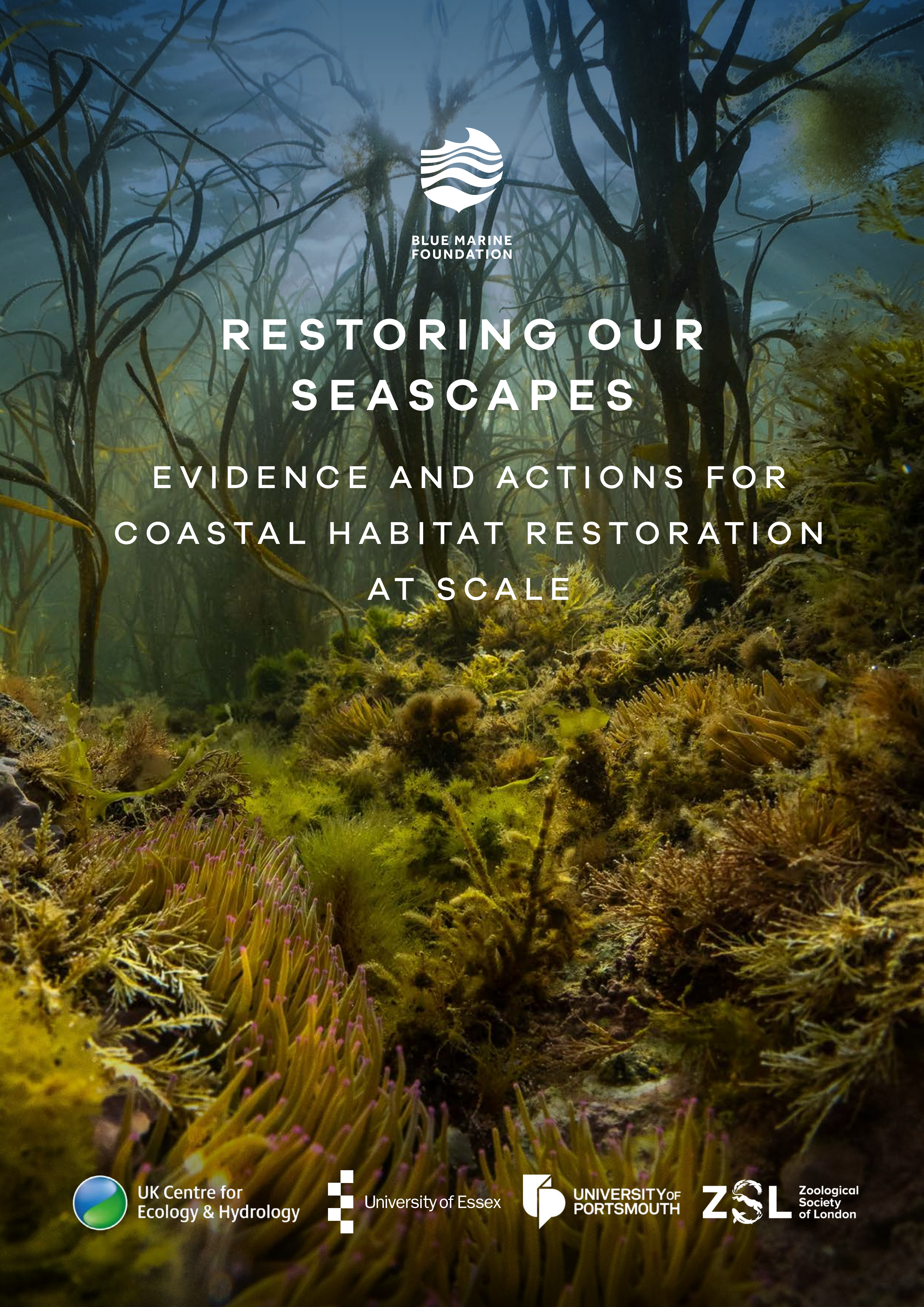

BLUE MARINE FOUNDATION

RESTORING OUR SEASCAPES

EVIDENCE AND ACTIONS FOR COASTAL HABITAT RESTORATION AT SCALE

UK Centre for Ecology & Hydrology

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UNIVERSITY OF PORTSMOUTH

ZSL Zoological Society of London

FOREWORD

UK seas have been integral to our heritage as an island nation. Vital marine and coastal ecosystems have supported a wealth of biodiversity and provided food, resources and jobs for people. Yet these habitats and species have faced unprecedented threats from human activity, causing widespread degradation and fragmentation. Globally, marine ecosystem restoration has never been more pressing, we are amid the United Nations Decade on Ecosystem Restoration, yet so far there has been significantly more focus on land than in the ocean.

In the UK, marine and coastal restoration efforts have primarily focused on single key habitats and are often viewed in isolation. There is an urgent need to better understand the ecological connectivity across these habitats within the seascape, and the benefits they collectively provide for people, nature and the climate. More must be done for seascape restoration to garner the same level of recognition, evidence and delivery as landscape restoration if we are to reach the global target to restore 30% of degraded ecosystems by 2030.

This report serves as an evidence-based guide for policymakers, practitioners and funders providing insights into historical loss, functions and restoration potential of key marine and coastal habitats. It highlights the critical importance of ecological connectivity in temperate marine environments and sets out policy recommendations that would enable the UK to become a world-leader in achieving seascape scale restoration.

Jenny Murray, Senior Restoration Projects Manager, Blue Marine Foundation

Cover Photo: **Theo Vickers**

Progression from saltmarsh to vegetated shingle to littoral shingle on in Langstone Harbour.
Photo: **Wez Smith**

PROBLEM:

Centuries of over-exploitation, habitat modification and pollution have led to the degradation, fragmentation and disconnection of UK coastal habitats, drastically reducing their ability to support wildlife and the goods and benefits that ensure healthy and resilient seas.

38 per cent of UK waters are designated as Marine Protected Areas (MPAs), yet the management of these areas protects individual features rather than larger sections of the environment. This 'feature-based' approach to protection means that destructive activity can still take place inside these 'protected' areas. Recent analysis has shown that bottom trawling and dredging takes place in more than 90 per cent of offshore MPAs[1] , and most inshore MPAs.

Evidence supporting the connectivity of features within MPAs and the ecosystem services they provide is lacking. Our ocean provides countless benefits, from supporting commercial fish stocks to regulating the carbon in our atmosphere. Evidence based policy reform is required to fully restore our vibrant seascape and protect our precious marine life for generations to come.

RECOMMENDATIONS

The UK should set a long-term national vision to enable strategic seascape restoration and move towards seascape-scale natural capital projects, supported by high-quality data, to create multifunctional and healthy ecosystems for people and nature.

The UK and devolved Governments should adopt a whole site approach to designating and managing marine protected areas prioritising connectivity between features for maximum ecosystem health.

The UK Governments should reform the marine licensing process for seascape restoration projects creating a new 'seascape scale' licence to enable efficient ecosystem recovery.

[1] Fishing Industry Bottom-Trawling 90 Percent of UK Marine Protected Areas, Data Shows - Yale E360

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PLATFORM EARTH

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INTRODUCTION

The concept of landscape ecology and its application to terrestrial restoration has been well established since the 1990s. Examples of successful landscape-scale, multi-habitat restoration projects* provide inspiring visual representations of healthy ecosystems, such as rewilding wood pasture at Knepp Estate, the return of apex predators to Yellowstone Park, or restoring bogs, ancient woodlands, rivers and lochs in the Scottish Highlands under the ambitious Caringorms Connect 200 year vision. **However, seascape ecology and restoration is still in its infancy.**

Seascape ecology is the more recent application of landscape ecology to the marine environment, defined as *'the study of the causes and ecological consequences of spatial and temporal patterning on marine systems'* (Pittman et al., 2011). At the heart of these landscape and seascape approaches is the recognition that life on earth is supported by a variety of different habitats and the connections between them. Referred to as 'ecological connectivity', this is a central theme of the seascape approach and essential to planetary and human wellbeing.

Sea Aster (Aster tripoloium) on a rising tide.
Photo: **Steffi Carter**

Over recent centuries we have lost large areas of the habitats that make up the seascape; including up to 92% per cent of seagrass meadows, 85% of saltmarsh habitats and 95% of native oyster reefs. Due to this severe loss, active restoration of these fragmented habitats is required to deliver a healthy, thriving ocean.

