expensive; * = optional indicators to assess seagrass status). In the carbon stock assessment section, before year five there will be minimal underground carbon storage. "Destructive" indicates an extractive or damaging activity.

TIMELINE AND FREQUENCY				
INDICATORS	**Year 0**	**Year 1–5**	**Year 6+**	**Note**
Structural Indicators:				
Cover/extent	After 1, 3, 6 months	Yearly	Yearly	£
Shoot density and leaf morphology	After 1, 3, 6 months	Yearly	Yearly	£
Biomass*	Once	Yearly	Yearly	££ Destructive
Epiphyte cover and disease assessment	After 1, 3, 6 months	Yearly	Yearly	£

TIMELINE AND FREQUENCY (CONTINUED)				
INDICATORS	**Year 0**	**Year 1–5**	**Year 6+**	**Note**
Functional indicators:				
Biodiversity	Before – Once	Year 5	Yearly	£££ Destructive
Water quality	Once	Year 5	Yearly	£
Sediment structure*	Before- Once	Year 5	Yearly	££
Carbon stock assessment, sequestration measurements	Before- Once	Year 5	Yearly	£££ Destructive
Genetic monitoring*	–	Year 5	Year 10	£££

REFERENCE BEDS

Seagrass bed characteristics are likely to differ from site to site, so it is essential to maintain reference site measurements for comparison. Reference site beds (a minimum of two) should be as similar as possible to the bed being restored in terms of exposure, tidal range, depth and physical characteristics (e.g. estuarine, lagoon). They should be measured and sampled at the same time as the bed being restored, and should also be as free as possible from anthropogenic stressors. See Chapter 2 and Figure 2.5 for the key ecological attributes of a reference ecosystem and the how the ecological recovery wheel can be implemented in the absence of a physical local reference site. If an appropriate reference site is not available locally, then a nearby degraded site with similar conditions to the restoration site is recommended, known as a control site. This will provide data for comparing environmental and ecological changes.

There are a range of UK government agency intertidal and subtidal seagrass monitoring programmes in place for water quality or marine protected area objectives. Previous survey methods can be found on the relevant SNCB webpages (e.g. UK-wide for Water Environment monitoring, and Natural England, Natural Resources Wales and NatureScot in marine protected areas), and it may be possible to link a reference site into one of these programmes to save costs and effort.

For genetic monitoring, reference beds should include nearby beds as well as large, healthy and non-isolated beds. Genetic data from these reference beds will give a clear indication of the level of genetic diversity and gene flow needed to obtain viable populations. Genetic data on source populations will also be needed to determine how much genetic diversity is present when the restoration site is created.

BRUV deployment being carried out by Project Seagrass, in Loch Craignish, Scotland. Photo: Lewis Jefferies.

BOX 4.1: KEY ECOSYSTEM ATTRIBUTES USED TO CHARACTERISE THE REFERENCE ECOSYSTEM

Baseline information:

Information collected before the start of the restoration project.

Reference site:

Reference sites are healthy beds that are physically (exposure and same depth) and biologically similar to the bed being restored.

Control site:

Control sites are beds with a similar degree of degradation to the bed being restored.

RECOMMENDED MONITORING METHODS

Structural universal metrics: Seagrass extent

Seagrass extent describes the area of sea floor covered by a seagrass bed, and provides a measure of seagrass abundance at specific tidal heights and water depths (subtidal and intertidal). The boundaries of seagrass beds are defined by OSPAR and UK government agencies as the area greater than or equal to 5% of the cover threshold.

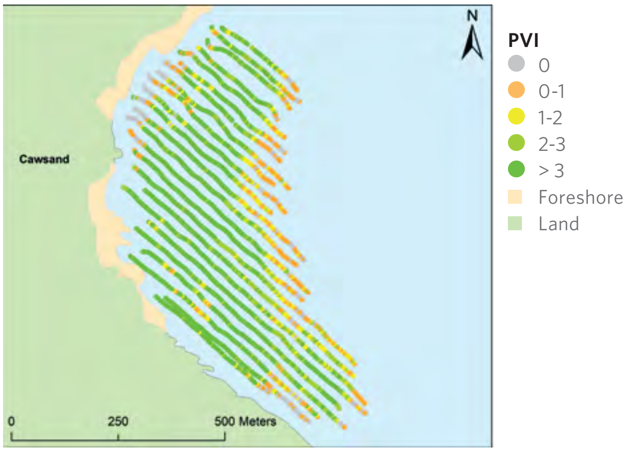
A variety of methods are currently used for monitoring seagrass extent, including optical remote sensing, acoustic monitoring, video and camera surveys, and detailed diver/snorkelling transects (Table 4.3). Extent can be measured using repeated video or acoustic transects or a grid of camera samples positioned across a bed (Figure 4.1). It is also important to measure the maximum depth at which colonisation occurs (the maximum water depth of the deepest-growing shoots) of the bed being restored to determine changes over time. The maximum colonisation depth is determined by UV light penetration and water clarity. Maximum colonisation depth can be determined by camera/video surveys or diver/snorkelers swimming along the deepest limit of the bed perimeter. It needs to be recorded at several points to ensure that water depth is measured at the same state of tide or corrected accordingly. All measurements should be carried out in the growth season (May to August). All walking surveys should be conducted at low tide (intertidal), while the shallow subtidal can be conducted via snorkel or SCUBA surveys. These methods can be used for both new and newly restored beds: an increase in seagrass extent indicates spatial success of the planting and seeding of the new bed.

Table 4.3: Seagrass extent mapping methods depending on the size and water depth of the area to be monitored. Green ticks (✓) indicate recommended methods, yellow ticks (✓) indicate methods with limitations and crosses (X) indicate methods that should not be used. Numbers 1 – 4 relate to note section below.

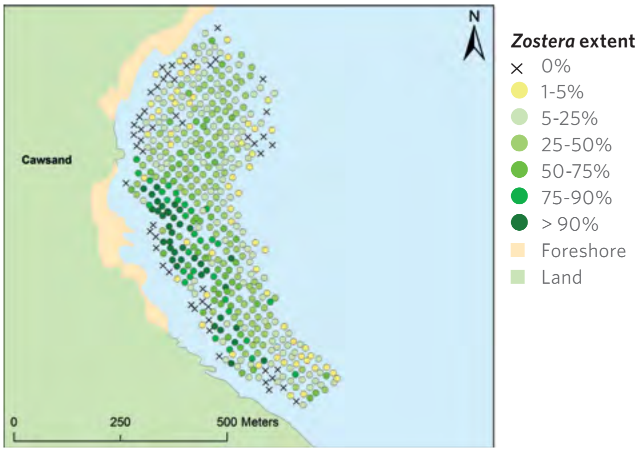
AREA	WATER DEPTH	IN SITU METHODS			REMOTE SENSING		
		Walking survey	Camera/ towed video	Diving/ snorkelling	Acoustic (echo sounder)	Aerial photo/ satellite imagery	Drone
< 1ha	Intertidal	✓	✓ (1)	✓	X (2)	✓ (3)	✓
	Shallow subtidal	X	✓	✓	✓	✓ (4)	✓ (3)
1ha–1km	Intertidal	✓	✓ (1)	✓	X (2)	✓ (3)	✓
	Shallow subtidal	X	✓	✓	✓	✓ (4)	✓ (3)

Note: (1)There may be safety issues operating in the intertidal zone. (2) Echo sounders require a minimum of 0.6m–1.0m water depth below the transducer to operate correctly, which might not be possible in intertidal areas. (3) Aerial photos struggle to differentiate between seagrass and intertidal green macroalgae and should be used with caution. (4) This works best in clear coastal waters such as off Cornwall and may struggle to differentiate between seagrass and macroalgae.

a) Echo sounder survey



b) Drop-camera survey



c) Comparison of interpolated extents between the two survey methods

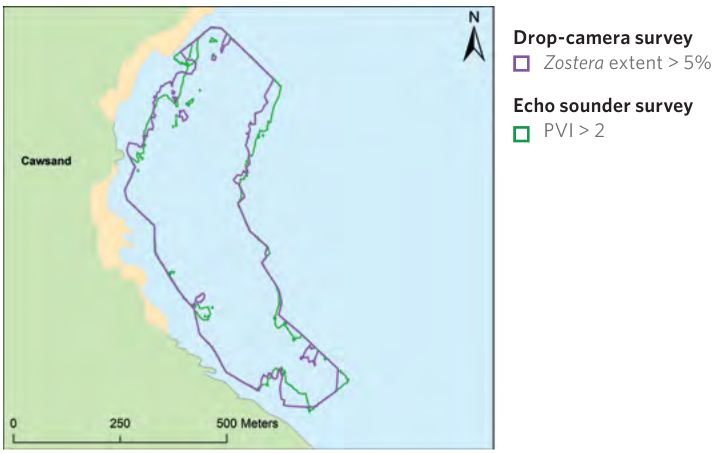


Figure 4.1: Example of seagrass extent determined using (a) a BioSonics echo sounder and (b) a drop-camera survey (at 25m intervals between sample points) of subtidal seagrass beds in Cawsand Bay, Plymouth in July 2018. The interpolated bed extent at greater than or equal to 5% cover (for the drop-camera survey) and equivalent percentage volume inhabited metric of 2 (PVI, an acoustic assessment of the percentage of the water column filled by vegetation from an echo sounder survey) resulted in broadly similar seagrass extent, with a difference of under 5% between the two approaches (c).

ABOVE-GROUND SEAGRASS CONDITIONS (SHOOT DENSITY, EXTENT AND LEAF MORPHOLOGY)

Shoot density refers to the number of seagrass shoots per m^2 (Figure 4.2). Shoot density is depth dependent, so it must be measured in relation to water depth. Shoot density is measured in a non-destructive manner by counting the number of shoots within quadrats in the bed. Two methods are commonly used: (i) randomly distributed quadrats, in which quadrats are placed anywhere in the bed at different tidal heights, or (ii) a transect line positioned perpendicularly to the strandline, extending out to the fringing edge of the bed, with a quadrat placed every 5 or 10m (transect length dependent). Once the quadrat is placed in the bed, the total number of shoots rooted within the quadrat are counted. Quadrat size and the number of quadrats must be determined before sampling and depend on the bed being sampled – for example, the quadrat should be $1m^2$ for patchy beds or $0.06–0.25m^2$ for uniform beds.

A valuable method, which does not require diving and enables an area to be covered quickly, is to undertake a visual assessment of the seagrass percentage cover within each quadrat. This can be carried out using drop cameras (e.g. for a subtidal survey) or a walking survey (if intertidal). This is a preferred method used by the EA, NRW and other agencies for their water quality and marine protected area surveys which are useful for long-term monitoring (Figure 4.2). It will enable calculation of the seagrass bed extent; the area of the seagrass bed at ≥ 5% cover.

Further detailed assessment is advised counting the shoot density and ideally the flowering parts (ideally including the number of seeds, fruits and flowers/flowering stems), as the number of flowering parts is a measure of seagrass reproductive ability. Within each quadrat, and within five randomly selected shoots, the number of leaves should be counted and the leaf lengths measured (Chapter 1, Figure 1.1). Leaf shoots are an important indicator of ecosystem shift: many leaves per shoot indicates a healthy seagrass ecosystem, while fewer than four leaves per shoot can mean that the ecosystem is stressed (Carr *et al.* 2012). This can be achieved non-destructively intertidally, but subtidally, the shoots will need to be removed. The number of shoots being removed should be carefully considered beforehand. If the shoots are removed, carbon to phosphorus ratio (C:P) and nitrogen to phosphorus ratio (N:P) can be analysed (see water quality section).

