Protecting and effectively managing blue carbon ecosystems to realise the full value to society- a sea of opportunities

An opinion piece by Dan Laffoley. November 2020

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Cover photos: (clockwise from top left) horse mussel bed, seagrass meadow, maerl bed, soft mud. All photos © NatureScot.

Index

Foreword

Increasing attention is being given to the climate mitigation potential of 'blue carbon' in coastal and shelf-sea ecosystems. The ecosystems currently recognised for blue carbon are seagrasses, salt marshes (sometimes referred to as tidal marshes) and mangrove forests. These ecosystems provide a host of benefits, from supporting the livelihoods of coastal communities, protecting them from the impacts of storms, and providing important habitat for fish, birds, and a variety of other species.

The importance of maintaining the integrity of carbon storage in marine soils, sediments and vegetation (preventing carbon dioxide release) is not in doubt; however, there are major knowledge gaps not only in pathways and sources of carbon, but also in the quantification of co-benefits and their true value to society in a multiplier context regarding ecosystems goods and services.

In addition to these vegetated ecosystems that are the focus for current action (salt marshes, mangroves, and seagrass meadows), science now shows that there are many other coastal and marine ecosystems rich in stored carbon and that sequester year-on-year. Such ecosystems are not yet recognised by policy makers for this role, and as a result are not being adequately managed and protected using all the policy tools at our disposal.

With this in mind, considering the importance of maximising the ocean's critical role in helping to tackle the nature and climate emergencies, and knowing Dan's history regarding the recognition of blue carbon ecosystems, we funded him to undertake this opinion piece.

We hope that this report can help to initiate a realistic conversation regarding not only the need to dramatically expand the scope of what is considered as 'blue carbon' and the value of protecting and restoring these ecosystems, but how far better use can be made of existing policy routes and processes to achieve more action now, alongside improving carbon accounting/reporting for shelf seas, and better securing of the associated social, economic and environmental benefits.

Dr Simon Walmsley

Chief Marine Advisor, WWF-UK

Executive summary

The COVID – 19 pandemic has shown how close, unsettling, and damaging our relationship with nature has become. The pandemic adds considerable weight to the urgency to address the ongoing and escalating biodiversity and climate crisis. One of the issues that lies at the heart of the climate and biodiversity crisis, alongside urgently halting the accelerating losses of species and ecosystems, is vastly improving the management and protection of carbon stored in natural systems. By sustaining such carbon sinks, we work with nature to support and recover resilience of ecosystems and strengthen the natural processes that help regulate carbon flows and atmospheric concentrations.

This opinion piece looks at 'growing back greener' from the impacts of the virus by taking opportunities to do far more to protect 'blue carbon' – the carbon that is stored in marine systems. With the ocean forming over 95% of the living space for species on the planet it is long overdue that such stronger action is taken. There has already been much encouragement to protect carbon in natural systems with increasing emphasis being placed on issues such as delivering nature-based solutions. Delivering joined up action that has real on-the-ground impact now is key.

As long ago as 2014 the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties called for joined-up actions and measures across relevant UN Conventions such as the UNFCCC and the Convention on Biological Diversity (CBD). Then the following year the UN Sustainable Development Goals (SDGs) were released providing a comprehensive policy framework to help achieve this. These goals form a key part of the United Nations agenda to end poverty, fight inequality and injustices, and tackle climate change by 2030.

More recently further weight to act has been provided by the Leaders Pledge for Nature. Through this Pledge political leaders participating in the United Nations Summit on Biodiversity in September 2020, representing 77 countries from all regions and the European Union, committed to reversing biodiversity loss by 2030. By doing so, these leaders sent a clear and united signal to step up global ambition. They are encouraging others to match their collective ambition for nature, climate, and people with the scale of the crisis at hand. The problem is that such calls over the years have still not yet been met with joined-up action delivered at the speed or sufficient scale perhaps anticipated or wished. Actions to keep natural carbon stores fully functional and in place are now increasingly seen as both urgent and essential.

The purpose of this opinion piece is to look at what can be done now to put such joined-up and meaningful actions in place in the marine realm, to protect and better manage such high value ecosystems, so they continue to deliver their extensive ecosystem services. This work accordingly draws attention to the diversity of marine ecosystems that are important for the carbon they contain. This goes beyond the initial three or so that have so far caught the policy makers eye, to highlight opportunities and challenges associated with expanding the protection given to a far wider range of blue carbon ecosystem not just under the UNFCC but also critically under the CBD and other multilateral agreements such as the Ramsar Convention.

It is critical to understand that the actions proposed in this report are additional to those already being taken under the UNFCCC. Indeed, it is arguable that without complementary measures being taken under other Conventions and multilateral agreements that there are high risks that marine carbon sinks that have yet to receive attention under the UNFCCC will otherwise be lost or severely degraded by the time action does occur. The actions proposed are accordingly complementary and synergistic ones that can be taken now alongside maintaining, strengthening, and further raising ambitions working through the UNFCCC to implement the Paris Agreement. This report should therefore be of interest to policy advisers and decision makers concerned with delivering far more widespread and rapid actions to counter the degradation now being seen in ocean health.

It is heartening to see that much good and welcome progress has already been achieved on blue carbon under the UNFCCC, but there is still considerable work left to be done. Taking inspiration from existing international calls to action, far more can and should now be done under the CBD and other agreements such as Ramsar to secure carbon sinks *in situ*, as a complementary mechanism to that being done under the UNFCCC, using existing policy tools such as MPAs. The sum of such coordinated action under multiple UN Conventions is likely to be far more than just having a principal focus on carbon management through one Convention alone.

The CBD route, which is used as the focus in this report to illustrate immediate opportunities for action, whilst already well defined in policy is, however, also not without its challenges to implement in a timely and effective manner. The major issue that emerges from the analysis underlying this opinion piece is that significant new effort is needed under the CBD to deliver on-the-water actions to secure blue carbon, and at the speed and in the manner needed, before the climate and biodiversity crisis becomes overwhelming. The good news is that many of the pieces needed to do this already exist, albeit in a fragmented way, and the following broad conclusions are reached:

- We need to embrace and demonstrably act on current policy imperatives to protect the resilience and functioning of carbon in natural systems – and that this explicitly includes the ocean. Better policy join-up, refinement and implementation are now what is urgently needed. Whilst good progress is being made in this respect under the UNFCCC and must be sustained and further strengthened, far more must be done to protect marine carbon stores under the CBD and other relevant agreements.

- Delaying action on such complementary measures by the CBD and others is closing off future opportunities, as marine carbon stores continue to be lost or degraded right now because of the widespread absence in MPAs of effective management measures. The priority must be to join up the science with radical improvements in MPA management to stop further degradation of such carbon stores, and through more appropriate management foster their restoration and recovery.

- We must act now across the board to protect the full range of coastal and ocean ecosystems naturally rich in carbon, introducing and using, as needed, standardised units to document the values. Such widespread actions need to focus not just on understanding how they relate to Governments' existing responsibilities in EEZs, but also the High Seas, and ensure in the latter that effective protection and management of blue carbon is provided for in the new Treaty under negotiation at the United Nations.

- In light of the above we need to avoid inadvertently tying the policy definition of 'blue carbon' to just the minority of carbon rich ecosystems that currently may qualify under UNFCCC (as IS happening) or overplay the sequestration/atmospheric links (as seems to be happening). This can make the protection/restoration of blue carbon ecosystems appear too much of 'just a climate issue', where in fact it should now be the focus for urgent action under all relevant conventions and agreements.

- We must also not just focus on MPAs but better manage human activities in the wider seascape that disrupt, damage, or cause the loss of natural carbon sinks and sequestration processes. Science shows how current activities permitted in MPAs are damaging and destroying marine carbon stores, and the case is no different for the broader seascape. Bottom contact fisheries are by far and away the biggest contributor to damage, deterioration and loss of marine carbon sinks.

In support of the above I recommend that there are five practical things signatories to the CBD and other agreements can do right now to make a real, significant and lasting difference. If done, they can help accelerate the implementation of real on-the-water measures to deliver and promote better protection and management of blue carbon.

- Recognise the full extent of blue carbon ecosystems present in MPAs as the basis for initiating climate/biodiversity joined up and effective management action.