Only a handful of active seascape restoration projects exist (e.g. Solent Seascape Project[2] , Stronger Shores[3] , Seawilding[4] and Sussex Bay[5]). This is due to the challenges of mapping, visualising and monitoring habitats covered by tides or underwater, combined with the limitations and cost of the current marine licensing process (needed to restore habitats at scale) and the complexity of overlapping access and usage rights of marine habitats. Alongside these barriers there has historically been a lack of Government acknowledgement of the ecosystem services (ESS) seascapes deliver, and subsequently little ambition to protect them. The current approach to Marine Protected Areas (MPAs) in the UK only protects specific features within a given boundary, ignoring the value of connectivity across the entire ecosystem. These factors combine to create a collective cultural 'sea blindness' making it difficult to recognise the intrinsic value, or our dependence on our coastal seas, even as an island nation.

The UK announced its intention to work together to help establish a new cross-administration UK Blue Carbon Evidence Partnership to progress the evidence base on blue carbon habitats in UK waters, advancing a commitment to protecting and restoring blue carbon habitats as a nature-based solution. **"Managing coastal and marine habitats on a seascape scale, with consideration of land and marine connectivity"** is one the five priority evidence needs the Partnership identified to advance blue carbon commitments[6]. England's current restoration ambition is to restore 15% of priority coastal habitats by 2043 through its Restoring Meadow, Marsh and Reef (ReMeMaRe) initiative. However, the delivery timeline needs to be accelerated to reverse the current climate change implications we are facing. Scotland, Wales and Northern Ireland have showed willingness to deliver restoration through various publications, but have not specified targets, making it difficult to monitor delivery.

Climate catastrophe is becoming more common across many parts of the world and the ocean is one of our greatest assets in tackling this current crisis; the conservation and rebuilding of marine life is vital to the cause. However, as this report highlights, **lack of awareness of the importance of connected and collocated coastal habitats is limiting the delivery of seascape restoration at scale.** Practical policy reform is needed to reverse long-term declines in coastal habitat extent, improve our knowledge on design and deliver large-scale multi-habitat coastal restoration.

WE HAVE LOST LARGE AREAS OF THE HABITATS THAT MAKE UP THE SEASCAPE:

92%
OF SEAGRASS MEADOWS

85%
OF SALTMARSH HABITATS

95%
OF NATIVE OYSTER REEFS

ABOUT THE STUDY:

In this report we focus on seascape habitats found in the UK: mudflat, salt marsh, oyster reef, seagrass meadows and kelp forest. Our aim is to summarise the goods and benefits that these habitats deliver and gather the available evidence to provide better understanding of how they interact. We see this as the starting point of a journey towards seascape scale, multi-habitat restoration in the UK.

There is a strong appetite among restoration practitioners, policy makers and funders to enhance the natural environment for biodiversity, climate and people and to meet our national and international commitments. We are positive that the challenges can be overcome and that the momentum to restore coastal and near shore habitats at scale will gather momentum to the point where it becomes standard practice, and the term 'seascape restoration' will be as widely understood, evidenced and delivered as its terrestrial counterpart.

Thongweed, kelp and snakelock anemones southwest reef
Photo: **Theo Vickers**

[2] Home - Solent Seascape
[3] Stronger Shores - Harnessing the power of nature
[4] Seawilding | Native Oyster and Seagrass Restoration, Scotland, United Kingdom
[5] Sussex Bay | Investing in Nature Conservation and Shoreline Restoration
[6] UK Blue Carbon Evidence Partnership - Evidence Needs Statement (cefas.co.uk)

WHAT IS ECOLOGICAL CONNECTIVITY

Ecological connectivity is an essential part of nature. It is necessary for the functionality of ecosystems, key for the survival of wild animals and plant species and is crucial to ensuring genetic diversity and adaptation to climate change across all biomes and spatial scales.

The Global Assessment on Biodiversity and Ecosystem Services released by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2019 revealed that maintaining and designing connectivity are essential for the functioning of many ecological systems and processes. The report also highlighted how mainstreaming connectivity into economic growth and development is essential to achieve the 2030 Agenda.

Ecological connectivity has been defined as:

- *The unimpeded movement of species and the flow of natural processes that sustain life on earth. (IUCN CMS 2020).*
- *The ability for animals on land or in water to move freely from place to place. Movement allows them to find food, breed and establish new home territories. The unimpeded movement of animals and the flow of natural processes sustain life on Earth (WWF 2024).*
- *The movement of geophysical, chemical and biological materials across landscape or seascape (Auffret et al., 2015).*

East Head to Downs Saltmarsh
Photo: **Paul Adams**

A SEASCAPE APPROACH TO COASTAL RESTORATION

The connection between people and the natural environment is at the heart of successful ecosystem restoration. Existing definitions of seascapes have been defined from a human perspective for policy and spatial planning (Blue Marine Foundation 2023). This report builds on the definition by including coastal species and habitat complexity and ecological processes (e.g. Pitman, 2018) into a concept that can be useful for both management and restoration of marine ecosystems.

The **definition** of a coastal seascape and accompanying **seascape restoration statement** are derived from expert opinion gathered at the Zoological Society of London (ZSL) symposium and workshop held in 2022[7]. The aim is to bring to life the seascape concept in a tangible way for non-specialists, while advocating an approach to restoration that acknowledges the reality of the ecology of coastal environments and the impact of their dynamic, connected nature on delivery of ESS and restoration goals.

DEFINITION OF THE COASTAL SEASCAPE:

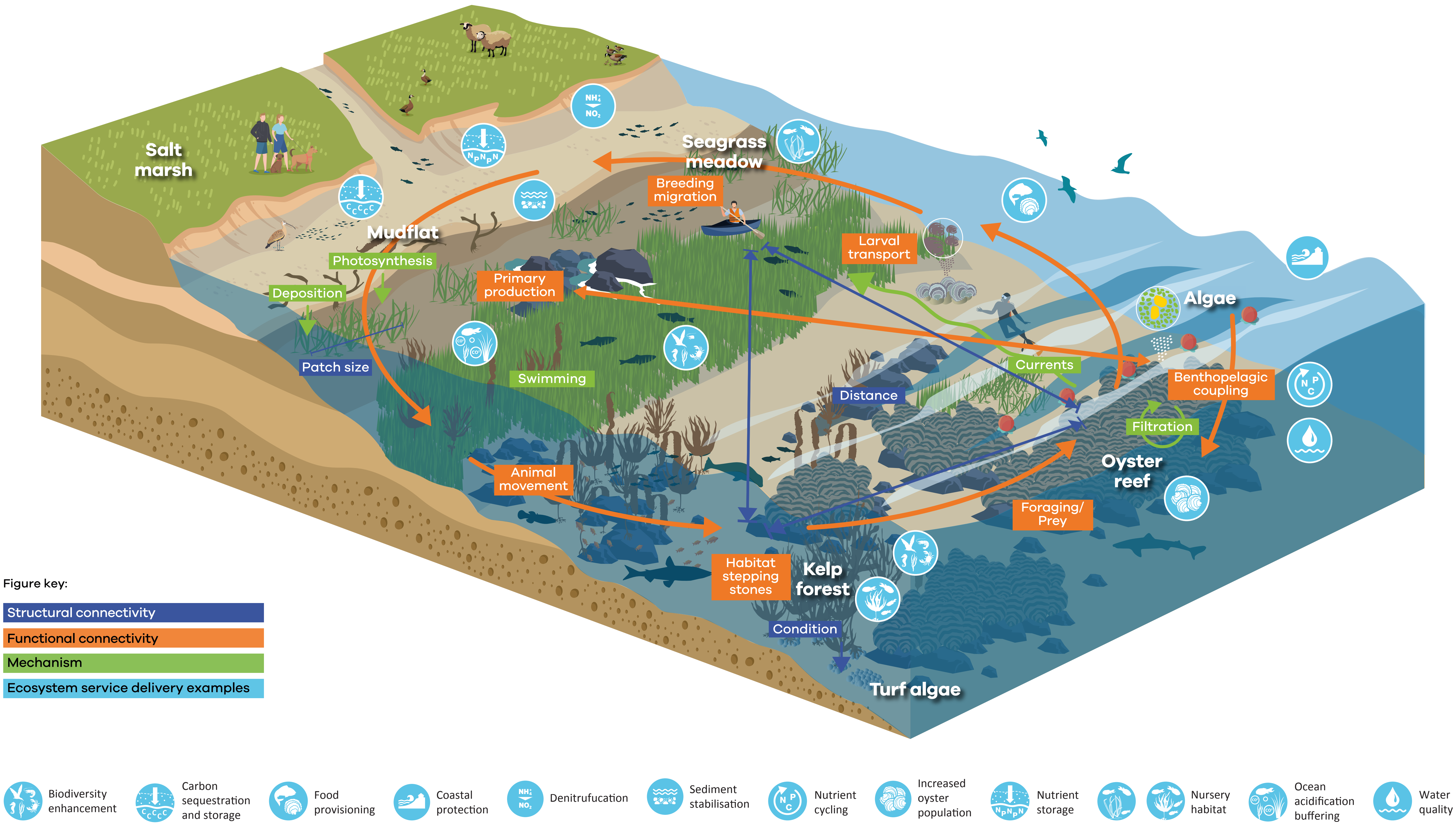
THE PHYSICAL MOSAIC OF INTERACTING HABITATS OCCUPYING THE COASTAL MARINE ENVIRONMENT ACROSS TIME AND SPACE.