Optionally, leaf area index (LAI) may be calculated from the leaf and shoot measurements. LAI is the area of leaf surface (usually one-sided) per unit area of ground (e.g. quadrat or m^2) and may be used as an estimate of above-ground productivity. A proxy for LAI that can be used to compare sites or time points involves multiplying the length of the longest leaf by the number of leaves per shoot, by shoot density.

LAI = longest leaf length x number of leaves x shoot density

Empty quadrats should be recorded, because the proportion of quadrats occupied by seagrass can be used as a measure of 'patchiness' or fragmentation. Seagrass is known to alter its local environment, particularly water clarity as it slows currents and traps sediment, resulting in self-facilitation. This makes beds susceptible to rapid switches between 'alternative stable states' (dense shoots vs. bare ground). As a result, 50% occupation has been found to be the critical threshold, above which self-facilitation promotes restoration. If the proportion of occupied quadrats increases year-on-year, this can be considered a positive indicator towards success.

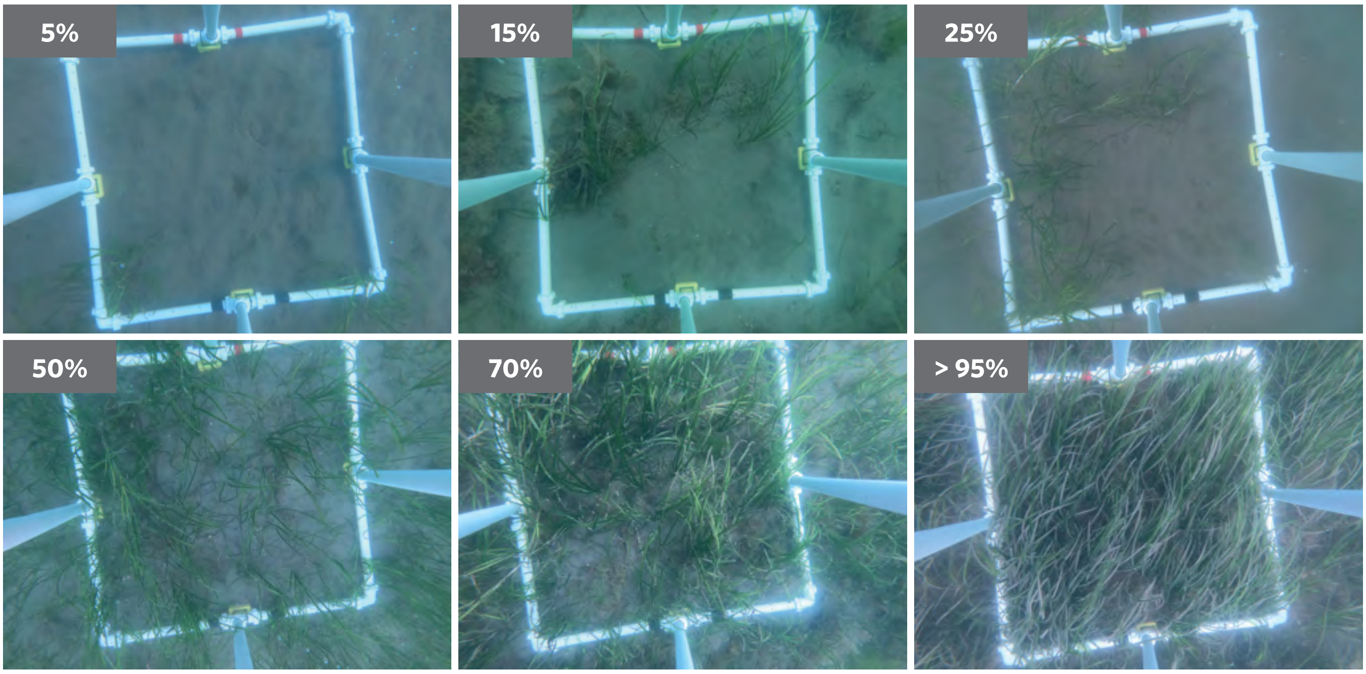
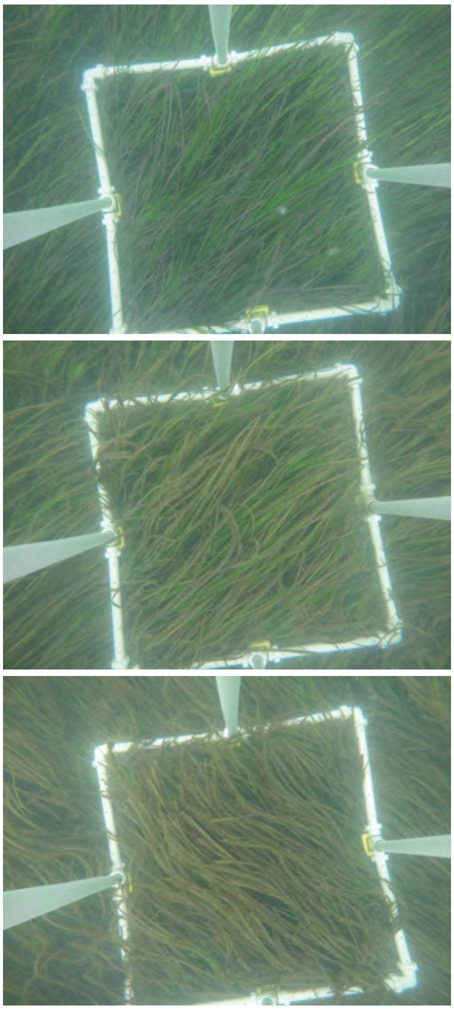


Figure 4.2: A range of common eelgrass (*Zostera marina*) percentage cover measurements from an EA drop-camera survey of seagrass beds in Torbay Marine Conservation Zone, 2019. The quadrat measures $1m^2$.

EPIPHYTE COVER AND DISEASE ASSESSMENT

Epiphytes such as hairy and filamentous algae growing on seagrass can be a consequence of excess nutrient levels. Epiphytes reduce the amount of light a seagrass shoot receives to the detriment of the plant. Epiphytes can be assessed visually (through camera, video or diver surveys) using a simple score of cover over a plant (Figure 4.3). Seagrasswatch.org suggests an approach for quadrats that first estimates how much of an average seagrass leaf surface is covered, then how many blades in the quadrat are covered (e.g. if 50% of blades in a quadrat each have an average of 20% epiphyte cover, overall coverage is 10%). Epiphytes can also be measured and weighed directly by scraping off the leaf as part of a biomass assessment.

Seagrass wasting disease (*Labyrinthula* spp.) was a cause of significant decline in seagrass across Europe in the 1930s and is still present today. It is best assessed by divers gathering seagrass shoots for biomass assessment, and can be scored as a percentage of the leaf infected with black mould (Figure 4.4).



LOW EPIPHYTE COVER

MODERATE EPIPHYTE COVER

HIGH EPIPHYTE COVER

Figure 4.3: Visual assessment of epiphyte cover from three 1m^2 quadrats of seagrass off Yarmouth, Isle of Wight in 2018. Photo: Environment Agency.

a)

SCORE	DESCRIPTION	% INFECTED
0	Uninfected	0
1	Minimal infection apparent	0-2
2	Up to a quarter of leaf infected	3-25
3	Up to half a leaf infected	26-50
4	Over half of leaf infected	51-75
5	Almost whole leaf infected	76-100

b) Wasting index key

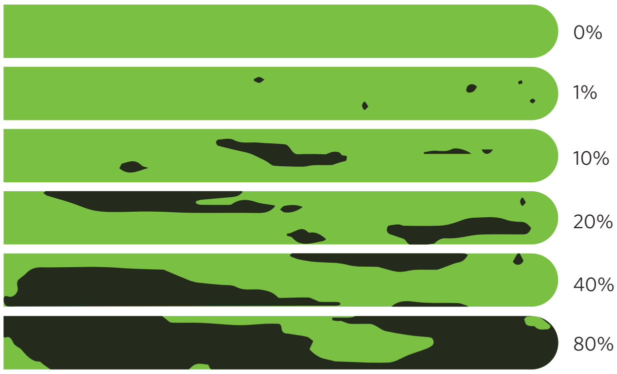


Figure 4.4: a) Scoring system used for recording *Labyrinthula zosterae* infection of seagrass leaves and epiphyte leaf cover from Field (2019), b) seagrass wasting index key from Burdick *et al.* 1993.

STRUCTURAL OPTIONAL METRICS

Biomass

Seagrass biomass is the weight (measured as fresh weight and dry weight in grams) of seagrass per m^2. This provides a volume measurement of seagrass abundance along the various tidal depths. Since biomass is depth dependent, seagrass biomass must be measured at different water depths.

Above-ground (leaf and flowering parts) and below-ground (rhizome) plant biomass samples need to be excavated (at a minimum depth of 10–15cm) using a small randomly placed quadrat (0.06–0.25m^2, depending on shoot density) and brought to the laboratory. Before undertaking this work, the relevant nature conservation authorities must be consulted to acquire all necessary permissions and licences (e.g. the local Natural England officer). To determine the dry weight biomass per unit area (grams per m^2), the shoots and rhizome must be rinsed and dried separately at 60°C for 48 hours. If the samples cannot be processed immediately, rinse them with distilled water and store them in a cool, dark place or freeze them. Biomass should be recorded annually. It is recommended that samples be taken randomly within the seagrass bed, avoiding bare areas. This will reduce variability within the estimates.

FUNCTIONAL UNIVERSAL METRICS

Biodiversity

Seagrass beds are an essential habitat for the juvenile and larval stages of many commercial, recreational and subsistence fish and shellfish (Beck *at al*. 2001). To estimate the development of this service, it is recommended that the abundance and diversity of diurnal fish, shellfish and crustaceans (crabs and shrimp) are quantified.

There are several techniques for assessing the abundance, diversity and biomass of fishes and epibenthic invertebrates. In turbid water, it is recommended to use gill nets, drop nets and standard monitoring units for recruitment of fish (SMURFs). In clear water, visual underwater census is recommended, which is less invasive. For a more in-depth analysis, infauna invertebrates (sediment-dwelling) may be sampled using sediment cores, looking for molluscs and crustaceans (Nienhuis 2001).

Water quality

Nutrient concentrations (particularly nitrogen), salinity, temperature and light attenuation in the water column are the most important water quality parameters affecting seagrass growth and biomass. Sampling must follow the standard scientific procedure. For example, replication and standardisation of sampling must be accomplished at the same state of tide (e.g. high-tide slack water).

Light attenuation (turbidity)

Light is one of the most important factors in the regulation of seagrass and its distribution at maximum depth. Light attenuation and turbidity can be measured by simply using a Secchi disc (see Nienhuis 2001). However, if more precision is required, a light meter can be used to measure photosynthetically active radiation (PAR) light levels at different depths in the water column. HOBO data loggers with light and temperature sensors can also be deployed for a continuous monitoring system (see Short *et al.* 2015). Light intensity can be measured in the reference bed for comparison.

A non-essential parameter related to turbidity is the rate of particulate sedimentation. The rate of suspended particle deposition on seagrass sediments can be measured using benthic sediment traps. These traps are placed 20cm above the sediment surface by divers/snorkelers.

