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Turning the Tide: Systems thinking for a sustainable ocean

March 2025

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2021 2030 United Nations Decade of Ocean Science for Sustainable Development

The Institution of Environmental Sciences

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Acknowledgements:

The IES would like to thank all those who took part in, or engaged with, the Turning the Tide project. Your knowledge and enthusiasm has been invaluable in expanding the horizons of our Marine & Coastal Science Community. Thanks also goes UN Ocean Decade for their endorsement and support of the project. We also extend our particular thanks to:

- Hilary Kennedy, Professor of Marine Biogeochemistry, School of Ocean Sciences, Bangor University
- James Sippo, Research Fellow, Faculty of Science and Engineering, Southern Cross University, Australia
- Thomas Brook, Ocean Conservation Specialist, WWF-UK
- Claire Evans, Principal Biogeochemist, National Oceanography Centre
- Denise Adaoyibo Okpala MIEnvSc, CSci CMarsci, ECOWAS Commission Nigeria

This publication reflects the overall balance of views expressed by participants in the Turning the Tide project and does not necessarily reflect the views of the individuals and affiliated organisations listed above.

About the Institution of Environmental Sciences

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Blue carbon

Supporting vegetative coastal ecosystems will be an integral part of developing ocean-based solutions to the climate crisis. The Blue Carbon Initiative defines blue carbon as 'the carbon stored in marine and coastal ecosystems'.[1] This definition will be used throughout this publication, though there is no globally-agreed definition of blue carbon. Usually included in definitions of blue carbon are the coastal ecosystems of saltmarshes, seagrass meadows, and mangroves. Saltmarshes and seagrass prevent carbon from entering the atmosphere as it becomes buried in the seabed beneath them, while mangroves hold carbon within their own structures. All are referred to as 'blue carbon ecosystems' throughout this publication due to their abilities to store carbon. It has been argued that blue carbon discussions should be expanded to include other ecosystems, such as kelps and other seaweeds; more research is needed to understand their potential role in climate mitigation. However, the mounting pressures on all marine and coastal ecosystems mean we must act to protect them now, rather than pausing conservation efforts while we learn more.

Framing the benefits of seagrass meadows, mangroves, salrmarshes (and any other ecosystems the definition grows to include) beyond climate change mitigation will be key: their state affects affects both marine and terrestrial environments, and thus the return on investment from protecting them may be larger than many outside the sector are aware of. Communicating their vital role within the complex system that is the land-sea interface will be central to continuing to conserve, restore and research their carbon sequestration abilities.

The United Nations have described the ocean as 'the world's greatest ally against climate change', referencing its role as generator of 50% of atmospheric oxygen, and absorber of 25% of all carbon dioxide emissions along with 90% of the excess heat generated by these emissions.[2] However, the amount of carbon dioxide emitted by anthropogenic activities, which is then absorbed by seawater, means the ocean is slowly warming and becoming more acidic. This puts marine ecosystems at risk, as they cannot adapt quickly enough to the changing conditions of their habitat, particularly increases in temperature. In the case of blue carbon habitats such as seagrass, saltmarshes and mangroves, unsuitable growing conditions also hamper their ability to store carbon.

The impact of blue carbon ecosystems

Vegetative coastal ecosystems are highly important, with three often given particular focus: mangroves, saltmarshes and seagrass meadows. All three perform important functions, such as reducing coastal erosion by binding sediment together with their root structures; protecting coastlines by dampening waves and currents; and providing protective habitats for smaller sea creatures to thrive away from predators and conditions in the open ocean.

In addition, mangroves, saltmarshes and seagrass meadows also act as carbon sinks, trapping and storing carbon in the seabed. As both the above- and below-ground vegetation dies, a proportion of the carbon it holds is incorporated into and buried in the sediment it grows from – this is termed autochthonous carbon. Suspended sediments and organic matter from marine and terrestrial sources are filtered and stored in the same way. If this has come from outside the ecosystem any carbon contained as a result is termed allochthonous. As the sediment is waterlogged, oxidation and decomposition of the carbon cannot readily occur and the carbon stays stored in the sediment for decades to millennia. It is important to ensure this carbon stays buried by protecting and maintaining vegetative coastal ecosystems – or else they risk becoming carbon sources instead of sinks.