The coastal seascape is ecologically and physically connected via a body of water through which living things (e.g.; plankton, larvae, and fish), genetic material (e.g., seeds, spores, and gametes), sediments (e.g. carbon, nutrients), pollution (e.g.; contaminants and litter) and energy flow. Seascape composition, scale, condition and spatial arrangement of habitat patches will affect the connectivity and functioning of coastal ecosystems influencing trophic (food) webs, patterns of biodiversity and ecosystem service flows (e.g. carbon sequestration or denitrification).

Connectivity across the coastal seascape operates at scales of metres to kilometres and extends from the intertidal to the shallow coastal shelf seas. The coastal seascape acts as a dynamic boundary where marine, terrestrial and atmospheric processes interact, and provides opportunities for actions to safeguard, restore and enhance coastal ecosystem integrity and resilience for the benefit of people and planet.

[7]The definition was later presented Coastal Futures in 2023 and refined by consultation with the public and conservation regulators and NGOs (Nature Scot, NRW, EA, NE, ZSL, Rewilding Britain) via ReMeMaRe followed by scientific peer review (Preston et al, in review).

FIGURE 1: THE RELATIONSHIPS BETWEEN STRUCTURAL CONNECTIVITY, FUNCTIONAL CONNECTIVITY, MECHANISMS AND ECOSYSTEM SERVICE DELIVERY IN A HEALTHY SEASCAPE (MODIFIED FROM PRESTON ET AL., *IN REVIEW*).



A SEASCAPE RESTORATION STATEMENT:

- A seascape approach to restoration is rooted in the understanding that coastal ecosystems are dynamic and heterogeneous mosaics of habitats interconnected by a body of water through which living things, nutrients, matter and energy flow.
- A seascape approach to restoration recognises the importance of the spatial and historical context of a site, habitat configuration and interconnectivity between neighbouring habitat types in shaping the outcomes of marine restoration projects.
- To restore complete trophic webs, enhance biodiversity and deliver ecological functions and services requires the existence of a healthy mosaic of coastal habitats, maintained by the flows that occur between them.
- Acknowledging the interconnected nature of these systems allows for more effective and holistic management, conservation, and restoration strategies.
- A seascape approach that enhances connectivity and hence restores optimal structure-function relationships is crucial for successful ecosystem restoration.

THE CONCEPT OF A SEASCAPE, MULTIPLE HABITATS APPROACH TO RESTORATION HAS FIVE MAIN PRINCIPLES:

1. The need and momentum for nature-based solutions (UN Decades) to maintain, preserve and restore the natural environment is becoming increasingly urgent in the face of biodiversity loss and a changing climate.
2. Extensive habitat loss has occurred across all temperate marine coastal habitats, and therefore we must prioritise restoring multiple habitats.
3. Each constituent of the mosaic of coastal habitats provides different ecosystem services, and therefore the range of benefits from restoring multiple habitats is greater than singular approaches.
4. Marine fish and other commercially important species utilise a range of habitats across their life stages, therefore restoration of multiple habitats supports food webs, biodiversity and fish stocks.
5. Positive interactions and feedback loops exist when multiple marine habitats occur near each other.Multiple habitat restoration is more efficient, effective and impactful than the sum of its parts (Vozzo et al., 2023).

HOW THE CURRENT MARINE LICENSING PROCESS CREATES BARRIERS TO SEASCAPE RESTORATION:

Like all marine developments, active restoration projects require interventions to the natural environment and so must be scrutinised due to possible impacts on the seabed. The current licensing application process that restoration practitioners must complete is long, complex, burdening and costly; from application to approval the process can take up to and over 12 months for licences which are themselves inconsistently time limited.

The licensing process currently in place is the same as for any large-scale developments (such as an oil platform or offshore wind farm) – a negative marking system looking only at potential damage to the marine environment, ignoring the ecosystem services these projects can bring. It is an outdated system, developed without considering active marine restoration projects.

To fully harness the potential of our coasts to deliver valuable ecosystem services we need to enable and accelerate actively restoring the precious ecosystems we have let disappear over the last century.

Black headed gull chick and adults.
Photo: **Wez Smith**

THE SEASCAPE HABITATS

MUDFLATS underlie and connect all soft coast intertidal and subtidal habitats around the UK and provide a source of sediment to adjacent vegetated areas, such as salt marshes (Robins et al., 2016; Ladd et al., 2019). They are rich in microbial and algal communities and mud dwelling animals (Underwood et al., 2022) providing high-value intertidal habitats and resources for vast numbers of overwintering wading birds (Dekinga and Piersma, 1993; Foster et al., 2013) as well as burrowing bivalves, polychaete worms, fish and seals (Beninger, 2018). Often viewed as "wasteland" and lacking distinctive visual features, mudflats have been lost from the coastal seascape, particularly since the early 20th century, where reclamation to build deeper water port facilities to accommodate larger ships have removed significant areas of this linking habitat. Today, port expansions continue to threaten mudflats.

Between seagrass, salt marsh and oyster beds lie intertidal mudflats which mediate the sediment dynamics crucial to the persistence of the seascapes and connections between them.

Single cell algae called diatoms colonise the mudflat surface binding it together preventing erosion. They are also the first step in the coastal food chain, providing food for invertebrates, small fish and bivalves such as oysters, cockles and mussels (Underwood et al., 2022). Mudflats sediments have a high denitrification potential; for example in the Colne Estuary, Essex, **mudflats remove 35% of the land-based nitrogen loading** (Nedwell et al., 2016); in the Solent, intertidal mudflats and those colonised by macroalgae are estimated to have a nitrogen removal value of £244 million and £119 million respectively. Burial of phosphorous in organic sediments is also high in mudflats, an ecosystem service in the Solent estimated to be worth £10 million and £135 million (Watson 2020). Like other seascape habitats mudflats are carbon rich, and due to their large spatial coverage their carbon sequestration value in the Solent has been estimated to be greater than other coastal habitats at £75 million per year (Watson et al., 2020).