Seagrass stable isotopic composition can also serve as a useful bioindicator of plant health (overall photosynthetic activity). Isotopes are a family of elements that have the same number of protons but a different number of neutrons. Stable isotopes analysis can be used to measure the ratio of carbon atoms to nitrogen atoms (C:N). Prolonged declines in light availability, which reduce photosynthetic carbon demand, result in increased fractionation against the heavier carbon isotope (13C) and progressively lighter δ13C values (Fourqurean *et al.* 2019). C:N is a robust early warning indicator of light reduction, albeit more expensive and destructive due to the need for leaf collection. For more detailed methods and context, see McMahon, Collier and Lavery (2013) and Jones and Unsworth (2016).

Nutrient concentrations

Seagrass thrives in low-nutrient environments. C:P has been identified as an indicator of environmental P limitation and N:P is an indicator of the balance in abundance of environmental nitrogen and phosphorus (the Redfield ratio defines N:P values of 25–30 as balanced abundance compared with light availability). As for C:P, this method is destructive as leaves will need to be collected. For seawater nutrients sampling methods, see Nienhuis (2001). δ15N can also be used to gather information about the presence of human-derived nitrogen in the area (Fourqurean *et al.* 2019).

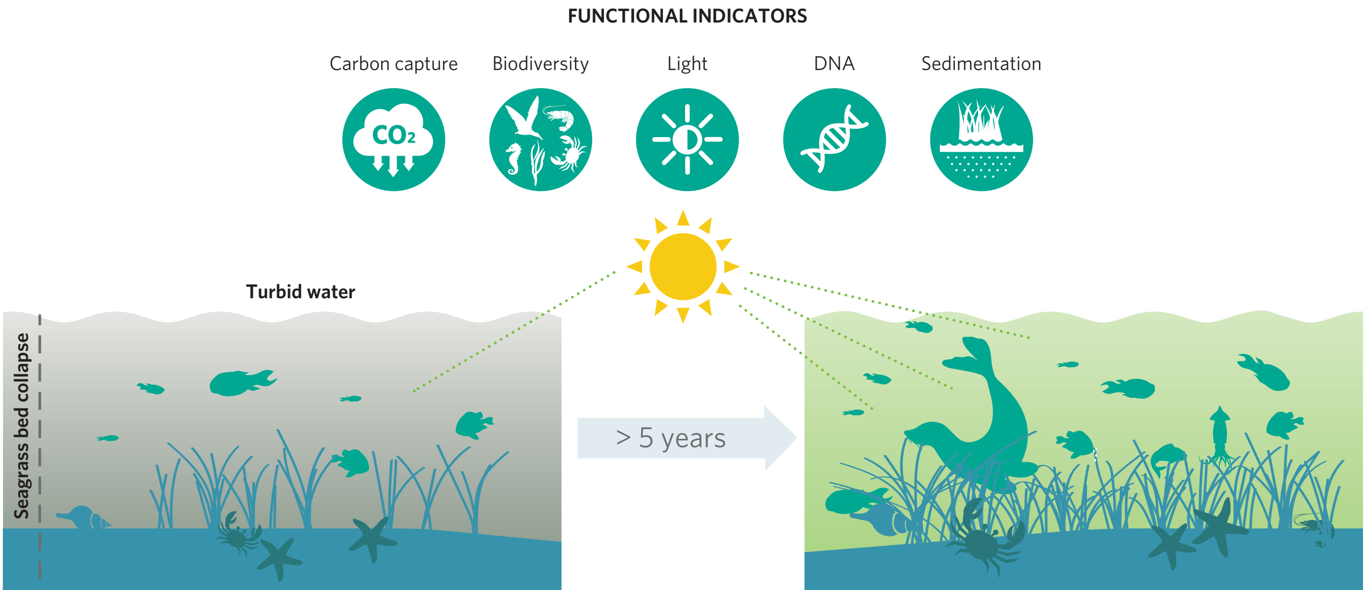


Figure 4.5: The metrics recommended to monitor changes in ecosystem functioning as a result of seagrass restoration.

Water column nutrients can be monitored to measure inorganic nutrient concentration in winter, and total nutrient concentration in summer. This requires specialist equipment which can be accessed via collaboration with a university or scientific consultancy.

Carbon stocks assessment

Seagrass beds contain two major carbon pools – living biomass (above-ground and below-ground) and sediment carbon – which can be considered in carbon stock assessments. As seagrass biomass varies seasonally, particularly in temperate climates, it should be measured when most abundant, with repeated sampling taking place at the same time in subsequent years. Sampling should also be based on depth intervals, since seagrass beds vary in structure along a depth gradient, which affects their ability to capture carbon (Howard *et al.* 2014). Living above-ground and below-ground biomass can be collected by inserting a large core tube (10–25cm in diameter) into the sediment through the above-ground plant material (the shoots), taking care not to cut any leaves, and into the upper root- and rhizome-dominated sediment. These cores are transferred to mesh bags, washed and separated into living above-ground and below-ground components, before being analysed for their carbon content. Each component's carbon content is determined using a different method (for more information on these methods, see Howard *et al.* 2014).

Sediment carbon is the largest pool in vegetated coastal ecosystems, which makes measuring its organic carbon content a crucial activity in determining long-term changes in carbon stocks. To accurately quantify the sediment carbon pool, sediment cores must be collected, subsampled and analysed for a specific depth (see Figure 4.6). For carbon stock assessments and greenhouse gas inventories, the Intergovernmental Panel on Climate Change (IPCC) recommends using sediment at a depth of 1 metre for calculations, as the upper 1 metre of sediment is vulnerable to management activities. However, seagrass sediments are often difficult to penetrate, with most studies sampling sediment cores of up to 30–50cm deep.

Steps for taking sediment samples in seagrass systems can be challenging, as the sediments are often saturated with water and therefore do not hold their shape. Moreover, driving a corer into the sediment will often compress it, causing depth-variable changes in the sample's bulk density, which could skew the carbon stock estimate. Efforts should be made to limit such compaction as much as possible and to record the depth interval for each sample, where necessary, to allow for corrections (see Howard *et al.* 2014 for the method to calculate the compaction factor). To accurately determine the sediment's carbon density, two parameters must be quantified: dry bulk density and organic carbon content. Once the dry bulk density (mass of dried soil/original volume) is determined, it can be used with the organic carbon content to determine the carbon density of the sediment at specific depth intervals. The total organic carbon stock from a sediment core can then be determined by summing up the values of organic carbon stock at all sediment depth intervals for the obtained samples.

FUNCTIONAL OPTIONAL METRICS

Sediment structure

It is recommended that a minimum of 10 random sediment samples be collected from the top 10–12cm of the sediment (the core should go as deep as the normal depth distribution of the roots of the seagrass species in question). From these cores, grain size (percentage of gravel/sand/silt and clay) can be measured (Conley *et al.* 2017). Prior to analysis, the cores should be divided into three sections to determine changes over time. Organic content (loss on ignition) and carbonate content (loss after acidification) can also be measured using the same cores. If resources are available, the carbon and nitrogen content of the sediment samples should also be analysed using a CN analyser (not high priority).

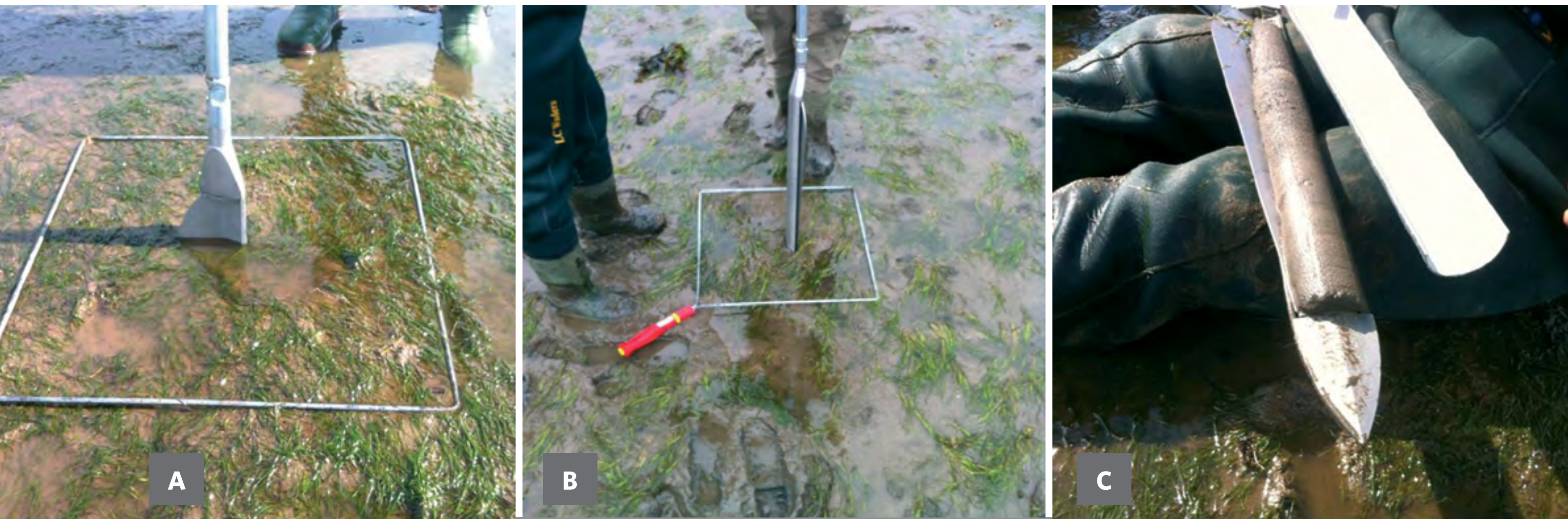


Figure 4.6: (A) Sediment coring in intertidal seagrass beds in Scotland. (B) Driving a 50cm-long Russian peat corer into the sediment. (C) Opening the corer chamber and moving the sediment sample onto a longitudinally sliced piece of plastic tubing for transport to the lab. Photos: Maria Potouroglou.

Genetic monitoring

Best-practice monitoring for conservation translocations (the deliberate movement of plants for conservation purposes) should include both molecular and morphological approaches, given the important roles of inbreeding depression (lowered fitness due to inbreeding with close relatives), outbreeding vigour (increased fitness due to breeding between distantly related parents), adaptation, phenotypic plasticity and clonality. Genetic monitoring reveals whether translocations have been successful and led to genetically viable and self-sustaining populations.

The ultimate fitness test for a species, and hence restoration success, is to develop self-sustaining populations that persist over time. Sexual reproduction (flowering parts) is crucial for this as it creates new gene combinations which can help plants adapt to environmental change. This, in turn, maximises their evolutionary resilience. Outbreeding, facilitated by gene flow, also has a positive effect on plant fitness. Genetic monitoring should therefore at the very least explore whether genetic diversity in restoration sites remains high and inbreeding rates remain low. This can be established a few years after translocations (e.g. two to five years) and should be repeated at a later stage (e.g. after 10 years). Analysis should include genetic diversity and inbreeding rates of adults as well as seedlings and seeds. Genetic data from seeds can determine the amount of inbreeding versus outbreeding in the restoration site and whether it is receiving genes from nearby beds – in other words, whether gene flow is present. This genetic data will provide important information on the population dynamics of restoration sites and indicate whether further action is needed, such as the introduction of more individuals, or new translocation sites to act as stepping stones for gene flow.

A tool for conservation practitioners has recently been developed by Van Rossum and Hardy (2021) which gives details and guidelines on the exact methods and analysis available for genetic monitoring. While genetic monitoring costs can be substantial, depending on the size and number of restoration sites, collaborations with research bodies could help mitigate these costs.