Other marine life, such as the macroalgae kelp, may also lead to the long-term storage of carbon. However, there are significant unknowns as the carbon produced by kelp is not buried on the rocky shores where it grows: we also don’t currently know exactly where in the marine environment kelp deposition occurs. It is possible that deposition would take place across national boundaries and potentially a significant distance from the area in which the kelp originated – as opposed to mangroves, saltmarshes and seagrass meadows where carbon is incorporated and buried in the sediment in which they grow. Additionally, it is not known yet how much, if any, of the deposited kelp carbon is oxidised, decomposed or buried. As a result, there will be further challenges when attempting to quantify how much kelp carbon is stored, which nation(s) can be accredited with removal of carbon, where the kelp grows or where its carbon is buried.

In addition to the effects of a changing climate, there are anthropogenic risks to these vital ecosystems. Mangroves are being cut down to be used as fuel or building materials or to make space for more financially profitable coastal vegetation like palm trees and aquaculture such as shrimp farming. Similarly, saltmarshes have historically been drained to make space for agri- or aqua-cultural ventures and salt harvesting, and those that remain are polluted via nutrient runoff from industries like sewage and farming. The same is true for seagrass: nutrients used on terrestrial crops can cause overgrowth of marine species such as algae, which clouds the water and limits the light that seagrass relies on. Other marine activities such as aquaculture, or the anchoring of boats, can also disturb the root systems and growth of seagrass and other vegetation. Given the multiple benefits that these ecosystems can provide for biodiversity and climate mitigation and adaptation, it is essential that they are protected and restored.

Blue carbon around the world

There are a range of approaches to managing blue carbon habitats. It is important that they are considered as part of a wider system to realise their multiple benefits. Equally however, they should have tailored management that reflects their locale and the unique pressures upon them, and as such there is a fine balance to be struck between many interlinked yet distinct factors. There is no single approach that works for every blue carbon habitat and its associated stakeholders, so understanding the potential applications, strengths and weaknesses of a range of strategies is key to developing bespoke management approaches that account for as many factors as possible.

Special Areas of Conservation in the UK

Seagrass meadows are recognised as a vital carbon sink and habitat in UK waters, though they are currently under threat from pollution, disease and physical damage caused by human activity. To protect seagrass from these pressures and restore degraded areas, Natural England, working with the Ocean Conservation Trust, designated five Special Areas of Conservation (SACs) on England's southern coastline. Two of these are Plymouth Sound and the Solent Maritime area. In 2019, these areas were found to be degraded, with seagrass struggling to flourish. Through a combination of protection and reseeding, around 8 hectares of seagrass have been replanted as of 2024.[3]

Two reseeding techniques were trialled during the project: seed broadcasting and seed translocation. Broadcasting utilised both seeds planted in hessian bags and dropped onto the seabed, and a novel injection device (HMS OCToPUS) to directly plant and distribute seeds across the restoration site; translocation was carried out through the use of coir mats to grow plants from seed in the aquarium and subsequently placed in preselected areas by divers. Early indications suggest that combining these approaches has been successful in beginning to restore seagrass in the SACs.

The team faced a unique challenge when collecting seagrass seeds for both methods. These precious seeds only appear annually and must be hand-picked by divers, meaning that they needed to be stored if they were to be used year-round as planned. To enable this, researchers designed a new storage system able to keep the seeds in a state of dormancy using recirculated, chilled salt water. This increased average germination rates by 28% over the course of the project, impressing the need for innovative approaches to conservation and restoration. The impact their learnings could have on seagrass restoration globally is significant.

Spotlight on Australia

In Australia, ongoing work is focusing on re-establishing coastal wetlands to take advantage of their carbon sequestration properties.[4] A significant amount of Australian coastal land has historically been drained to enable activities like agriculture to take place, meaning the land is now degraded and unable to act as a carbon sink. The Australian Blue Carbon Method has been developed to remedy this: tidal gates are installed in place of bunds and other impassable defences, allowing for the controlled flooding of the land. As a result, emissions from agricultural land are reduced and carbon sequestration increases as the blue carbon ecosystems re-establish. Incentivising farmers to allow these transitions to take place on their land is essential, so the Australian Government pays them in Australian Carbon Credit Units, which are calculated per tonne of carbon dioxide equivalents and available to anyone eligible to take part in the country's Voluntary Carbon Market scheme. The tool 'BlueCAM' was developed to support this, calculating net abatement (carbon sequestered + avoided greenhouse gas emissions – ecosystem transition emissions – fuel emissions) occurring in newly-flooded land. BlueCAM is a free tool that was developed to model blue carbon projects in Australia and is able to estimate net abatement for a variety of Australian ecosystems. Because all the data underpinning the model is from Australia, this tool is not calibrated to blue carbon ecosystems in other countries. However, the tool does greatly simplify blue carbon accounting and could be adapted to different locations. This approach to carbon accounting – both accurate and easily available to landowners is crucial to encouraging sustainable initiatives globally, prioritising learning and improvement rather than risking wasted resources through duplication.