- Take additional management measures straight away to secure the carbon values of well-documented blue carbon ecosystems.

- Take additional management measures to secure the carbon values of less well-documented blue carbon ecosystems, which may need to include mapping their extent and quality within current MPAs before enacting relevant management measures.

- Designate new MPAs based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs, rather than just focusing on traditional biodiversity values alone. This step can be enacted alongside any other step and as early as resources allow as a key element of delivering the CBD's existing (Aichi) and future biodiversity targets.

- Take measures to complement the MPAs using tools such as marine spatial planning and fisheries management measures to recognise, protect and enhance and restore blue carbon across seascapes.

It is important that countries should also ensure that their MPAs meet the CBD/IUCN definition and MPA Standards - this includes that 'nature comes first', and rules and regulations are in place and are actively being used to secure effective management on the water.

This report will help countries implement these five practical steps set out above, as it explores both the wide range of marine blue carbon ecosystems, as well as the relationship between their presence in MPAs and where management interventions are going to be needed. Well-documented blue carbon ecosystems whose presence is usually obvious in MPAs include mangroves, salt marsh and seagrasses, biogenic reefs, maerl beds, macroalgal forests, and thick muds, whilst ones that may need more mapping to define their 'boundaries' include stable to semi stable sediments such as both sand and muds.

These practical steps give ways for countries to help level the 'climate action' policy playing field across the land/sea divide, to recognise carbon in marine systems using a multi-convention approach, and now to urgently act to protect such carbon features in the ocean. This approach complements actions already in play under the UNFCCC to implement the Paris Agreement, and should also help form the centre of a 'grow back greener' no-regrets approach to tackling the climate and biodiversity crisis, that is long overdue.

1. Introduction

The trends we see in the natural world around us are extremely troubling. Species are in decline; extinction rates are increasing, and nature is experiencing a global fragmentation crisis. Despite all efforts by mid-2020 only 15.03% of land and 7.56% of the ocean are under any form of protected areas (WDPA, 2020). Over 50% of land is already subject to some form of anthropogenic use, while some 55% of the ocean is subject to industrial fishing - an area four times larger than that covered by land-based agriculture (Kroodsma et al., 2018). In the UK context, for areas that are within MPAs some 97% of them are still subject to bottom-trawling[1], despite clear science showing the damage that such an activity does to marine ecosystems.

Alongside this ongoing and serious decline in natural resilience are increasing problems of climate disruption caused by human activities. The grossly elevated greenhouse gas concentrations now in the atmosphere have serious consequences. For the ocean these are resulting in increasing and elevated ocean temperatures (Laffoley & Baxter, 2016), increasing and elevated levels of acidification, increasing declines in the amounts of dissolved oxygen (Laffoley & Baxter, 2019), all exacerbated by increasing numbers of 'hot spots' where such effects are more pronounced than the global averages. This is now being accompanied by worrying trends in changes to the major ocean current systems, and serious declines in polar ice.

Alongside this, and over the winter of 2019/20, the world was reminded of how precarious our relationship has become with the natural world when the COVID – 19 global pandemic broke out from China. As the world grapples with bringing the virus under control so the global population can resume some form of new normality, many individuals, organisations[2] and countries[3] are thinking of how to 'grow back greener', and the role nature-based solutions[4] can play to tackle the increasing range of problems that confront us. 'Blue carbon' contained in coastal and marine ecosystems is one such solution, which has yet to be implemented to any way near its full potential, hence encouraging the need for more practical action through this opinion piece.

Since 2009 a growing array of international efforts have been directed at recognising the blue carbon stored in mangroves, seagrass meadows and salt marshes and taking measures to integrate it into carbon action through the policy routes offered under the UNFCCC. But in the same period science has shown us that many other coastal and marine ecosystems (particularly permanently submerged ecosystems in the ocean) also contain similarly vast stores of carbon, and yet have still to receive the amount of attention and conservation action that is needed. This is despite the fact that there are already established international policy instruments in place, such as the overarching framework provided by the UN SDGs, and well-trodden paths to secure the *in situ* conservation of such ecosystems and their associated biodiversity and ecosystems services, such as commitments made by countries under the UN CBD and other conventions such as Ramsar. So how can we quickly increase practical action to protect and best manage carbon stores in the ocean? This opinion piece is a contribution to that process and the post COVID-19 ambitions to grow back greener. It explores how we can do far more using existing approaches to protect the natural systems that help keep our

[1] https://www.theguardian.com/environment/2020/oct/09/revealed-97-of-uk-offshore-marine-parks-subject-to-destructive-fishing
[2] https://files.wri.org/s3fs-public/covid-19-response-and-recovery-joint-policy-recs-nov-9-en.pdf
[3] https://www.euractiv.com/section/energy-environment/news/eu-leaders-back-green-transition-in-pandemic-recovery-plan/
[4] https://www.iucn.org/sites/dev/files/promoting_nbs_in_the_post-2020_global_biodiversity_framework.pdf

world more in balance than it will otherwise be. It sets out a simple practical 'action plan' that countries can take under existing commitments through the CBD and other agreements to complement, support and reinforce ongoing work under the UNFCCC that must continue and be strengthened. The sum of such outcomes is certainly more than the parts. This report should accordingly appeal to policy advisers and decision makers who wish to accelerate the implementation of actions to safeguard the ocean, the ecosystems, and species it supports, and their link to climate change mitigation, adaptation, and resilience.

2. The origins and development of blue carbon

Coastal and marine ecosystems are well documented as providing a host of benefits, such as supporting the livelihoods of coastal communities by providing food and raw materials, by protecting coastal communities from the impacts of storms, and by providing important habitat for fish, birds, and myriad other species.

Figure 1. The three blue carbon ecosystems that are currently the focus of global climate policy action: mangrove forest, seagrass meadow, and salt marsh. © Dan Laffoley

Some of these same ecosystems have also been recognised for the rich stores of carbon they contain, just like forests, peatlands, and soils on land. Whilst recognition of the need to act to protect natural carbon stores, and the associated processes that annually sequester more carbon into such stores each year, continues apace on land, in the ocean the uptake has until now been far more limited, but massive potential exists to do more, and to take that action now.

In 2009, after four years of research, I led the publication of what is now considered a landmark report on blue carbon. The report focused on the management of coastal and marine carbon sinks (Laffoley & Grimsditch, 2009), and was one of the first to promote global policy engagement on this important topic. This was at a time when the focus on carbon management policy actions was predominantly on tropical forests, peatlands, and some soil types. The 2009 report was one of two reports that year (Nellemann et al., 2009) that were instrumental in stimulating other publications, in creating the movement that devised the 'blue carbon' policy agenda, and in inspiring many more organisations and people to work around the world to protect these globally significant ecosystems.