DATA COMPARISON (HOW TO MEASURE SUCCESS AFTER FIVE YEARS)

Measuring the success of a seagrass restoration site is not an easy task (Society for Ecological Restoration [SER] 2004; Ruiz-Jaen and Aide 2005; Figure 4.7). The monitoring metrics recommended earlier will provide evidence on the three major ecosystem attributes (diversity, vegetation structure and ecological processes) and the data needed to calculate restoration success. The SER also highlights the importance of using a minimum of two reference beds.

A good basis for measuring success is to consider the concept of resilience (the ability of an ecosystem to deal with change). Maybe the most relevant component of resilience to a restoration project is resistance – how much an ecosystem can be disturbed before it undergoes major change (for example, to an alternative stable state) or collapse. Measuring resistance by deliberately disturbing an ecosystem to the point of collapse is clearly not desirable, so one generally accepted approach is to measure its natural parameter value range. If the restored seagrass beds sit within the natural parameter value ranges of the reference beds, it can be assumed that they can resist natural disturbance. The challenge is to define the limits of that natural range. If long-term monitoring of reference sites is available, the limits should be the annual variability (see Isles of Scilly case study in Chapter 2). Where this is

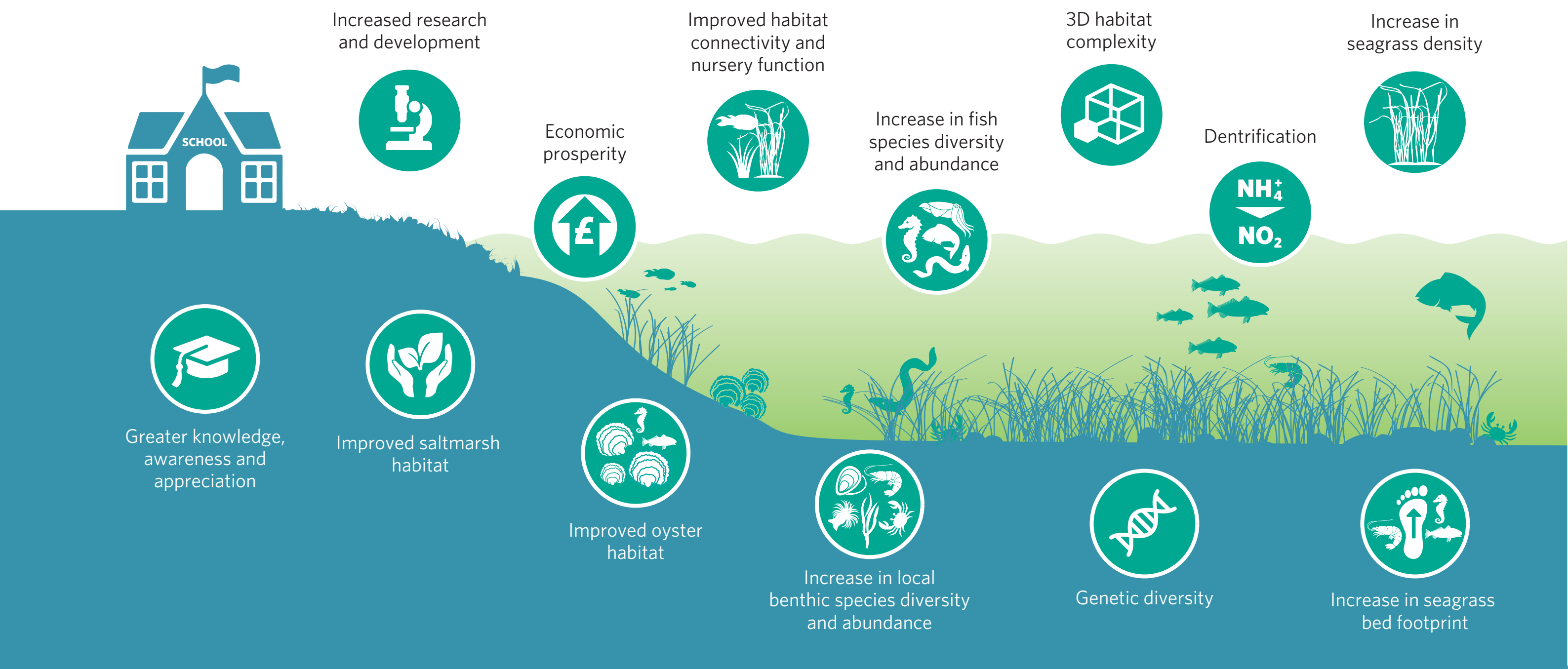


Figure 4.7: Key indicators to quantify the success of a seagrass restoration project.

not available, variability across space may be used. As an example, the *Handbook for Eelgrass Restoration in Sweden* (Moksnes *et al.* 2016) proposes one standard deviation of the natural spatial variation as this limit.

When assessing the quality of the restored bed, key parameter values (e.g. shoot density) are compared with the reference beds by calculating a quality ratio. This value is then assessed against a threshold value that takes into account the natural variation of the same key parameters in the reference beds (Short *et al.* 2000) (see the example calculation).

If reference beds are not used, changes in extent and shoot density can be assessed over time following Water Environment Regulations approaches and thresholds. An annual loss of 30% or more of bed extent and/or shoot density would be considered unfavourable following this approach and would be assessed as "less than good ecological status".

If a control site, rather than reference bed, has been used, the parameter values within the restored sites need to be better than those measured at the control sites.

BOX 4.2: HOW TO MEASURE SUCCESS USING THRESHOLD VALUE AND QUALITY RATIO

For example, shoot density per m^2 in the restored bed can be compared with the reference bed(s) using a minimum of 10 randomly placed quadrats in each bed. Shoot density in the restored bed after five years was averaged to 515 shoots per m^2.

The shoot density of the reference beds was measured at an average of 560 ± 102 (mean ± SD) shoots per m^2. Thus, the quality ratio is 515/560 = 0.92. Threshold value = (560-102) / 560 = 0.82.

Quality ratio > threshold value (0.92 > 0.82). This means that the restoration was successful.

The threshold value can also be used to determine whether there have been increases in (i) biomass, (ii) maximum depth distribution (iii) sediment variables, and (iv) the abundance and diversity of fish and invertebrates.

A threshold value is a point at which a significant change has occurred within the restored bed:

Threshold value = (average of parameter *a* – 1 SD in reference beds) / (average of parameter *a* in reference beds). Note: parameter *a* can be any parameter (e.g. shoot density or extent).

Where SD is the standard deviation.

Quality ratio = (average of parameter *a* in the restored bed) / (average of parameter *a* in the reference bed)

If the quality ratio is greater than the threshold value, the restoration project has been a success.

Quality ratio > threshold value. Project successful

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CHAPTER 5
PUBLIC ENGAGEMENT AND COMMUNICATIONS FOR RESTORATION PROJECTS

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KEY SUMMARY POINTS

- **As seagrass habitats typically overlap with human activities, engaging positively with local communities from the start is crucial to successful project outcomes.**
- **Scheduling time to develop a project communication plan is fundamental in order to successfully communicate your restoration project and engage with stakeholders.**
- **Depending on the marine licence requirements, evidence of stakeholder engagement might have to be provided to support licence application and help ensure success in gaining the licence.**
- **There are a range of communication and engagement tools to choose from. It is advised that the appropriate method(s) is selected based on the desired outcome or goal.**
- **Monitoring engagement and outreach activities, media coverage and volunteer/community participation is an important way of showcasing the real-life impact of the project and is often required by funders.**

INTRODUCTION: IMPORTANCE OF EFFECTIVE COMMUNICATION

A communication strategy for seagrass projects should consist of public outreach and stakeholder engagement. It typically has three distinct targets: local stakeholders, the general public and volunteer participants (if required). The term '**outreach**' typically refers to disseminating information and raising awareness among the general public as a whole, whereas '**engagement**' tends to cover more active involvement and interaction with local communities and stakeholders. Communication planning, monitoring and impact assessment may have to take each of these aspects into consideration.

RAISING PUBLIC AWARENESS AND OCEAN LITERACY

Encouraging both local community engagement as well as increasing public awareness (through outreach) are critical to any conservation management activity, including restoration of seagrass. Lack of local public appreciation of the value of seagrass habitat is perhaps the greatest risk to its ongoing survival as public opinion can impact restoration funding, policy, stakeholder engagement and involvement. Increased ocean literacy – the understanding of our individual and collective impact on the ocean and its impact on our lives and well-being – and awareness of the value and role of seagrass will raise its public profile, increase public support for the project, build local stakeholder support and attract funding and volunteers. As restoration practitioners, it is easy to assume that there is wider public support for conservation actions, but for many people, the value and function of seagrass and the consequent need to restore it are not on their radar.

Even people who do recognise the problems faced and the need for interventions such as seagrass restoration may not see it as relevant to their lives personally. Equally, different stakeholder groups have diverse perspectives regarding the acceptability of activities, and restoration activities may be contentious, particularly if interventions are perceived to have an impact on a group's normal activities.

UNDERSTANDING STAKEHOLDERS

As seagrass habitats in the UK are typically found in shallow water or in intertidal and sheltered areas, they overlap with human use, such as recreational boating and sailing areas, permanent and seasonal mooring sites and anchoring safe havens. Understanding these constraints is crucial when planning and conducting a restoration stakeholder process, which ideally would begin a considerable time before the project is launched on the ground. Spatial models for restoration suitability can help alleviate community concerns, demonstrating that the project proponents are already considering the siting of restoration and its impact on other users.

For restoration to be a success, it is essential that local understanding and support are gained from the beginning, as they will influence a project's impact and therefore the potential for its expansion. Pre-project community engagement must form part of any social impact assessment. Some sites may have been through stakeholder engagement processes for past projects and any restoration projects should seek to understand the local history and the wider marine policy context to best address their specific stakeholder concerns. In addition, the general public and the boating and fishing community are generally not aware of the value of seagrass habitats. This makes the communication plans crucial to the success of the project.

The goal for community involvement can also be practical. Many restoration activities are labour-intensive and costs associated with the collection and deployment of restoration material, and post-restoration monitoring, can severely limit actions on the ground. Engaging citizen scientists or volunteers, such as Seasearch divers, can overcome this problem while also increasing public awareness of seagrass bed value and plight. See more about attracting, managing and retaining volunteers on page 74.

Figure 5.1: Bilingual interpretation pop-ups used during community events in Dale, Pembrokeshire, Wales. Photo: Sue Burton.