Engineering solutions in China

Coastal engineering can represent an agile coastal management approach, identifying weaknesses in an ecosystem's self-sufficiency and creating the conditions to mitigate this. Though care must be taken to recognise the impacts physical interventions could have across a wider system (for example cutting off marine migration routes or changing the makeup of an established habitat). In areas where the benefits outweigh the risks there can be positive outcomes. In North Hangzhou Bay, Shanghai, there were historically naturally occurring saltmarshes and a beach that was well-used by local people. When sea defences were built to protect coastal developments from projected sea level rise, this caused the bay to be altered to a lagoon and degraded the naturally occurring saltmarshes that had once been the primary feature of the bay, and as a result multiple species were in decline.[5] In addition, the stagnancy of the water had allowed sediment and pollutants to build up, making it unsafe for bathing.

After research identified that the constrained ecosystem had altered the bay's biodiversity, a management strategy was developed that involved engineering both islands and submerged areas to allow for improved water flow through the saltmarsh. This flow helped to purify the main body of water behind the sea wall, enabling it to be safely used for bathing once more. Its increased usability supported the connection felt by local people to the beach, improving the likelihood that they act as stewards and protect the new ecosystem. This engagement will likely be crucial: a second step in the efforts was to focus on revegetation, encouraging the wildlife which had previously lived in the area to return. This was particularly successful with bird populations, which have re-settled and are beginning to thrive. They will, however, have to be monitored and protected, both by researchers and the wider community of North Hangzhou Bay.

Designating Marine Protected Areas (MPAs) is an approach that supports the long-term conservation and protection of blue carbon ecosystems by ensuring that extractive, or otherwise damaging, activities are not carried out within agreed zones. Though it is true that the interconnectedness of the marine system means causes and effects transcend any static area, this approach can have significant positive impacts when protecting specific species that are known to remain broadly in one place. This benefit can be compounded if the functions they perform support the wider ecosystem. For example, it has been found that kelp forests guarded by sea otters are more productive, and able to incorporate carbon into their structures 12 times more effectively than unguarded forests due to the role played by the otters in managing sea urchin populations — which, if left unchecked, can consume vast amounts of marine vegetation.[6] If, or when, the role of kelp in climate change mitigation is proven, designating known kelp-rich sea otter habitats as MPAs could therefore potentially support kelp carbon burial in sediments through the reduction of anthropogenic pressures, allowing the otters to continue instinctively stewarding blue carbon stores.