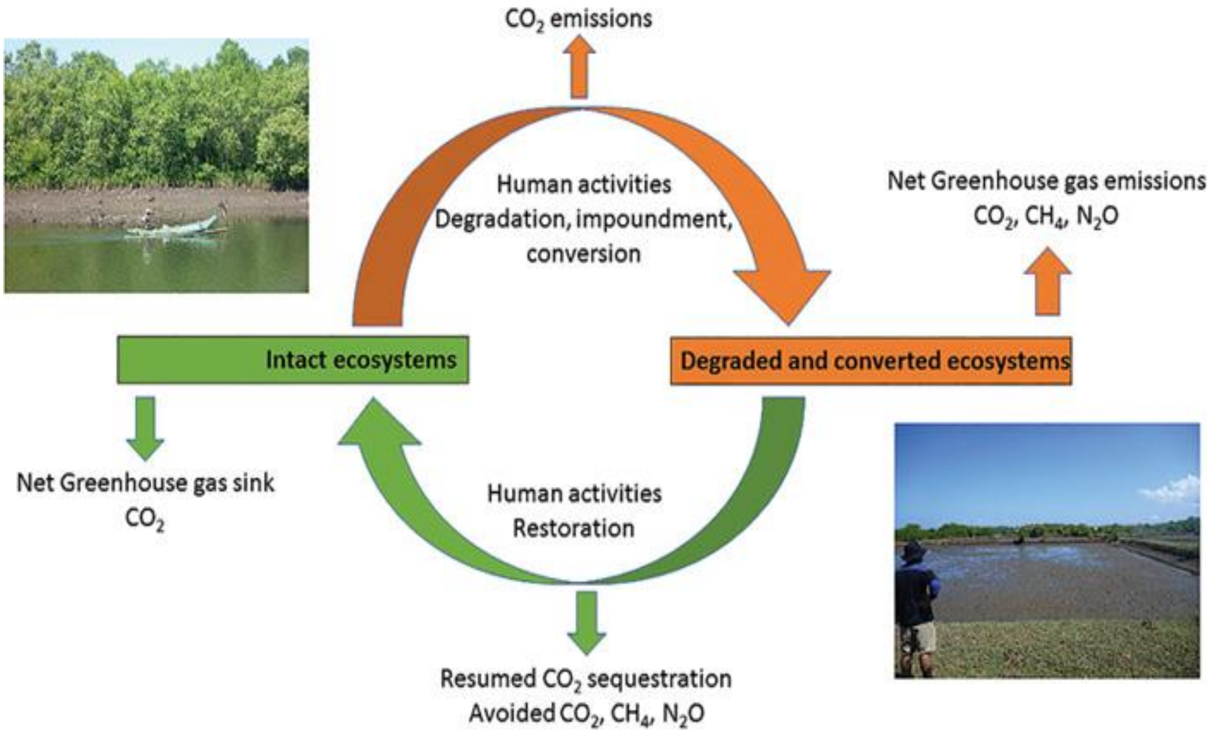

Figure 2. The blue carbon challenge of moderating human impacts to preserve greenhouse gas sink opportunities provided by these coastal ecosystems (Lovelock et al., 2020).

What the 2009 IUCN report established was that there was enough science back then to support the ambition to start to recognise marine and coastal ecosystems for their carbon values, just as had already happened at that point on land. In 2009 the science was strongest in establishing the carbon sequestration and storage role of seagrass meadows, salt marshes and mangrove forests, and these then became the logical focus for policy action in the ensuing years. This 'three ecosystem approach' has continued right up to the present day. By recognising the carbon values of such ecosystems this immediately raised their importance up the political agenda and resulted in far greater attention being given to their conservation, and the increasing priority being placed by Governments on policies for effective carbon management to counter the increasing scale and intensity of climate disruption experienced by countries around the world. Despite these ecosystems being lost twice as fast as forests, by adding in the carbon storage ecosystem service along with the many other services they provide, it is now heartening to see global actions being taken to rehabilitate and restore them as never before. These ecosystems already provide many essential ecosystems services in their own rights, and it is still my contention that carbon values should be considered on top of all these existing values to society and to the planet, in order to stimulate greater conservation action through all available policy routes.

Looking forward to the next decade of action on blue carbon, one of the challenges will be how to rapidly expand implementation of blue carbon to complement and reinforce current actions under the UNFCCC, to all blue carbon ecosystems under a multi-convention approach. The reality is that there are existing policy routes such as the UN CBD, using marine protected areas, the Ramsar Convention, and wider spatial measures, alongside other efforts directed at banning trawling on carbon-rich shelf-sea ecosystems that would be very strong complementary measures to those taken under the UNFCCC. Indeed, it is arguable that action must be taken via other conventions to support the Paris Agreement, as such conventions can be used right now to implement suitable on-the-water management to halt the decline of blue carbon ecosystems that is now being observed.

What is welcome is the fact that there is the ability, through the existing achievements of countries to put in place significant numbers of MPAs, to act quickly and at scale to achieve the vast scaling-up in effective management action now needed. Time is not on our side. If governments realised that improved carbon management could also be delivered through explicit recognition of blue carbon ecosystems and services in MPAs, in marine spatial planning and in fisheries management across the wider seascape, then the world would be in a better place.

Action is needed, not just words. And those measures need to be acted upon and put in place now.

3. The importance of the services associated with the 'current' blue carbon ecosystems

To understand the importance of acting in a unified way to protect blue carbon ecosystems is to understand the diversity and value of the services they provide, and the relative importance of the carbon service compared to carbon stored in ecosystems on land. These elements come together to provide a compelling picture of the importance of such ecosystems, and why there is an urgent need to scale-up action across UN Conventions and other mechanisms for their conservation and protection.

The original context for my 2009 blue carbon report that helped launch this topic into the global policy arena was that by elevating carbon value awareness there would be greater uptake of action to protect and conserve vulnerable coastal ecosystems. The logic being that conserving biodiversity for biodiversity's sake had not alone been a strong enough driver to deliver the change in protection needed at the speed required. By using the carbon angle, the resultant policy uptake for conservation action since 2009 has improved considerably, as measured by the range and diversity of blue carbon projects that have been created around the world (see for example Jiao et al., 2018). This has demonstrated the success of this strategy, with widespread awareness and action subsequently being taken by many nations on blue carbon. This effect is particularly marked in terms of efforts directed at acknowledgement, engagement, and uptake under the UNFCCC (see for example Herr & Landis, 2016; Herr et al., 2017; Martin et al., 2016). Whilst progress under the UNFCCC is good and needs to continue as quickly as possible, there are limitations to how fast such actions can go. The speed by which the underlying science can be generated, methodologies introduced, adapted, or improved, and how markets can recognise and adapt to taking on board blue carbon all takes time.

Figure 3. Blue carbon ecosystems provide a wide range of ecosystem services – species such as the mangrove crab (*Ucides cordatus*) are an important food item for local communities in mangrove forests around the world. © Dan Laffoley

Alongside the UNFCCC work more needs to be done to stimulate and deliver better recognition, protection, and management more widely by integrating carbon values into stacked ecosystem services. By exploring such inter-relationships, it shows both the need and urgency to act in unison across relevant UN Conventions. So, what does such an integrated agenda and stacked services approach look like, and how does carbon add to the existing valuations?

Coastal and marine ecosystems are now known to store up to six times more carbon per unit area than all other forests, even undisturbed rainforests (Mcleod et al., 2011). However, they are often overlooked or at best misunderstood, especially concerning the quantification of stacked services and co-benefits (see Figure 3). Thus, their true value to society is not fully recognised. From a carbon angle and policy perspective the carbon contained in mangroves, salt marshes and seagrass meadows compare very favourably by unit area to ecosystems that otherwise would dominate the policy domain such as tropical forests (Figure 4). Despite such ecosystems occupying smaller areas relative to tropical forests, the density and quality of carbon stored (in this respect with less propensity to also emit other powerful greenhouse gases such as methane, although this attribute is highly dependent on local situations) means that they warrant attention from policy makers and better protection and management (Figure 6). As Herr et al. (2017) stated 'although the combined global area of the three blue carbon ecosystems currently widely recognised – mangroves, salt marshes and seagrasses – equates to only 2–6% of the total area of tropical forest, their degradation is equivalent to up to 19% of carbon emissions from global deforestation (Pendleton et al., 2012)'. So, actions to secure their wellbeing should not be in doubt.