DEFINING SUCCESS – MEASURING IMPACT

Any proposed seagrass restoration project should consider project 'framing', i.e. defining what success would look like to the project. What is hoped to be achieved? Where? With whom? It is important to have a clear idea of the project's aims and rationale and to identify a number of measurable outcomes, which can be as simple as "a wider range of people will engage with the marine environment" or "people will have acquired new skills". These will help set out the goals for the engagement strategy and will focus on target audiences early on. The goals of engagement may differ between restoration projects, due to location, demography of the

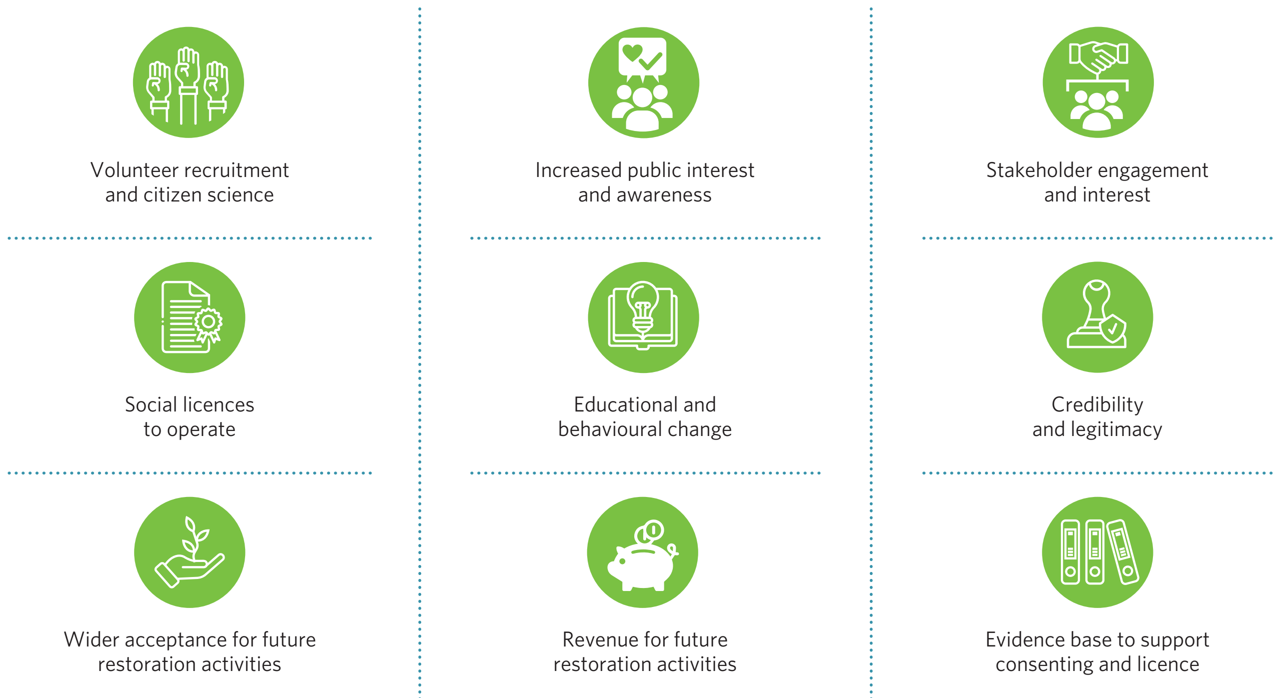


Figure 5.2: Goals for engagement in seagrass restoration activities.

community, drivers for restoration and the presence of either conflicting or complementary activities (Figure 5.2). In Australia, the Seeds for Snapper seagrass restoration project gained widespread community involvement and industry support once recreational fishers had recognised the value of seagrass beds as fish nurseries.

Once this project framing is clear, the next key step is stakeholder engagement – sharing the vision for the project with local communities. Testing whether this vision is shared is central to any project's success. Taking the time to understand local perspectives and the existing use of the environment will help address any potential conflicts and will ensure that the project has stakeholder support from the outset. Focus on solutions and be willing to work to resolve any perceived conflicts. And remember, it is likely this same network that will offer stewardship of the restored site in the long term. It is important at this stage to not 'oversell' the benefits of the restoration project, meaning trust and authenticity are key. Be as accurate as possible in the use of the science (e.g. ecosystem service claims need to be UK-based and not imported from the headline figures of seagrass beds overseas) and if you are not sure, check with someone who knows. Remember that taking photos, be that on a phone, DSLR camera or anything in between, is invaluable, allowing others to see the ongoing project work and enabling project staff to reflect when looking back through albums. See Table 5.1 for various tools for engagement and outreach, and see the case studies at the end of the chapter for specific successful examples.

If outreach is conducted in an effective manner, it can help projects engage with and receive help from volunteers, inform and persuade policymakers or decision makers, share knowledge, streamline processes and access, secure funding sources, and/or improve ocean literacy of the local community.

Used efficiently, a combination of outreach and engagement mechanisms can be a powerful way of scaling up the impact of a project, to get more people actively involved and ultimately more seagrass in the water. By reaching out to the local community, a sense of stewardship can be established, which in turn increases the number of people involved in spreading the word, thus saving time and money.

COMMUNICATION, ENGAGEMENT AND BEHAVIOURAL CHANGE

The root causes of many environmental issues can be linked to human behaviour and its consequences. Some of the most pressing issues facing seagrass are complex and difficult to tackle, such as controlling water quality or reducing coastal development. Some, such as not anchoring on fragile seagrass beds, are much easier to address. A successful seagrass restoration strategy must also tackle the degradation of the coastal sea, while the communication strategy can play a huge part in raising awareness of these more complex issues, once people have become more aware of the value of seagrass and their interest has been sparked. Restoration projects can join forces and work together with other local and/or national environmental campaigns, setting up events and stalls together, releasing joint media statements and enforcing each other's messages.

Traditionally, awareness-raising has been relied upon to change people's behaviour, believing that all that is lacking is knowledge. This approach works from the premise that if we all knew the impact of our actions, surely we would change our ways? Unfortunately, this is not the case. Research on environmental psychology and behavioural change informs us that knowledge is only one determinant of behaviour. Other influences include past behaviour, emotions, attitudes, social norms, and perceived behavioural control. All of these can be addressed by effective communication and media engagement.

Read more:

Delivering behavioural change at scale: What conservation can learn from other fields. (Travers *et al.* 2021) sciencedirect.com/science/article/pii/S0006320721001440

Behaviour change measures in conservation, www.ecos.org.uk/behaviour-change-measures-in-conservation

COMMUNICATION PLANNING

The Restoration Guidelines for Shellfish Reefs, Chapter 9 includes detailed planning steps for communication planning. Furthermore, the Reef Resilience Network has developed materials on strategic communication for conservation, which provide all the tools needed to successfully plan project communications. A different take can be found in the Saltmarsh Creation Handbook: A Project Manager's Guide. You are advised to refer to these materials when creating a communications plan and a public and stakeholder engagement plan.

As highlighted in Chapter 2, it is imperative to engage with identified project stakeholders (Figure 2.6) at the beginning of your project and to continue to do so as the project develops. It is useful to build a team of key contacts relevant to the communication aspect of the project, such as by developing a communications steering group, and to develop the communication and engagement plans in collaboration with them, holding regular meetings. Figure 5.3 shows a checklist of the communications planning process, from establishing the project communication goals and objectives, to assessing the context of efforts, identifying audience, creating messages, and finally creating a summary of the communications plan and subsequently measuring its impact.

Include **ADEQUATE TIME AND FUNDING** *for planning communications and stakeholder engagement.*

DEFINE YOUR GOALS, *describe your outcomes and decide on activities used to achieve these.*

DO THE GROUNDWORK *to understand the local context.*

IDENTIFY ALL RELEVANT STAKEHOLDERS *and their needs, which will differ depending on their level of understanding.*

INVOLVE STAKEHOLDERS *and create opportunities for involvement from the very beginning.*

Pay **SPECIFIC ATTENTION TO BOAT AND FORESHORE USERS** *to ensure that they are clear about what restoration will and will not mean for them.*

Utilise **MULTIPLE ENGAGEMENT METHODS** *to ensure that information is clearly provided and received.*

Assess your **IMPACT.** *Use adequate metrics to evaluate and communicate your impacts with reference to your original goals.*

Figure 5.3: Planning your communication strategy.

ENGAGING WITH THE MEDIA

Attracting the attention of the mainstream media (standard online and print news) can be difficult. A quick online search for "seagrass" typically brings up baskets and flooring, and searching #seagrass images on Instagram brings up a lot of photos of marram grass and other terrestrial coastal grasses. Like many UK marine habitats, seagrass beds have to compete with coral reefs and tropical waters, often making engaging visual representation challenging. Seagrasses need to be presented to people as beautiful, vibrant habitats, rich in marine life, with both a significant ecological and economic role to play.

Journalists need a hook and often that is linked to a human connection. To garner interest, perhaps explain the many benefits of seagrass beds to humans. From sediment stabilisation and carbon sequestration to habitat creation and nursery function, the ecological benefits of seagrass restoration are significant. Restoration efforts can create job opportunities. Think creatively to make seagrass relatable to everyone and remember that language is important. The term 'seagrass meadow' conjures up images of beds full of life and biodiversity (think wildflower meadows), whereas a 'seagrass bed' does not capture that vibrancy in the same way.

Different audiences have different interests. Use these to best advantage. The use of infographics (e.g. Project Seagrass's "One Hectare" campaign) and powerful imagery (e.g. iconic species association such as seahorses clinging to seagrass) have had success in attracting the interest of new audiences. Other engagement opportunities exist through art and gameplay (see *Case Studies: Restoration awareness through gameplay*) and by relaying messages in a more relatable way (Figure 5.4).

Figure 5.4: Information typically found on a seed packet is research data to which the public can directly relate. Photo: Emma Jackson.

The rewards of these efforts can be a change in perception, from people thinking seagrass is 'just grass' to seeing it as a 'superhero' of the seas. This requires clear and well directed messaging.

To make it easier for journalists to select the story, make sure there is:

- a plain-language media statement and clear take-home messages
- high-resolution visual assets such as videos or images
- a spokesperson they can interview

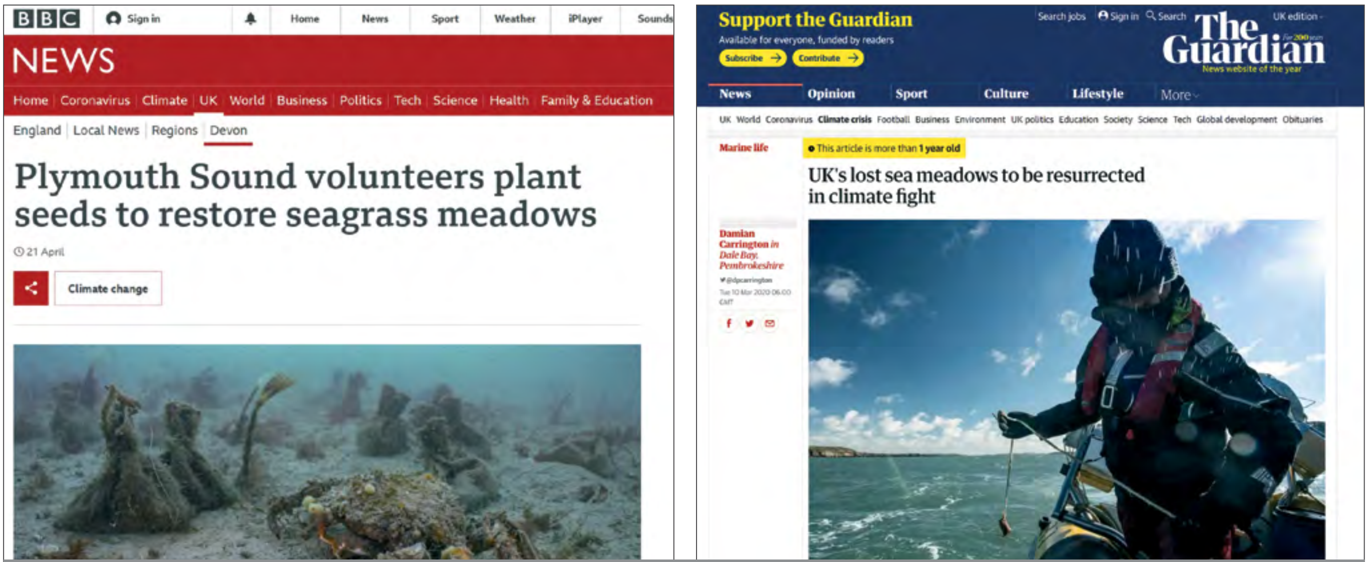


Figure 5.5: Online screenshots of successful national seagrass media stories.