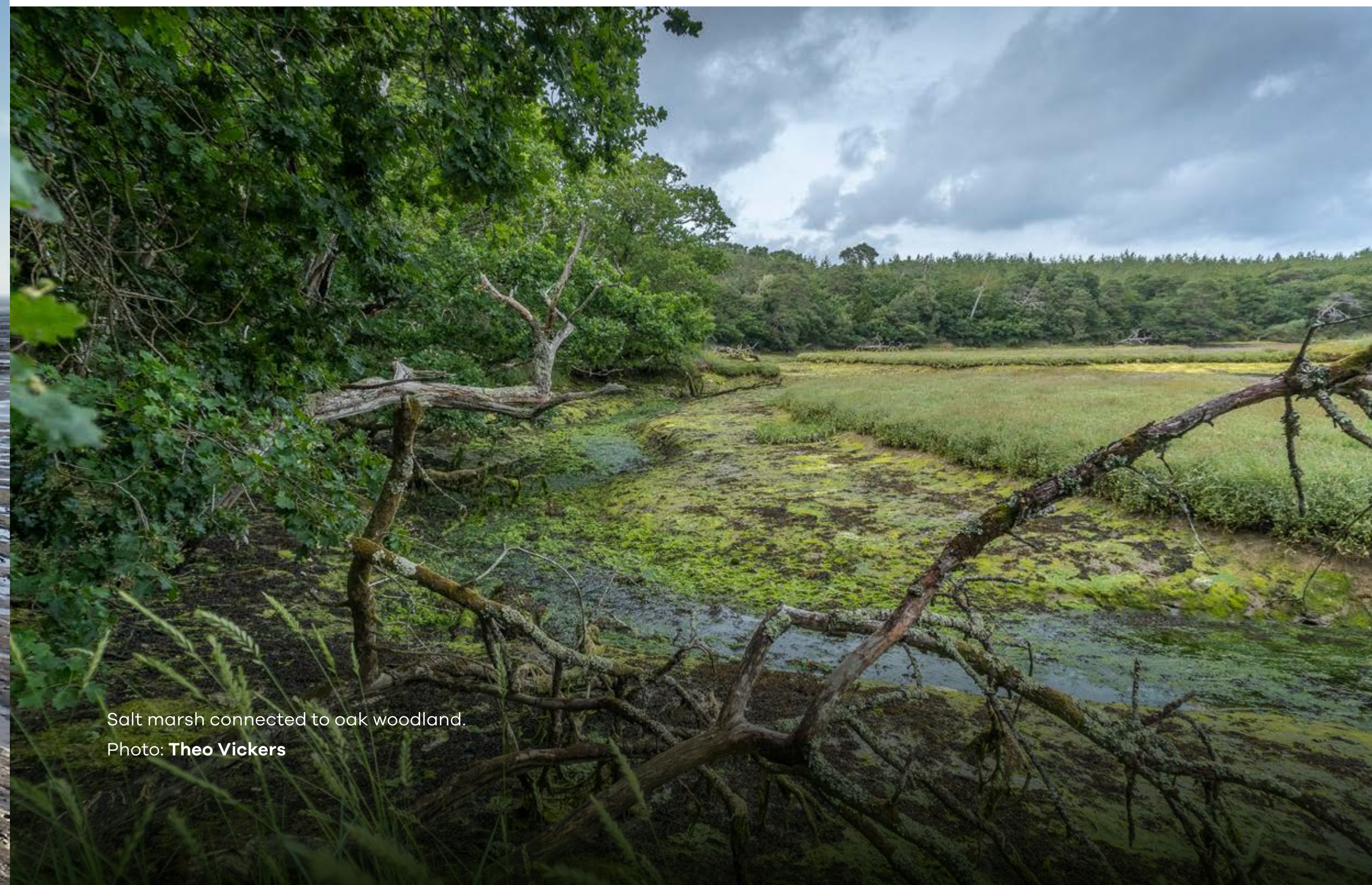
Mud flat.
Photo: **iStock.com**

SALT MARSH is widely distributed around the UK at the interface of marine and terrestrial environments. They support a wide range of specialist plants, invertebrates and birds with a range of nationally and locally rare species. England has lost 85% of salt marsh since 1860 and the current extent of the habitat is 45,000ha. This loss is primarily due to large areas being enclosed by sea defences and subsequently drained to use for agriculture (Morris et al., 2004); more recently salt marsh has been lost to activities such as port development. Sea-level rise also poses a threat through coastal squeeze – where the natural landward migration of salt marshes in response to sea-level rise is restricted by sea defences.

Across the UK salt marshes are widely recognised for their contribution towards coastal protection. They act as buffers against wave energy and storm events, helping to reduce the need for expensive coastal defences and protecting valuable agricultural land, train lines and urban areas.

The estimated value of flood mitigation by salt marsh across England and Wales is £2.05 billion (ONS 2022).

Blue carbon is carbon that accumulates and stored in marine and coastal habitats as a result of their high productivity and sediment-trapping ability. **It is estimated that these accumulate up to around 46,563 tonnes of carbon a year and the top 10 cm of UK saltmarsh soil hold a total of around 5.2 million tonnes** (Smeaton et al., 2023). They can also play a key role in absorbing nutrients and pollutants and are estimated to be worth around £3 million annually to the commercial landings of European seabass, common sole and European plaice (McCormick et al., 2021).



Salt marsh connected to oak woodland.
Photo: **Theo Vickers**

Native oysters.
Photo: **Luke Helmer**

THE EUROPEAN NATIVE OYSTER, or flat oyster, *Ostrea edulis* was once found in high densities within UK waters and across its Pan-European range (Airoldi & Beck, 2007, Preston et al., 2020a, Thurstan et al., 2024). This species occupies a range of environments including estuaries, bays, sheltered inlets, sea lochs and coastal open seas. Native oyster populations have declined by 95% since the mid-19th century making their reefs one of the most threatened marine habitats in Europe (Beck et al., 2011). The remaining populations are facing threats from pollution, habitat destruction, overfishing and competition from invasive species like Pacific oyster (Helmer et al., 2019, Preston et al., 2020b). Climate change exacerbates these issues, with impacts such as ocean acidification, temperature fluctuations, and increased storm frequency posing additional challenges for the survival and adaptation of the native oyster.

Oyster reefs act as ecosystem engineers, as years of settlement of larvae on shells can build entire reefs, adding structural complexity to soft-sediment habitats. The reefs are composed of irregular surfaces and gaps which create drag, reducing wave energy and height (Wiberg et al., 2019). Reefs provide a substrate for sessile organisms including sea squirts, anemones, and bryozoa to settle and spawn, with the interstices providing burrows and hiding places for resident crabs, brittle-stars and fish. These rich assemblages are ideal places for juvenile fish such as commercially important European Seabass to live and for transitory predators and grazers to feed (Christianen et al., 2018). **Oysters are filter feeders, cleaning the water reducing particulates and levels of pathogenic bacteria and viruses** (Burge et al., 2016; Harrison et al., 2022). The cleaner, clearer water provided by oysters can improve recreational activities such as sport fishing, diving and swimming.

There are two **SEAGRASS** species found in the UK, *Zostera marina* (common eelgrass) and *Zostera noltii* (dwarf eelgrass). *Z. marina* grows predominantly below the low tide mark, and *Z. noltii* occurs intertidally. These submerged flowering plants create dense beds, covering an estimated 8,500 hectares along the UK coastline and playing a pivotal role in marine ecosystem health (Green et al., 2021). **Seagrass beds provide shelter, feeding grounds, and nurseries for over 70 fish species, including commercially significant ones like the Atlantic cod and European plaice, as well as rare seahorse species.** Historically abundant, seagrass meadows in the UK have faced a decline of up to 92% over the past century, primarily due to disease, coastal development, pollution and physical disturbance from human activities. The current condition of seagrass habitats is precarious, with remaining meadows facing threats such as nutrient pollution and climate change impacts.

Seagrass meadows provide habitat for diverse and vibrant communities of plants and animals, opportunities for wildlife watching, cleaner waters for swimming, coastal protection and more stable shorelines. Seagrass meadows capture sediment due to changes in flow velocity near the canopy and stems, filtering up to 50% of suspended solids from the water column which reduces pathogen content and improves water quality.

Common seagrass and pipefish.
Photo: **Paul Naylor**

KELP AND LARGE BROWN MACROALGAE forests grow in high energy, intertidal and shallow subtidal regions and support diverse assemblages of understory and turf coralline, red, green and brown seaweeds providing abundant and critical habitats for a range of fauna including shellfish, crustacea, fish, mammals and birds (Smale et al., 2020). Rocky shores are often dominated by diverse seaweed (fucoid) communities. Below the low water mark, kelps such as *Laminaria hyperborea* and *Saccharina latissima* create structurally complex and biodiverse forests, which support numerous transient and inhabitant invertebrates and fish. These key habitat forming species are amongst more than 900 species of seaweeds found in the UK, many of which grow associated with or on dominant perennial species.

Rising sea surface temperatures are causing community wide ecological changes in intertidal communities (Burrows et al., 2020) and there has been an overall decline in brown habitat forming seaweeds (Yesson et al., 2015). Warm water kelp species such as *Laminaria ochroleuca* that support less diverse associated plant and animal communities have the potential to outcompete the perennial, encrusted cold water species (Moore & Smale, 2020). An increase in invasive non-native species are also causing increasing ecological shifts across UK coastlines.

Kelp and large brown macroalgae forests provide coastal protection, provisioning and cultural services in addition to their crucial role as habitats for many plant and animal species. Seaweeds provide climatic regulation in coastal regions by oxygenating the water, increasing the pH and encouraging cloud formation due to the release of iodine (Duarte et al., 2017). Wrack (the broken of fronds of large seaweeds) provides nursery habitat and nutrition for organisms in surface waters, surf zones, beaches and the deep sea (Krumhansl & Scheibling 2012).

Wrack can also be washed up on seashores providing nourishment of sandy beach-dune ecosystems, increasing biodiversity and promoting growth of sediment-stabilising dune flora and thus further coastal protection (Joyce et al., 2022). Carbon transported to neighboring coastal and benthic habitats is sequestered in sediments (Queirós et al., 2019), and there is growing interest in commercial cultivation of macroalgae as donors of carbon to blue carbon storing habitats, nutrient bioremediation from aquaculture and products such as food, fertiliser, nutraceuticals and pharmaceuticals.