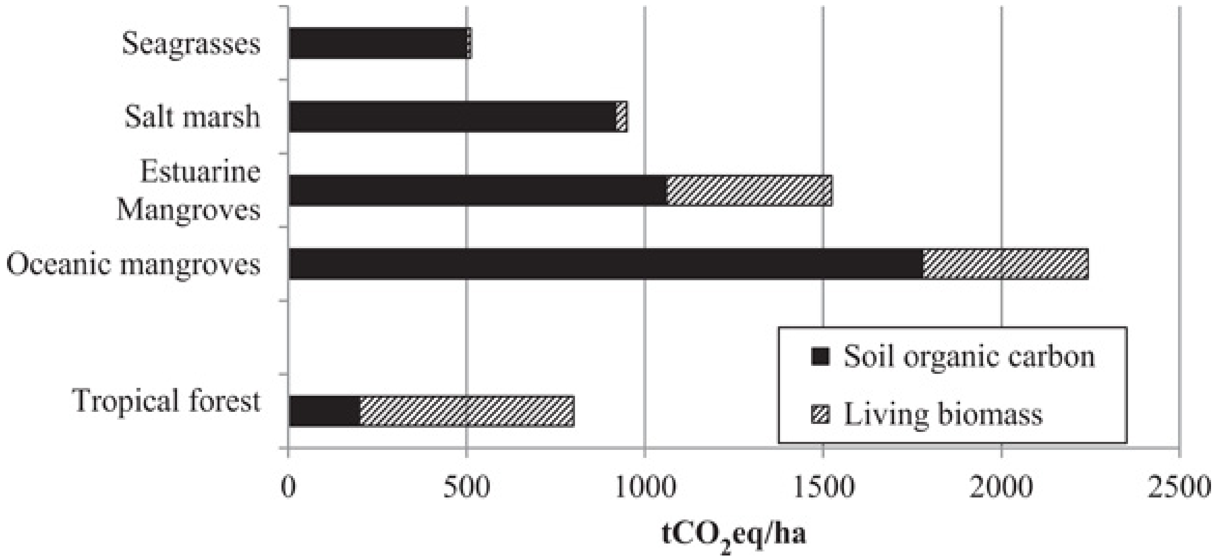

Figure 4. The global average values (top metre only) for soil organic carbon and living biomass carbon pools of mangroves, salt marshes, and seagrass meadows, compared to tropical forests (measured by carbon dioxide equivalents). (Pendleton et al., 2014)

Whilst these overall carbon values are critical to engaging the wider community and fostering action under the UNFCCC, such values only constitute a part of the wider array of ecosystem services provided by mangroves, salt marshes and seagrass meadows (Table 1).

What is interesting to note is that despite the attention on blue carbon, this service is not the only or most important service provided by each of the three ecosystem types that are the current focus for 'blue carbon' action. Quantifying the full range of services provided by mangroves, salt marsh and seagrasses is not quite as straightforward as it might at first seem, as there is a lack of comprehensive studies at the global scale, and general 'rules' can often be confounded by regional or local conditions that lead to an emphasis on particular services over others. Recent work has, however, pieced together the general picture to provide an overall perspective, but even here the positioning of the blue carbon element is not especially clear (Table 1).

What such relative positioning means in terms of perceived economic values at the global scale is difficult to determine in a credible way due to paucity of comprehensive global studies, compounded by regional and local variances due to differing settings of study locations and methodologies used, but some figures can nevertheless be proposed (Table 2).

It is often difficult to monetarise the service values, which is perhaps why mangrove carbon valuations, which are easier to define and most like 'forests', have come to the fore. Despite any shortcomings in how they can be calculated, these global values emphasise the wide range of services and associated values that each of these three blue carbon ecosystems provide socially, economically, and environmentally, alongside the often referred to carbon values.

Table 1 Relative magnitude of the ecosystem services provided by coastal marshes, mangroves, and seagrass meadows (for details and classification of H, M, and L see Vegh et al., 2018)

			Relative Magnitude of known or Perceived Ecosystem Services Derived per Unit Area (H,M,L)[a]		
ES Category	**Example ES Types**	**Ecosystem Process or Function**	**Coastal Marshes**	**Mangroves**	**Seagrass Meadows[b]**
Cultural	Recreation, spiritual	Tourism and recreational activities; Personal feelings and well-being	H	L	L
	Aesthetic	Appreciation of natural features	M	L	NA
Provisioning	Food	Fish, algae, invertebrates	H	H	L
	Freshwater	Storage and retention of water; provision of drinking and irrigation water	L	L	NA
	Other raw materials and products	Production of timber, fuel wood, peat, fodder, aggregates; extraction of materials from biota; medicines, genes for pathogen resistance, ornamental species, etc.	L	L	NA
Regulating	Climate and Biology	Regulation of GHG, temperature, precipitation; resistance to species invasions, regulating trophic interactions	H	H	L
	Natural hazards	Attenuates and/or dissipates waves; flood control	H	H	M
	Pollution control and detoxification	Provides nutrient and pollution uptake, as well as retention, particle deposition	H	H	L
	Erosion control	Provides sediment stabilization and soil retention in vegetation root structure	M	H	L
Supporting	Maintenance of fisheries	Provides sustainable reproductive habitat and nursery grounds, sheltered living space	M	M	L
	Soil formation; nutrient cycling	Sediment retention and organic matter accumulation; storage, recycling, processing and acquisition of nutrients	M	M	NA

Sources: MEA (2005); Barbier et al. (2011).

[a] Of inland and coastal wetland ecosystem types.

[b] Recent research illustrates higher magnitude of ESs derived from seagrass meadows that what is reported in MEA (2005).

Table 2. Examples of ecosystem service values for mangroves, coastal marshes, and seagrass meadows (from Barbier et al., 2011). N/A in the table below means value not available.

Ecosystem Service	Ecosystem Process or Function	Ecosystem Service Value Example: Mangrove	Seagrass Meadow	Coastal Marsh
Raw materials and food provisioning	Generates biological productivity and diversity	\$484–595 ha^{-1} year^{-1} (2007 USD)	N/A	GBP 15.27 ha^{-1} year^{-1} (1995 GBP)
Natural hazard regulation	Attenuates and/or dissipates waves	\$8,966–10,821 ha^{-1} (2007 USD)	N/A	\$8,236 ha^{-1} year^{-1} (2008 USD)
Regulation of erosion	Provides sediment stabilization and soil retention in vegetation root structure	\$3,679 ha^{-1} year^{-1} (2001 USD)	N/A	N/A
Regulation of pollution and detoxification	Provides nutrient and pollution uptake, as well as retention, particle deposition	N/A	N/A	\$785–15,000/ acre (1995 USD)
Maintenance of fisheries	Provides sustainable reproductive habitat and nursery grounds, sheltered living space	\$708–987/ha (2007 USD)	\$18.50/ha (2006 AUD)	\$981–6,471/acre (1997 USD)
Organic matter accumulation	Generates biogeochemical activity, sedimentation, biological productivity	\$30.5 ha^{-1} year^{-1} (2011 USD)	N/A	\$30.5 ha^{-1} year^{-1} (2011 USD)
Recreation and Aesthetics	Provides unique and aesthetic submerged vegetated landscape, suitable habitat for diverse flora and fauna	N/A	N/A	GBP 32.80/ person (2007 GBP)

Further information and insight on the relative positioning of the carbon sequestration service against other services can be gained at a more regional level where more credible economic service valuations become possible, and where comparative ecosystem service ranking becomes more achievable.

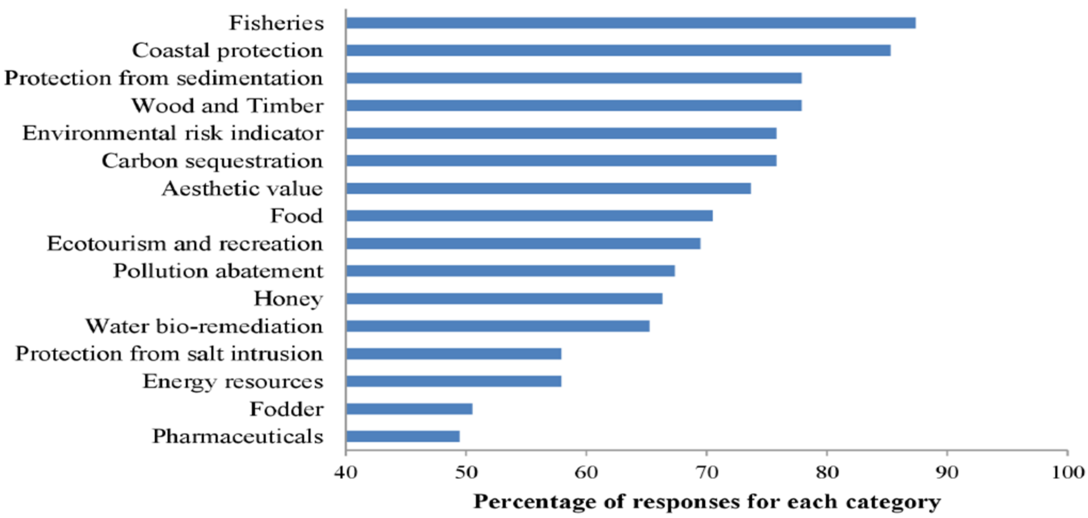

Figure 5. Ranked ecosystem services categories of mangroves based on a score given by experts in the Delphi technique (Mukherjee et al., 2014).