Unlocking the potential of blue carbon ecosystems

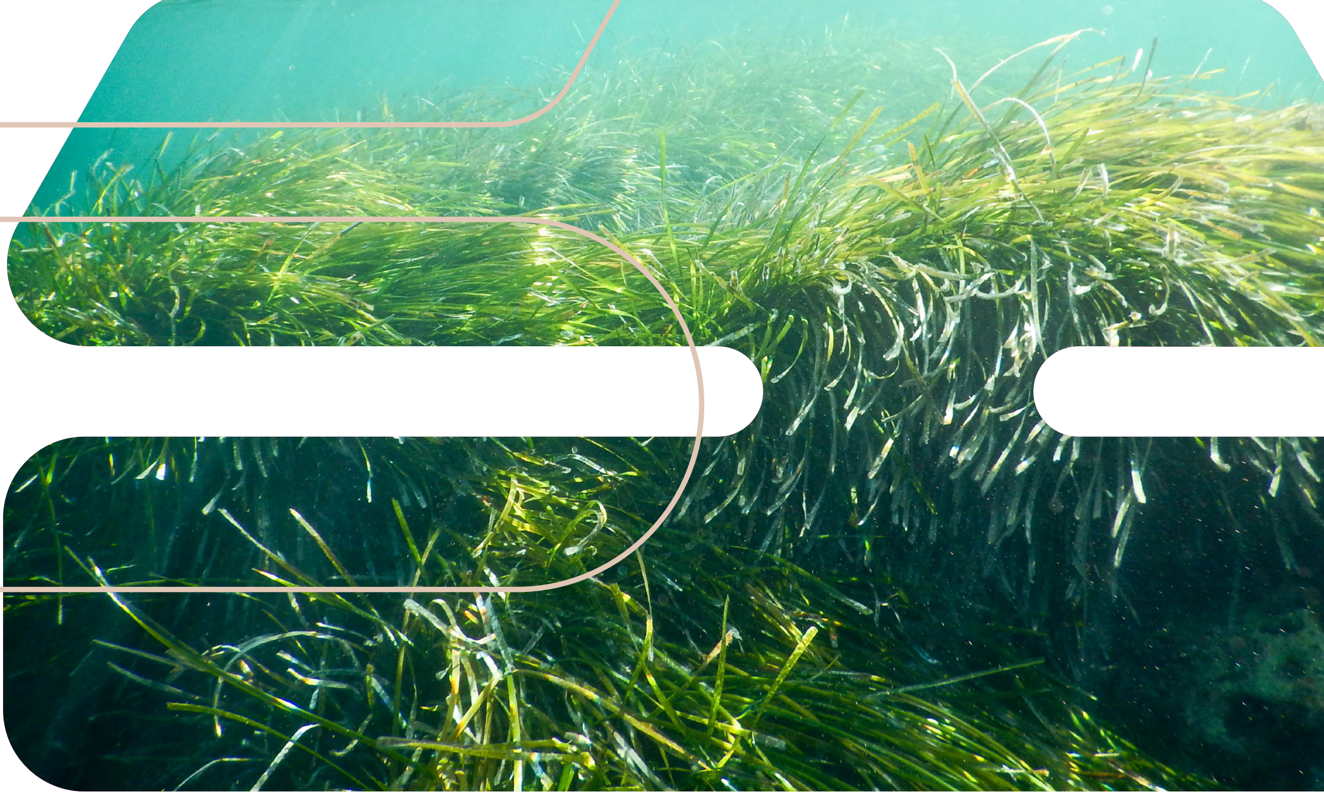
In June 2023, the UK Blue Carbon Evidence Partnership published its Evidence Needs Statement, which outlined five key areas where further evidence is needed to support UK blue carbon objectives:[7]

- Working towards the potential inclusion of saltmarsh and seagrass in the UK Greenhouse Gas Inventory;
- Encouraging and enabling investment in blue carbon habitats;
- Reducing the impacts of human and environmental pressures, including climate change risks, on blue carbon habitats;
- Managing coastal and marine habitats on a seascape scale, with consideration of land and marine connectivity; and
- Achieving climate change mitigation, adaptation and biodiversity benefits from blue carbon habitats as nature-based solutions.

These represent an important step towards a governance landscape that supports blue carbon environments. It is also a call to action for researchers and funders, a topic that is discussed in more detail in the next section.

It is essential that these Evidence Needs are acted upon quickly: if saltmarshes' importance can be quantified in the UK Greenhouse Gas Inventory, for example, there may be additional political will to protect these environments, which are threatened by sea level rise and could thus represent an additional incentive to contribute to global work to mitigate this well into the future.

In terms of having impact in the governance space, it is crucial that researchers and lobbyists communicate the socioeconomic benefits of action on climate change, and where applicable make those in decision-making positions aware of the potential returns associated with supporting initiatives in blue carbon habitats. As much as the ecological benefits may be of paramount importance to those in the environmental sciences, it must be recognised that different organisations have different priorities and selecting sector-relevant benefits to highlight is key to garnering support. Additionally, when addressing problems that will require behaviour change or other disruption to the norm, it is vital that the net positive outcome is made clear to all stakeholders to increase buy-in. Moreover, articulating the multiple benefits that blue carbon habitats can provide may improve buy-in



from different stakeholders. For example, blue carbon habitats do not only play a role in climate change mitigation but can also support biodiversity, climate adaptation and water quality. However, awareness of the benefits alone is unlikely to prompt the investment needed from coastal landowners to restore and manage these habitats without incentives attached. In the UK, organisations led by the UK Centre for Ecology and Hydrology are currently developing and piloting a Saltmarsh Code, which, if successful, would allow for the valuation and purchase of saltmarsh carbon.[8]

Interdisciplinary engagement is also integral to the success of any blue carbon projects. If scientists and local practitioners are given the platform to communicate with decision-makers, who in turn can ask questions and avoid being intimidated by the scale and technical complexities of the marine environment, it is more likely that decisions will be both scientifically sound and implemented sooner.