Kelp forest.
Photo: **Paul Naylor**

RESTORING CONNECTIVITY ACROSS A MULTI-HABITAT SEASCAPE

Habitats across the coastal seascape do not work in isolation. They are physically and functionally connected to each other by the overlying sea through which energy, particles and animals move across the seascape. For example, in tropical waters coral reefs act as wave breakers, reducing wave energy and enabling seagrass to grow in sheltered landward lagoons; coastal mangroves trap large quantities of sediment and carbon, maintaining coral reef health and water quality; tropical fish depend on mangroves, seagrass meadows and corals to feed, breed and refuge. Such interactions also occur in the cooler, murkier temperate seas of the northern hemisphere but these are less visible and less documented. Despite its relevance to ecosystem function, connectivity is not currently a factor in the MPA designation process.

CONNECTED SEASCAPE HABITATS ARE IMPORTANT BECAUSE:

CARBON STORAGE AND FLOWS

i) **Salt marshes, seagrass beds, oyster reefs and mudflats are all biogenic habitats which both produce carbon rich organic matter for export into coastal seascapes and retain it through trapping of sediment and detritus.** Algae growing on plants, seaweed, oyster shells, in the water column and on the surface of the sediment form a key part of the seascape carbon cycle, taking up dissolved inorganic carbon (DIC) from the water column via photosynthesis and producing organic matter to be consumed within the coastal food web. Consumption of organic matter by resident organisms can result in eventual burial in sediments, remineralisation of the carbon and nutrients, or "trophic relay" of carbon to other habitats by transitory organisms (Hyndes et al., 2014).

ii) **The transport and deposition of seaweed and seagrass wrack into seagrass beds, salt marshes, beaches, surf and open coast ecosystems provides food and habitat for invertebrates and birds** (Hyndes et al., 2022; Ince et al., 2007), the detritus from which enhances growth of grasses which boosts recovery and stabilisation of dunes (Joyce et al., 2022). Here, it can elevate the shore, changing flow of sediment and organic matter throughout the systems, and protecting the sediment from erosion (Karstens et al., 2022).

iii) **Oysters produce calcified shells, a process which emits CO_2. If shells are retained in the long-term as part of a reef matrix or buried, this could potentially be considered as a carbon sink.** The fluxes of carbon are site specific and dependent on size and shape of the reef, preservation of shell material and accretion rates. One study found that saltmarsh fringing *Crassostrea virginica* oyster reef sequestered more carbon due to higher rates of sediment accretion, compared to oyster reefs on sandflats which were net sources of CO_2 (Fodrie et al., 2017). Co-location of oysters with seagrass is hypothesised to benefit growth of oysters due to reduction of seawater acidity during uptake of DIC for photosynthesis (Ricart et al., 2021).

Avocets over the salt marsh.
Photo: **Steffi Carter**

PHYSICAL PROCESSES (FLOOD AND COASTAL DEFENCE)

i) **Oyster reefs can act as natural breakwaters, attenuating waves and reducing the erosive impact of storm surges** (Donadi et al., 2013a; Scyphers et al., 2011). Research on *Crassostrea virginica* reefs in the USA has shown that intertidal oyster reefs located near tidal marshes can reduce marsh edge erosion by reducing sediment wave energy (Manis et al., 2014). This reduction in wave energy can lead to enhanced sediment accretion and stabilisation on nearby mudflats and salt marshes (Chowdhury et al., 2019; Hogan et al., 2022). *Crassostrea* "breakwaters" can reduce shoreline recession by up to 40% (McGlathery et al., 2013, Morris et al., 2018 Choudhury et al., 2019). Oysters remove sediment, microalgae, and other particles, leading to improved water clarity and local sedimentation processes (Nelson et al., 2004; Newell and Koch, 2004; Porter et al., 2004; Southwell et al., 2017). The lack of extensive European native oyster beds and reefs prevents our understanding of these connections in UK seascapes.

ii) **Salt marshes, seagrass beds, intertidal flats and subtidal habitats are connected through annual and inter-annual patterns of sediment movements within the 27 primary coastal sediment cells of the U.K** (Green and Coco, 2014; Callaghan et al., 2010; Bouma et al., 2016). Waves and tidal currents move sediment offshore and onshore, with coastal sediments "biostabilised" by salt marsh vegetation, microalgal biofilms, seagrass, and subtidal oyster reefs. Biostabilised sediments dissipate tidal and wave energy (Spencer et al., 2015, Moeller et al., 2014) reducing the risk of sea defences being overtopped and coastal flooding occurring (Environment Agency, 2023; Fairchild et al., 2021; Morris et al., 2021). Losses of biostabilising habitats in a seascape is associated with greater suspended sediment loading which can impact other habitats, primary productivity and food webs (Liu et al., 2021, Capuzzo et al., 2015).

iii) **Sediment is always moving between salt marshes and adjacent intertidal and subtidal flats** (Callaghan et al., 2010, Robins et al., 2016). During calm conditions fine sediment is moved into marshes, while winter storms mobilise sediment back into the water column and onto tidal flats (Green and Coco, 2014). Mass sediment deposition by storm events onto marshes can allow initial accretion rate greater than sea level rise. However, such mass movements lowers the adjacent mudflats and steepens the marsh, exposing edges to lateral erosion (Schuerch et al., 2019). Small increases in wave energy, resulting from deeper water over tidal flats due to sediment losses or sea level rise, can significantly reduce the recovery of vegetation from eroding marsh edges (Zhu et al., 2019). The shapes of marshes and creeks, wave fetch-driven sediment resuspension, and wave dissipation across mudflats are all predictors of long-term (decadal) changes in salt marsh expansion or erosion (Ladd et al., 2019, Callaghan et al., 2010, Mariotti and Fagherazzi, 2013).

NUTRIENT DYNAMICS

i) **The majority of nutrient inputs to the coastal waters of high population density, industrially-developed nations are derived from land-based (agricultural) run off and treated wastewater** (McMellor and Underwood 2014, EA State of the Marine and Coastal Environment Report 2023). Dissolved nutrient concentrations decline with distance out to sea, due to dilution with seawater (conservative mixing), removal by abiotic processes (i.e. flocculation) and utilisation by biological activity (Jickells et al., 2014, Nedwell et al., 2016). The areas of different intertidal and subtidal habitats, and the spatial relationship of different habitats along nutrient concentration and salinity gradients affect how much nutrient removal can occur (Thornton et al., 2007).

ii) **Reduction of nutrient loads as water traverses seascapes of salt marsh, seagrass and oyster reef habitats, interconnected by intertidal and subtidal sediments is a major consideration for seascape functioning.** Denitrification (the transformation of nitrate (NO_3-) into nitrogen gas and N_2O) is a key anaerobic process. Denitrification rates are driven by the availability of organic matter and water column nitrate concentrations, and nitrification of ammonium to nitrate (an aerobic process, stimulated by benthic photosynthesis) between them can remove up to one third of the nitrogen loads in estuaries (Dong et al., 2000; Nedwell et al., 2016, Underwood et al., 2022). Flocculation and capture in sediments is a cause of significant removal of phosphorus in the freshwater - brackish regions of estuaries (McMellor and Underwood 2014, Watson et al., 2020). Phosphorus loading is one cause of coastal phytoplankton and macroalgal blooms which can produce toxins and reduce oxygen levels in estuaries (Nedwell et al., 2002, Bardsley et al., 2020, EA State of the Marine and Coastal Environment Report 2023).