For mangroves what becomes clear is that blue carbon is but one and not necessarily the most important service they provide (Figure 5).

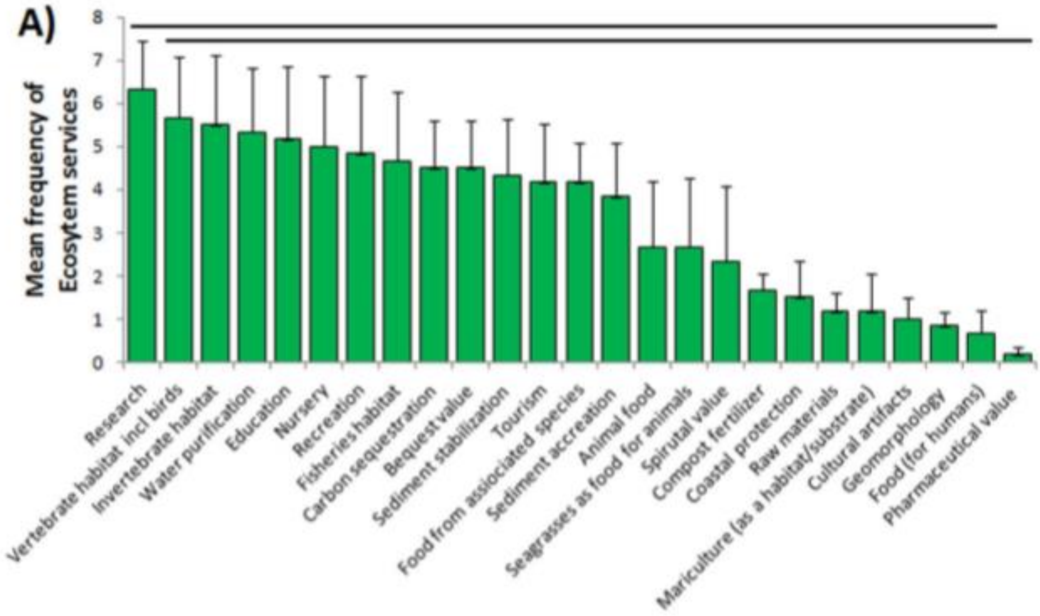

Figure 6. Global mean frequency of perceived provision of seagrass ecosystem services. Horizontal bars represent homogenous subsets (Tukey test) (Nordlund et al., 2016)

For seagrass meadows a similar picture emerges where again the carbon sequestration value is but one of the important values associated with the ecosystem services this blue carbon ecosystem provides (Figure 6).

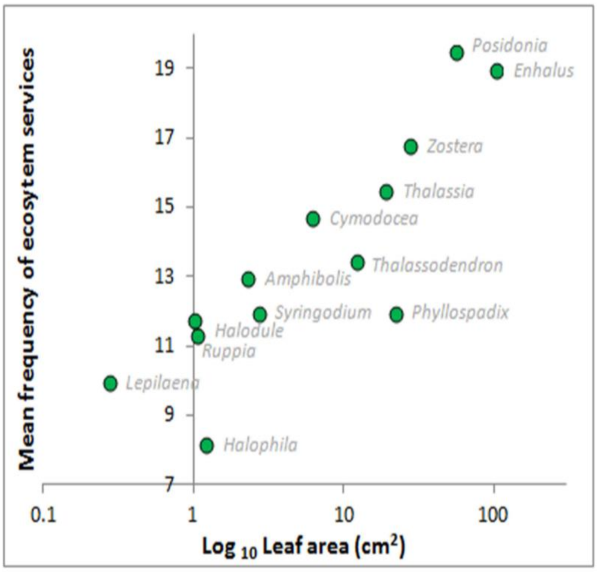

Figure 7. Relationship between mean perceived number of ecosystem services provided and seagrass shoot area (size) (Nordlund et al., 2016).

What research shows for seagrass meadows, perhaps more directly than for tidal marshes and mangroves, is that there is a clear relationship between the genera present and the number of ecosystem services that are provided (Figure 7). Vast stores of carbon can be present in the underlying sediments depending on the species of seagrass. The greatest stores of carbon – many metres deep and laid down over thousands of years - lie in the accreted remains under species such as *Posidonia* in the Mediterranean (Figure 8, Pergent et al., 2014).

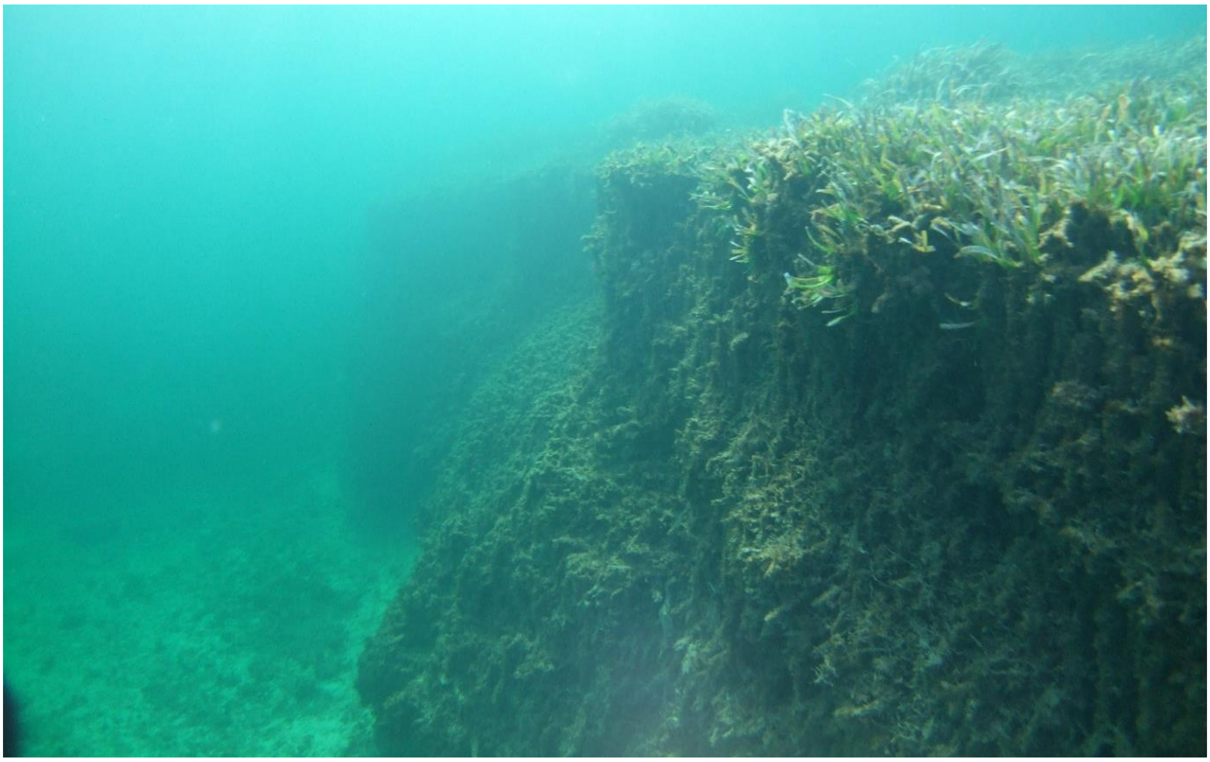

Figure 8. Heavily eroded seaward edge of an ancient *Posidonia* seagrass meadow, revealing several metres of accreted carbon lying under the living surface layer. © Dan Laffoley

Seagrass ecosystems, aside from their carbon values, are also critically important areas for stabilising sediments, and for the biodiversity they support, including providing valuable nursery grounds for many species of fish of commercial value. For salt marshes carbon sequestration is also but one of the key services such ecosystems provide (Table 3).