Collaboration is needed at the international level to unlock the benefits of blue carbon. Progress is being made in this space; COP29 played host to an Ocean Pavilion, during which partner organisations presented the Baku Ocean Declaration.[9] This outlined priorities for the marine environment, including investment into observation, research and mapping to achieve goals on climate, biodiversity and other UN targets. These include priorities to:

- Expand international collaboration to achieve progress in addressing the Earth's climate, biodiversity, and freshwater crisis;
- Enhance public and private funding to scale-up and diversify support of long-term ocean observation, research, and innovation for decision-making;
- Build capacity and access, particularly in small-island developing states, low-lying coastal regions, and other under-represented people and places to further develop ocean data, knowledge, and innovation; and
- Improve awareness of the ocean's role in planetary systems and the need for its preservation as a vital step towards mobilising decision-makers to prioritise ocean protection and restoration.

Mapping unknowns and encouraging pioneers

Blue carbon ecosystems have been, and in some cases still are, under researched, and gaps in our understanding can create barriers to protection and maintenance. One example of this is mapping the current extent of these ecosystems to measure their change due to degradation or positive interventions. In the case of mangrove ecosystems, which mostly occur in the tropics, it is relatively easy to understand their extent as they rise above the water and are therefore visible in satellite imagery. In the case of mangrove ecosystems, which mostly occur in the tropics, it is relatively easy to understand their extent as they are easier to identify through satellite imagery. Seagrass and saltmarshes can be trickier to quantify as they cannot always be identified from above.

Another key unknown is how vegetation may respond to the effects of climate change and their resilience in the face of a changing environment, for example rising sea levels or warmer temperatures. As such, any long-term conservation or restoration schemes must accept that adaptation is likely to be necessary and plans will have to be agile. In the same vein, science may not be able to provide all the answers needed to futureproof marine environments in time for perfect action to take place. This means that some efforts to support blue carbon environments may come up against unexpected barriers or consequences.

However, it is crucial that the research community views any such hurdles as learning experiences rather than reasons to stop action.

Despite challenges in exact quantification, it is imperative that these ecosystems are protected and restored. Given the timescales involved for effective climate action, we must move forward with projects in lieu of perfect evidence and take an adaptive approach to managing these habitats, informed by learning that we gain through the process. We will understand more about their functions over time, and until then they will continue to store carbon if properly managed and restored. If they are irreversibly damaged this opportunity will be lost entirely. As such, the marine and coastal sector needs to accept that work surrounding these ecosystems will have to be truly pioneering, as without certainty there will need to be courage (and enablement by funders) to try, fail, learn, and try again.

Blue economy

This topic will be discussed in more depth in our upcoming publication on the blue economy-specific theme of Turning the Tide – regardless, it is an area with clear links to blue carbon so should be considered within this theme.

There is discussion about the semantics of the term 'blue economy' in the context of blue carbon ecosystems. When looking to capture the interest of potential financiers, holistic phrases like 'nature credits' may work most effectively, as those outside of the marine and coastal sector may not understand the interconnectedness of marine and terrestrial ecosystems, and may overlook blue carbon projects when looking to invest for offsetting purposes, for example. This could also attract investment from those who may not have a specific interest in the marine environment but are looking to support wide-reaching interventions. As marine net gain continues to gain traction there is also the likelihood that habitat banks for the marine environment could lead to opportunities for credit stacking for biodiversity and carbon credits.