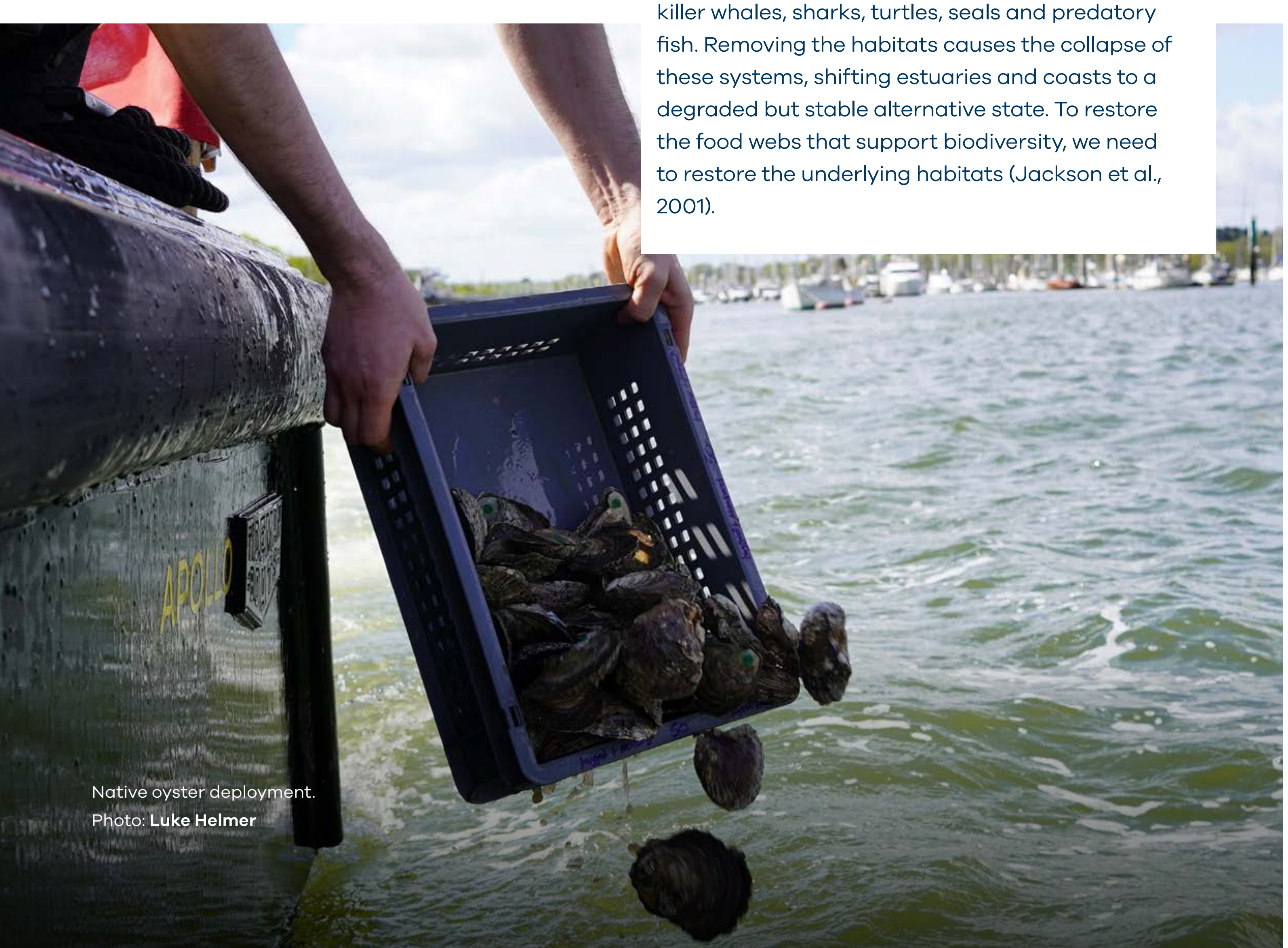
iii) **Salt marshes have an important role in nutrient cycling and storage,** ameliorating the impacts of excessive inputs from freshwater and other sources (Nedwell et al., 2016). Excessive nutrient inputs (principally nitrogen and phosphorous) are causing eutrophication, leading to a decline in water quality and an increase in the growth of green macroalgae on intertidal mudflats in particular. Temperate salt marshes have been estimated to have denitrification and burial rates of 25.2 g N $m^{-2}y^{-1}$ and 10.8 g N $m^{-2}y^{-1}$ compared to seagrasses 15.1 g N $m^{-2}y^{-1}$ and 4.9 g N $m^{-2}y^{-1}$ respectively (Watson et al., 2020). Existing habitats in the Solent could remove 3,590 tonnes of N yr^{-1} and 811 tonnes of P yr^{-1} based on each habitat's current Water Framework Directive condition status .

BIODIVERSITY FUNCTIONING

i) **A mosaic of structured habitats supports greater biodiversity:** Complex habitats support a greater abundance and diversity of species than a habitat in isolation. Different types of habitats support different species assemblages, meaning coastal ecological communities are also driven by type of habitat, not just the complexity (Pinnell et al., 2021). There is strong evidence that multiple and co-located seascape temperate habitats support a greater diversity of organisms and are utilised by species at different life stages. However, most evidence for biological diversity is from overseas (this is due to the very recent initiation of marine restoration in the UK, and a lack of data from habitats, particularly oyster reefs).

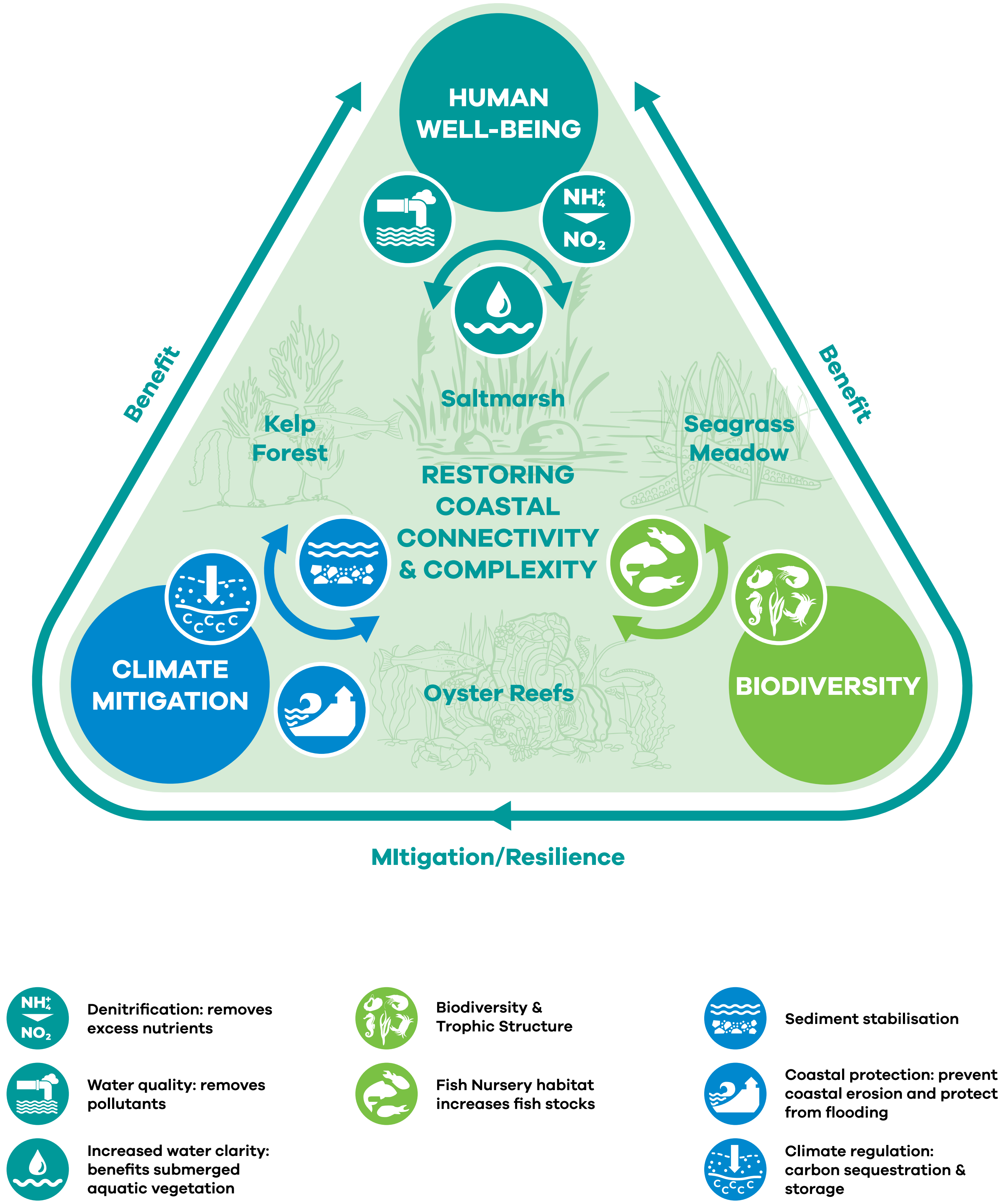
ii) **Coastal habitats support fish stocks:** Temperate fish assemblages use multiple habitats across the seascape mosaic and submerged vegetation (seagrass, salt marsh, macroalgae) connected by soft sediments providing essential nursery habitats (e.g. Kritzer 2016). Fish also use different habitats across different life stages and sizes (Nel et al., 2017). A healthy and well-connected seascape is essential to support fish stocks providing prey-rich habitats (salt marsh, seagrass, oyster reefs) that supports growth, biomass and stocks of offshore species to top predators (e.g. Salmon, Davis et al., 2022), acting as nursery grounds for inshore and offshore species (Lefcheck et al., 2019)

iii) **Biogenic habitats,** such as kelp forests, oyster reefs and seagrass meadows are the foundations of food webs that support apex predators such as killer whales, sharks, turtles, seals and predatory fish. Removing the habitats causes the collapse of these systems, shifting estuaries and coasts to a degraded but stable alternative state. To restore the food webs that support biodiversity, we need to restore the underlying habitats (Jackson et al., 2001).