Table 3. Ecosystems services provided by salt marshes (derived from Barbier et al., 2011)

Ecosystem services	Ecosystem process and function
Raw materials and food	Generates biological productivity and diversity
Coastal protection	Attenuates and/or dissipates waves
Erosion control	Provides sediment stabilisation and soil retention in vegetation root structure
Water purification	Provides nutrient and pollution uptake, as well as retention, particle deposition
Maintenance of fisheries	Provides suitable reproductive habitat and nursery grounds, sheltered living space
Carbon sequestration	Generates biogeochemical activity, sedimentation, biological productivity
Tourism, recreation, education, and research	Provides unique and aesthetic landscape, suitable habitat for diverse fauna and flora

In all these representations and valuation of ecosystem services provided by the three blue carbon ecosystems there is a note of caution in that such assessments, because whilst they give clear perspectives, are still incomplete to one degree or another. They therefore underestimate the range but especially the value of services as methodologies are still needed to provide such a comprehensive perspective. For example, for seagrass services there are still gaps and further efforts needed, as illustrated in Table 4; there are similar service and valuation gaps for other blue carbon ecosystems.

Table 4. Unvalued ecosystem services of *Posidonia* seagrass and suggestions of how such gaps might be filled (adopted from Campagne et al., 2015).

Unvalued ecosystem service	Suggestions for economic valuation
Regulation and maintenance services	
Tourism's contribution: water purification, sequestration of nutrients and contaminants and coastline erosion protection	Study of the impact on tourism of the presence of the species *P. oceanica*
Decrease of the sound of waves thanks to *P. oceanica* banquettes and the meadows near the coastline	Sound comparative study between tracks with or without seagrass and economic evaluation of willingness to pay for this service
Habitat for protected species	Stated preferences methods
Limitation of invasive species invasion like *Caulerpa taxifolia* thanks to *P. oceanica*	Study of the limitation of the invasion of invasive species based on the presence of seagrass and review of actions taken against invasive species
Cultural services	
Visit of *P. oceanica* meadows: snorkelling and submarine vision boat	Production function or travel cost method
Fishing cuttlefish, angling in the *P. oceanica* meadows	
Education opportunities	Stated preferences methods (contingent valuation method or choice modeling)
Cultural value and heritage	
Artistic inspiration: theatre, painting, sculpture	
Emblematic species of the Mediterranean Sea	
Enjoyment of wild and charismatic species existing	
Willingness to preserve for future generation	

4. Expanding the scope of blue carbon action to other carbon-rich marine ecosystems

One of the challenges in realising the true potential of blue carbon is understanding, recognising, and acting on the full range and variety of carbon ecosystem values involved.

The original report on marine and coastal carbon sinks (Laffoley & Grimsditch, 2009) focused on a select few ecosystem types. Back in 2009 this was simply a practical necessity as no one had, up until then, done a report of the type we produced, and the experts on blue carbon at that time still lay 'hidden' within the scientific community.

Since 2009 there has been a surprising dedication to just three of the original ecosystems identified for carbon values (mangrove forests, salt marshes and seagrass meadows) despite a growing awareness that many other aspects of carbon in the ocean are also important and worthy of protection. For example, a couple of global studies then emerged focused on carbon in the offshore ocean environment, exploring the role of krill, fish, *Sargassum* weed and even the deep-sea environment (Laffoley et al., 2014; Lutz & Martin, 2014).

There was subsequently little uptake of interest on offshore carbon sinks and pathways which is surprising given the possibilities back then of industry such as fishing having impacts on such sinks due to widespread bottom contact of fishing gear and the likely impacts on sediment composition, geochemical cycling and mobility. The conclusion that can be drawn is that despite these early efforts to expand the scope of consideration to other ecosystems and to marine species it seems that such efforts were perhaps a little too early, and indeed the global community has persisted policy-wise with the 'current' set of ecosystems that they were alerted to over a decade ago (mangrove forests, salt marshes and seagrass meadows).

There is, however, clearly a much greater range of coastal and marine ecosystems that contain significant stores of blue carbon. It is important that these are considered by not just policy advisers and decision makers, but also that the science is made available to those responsible for designating and managing MPAs and other effective area-based measures so that responsible climate-related management actions can be taken.

What is particularly good news is that in recent years there has been a re-emergence of efforts to expand blue carbon so that the full potential and scope can be managed and protected. This has most notably happened in Scotland where pioneering work has been undertaken to expand the focus from the original coastal ecosystems to a much greater array of marine habitats and sediment types in inshore waters.

Two reports were produced in Scotland: one looked at the extent of the various habitats around Scotland and their capacity to trap and store carbon (Burrows et al., 2014), while the second followed-up by estimating the blue carbon resources of the Nature Conservation Marine Protected Areas and Special Areas of Conservation (Burrows et al., 2017, Table 5). The logic of these studies was to focus on both biogenic reef habitats and sediments that had high potential to trap organic and inorganic carbon, as well as those habitats such as seagrass beds, salt marsh and kelp forests that were already widely known to sequester carbon.

This research concluded that there are indeed very appreciable amounts of carbon stored in the inshore water ecosystems and sediments and located in MPAs and Special Areas of Conservation.

Table 5. Summary of the blue carbon category classification scheme used in Scotland (Burrows et al., 2017).

Biological	Geological
Kelp forest	Rock
Intertidal macroalgae	Gravel
Subcanopy algae	Gravel/Mud
Maerl beds	Gravel/Sand
Seagrass beds	Sand
Saltmarshes	Sand/Mud
Horse mussel (*Modiolus modiolus*)	Sand/Mud/Gravel
Flame shell (*Limaria hians*)	Mud
Lophelia pertusa reef	Sea Loch Mud
Tubeworm (*Serpula vermicularis*) reef	
Brittlestar beds	
Blue mussel (*Mytilus edulis*)	
Sabellaria reefs	

The greatest repositories of carbon in Scotland's marine environment are in the coastal and offshore sediments (Table 6) where an estimated minimum 18 million tonnes (MtC) of organic carbon are stored in the top 10 cm of sediments across the 470,000 km² area of Scotland's seas. An estimated 1,738 million tonnes (MtC) of inorganic carbon are similarly stored as non-living shell material. The main producer of carbon entering the long-term storage in sediments is phytoplankton, 3.9 MtC/yr, with coastal plants (predominantly kelp) potentially contributing a further 1.8 MtC/yr.

Table 6. Scotland's marine carbon budget summarised by habitat. Shaded cells indicate assumed zero values (e.g. production of carbon in sediments is negligible since most marine sediments are too deep for production from photosynthesis) (Burrows et al., 2014)

		Organic carbon								*Inorganic carbon*					
Habitat	Extent (km^2)	Standing stock (Mt)	Production rate (g C/m²/yr)	Total production (Mt C/yr)	Outflux (Mt C/yr)	Influx (Mt C/yr)	Sequestration rate (g C/m²/yr)	Sequestration capacity (Mt C/yr)	Sequestration timescale (half life)	Standing stock (Mt)	Sequestration rate (g C/m²/yr)	Sequestration capacity (Mt C/yr)	Outflux (Mt C/yr)	Influx (Mt C/yr)	Sequestration timescale (half life)
Phytoplankton	469960		81	39.0	3.9	0							1.09	0.00	
Shelf Sediment: Coarse (top 10cm)	115004	0.0				1.4	0.2	0.0	1000	798	1.05	0.12		0.27	2000
Shelf Sediment: Fine (top 10cm)	171660	17.6				2.1	41.1	7.0	1000	468	0.84	0.14		0.40	500
Offshore Sediment (shelf/deep)	183296	0.1				2.2	0.1	0.02	1000	472	0.95	0.17		0.42	
Sea lochs: Mud	847	0.3				0.01	155.2	0.1	1000						
Biogenic habitats	2283	0.4	662	1.8	1.8	0.0		0.015		0.58	109	0.00093			
Total	473089	18.5	84	40.8	5.7	5.7		7.2		1739		0.44	1.09	1.09	

In the overall carbon budget, habitat-forming species on the coast (seagrasses, salt marsh, bivalve beds), even though they are highly productive, made only a small contribution because of the limited extent of each habitat. Iconic species such as maerl ('hard' coralline

Table 7. Contribution of biogenic habitats to Scotland's marine carbon budget. Shaded cells indicate assumed zero values, either known (e.g. beds of intertidal algae are not long-term carbon stores) or unknown (e.g. fluxes of organic carbon into and out of salt marshes and seagrass beds) (Burrows et al., 2014)