Collect as much visual material as possible during all stages (ideally during an event or activity happening in the field) of the project, as this will prove extremely useful for a variety of outreach mechanisms later. Journalists may enjoy getting out of the office, so invite them if there is restoration activity planned, especially one with community volunteers. They may like to get involved themselves, which opens up opportunities for nature broadcasts such as the British Broadcasting Corporation (BBC)'s *Countryfile*, BBC *Springwatch* or BBC Radio 4's *Farming Today programme.*

Beyond mainstream media, there are also specialist science outlets, such as Mongabay, *BBC Wildlife Magazine* and *New Scientist*, where scientific papers or reports can be pitched. Invite them to conferences and work with publication journals to send science papers under embargo to make the news agenda. There are lots of topical elements to seagrass, such as climate change, biodiversity decline, plastics. The key is to find an appropriate 'hook' for the story you want to tell. Use these opportunities to amplify local voices in restoration, celebrate diversity and make a point of inclusivity. The restoration project does not have to be a narrative about ecological restoration: it could be one of community development or mental health and well-being.

Do not try to reinvent the wheel or to do it alone. There are bigger 'brands' out there that are working on the same things, so do not be afraid to leverage those brands to give the project a platform and increase its reach. These organisations/individuals are also likely more connected to the media, and so could perhaps put the project in touch with media contacts or at least offer suggestions.

Finally, the single best vehicle for articulating the seagrass restoration project is via the United Nations Decade on Ecosystem Restoration 2021–2030 and the #GenerationRestoration movement. Explore the decade's partnership framework, engage with the #GenerationRestoration hashtag and messaging, and place the project within a global community of ecosystem restoration practitioners.

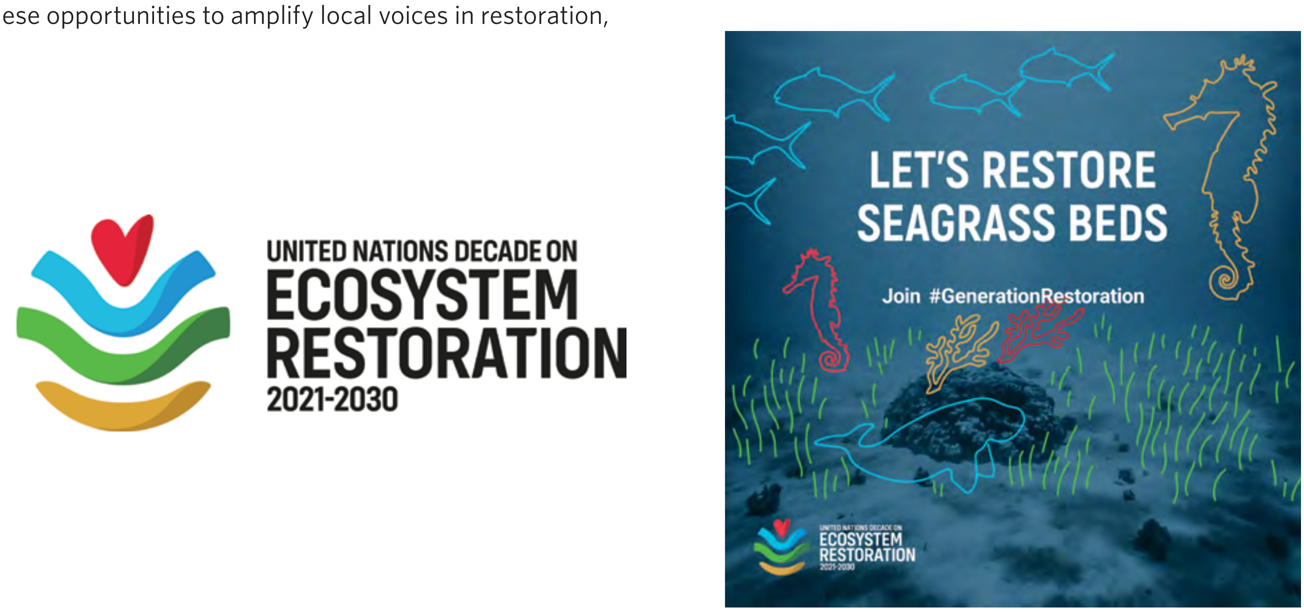


Figure 5.6: United Nations Decade on Ecosystem Restoration logos and hashtags.

ENGAGEMENT TOOLS

The internet is full of engagement tools and information for all ages. Check whether suitable material is already available, before spending time and money on designing new resources and content.

Table 5.1: Summary table of the existing outreach and engagement mechanisms available to restoration projects, how they are delivered and to which audience, as well as the relative financial and time investments required.

Note: Costings and time investments are relative and not specified amounts. The costs indicated by a human symbol are instances where existing staff can factor these activities into their time, therefore no additional staff funding is required.

ENGAGEMENT	DELIVERY	AUDIENCE	COST	TIME
Educational outreach	**In person and online** **How?** School visits, work experience, presentations, lesson plans, downloadable resources, webinars via Skype/Zoom, gameplay *etc.* **Hints & tips** Offer involvement in practical aspects such as seed bag filling. Use games with educational learning objectives. Link to curriculum for greater uptake.	Primary/ secondary schools High schools/ Colleges/ University/ Extracurricular groups Academic conferences	👥 – £ 👥 – £ 👥 – £££	Initial investment (lesson planning, gathering materials, curriculum matching) 🕓🕓🕓 Once materials are in place 🕓
Festivals/ events	**In person** **How?** Festivals, workshops, science events Events e.g. boat shows Public talks, pub quizzes, seagrass trivia events Art exhibitions, photo competitions **Hints & tips** Streamline the gear needed for events, so it can be displayed and put away quickly and easily into a couple of bags. Ensure all relevant information is clearly displayed. Festival stands tend to be small so condensing your festival set-up to include key information and contact details is important. Work with local and known artists or celebrities to reach wider audiences.	General public	👥 – £ Initial cost of designing and purchasing stand and visual displays ££ – £££ Cost of attending 👥 – £	🕓🕓 Travel and weekends
Website/ web page	**Online** **How?** Website hosting platforms e.g. WordPress, Wix **Hints & tips** Lots of images, regular updates, targets (seed counter), promote contributions (e.g. adopt a seagrass transplant).	General public, project partners, science community	👥 – ££ Maintenance: £ – £££	Initial investment 🕓🕓🕓 Continuous 🕓

ENGAGEMENT	DELIVERY	AUDIENCE	COST	TIME
Community engagement	**In person** **How?** Stakeholder meetings allowing open discussion. Form a local working or focus group. **Hints & tips** Providing basics, such as tea and biscuits, goes a long way to boosting morale and securing returnees. Evening meets allow a wider attendance and encourage turnout.	General public Public talks	👥 – £ 👥 – ££	🕒🕒
Volunteers and citizen scientists	**In person** **How?** Practical assistance Fieldwork (seagrass monitoring and surveys, seed collection, planting). Lab work (seed sorting, planting preparation). Target core community volunteers first, but look to widen participation. **Hints & tips** See Box 5.2 and 5.3.	General public University students Recreational dive clubs Community partnerships	👥 – £ 👥 – ££ 👥 – ££ 👥 – £	🕒 – 🕒🕒🕒 One-day visits, one-week work experience or longer summer placements
Communications & marketing	**Online** **How?** Social media platforms e.g. Twitter, Instagram Outreach films Documentaries Student projects YouTube channel Infographics **Hints & tips** Regularly take progress images and videos, utilise 'story' functions on apps such as Instagram. Regularly engage with popular hashtags e.g. #TeamSeagrass and #seagrassrocks. Work with local media student projects, encourage others to create films and content. Make everything shareable.	General public Funders Government agencies Project volunteers	Images 👥 – £ Documentary /film: ££ – £££	Initial investment in designing and creating effective materials 🕒🕒 – 🕒🕒🕒 Materials and information need to be continuously updated 🕒

ENGAGEMENT	DELIVERY	AUDIENCE	COST	TIME
Merchandise	**In person and online orders** **How?** Project clothing Crowdfunder rewards Mail delivery Celebrity/brand endorsement Membership packages **Hints & tips** Make rewards sustainable and desirable, not something people will want to throw away.	Project restoration practitioners, local supporters, volunteers	£ – £££ (Proportionate to the number of orders)	Initial investment in designing products and ordering 🕓 – 🕓🕓 Continued cost of orders 🕓

BOX 5.1: SOCIAL MEDIA TIPS

Social media is the key to sharing and promoting your restoration story. Different platforms allow a wider reach, for example Twitter targets an academic audience while Instagram has a younger following.

Taking and sharing numerous photos and videos at each stage of your project boosts engagement. Ensure regular interaction with your followers and other key influencers, and use relevant hashtags, such as #TeamSeagrass and #GenerationRestoration.

In-favour platforms will change with trends, so keep it relevant, and critically keep it authentic.

Extra resources for engagement and education in seagrass restoration

projectseagrass.org/education/

seagrasswatch.org/education/

wildlifetrusts.org/habitats/marine/seagrass

national-aquarium.co.uk/explore/conservation-projects/seagrass-restoration/

worldwildlife.org/stories/seagrass-the-lesser-known-superstar-in-the-fight-against-the-climate-crisis

discoverwildlife.com/plant-facts/water-plants/seagrass-guide-what-is-it-and-why-is-it-so-important/

Useful resources and toolkits for impact measuring

publicengagement.ac.uk/do-engagement/evaluating-public-engagement

mycommunity.org.uk/how-to-measure-and-show-the-impact-of-your-project

mooreks.co.uk/upload/pdf/ImpactToolkit2013_updated_FINAL_1.pdf

theoryofchange.org/what-is-theory-of-change/

ATTRACTING, MANAGING AND RETAINING VOLUNTEERS

Seagrass cannot be restored at scale without the help of volunteers. They are the best donors, the strongest advocates and the most efficient engagement tools. Attracting, training and retaining volunteers is central to a successful restoration programme. Although volunteer motivations vary, usually people volunteer because they believe in the cause, want to change the world and hope to learn new skills while enjoying themselves. Volunteers that do not feel valued will quickly lose interest. Volunteer management and coordination is therefore an important role that should not be overlooked.

Tip: Make sure to stay GDPR (General Data Protection Regulation) compliant with any form of personal data collection, be that surveys or health and safety volunteer sheets.

Figure 5.7: Seagrass volunteers at work in Dale, Pembrokeshire, Wales. Photo: WWF-UK/Joseph Gray.

BOX 5.2: TIPS FOR ATTRACTING, MANAGING AND RETAINING VOLUNTEERS

ATTRACTING VOLUNTEERS

- Use social media, activity groups and university societies to rally volunteers.
- Assign a volunteer coordinator as the main contact for volunteers.
- WhatsApp groups can be a useful way of organising and communicating with large groups.

SAFETY & LOGISTICS

- Have a dedicated, first-aid trained shore cover who knows where everyone is (in or out of the water) and is ready to take the lead in an emergency situation.
- For in-water work, follow strict safe diving/snorkelling protocols.
- Provide adequate training and personal protective equipment (PPE) if needed.
- Ensure volunteers have read the risk assessment and have signed an indemnity waiver.
- Give a thorough and detailed briefing to staff and volunteers at the beginning of each event.
- Communicate regularly and provide a plan of volunteer action with detailed kit list, location, timings, methods and risks as early as possible.