Native oyster deployment.
Photo: **Luke Helmer**

FIGURE 2: ECOSYSTEM SERVICES ARISING FROM A HEALTHY AND CONNECTED SEASCAPE, WHICH SUPPORTS CLIMATE MITIGATION, BIODIVERSITY AND UNDERPINS HUMAN WELLBEING (MODIFIED FROM PRESTON ET AL, IN REVIEW).



SOLUTIONS

Our seascape habitats are incredibly complex, fragile and susceptible to catastrophic loss. We believe that we must see reforms and additions to policy levers to reverse long term declines in coastal habitat extent, improve our knowledge on design and deliver critical large scale multi-habitat coastal restoration and ecosystem services.

RECOMMENDATION 1:

The UK should set a long-term national vision to enable strategic seascape restoration and move towards seascape-scale natural capital projects, supported by high-quality data, to create multifunctional and healthy ecosystems for people and nature.

There is an urgent need to set a long-term national vision to enable strategic seascape restoration for the benefit of ecosystem and human health. The goal is to enable a mosaic of self-sustaining, connected and resilient habitats at scale, to enable delivery of the multiple benefits that intertidal flats, seagrass, oyster reef and salt marsh provide.

There are many excellent habitat and species focussed projects already underway across the UK and a handful of projects that are starting to enact the seascape concept by considering the flows and interactions of materials, biodiversity and functions across the systems. Governments must properly utilise the data coming from these projects and collate a body of evidence of seascape connectivity in temperate UK waters.

By using this data Governments can map the long term vision, and foster political and financial confidence in the importance of our coastal ecosystems.

Heathy sub-tidal common seagrass.
Photo: **Theo Vickers**

RECOMMENDATION 2:

The UK and devolved Governments should adopt a whole site approach to designating marine protected areas, analysing and prioritising connectivity between features for maximum ecosystem health.

The UK's MPA designation process uses a 'feature-based' approach to conservation; whereby protection of listed species and habitats are prioritised. While this method aims to protect and recover specific features in any given MPA, it means that 92 per cent of the UK's MPAs do not have site-wide protection against the most destructive types of fishing. Destructive fishing and invasive activities cause incredible damage to flora and fauna within the marine environment, destroying the seabed and disturbing and releasing the carbon stored in the sediment.

As noted throughout this report, the importance of connectivity within the marine environment is crucial to helping our ecosystems function; it can provide flood and coastal defence, support biodiversity, promote a healthy food chain and support carbon sequestration and nutrient flows. Our current MPA designations compromise the ability of our seascapes to properly function and deliver these benefits.

We recommend that during MPA selection process the connectivity of features at given sites is assessed and factored into the designation; ensuring that the ecosystem function is properly protected, alongside specific features.

RECOMMENDATION 3:

The UK Governments should reform the marine licensing process for seascape restoration projects creating a new 'seascape scale' licence to enable efficient ecosystem recovery.

To deliver active restoration projects in the UK, practitioners must apply for a marine license. As previously discussed, the current licensing application process that restoration projects must complete is laborious and approval can take incredibly long for licenses which are themselves inconsistently time limited.

Effective marine licensing has a significant role to play in safeguarding our coastal ecosystems. It is a necessary process to ensure activities, developments and restoration projects can take place in appropriate sites and do not negatively impact protected features. However, in its current form, the licensing framework acts as a barrier to active restoration and in particular, seascape projects which often need to apply for multiple licences.

A reform of the marine licensing process must be developed for habitat restoration projects to continue effectively in the short term, while a new approach is developed for large-scale seascape projects that consider multiple habitats together, benefiting both the environment and communities.

Scottish Government recently held a consultation on legislative proposals to address barriers to scaling restoration projects highlighting the challenges around securing licenses, permits and consents for restoration; and lack of clear mechanisms to protect habitats and species once restored. While this work is encouraging it needs replication across all UK nations to fully maximise the potential of our national seascape.

We suggest that seascape projects in their entirety, should be able to apply for one licence that encompasses the necessary activities to fully restore all features of the ecosystem. By reducing the complexity and cost of the required marine licences for restoration we hope to see an increase in these initiatives being taken forward.

CONCLUSION

Our island nation has 12,500km of incredible coastline containing precious marine habitats. They provide millions of pounds of ecosystem services to our communities and our economy, but are currently fragmented, degraded and at risk of permanent loss from UK shores.

This report highlights the incredible capabilities of our connected seascapes to turn the tide on climate change; sequester carbon, support commercial fish stocks and even provide flood defences. If we are to meet the triple challenges of biodiversity loss, climate change and deteriorating ecosystem and human health we must prioritise restoring the nature we have depleted over the last century.

We have set out three recommendations that we believe must be adopted to properly protect, maintain and restore nature in the marine environment. If the UK and devolved Governments are committed to meeting our international targets on climate change and effectively achieving 30x30, restoration and protection of our complex seascapes must be prioritised by policy makers across the nation.

Black-tailed godwit feeding before migration.
Photo: **Steffi Carter**

REFERENCES AND ANNEX FOR ANY SUPPLEMENTARY INFO

Auffret, A. G., et al., (2015). The spatial and temporal components of functional connectivity in fragmented landscapes. Ambio, 44, 51–59. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4289002

Airoldi, L., & Beck, M.W. (2007). Loss, status, and trends for coastal marine habitats of Europe. Oceanography and Marine Biology, 45, 345-405.

Bardsley, L., Brooksbank, J., Giacomelli, G., Marlow, A., & Webster, E. (2020). Review of Chichester Harbour sites: intertidal, subtidal and bird features. Natural England Research Report, Number 090.

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., Defeo, O., Edgar, G.J., Hancock, B., Kay, M., Lenihan, H.S., Luckenbach, M.W., Toropova, C.L., Zhang, G., & Guo, X. (2011). Oyster reefs at risk and recommendations for conservation, restoration and management. Bioscience, 61, 107-116.

Beninger, P.G. & Paterson, D.M. (2018). Introduction: Mudflat Basics. In Beninger, P. G. (Ed.), Mudflat Ecology. Springer Nature. https://doi.org/10.1007/978-3-319-99194-8_1

Burrows MT, Hawkins SJ, Moore JJ, Adams L, Sugden H, Firth L, Mieszkowska N. (2020) Global-scale species distributions predict temperature-related changes in species composition of rocky shore communities in Britain. Global Change Biology. 2020 Apr;26(4):2093-105.

Callaghan, D. P., Bouma, T. J., Klaassen, P., Van der Wal, D., Stive, M. J. F., & Herman, P. M. J. (2010). Hydrodynamic forcing on salt-marsh development: Distinguishing the relative importance of waves and tidal flows. Estuarine, Coastal and Shelf Science, 89(1), 73-88.

Capuzzo, E., Stephens, D., Silva, T., Barry, J., & Forster, R. M. (2015). Decrease in water clarity of the southern and central North Sea during the 20th century. Global Change Biology, 21, 2206–2214. doi:10.1111/gcb.12854

Christianen, M. J. A., et al., (2018). Harbour seals are regaining top-down control in Dutch Wadden Sea. BioRxiv, 267567. DOI: 10.1101/267567.

Dekinga, A., & Piersma, T. (1993). Reconstructing diet composition on the basis of faeces in a mollusc-eating wader, the Knot Calidris canutus. Bird Study, 40(2), 144–156. https://doi.org/10.1080/00063659309477140

Donadi, S., et al., (2013). Seasonal changes in sediment structure and bed level dynamics on an intertidal flat: implications for ecosystem engineers. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.

Duarte, C. M., et al., (2017). Seagrass meadows as a globally significant carbon stock. Marine Ecology Progress Series, 335: 1-5. DOI: 10.3354/meps11342.

Dunkley F. & Solandt J-L. (2020) Unprotected Areas: A case for a just transition to ban bottom trawl and dredge fishing in offshore Marine Protected Areas. Ocean Recovery Department Marine Conservation Society, UK.

Environment Agency (2023). State of the Marine and Coastal Environment Report.

Fairchild, T. P., et al., (2021). Estuarine Mapping and Eco-Geomorphological Characterization. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.

Foster, G., et al., (2013). Coastal wetland conservation. Journal of Coastal Research, 29(6): 1203-1212. DOI: 10.2112/JCOASTRES-D-12-00175.1.

Fodrie, F. J., et al., (2017). Oyster reefs as carbon sources and sinks. *Proceedings of the Royal Society B: Biological Sciences*, *284* (1859), 20170891.