		Organic carbon								*Inorganic carbon*					
Habitat	Extent (km2)	Standing stock (1000t C)	Production rate (g C/m²/yr)	Total production (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Sequestration rate (g C/m²/yr)	Sequestration capacity (1000t C/yr)	Sequestration timescale (half life)	Standing stock (1000t C)	Sequestration rate (g C/m²/yr)	Sequestration capacity (1000t C/yr)	Outflux (1000t C/yr)	Influx (1000t C/yr)	Refractory period
Biogenic habitats															
Kelp beds	2155	404	685	1732.4	1732.4					0					
Intertidal macroalgae	24.1	11.8	685	19.3	19.3					0					
Maerl beds	7.1									440.6	74	0.5			
Seagrass beds	15.9		261	4.2			83	1.3		0					
Saltmarshes	67.5	8.6	210	14.2			210	14.2		0					
Biogenic reefs															
Modiolus modiolus bed (Noss Head)	3.9									15.4	40	0.1540			
Limaria	1.4									0.1					
Lophelia pertusa reef (Darwin Mounds)	1.4									13.5	5	0.0072			
Lophelia pertusa reef (Mingulay)	5.4									112.0	35	0.1890	0	0	1000
Serpula vermicularis reefs	1.3									1.0	420	0.0546	0	0	10
Brittlestar beds (shelf seas)											82				

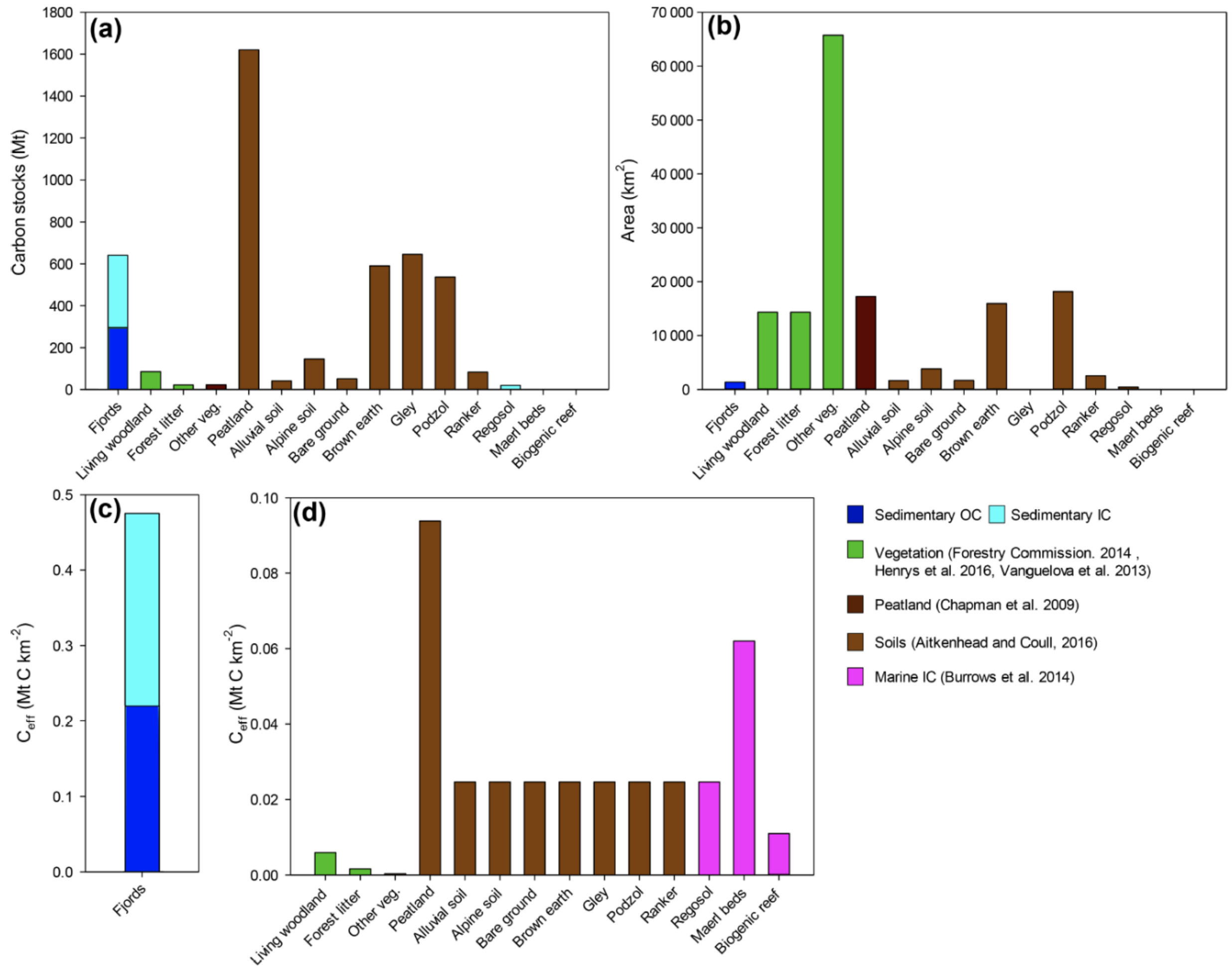

Figure 9. Comparison of Scotland's national fjordic sedimentary carbon store and other national inventories of carbon. (a) Carbon stocks (Mt). (b) area of storage (km²) and (c) effective carbon storage (Mt C km⁻²) for the 111 fjords. (d) Effective carbon storage (Mt C km⁻²) for the other national Scottish C stores (Smeaton et al., 2017).

seaweed) beds and cold-water coral reefs contribute 0.5MtC of inorganic carbon to the standing stock. While their growth rates are relatively slow providing small annual sequestration capacity of inorganic carbon, their longevity (centuries/ millennia) means that large quantities of sequestered carbon are locked away at geological time scales (Table 7).

Subsequent work (Smeaton et al., 2017) on carbon budgets (Figure 9) concluded that in Scotland the 111 fjordic sea lochs, by unit area, are a more effective carbon store than the terrestrial environment. They contain an estimated 640Mt of carbon with an additional 31,139-40,615 t being buried each year. This work rewrites the emphasis in Scotland on where effort should also be directed to secure carbon within natural systems.

The latest development in Scotland is to undertake blue carbon audits of key locations to map out the distribution and density of blue carbon so that it can be more readily considered and factored into regional marine management plans (Figure 10). Attention is also expanding in policy circles to considering whether 'blue carbon' should be a focus in its own right for future designation of MPAs, alongside more traditional biodiversity reasons.