Language is important more broadly, too – a lot of definitions and buzzwords can be intimidating for someone outside the environmental science sector. Those with the finance to support blue carbon markets would likely benefit from more conversation with experts to understand where their investments would be most impactful. Alongside jargon-busting, it may be beneficial for environmental scientists to consider how investment in the stewardship of blue carbon environments could provide returns for investors. This may take the form of a quantifiable carbon offset, and where possible (and genuinely beneficial for the ecosystem in question) scientists may consider producing cost-benefit analyses in this vein if attempting to attract investment.

In October 2024, Natural England published their first State of Natural Capital Report for England,[10] which includes a list of 11 priority actions it feels the Government must act on to meet Net Zero targets and adapt to the realities of climate change while maintaining economic resilience. Several of these explicitly relate to blue carbon environments: 1. Use sea and land-use planning measures to ensure the protection and enhancement of ecosystem assets; 2. Minimise damage to the seabed through good fishery management; 3. Ensure space and sediment supply for saltmarshes and sand dunes with sea level rise; and 8. Create, protect and conserve natural carbon sinks and stores. Research estimates that blue carbon environments such as saltmarshes and other subtidal ecosystems play a part in sequestering carbon worth between £742 million and £4,259 million (in 2019 prices), so it is clear to see the fiscal value of protection and restoration along with the environmental benefits.[11] Put simply in Natural England's report, 'We need to invest in natural capital now, to reduce risks and reap rewards. Acting quickly to prevent and address the degradation of nature makes economic sense. It secures and enhances the benefits we depend on, now and for the future, meaning it will be cheaper and more effective in the long run'. This echoes the pioneering approach needed in marine and coastal research: even if the returns are not explicitly quantifiable, the investment will be beneficial and needs to be made now. Moreover, not investing would be to gamble the known storage properties of these ecosystems, and run the risk of degradation being irreversible when they have a vital role to play in slowing the effects of climate change.

Systems thinking

Blue carbon environments are a perfect example of the importance of systems thinking and approaches. Though it is possible to indicate the boundaries of a seagrass meadow, for instance, the fate of the seagrass within that boundary is significantly influenced by factors entirely outside of it. This takes place on both a local and global scale and involves both terrestrial and marine environments – as such, the need for collaboration between a large range of stakeholders is central. Similarly, the beneficial effects produced by that seagrass extend far beyond its growing range.

The benefits of blue carbon environments are not limited to carbon storage. The vegetation cover along coastlines by mangroves and seagrass provides habitats for a plethora of species who could not survive in open water or exposed areas; the intertidal zone of saltmarshes provides a perfect scavenging ground for many breeds of seabird. The roots of mangroves protect the coastlines of many tropical regions from the worst effects of extreme weather and related erosion by shielding otherwise exposed areas. Similarly, the root systems of seagrass bind sediment to the seabed, making it more resilient to strong currents and tidal erosion.

When engaging with decision makers, it is necessary to remain aware of the many layers of interconnected systems at play. It is impossible to separate people and ocean when thinking about the barriers to, and opportunities for, sustainable blue carbon habitats. Recognising this is essential to working within the system – holistic, interdisciplinary thinking must be applied.

Finally, it is also important to consider blue carbon habitats as systems of their own: they perform many functions aside from carbon storage, such as providing habitats for a wide range of organisms and should be recognised for their importance outside of the context of this theme. Their other functions and interactions directly impact their carbon storage abilities and are thus directly relevant from a systems perspective.

What's next?

The work done by the Marine and Coastal Community to develop and deliver Turning the Tide is reflected in the IES' updated Message to Government.[12] This document puts forward the key priorities identified by our Communities to ensure that the climate crisis is addressed with clear direction and urgency.

To supplement this publication, and its predecessor 'Bridging the gap between land and sea', we will be releasing summary publications for the other two themes covered in Turning the Tide: Blue economy; and Turning the Tide: Marine conservation and restoration.

The next theme, blue economy, is intrinsically linked to the future of blue carbon ecosystems. To ensure that marine and coastal areas are managed for the benefit of ecosystems and communities ahead of economic interest, it is important that there is cohesion in governance to ensure only sustainable, responsible development takes place. As with blue carbon, there are clashing definitions of a blue economy, ranging from sustainable to focused on extractive activities, and as such it is an evolving space with many stakeholders.

If you haven't already joined, why not become part of the IES' Marine and Coastal Sciences Community? You can also request to join our Marine and Coastal Science LinkedIn group to connect with like-minded peers working, or interested in, the sector.

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