DIVERSITY & RESPECT

- Make sure you allow people of different abilities to participate and make provisions for this in advertising, training and project implementation.
- Value volunteers' time. They are donating their time and energy to the project.
- Listen to volunteers' suggestions and feedback and ask for their opinions.
- Volunteers deserve to be treated like major donors. Do not overlook the fact that they give their time, energy and sometimes funds.

TRAINING & SKILLS

- Volunteers' existing professional skills and expertise can be great for the project, but respect if people are wanting to learn new skills.
- Ensure you provide adequate resources, training and instructions for all tasks and evaluate people's contribution and performance.

HAVE FUN

- Buddy up a staff member with volunteers. They can show them marine life, chat about your project and seagrass, and check they are safe and happy.
- Provide lots of tea and cake!
- Have regular get-togethers and the occasional party. Remember to feed back the outcomes of the project.

CREATE A VOLUNTEER ENGAGEMENT POLICY

- Long-term projects and projects with regular returning volunteers should have a policy that clearly lays out your volunteers' rights and responsibilities.
- For inspiration, see npengage.com/nonprofit-management/retain-volunteers/.

MONITORING THE SUCCESS OF ENGAGEMENT AND OUTREACH

Monitoring the success of outreach efforts provides crucial information about the impact of the project, its effect on societal well-being and the ability to gain future funding. It also provides key opportunities to learn tips and tricks from the experience to make future restoration projects more successful. It will be easier to tackle repeated and novel problems, and to be able to plan to scale up.

Tip: Note that in order to measure the achievements, it is important to know what success will look like and to plan which data need to be gathered.

Some monitoring techniques are simple lists and Excel tables of activities and participants, while others require a more interactive approach in the form of surveys, including questionnaires or interviews and analysing the results. There are plenty of easy-to-use tools online (such as SurveyMonkey and Microsoft Forms) and Google Analytics, which tracks the performance of social media campaigns.

The impact of any project is measured not only by the area of seabed restored but also by the message it sends out and the number of people reached. Restoration happens with the help of people and communities and, crucially, should be maintained by local communities in the future. Being able to show the impact a project is making allows you to:

- Evaluate how the project is doing and how to improve.
- Better plan what the project is going to do next.
- Tell the story and inspire others.
- Attract further funding and investment.
- Raise awareness in the local community.

BOX 5.5: WHAT TO MEASURE?

Depending on the project's objectives, and the stakeholders' and funders' requirements, there are various metrics that can be collected and assessed:

- descriptive information on all engagement activities (what, where and when?)
- record of project activities with volunteer involvement as well as those intended for the general public, for example science festivals
- the number of participants or volunteers, and hours of involvement (to record who you are engaging)
- descriptive demographics (useful for measuring diversity reach and planning ahead next time)
- likelihood of repeat interaction for the volunteers and participants (are volunteers being retained?)
- behavioural, attitudinal or normative change caused by the activities (the impact on participants, stakeholders or the public – how are opinions changing over the course of the project?)
- media coverage for engagement activities (impact metric that is also useful for attracting future volunteers)

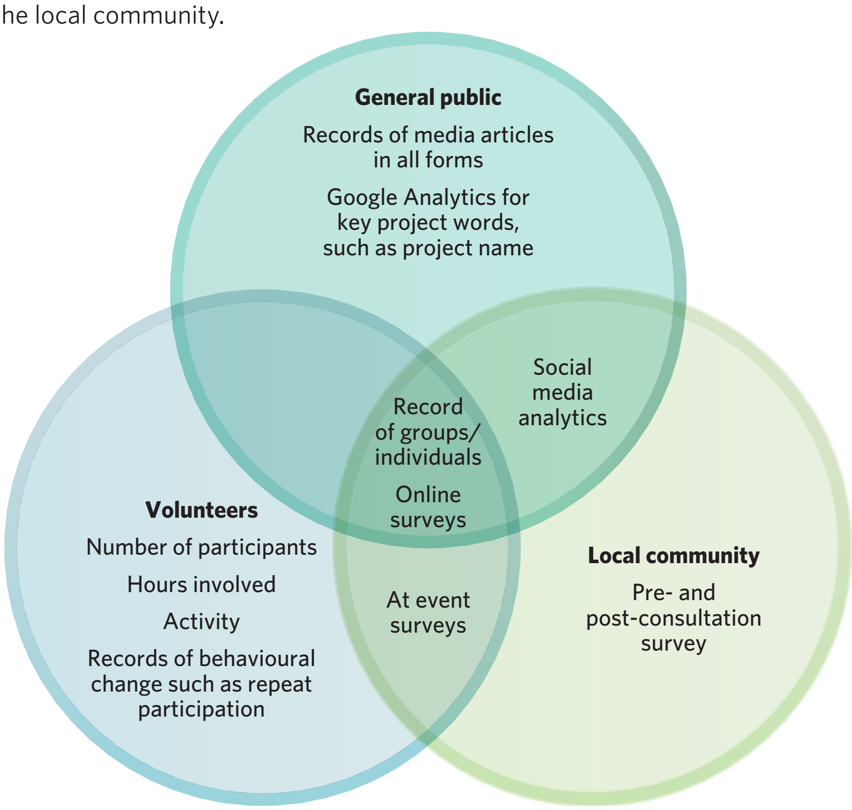


Figure 5.8: Methods to evaluate project engagement and impact.

CASE STUDY: Seagrass Ocean Rescue: lessons learned from extended stakeholder engagement

AIM: To demonstrate successful restoration methods and community involvement in a multi-use seabed area in Dale, Pembrokeshire, Wales.

The project was not just about planting seagrass to restore a site. It was intended to demonstrate how marine conservation needs to be people-centred. Communities are central to conservation and sustainability goals, so ignoring or side-stepping communities ultimately undermines these goals.

Some community members in Dale, West Wales were concerned that marine conservation and restoration initiatives would negatively affect their daily lives and livelihoods. Mindful of this, the team proceeded to take a transparent and widely inclusive approach in an attempt to build trust and move forward positively. Local stakeholders' passion for protecting their environment and livelihoods and the legacy of distrust within the local community meant that information needed to be carefully addressed and the intensive engagement in the run-up to planting took longer than originally planned.

It was made clear to stakeholders from the outset that their input was genuinely needed and that it would influence the project. The project underwent changes as it progressed, including the specific locality for planting which then affected the timescale, but with the input of multiple stakeholders it managed to achieve its goals: over 1 million seeds were planted in Dale Bay with the acceptance and support of the local community. Fortunately, Sky Ocean Rescue and WWF-UK (World Wide Fund for Nature) provided the resources needed for increased stakeholder engagement to support the project and facilitate its ultimate success. Many lessons were learned on the journey. Key lessons included:

- **Engagement needs to start early. Ensure that adequate, early engagement of key stakeholders is built into your project and appropriately resourced**. Although the Dale seagrass restoration project had excellent backing and benefitted from pre-planning, ultimately the process did not start early enough. A longer timeframe not focused on the summer months – when Dale, a popular visitor destination, and its local community were at their busiest – would have allowed local stakeholders more quality time to get to know and understand the project.
- **Clear communication about the need for seagrass restoration is essential.** The importance of seagrass, why and how it is protected, basic seagrass ecology, activities likely (and unlikely) to impact upon seagrass and, in particular, the benefits a healthy seagrass bed could bring to the area all needed to be explained clearly. Gaining first-hand statements in support of the project from statutory stakeholders and neutral contributors (from other areas in the UK) was helpful. Using multiple engagement methods and providing enough information (do not assume less is more – some people want a lot of detail) was important to achieving good communication and ultimately understanding of the project.
- **Transparency and reassurance about seagrass management is vital.** The fear of the seagrass leading to activity (mainly fishing and recreational boating) restrictions due to the increased conservation value of the area (especially if seahorses were found) was probably the greatest issue faced. Letters of support and communications from statutory managing authorities were gathered. Eventually, a suggestion from a community member for an agreed addendum to the Management Scheme, facilitated by the Special Area of Conservation (SAC) Officer for the local Marine Protected Area provided adequate reassurance.
- **Build flexibility into your project plan.** Compromise may be necessary; you may need to accept some risks or less ideal scenarios for a project to go ahead.

Figure 5.9: The in-water seagrass signage buoys for the Dale Seagrass Ocean Rescue project. Photo: Sue Burton.

Figure 5.10: Discussing area planting location options with stakeholders during the Dale Seagrass Ocean Rescue project. Photo: Sue Burton.

CASE STUDY: Seagrass Ocean Rescue: engaging with volunteers

AIM: To demonstrate successful restoration methods and community involvement in a multi-use seabed area in Dale, Pembrokeshire, Wales.

Seagrass Ocean Rescue was the first large-scale seagrass restoration project in the UK, making community involvement and acceptance key to reaching its goal.

Workshops were held at educational institutes across the UK with children aged 3 and above to help prepare the materials needed for planting. Actively helping with the project fostered participants' interest in seagrass and its restoration, with them gaining a sense of satisfaction from helping the project rather than just learning about it. The project highlighted how crucial community level engagement is to ensure a sustainable future. In total, over 2,000 volunteers provided manual labour for the project, with many more learning about seagrass and its benefits through media coverage, festival stalls and focused workshops.

The project had a strong media campaign using multiple platforms from TV, radio and newspaper through to Twitter and Instagram. This was key to building excitement and support for the project, both physically, socially and financially.

One of the most successful aspects of Seagrass Ocean Rescue was working with school children across the UK to build the 20,000 small sandbags to house the seeds. The children were often elated to be doing something positive for the environment, which eased their climate anxiety, and were eager to dress up in SCUBA gear ready to follow their newfound passion for the marine world.

This enthusiasm was often reflected in older volunteers, with many keen to be involved in future restoration efforts, commenting how actively working with others to combat climate change has positively impacted their mental well-being.

Figure 5.11: School children from Coastlands CP School, Haverfordwest, helping bag up seeds during the final stage of planting preparation for the Dale Seagrass Ocean Rescue project. Photo: Sue Burton.

Figure 5.12: Volunteers helping during planting week in Dale, Pembrokeshire for Seagrass Ocean Rescue. Photo: Joseph Grey.

CASE STUDY: Craignish Restoration of Marine and Coastal Habitats (CROMACH)

AIM: To promote, protect and restore the well-being of Loch Craignish, which lies just outside the Loch Sunart to the Sound of Jura Marine Protected Area (MPA) for flapper skate and inside the Argyll Hope Spot.

In 2016, the Ardfern community in Argyll on the west coast of Scotland formed the CROMACH volunteer group with over 60 members. The community-led project relies on the active support and goodwill of the 600 local residents from this tight-knit community.

In autumn 2020, Project Seagrass, NatureScot and the Royal Botanic Garden Edinburgh began a national survey and monitoring project to better understand the genetic connectivity of Scottish seagrasses. After the initial round of surveys in the autumn, the need for more data from Argyll was identified, and in early 2021 CROMACH volunteers were able to support further data collection across a number of sites to drive the pilot project forward. Donating their time and equipment, community volunteers helped collect seagrass samples for genetic analysis, and they recorded seagrass bed characteristics using established Seagrass-Watch scientific monitoring protocols.