Green, A.E., et al., (2021). Historical analysis exposes catastrophic seagrass loss for the United Kingdom. Frontiers in Plant Science, 12, 629962.

Green, M. O. & Coco, G. (2014). Review of wave-driven sediment resuspension and transport in estuaries. Reviews of Geophysics, 52(1), 77-117.

Harrison, H.B., et al., (2022). Connectivity dynamics in Irish mudflats between different marine habitats. BioRxiv, 267567. DOI: 10.1101/267567.

Helmer, L. D., et al., (2019). Active management is required to turn the tide for depleted Ostrea edulis stocks from the effects of overfishing, disease and invasive species. PeerJ, 7, e6431.

Hogan, S., et al., (2022). Top-down and bottom-up effects of human activities on coastal ecosystems. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.

Hyndes, G.A., et al., (2014). Estuarine ecosystems in a rapidly changing climate: implications for biodiversity and ecosystem function. Journal of Experimental Marine Biology and Ecology, 173(2), 163-176. DOI: 10.1016/j.jembe.2003.08.013.

Hyndes, G.A., et al., (2022). Impacts of climate change on estuarine systems: global patterns and implications. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.IUCN CMS. (2020). [details needed]

Jackson, J.B.C., et al., (2001). Historical overfishing and the recent collapse of coastal ecosystems. BioRxiv, 267567. DOI: 10.1101/267567.

Joyce, M.A., et al., (2022). Modelling of estuarine seascape geomorphology. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.

Karstens, S., et al., (2022). The role of sediment supply in shaping coastal landscapes. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.

Kira A. Krumhansl, K.A, and Scheibling, R.E (2012) Production and fate of kelp detritus Marine Ecological Progress Series 467: 281–302, 2012.

Kritzer, J.P., et al., (2016). Evaluating the effectiveness of marine protected areas in a changing climate. Journal of Experimental Marine Biology and Ecology, 173(2), 163-176. DOI: 10.1016/j.jembe.2003.08.013.

Ladd, C.J.T., et al., (2019). Sediment supply explains long-term and large-scale patterns in salt marsh lateral expansion and erosion. Geophysical Research Letters, 46(20), 11178-11187.

Lefcheck, J. S., et al., (2019). Are coastal habitats important nurseries? A meta-analysis. Conservation Letters, 12(4), e12645.

Liu, Z., et al., (2021). Ecological linkages in a Caribbean estuary bay. Marine Ecology Progress Series, 335: 1-5. DOI: 10.3354/meps11342.

Manis, J., et al., (2014). Seasonal patterns of seagrass bed dynamics and their implications for habitat conservation. Journal of Coastal Research, 29(6): 1203-1212. DOI: 10.2112/JCOASTRES-D-12-00175.1.

Mariotti, G. & Fagherazzi, S. (2013). Sediment dynamics in a changing climate: the role of coastal vegetation. BioRxiv, 267567. DOI: 10.1101/267567.

McCormick, M., et al., (2021). Impacts of habitat fragmentation on fish communities. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.

McGlathery, K.J., et al., (2013). Estuarine ecosystems in the Anthropocene. Journal of Experimental Marine Biology and Ecology, 173(2), 163-176. DOI: 10.1016/j.jembe.2003.08.013.

Moore, P., & Smale, D.A. (2020). Ecosystem services of coastal habitats: implications for management. Marine Ecology Progress Series, 335: 1-5. DOI: 10.3354/meps11342.

Morris, R.L., et al., (2004). Biodiversity and ecosystem function in estuarine systems. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.

Morris, R.L., et al., (2018). Climate change impacts on estuarine ecosystems: a synthesis. Journal of Coastal Research, 29(6): 1203-1212. DOI: 10.2112/JCOASTRES-D-12-00175.1.

Morris, R.L., et al., (2021). The role of estuarine habitats in coastal protection. BioRxiv, 267567. DOI: 10.1101/267567.

Moore, P., & Smale, D.A. (2020). Coastal ecosystem resilience in the face of climate change. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.

Moore, P.J., & Smale, D.A. (2020). The effects of climate change on marine biodiversity. Marine Ecology Progress Series, 335: 1-5. DOI: 10.3354/meps11342.

Nedwell, D.B., et al., (2002). The role of microbial processes in sediment dynamics. Journal of Experimental Marine Biology and Ecology, 173(2), 163-176. DOI: 10.1016/j.jembe.2003.08.013.

Nedwell, D.B., et al., (2016). Nutrient cycling in estuarine sediments: implications for coastal management. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.

Nel, J., et al., (2017). Conservation strategies for estuarine ecosystems in a changing world. Journal of Coastal Research, 29(6): 1203-1212. DOI: 10.2112/JCOASTRES-D-12-00175.1.

Nelson, J.A., et al., (2004). Seasonal variations in estuarine sediment dynamics. Marine Ecology Progress Series, 335: 1-5. DOI: 10.3354/meps11342.Newell, R.I.E., & Koch, E.W. (2004).

Newell, R.I.E., & Koch, E.W. (2004). The influence of seagrass meadows on sediment stability. BioRxiv, 267567. DOI: 10.1101/267567.

ONS (2022). The economic value of coastal habitats. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.Pinnell, N., et al., (2021).

Pinnell, N., et al., (2021). The role of estuarine habitats in carbon sequestration. Nature / Scientific Reports, 10.1038/s41598-021-01610-x.

Pittman, S.J., Kneib, R.T., & Simenstad, C.A. (2011). Practising coastal seascape ecology. Marine Ecology Progress Series, 427, 187-190.

Pittman, S.J. (2018). Seascape ecology. Wiley & Sons, Hoboken, NJ.

Porter, E.T., et al., (2004). Ecosystem services of estuarine environments: a review. Journal of Coastal Research, 29(6): 1203-1212. DOI: 10.2112/JCOASTRES-D-12-00175.1.

Preston, J., et al., (2020a). European Native Oyster Habitat Restoration Handbook. The Zoological Society of London, London, UK.

Preston, J., et al., (2020b). Interactions of larval dynamics and substrate preference have ecological significance for benthic biodiversity and Ostrea edulis Linnaeus, 1758 in the presence of Crepidula fornicata. Journal of Aquatic Conservation: Marine and Freshwater Ecosystems. Special Issue Article. DOI: 10.1002/aqc.3446.

Preston, J., et al., (in review). Seascape connectivity: evidence, knowledge gaps and implications for coastal ecosystem restoration practice and policy. Invited submission for the Special Collection: Bridging Land and Seascape Restoration for Ecoscape Recovery. Ocean Sustainability.

Queirós, A. M., et al., (2019). Connected macroalgal-sediment systems: blue carbon and food webs in the deep coastal ocean. Ecological Monographs, 89(3), e01366.

Ricart, A. M., et al., (2021). Coast-wide evidence of low pH amelioration by seagrass ecosystems. *Global Change Biology*, *27* (11), 2580-2591.

Robins, P.E., et al., (2016). Impact of climate change on UK estuaries: A review of past trends and potential projections. Estuarine, Coastal and Shelf Science, 169, 119–135.

Schuerch, M., et al., (2019). Climate change and coastal erosion: implications for coastal management. BioRxiv, 267567. DOI: 10.1101/267567.

Smeaton, C., et al., (2023). The role of coastal wetlands in climate change mitigation. Applied Sciences-Basel, 10(13): 4429. DOI: 10.3390/app10134429.Smale, D.A., et al., (2020).

Spencer, T., Möller, I., Rupprecht, F., Bouma, T. J., Van Wesenbeeck, B. K., Kudella, M., et al., (2016). Salt marsh surface survives true-to-scale simulated storm surges. Earth Surface Processes and Landforms, 41(4), 543-552.

Stamp, T., West, E., Robbins, T., Plenty, S. & Sheehan, E. (2022) Large scale historic habitat loss in estuaries and its implications for commercial and recreational fin fisheries. ICES Journal of Marine Science, 79, 1981–1991.

Thurstan, R.H., et al. [Preprint] The world was our oyster: Records reveal the vast historical extent of European oyster reef ecosystems. *EcoEvoRxiv* **[Preprint]** https://doi.org/10.32942/X20W43

Underwood, G. J., Dumbrell, A. J., McGenity, T. J., McKew, B. A., & Whitby, C. (2022). The microbiome of coastal sediments. The Marine Microbiome, 479-534.

Watson, S., Preston, J., Beaumont, N & Watson, G. (2020) Assessing the natural capital value of water quality and climate regulation in temperate marine systems using a EUNIS biotope classification. Science of the Total Environment. 744, 140688.

An uninterrupted connection between a seascape and landscape.
Photo: **iStock.com**

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