Participating in this research enabled the CROMACH community to not only better understand the characteristics and distribution of seagrass beds in and around Loch Craignish, but also to learn about the genetic diversity of these local beds and how they relate to those found elsewhere across the UK. This study ultimately paved the way for Scotland's first community-led seagrass restoration project in Loch Craignish and ensured that the decision-making that informed the project was evidenced-based from the outset. The project is currently planning further outreach, including a programme of talks, volunteer dive-surveys and species identification training days. Community engagement in the project is high because people care about the marine environment and welcome a chance to become actively involved. Local buy-in, along with community ownership, has helped secure sustained interest in the project and the long-term commitment of stakeholders to the protection and sustainability of the restored seagrass beds.

Figure 5.13: Restoration fieldwork taking place in Loch Craignish, Scotland, UK. Diver collecting seagrass samples (top left) and collected samples (top right). Mapping seagrass beds via paddleboard (bottom left), and snorkeler planting hessian bags of seagrass seeds (bottom right). Photos: Seawilding (top left), Richard Lilley (top right), Lewis Jefferies (bottom images).

CASE STUDY: Mapping Orkney's seagrass through local ecological knowledge and remote sensing

AIM: To work in partnership to map the distribution of Orkney's coastal seagrass beds.

In January 2021, Marine Scotland funded a collaborative project between NatureScot and Project Seagrass to collect both anecdotal and empirical evidence of seagrass presence, and to support the development of local knowledge and interest in Scottish seagrass beds.

There is a thriving scallop-diving fishery on Orkney, but due to repeated COVID-19 lockdowns and various complications, the demand for hand-dived Orkney scallops has declined. While these conditions were challenging for the fleet, it was also an opportunity to enhance resilience and develop skills within the fishing community, and to set up a positive research collaboration to expand Marine Scotland's existing seagrass GPS (point) data into more useful seagrass habitat area (polygon) data.

As scallop divers spend a lot of time in the water, they have an intimate knowledge of the local seabed. Working with a local scallop diver who records sightings of seagrass on SeagrassSpotter.org, Project Seagrass has been able to follow up these sightings and map these beds from the air. As part of the project, Marine Scotland funded the purchase of a bespoke survey drone and the training required to safely fly it.

The aim of the project was to ground-truth remotely sensed and anecdotal indications of seagrass presence in Scotland and, critically, to establish area and extent, making the results publicly available. This project is enabling a better understanding of the potential seed supply and restoration potential of these existing beds. It also provides maps for further research into the ecosystem services these habitats provide.

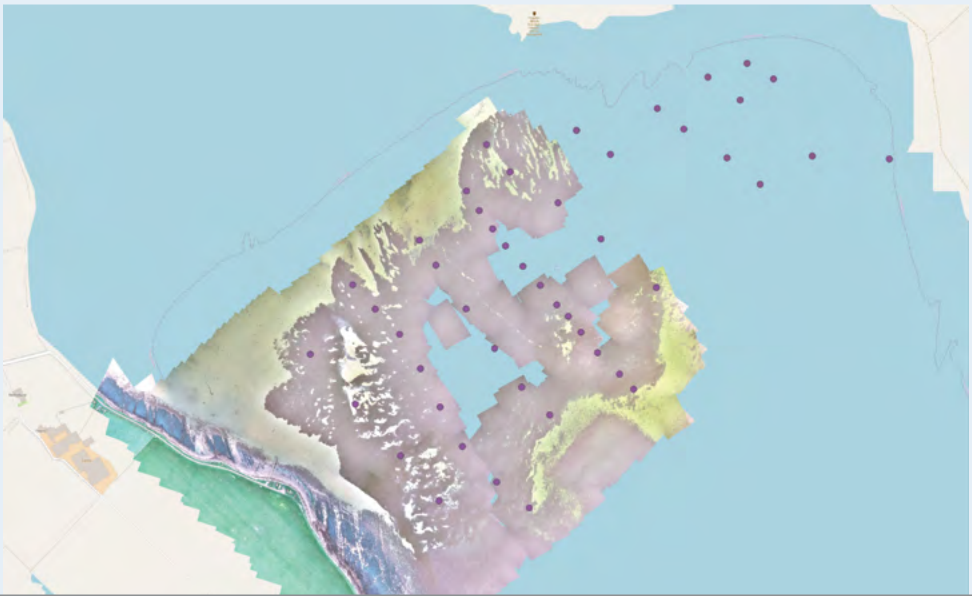


Figure 5.14: Seagrass beds in Orkney, Scotland, UK. *Corallinales* and *Zostera marina* beds (top image). The output of seagrass meadow mapping in the Bay of Tuqouy, Westray, Orkney (bottom image). The purple GPS points indicate a positive ground-truth for seagrass. Photos: Richard Shucksmith, Richard Lilley.

CASE STUDY: Community art-science installation

AIM: Increase public awareness of the value and plight of seagrasses in an industrialised community, targeting the general public and school students.

Seagrass beds do not always lend themselves to practical field visits. In Queensland, Australia, seagrass sites are difficult to access due to deep mud, strong currents and dangerous animals (crocodiles), limiting the reach of such activities. Consequently, creative ways must be employed to communicate positive environmental messages to children and the wider community. In 2017, the Queensland Museum and Queensland Gas Corporation (QGC) sponsored the World Science Festival to travel to regional areas in Queensland. An art-science collaboration was developed by academics working in the area of education and professional development, artist Margaret Worthington, welder Clive Rouse and seagrass restoration scientists, in which science (seagrass species and ecology) and industry (aluminium) were brought together through the medium of visual arts (sculpture and imagery). The goal was to increase awareness of seagrass habitats in Queensland's largest multi-commodity port, and encourage volunteer recruitment to a seagrass restoration project.

The aluminium sculptures of five tropical seagrass species captured elements of their biology (flowers and root systems) and ecology (faunal interactions) and highlighted key distinctive features to help identify the different species: the cross veins on eelgrass (*Zostera muelleri*); the hairs on the leaves of paddle grass (*Halophila decipiens*); and the triple-pointed leaf tip of narrowleaf seagrass (*Halodule uninervis*). The sculptures also hinted at the roles that seagrass plays in the wider ecosystem, with bitemarks on the ends of leaves signifying the presence of grazing fish, turtles and dugong, 'magnification circles' on the leaves showing plant and animal epiphytes and the small bivalve mollusc (*Solemya* sp.) highlighting its three-way symbiotic relationship with seagrass (Figure 5.15).

The sculptures were exhibited at various exhibitions, including the World Science Festival (which had over 4,000 visitors), with timelapse videos of seagrass ecosystems projected onto the sculptures. Locally, the sculptures are used in citizen science events for seagrass restoration, and the whole project has resulted in a significant increase in first-time 'environmental volunteers' within the community.

Figure 5.15: Seagrass bed in Port Curtis with narrowleaf seagrass and paddle weed (*Halophila ovalis*) sculptures (left images). Mudflat adjacent to the liquified natural gas plants with eelgrass and paddle grass sculptures (right images). Photos: William Debois (left) and Bill Watson (right). Sculptures: Margaret Worthington (artist) and Clive Rouse (welder).

CASE STUDY: Restoration awareness through gameplay

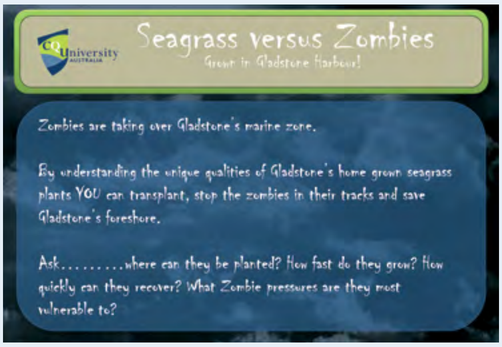
AIM: Increase public awareness of the value and plight of seagrasses in an industrialised community.

In 2015, staff at CQUniversity Australia developed the *Seagrass Versus Zombies* board game based on the popular video game *Plants vs Zombies* to attract the interest of non-traditional audiences in seagrass restoration and to be used as a teaching resource in local schools. The game could be easily set up at events such as the local environmental festival Ecofest and played by children, parents and teachers, with the aim being to raise awareness of seagrass ecology, pressures and restoration in a fun yet informative way.

The success and take-up of the game were unexpected. Seagrass avatars represent local species of seagrass, each with a 'superpower' (thresholds and tolerances to environmental pressures) and limits as to where they can be 'planted' (either upper and lower intertidal, or shallow subtidal). This can prompt further discussions on the ecology, importance and vulnerability of different species of seagrass and the challenges of seagrass rehabilitation. Following the discussion, players plant their seagrasses on the board. Once planted, the 'zombies' attack. Each zombie represents a common pressure or disturbance facing seagrasses. The Light Lyncher depicts pressures from reduced light caused by, for example, flood events, dredging and storms, which the lower-light-tolerant species may survive depending on the depth at which they were planted. The Reclaim Reaper (land reclamation) causes the ultimate wipe-out of any seagrasses planted in the intertidal areas. Each zombie attack provides an opportunity to learn about different pressures faced by seagrass (Figure 5.16).

Multiple attacks illustrate multiple pressures and the idea of resilience. The number of seagrass plants remaining tells players how well they have done. Usually, their strategy improves the more they play and the more they understand and work with the ecology of the different species. Educators can discuss the growth rates and recoverability potential of different species.

An educator games package with all the avatars, board, instructions and information posters was produced and taken up by over 50 educators, student group leaders and other universities. This novel approach facilitated media interest nationally and wider uptake. A life-size version of the game was created by the Edith Cowan University for the ConocoPhillips Science experience.



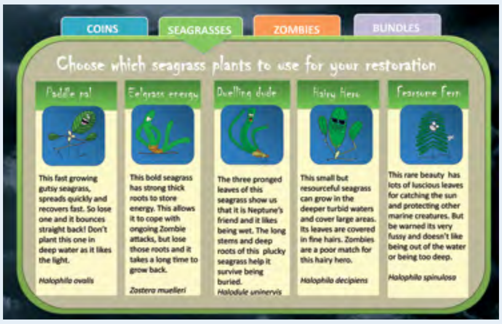


Figure 5.16: *Seagrass Versus Zombies* board game (left). Seagrass and zombie avatars (right).
Photos: William Debois (left) and Emma Jackson (right).

CASE STUDY: Establishing a Welsh seagrass network

AIM: To bring together national and local stakeholders in Wales around seagrass conservation and restoration projects.

Following various stakeholder engagement for seagrass initiatives in Pen Llŷn a'r Sarnau and Pembrokeshire Marine Special Areas of Conservation, The Welsh Seagrass Network was set up through Project Seagrass as a centralised platform for key stakeholders to communicate around the monitoring, management, protection and restoration of Welsh seagrasses. The network will meet periodically to coordinate dialogue around restoration work in a way that promotes transparency and mitigates confusion by encouraging open discussion and dissemination of seagrass science.

In early 2021, the first online workshop took place with representatives from a variety of backgrounds and organisations, including Natural Resources Wales, Port of Milford Haven, British Sub-Aqua Club, WWF and the National Trust. This initial meeting introduced the network's long-term ambitions and discussed the challenges facing conservation of seagrass in Wales. A valuable part of this conversation was to pinpoint the key stakeholders who were missing from the network, which included fishers, farmers, mooring owners and members of coastal and upstream communities. As this initiative moves forward, the hope is to create a unified community that welcomes open discussion, shares knowledge (both local and scientific) and breaks down the communication barriers that exist between stakeholders and restoration implementers.

Follow and join in on Twitter via @WelshSeagrass.

welsh seagrass network

Figure 5.17: Welsh Seagrass Network logo.

Figure 5.18: Volunteers placing seeds inside hessian bags for Seawilding project. Photo: Lewis Jefferies.

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