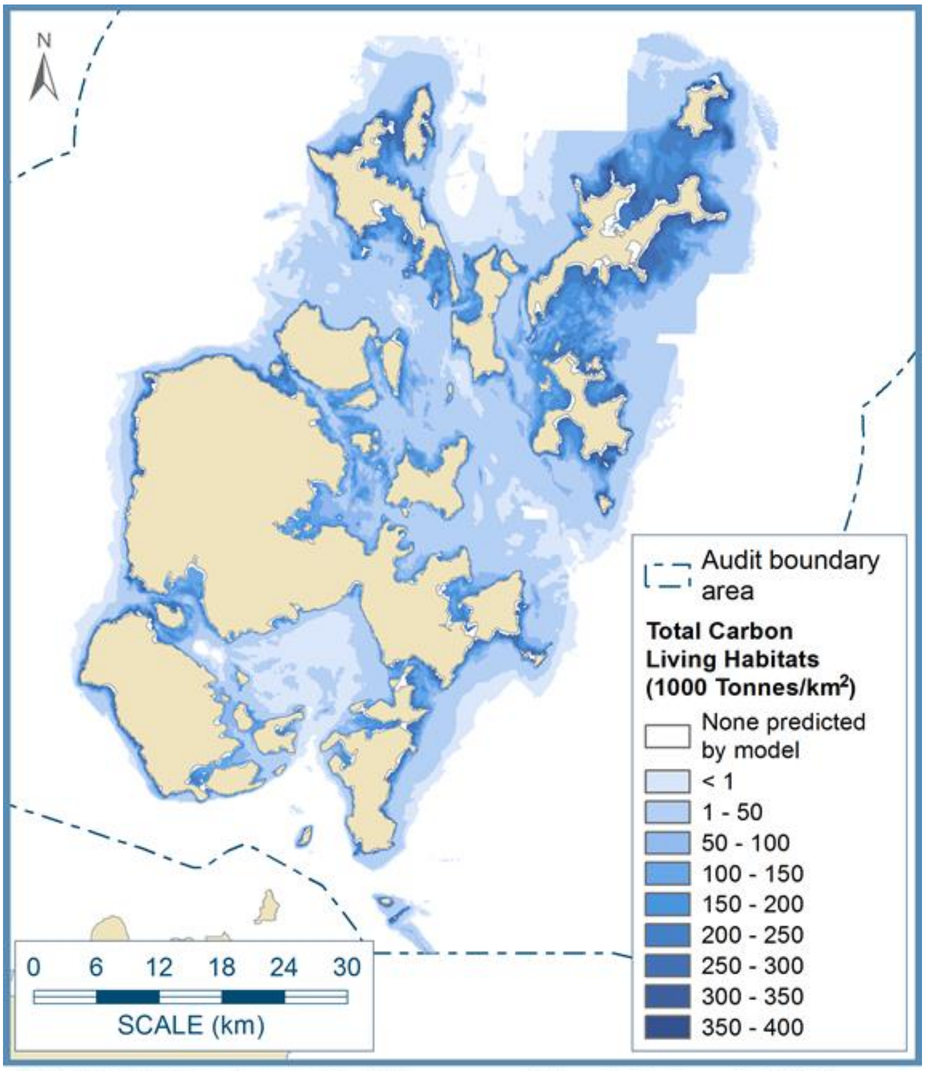

Figure 10. The blue carbon audit of Scottish waters – the Orkney Islands case study (Porter et al., 2020)

The analyses undertaken for Scotland on the distribution and values of carbon involved show that there is considerable potential to better manage carbon stocks in inshore waters globally due to their interactions with human activities. The research in Scotland concluded that for area-based conservation measures the threats to organic carbon stores are primarily coming from physical disturbance of the sea bed, moorings, coastal developments, and renewable energy, causing a breakdown of previously buried material.

The study in Scotland also considered that ocean acidification may pose a threat to inorganic carbon in sediments stored as carbonate, but the mechanisms whereby that threat may be realised are as yet unclear. Ocean acidification also may have a direct negative effect on the capacity of calcareous reef builders and maerl to build carbonate skeletons, but algae such as kelp may benefit through enhanced photosynthesis due to higher carbon dioxide levels.

What the Scottish work brings into sharp focus is that the definition or people's perception of blue carbon needs to be urgently revisited. If the focus remains on the 'current' three blue carbon ecosystem types identified in the original 2009 study, then clearly the full scope and opportunity for joined-up climate and biodiversity action will be missed by many coastal countries throughout the world.

5. The need to increase the scope and scale of action across UN Conventions to better protect blue carbon ecosystems

The ocean is now widely acknowledged as having been missing for far too long as a central component of the climate change and biodiversity debates, policy and action. Understanding the ocean and the position it has to have in global policy is key, as the ocean provides well over 95% of the living space on the planet for species, and shapes and determines the weather on land, alongside many other 'hidden' benefits.

The ocean is the major regulatory system on the planet that through feedback loops keeps conditions right for life on Earth. Earth history shows that if the ocean is significantly impacted then conditions for life change – if conditions become too hot species die out, and if they turn too cold similar extinctions occur (Strona & Bradshaw, 2018). The ocean keeps conditions right, and is particularly key to our future climate actions, as it absorbs hugely significant amounts of excess carbon dioxide and excess heat generated in the atmosphere through the greenhouse effect from our activities (IPCC, 2019).

There is a cost to these regulatory processes arising from our activities, and their anthropogenic consequences, as emissions continue largely unabated. The ocean is now rapidly heating, tending towards more acidic conditions, and starting to suffer from reductions in oxygen levels. Significant changes across the whole ocean are now being observed, exacerbated by regional variance and local conditions. Such changes to the ocean are thought to have accompanied the last five major extinction events in Earth's history (Barnosky et al., 2009). If humanity is to live in greater harmony with nature in the coming decades, the ocean must be placed at the heart of the debate and a renewed strategy agreed to address both climate change and biodiversity losses. Improved implementation of existing ocean policy is urgently needed if we are to get ahead of the climate emergency and associated biodiversity crisis. The ocean lies at the heart of both the problem and the solution.

In order to properly embrace the ocean as a key part of the solution and the need to better protect it and better manage our impacts on it, there are a number of policy problems to resolve, but two major issues immediately come to mind. First, in the context of tackling climate change via carbon management, it is the view that some may hold that coastal and marine blue carbon is not that significant when compared to other carbon stores. What is all too often forgotten is the density and quality of the stored carbon and the significant stacked services and co-benefits that are provided. Second is the assumption again by some that by embracing the ocean we simply get more of the 'same policy but with more complexity', and if policy could just focus on the terrestrial- and atmospheric-centric perspectives all will be right. This is totally wrong as the ocean climate signal shows not just specific responses such as ocean warming, acidification and deoxygenation, but also that there is a clear acceleration in the scale and nature of these and related impacts that affect the Earth's regulatory process.

Ocean warming and its impacts are not just present and evident everywhere, but this is now driving unprecedented gross ocean changes that have the potential to seriously impact climate, such as the speeding up of the major ocean currents since 1990 (Hu et al., 2020), and high regional losses of ocean oxygen (Laffoley & Baxter, 2019). It is critical that joined-up policy implementation by countries gets on top of these deficiencies, so that measurable actions at local and regional levels using nature-based solutions can have the greatest opportunities for success and play as full a role as possible.

The good news is that there are many existing policy frameworks, agreements and statements that embrace the need to better protect and manage marine ecosystems, alongside actions already welcome and underway through the UNFCCC. For example, under the CBD countries have agreed global targets that relate to not just protecting marine biodiversity but also ensuring effective management. Such targets are now up for review and whilst the content of those future targets remains to be seen, several of the existing interrelated Aichi targets are clearly of direct relevance:

- *Target 11 - By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.*
- *Target 14 - By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.*
- *Target 15 - By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.*

As implementation of the CBD targets has advanced through the efforts of countries throughout the world it is often the case that many blue carbon ecosystems are named as the reason for designation of many of the MPAs that exist today. It is just that the current management of such areas have not made the connection between reasons for designation and introduction of the right management regimes to sustain the biodiversity *and* carbon values. Indeed, in so many cases, effective management is often absent with few differences observed between human uses occurring inside and outside such areas.

A further welcome development has been the Sustainable Development Goals (SDGs) adopted more recently in 2015. These provide a strong mechanism to help guide renewed actions through international conventions, as well as national policy making and implementation. These goals are part of the 2030 United Nations agenda to end poverty, fight inequality and injustices, and tackle climate change by 2030. SDGs 13 and 14 are the most relevant to blue carbon, focusing as they do on climate action and life below water, but other SDG goals have some relevance also (https://www.iucn.org/regions/europe/our-work/policy/sustainable-development-goals).

- *13.1 'strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries.'*

- *13.2 'Integrate climate change measures into national policies, strategies and planning.'*

- *14.2 'By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.'*

- *14.5 'By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.'*

- *14.c 'Ensure the full implementation of international law, as reflected in the United Nations Convention on the Law of the Sea for States parties thereto, including, where applicable existing regional and international regimes for the conservation and sustainable use of oceans and their resources by parties.'*

The outcome of the UN Ocean Conference in 2017 provided further impetus by calling on all stakeholders to "*develop and implement effective adaptive and mitigation measures that contribute to increasing and supporting resilience to ocean and coastal acidification, sea-level rise, and increase in ocean temperature, and to addressing the other harmful impacts of climate change on the ocean as well as on coastal and blue carbon ecosystems such as mangroves, tidal marshes, seagrass, ….*". In 2019, the UN General Assembly declared that 2021 to 2030 will be the Decade of Ecosystem Restoration. It is a recognition of the problem and it is a great opportunity to restore ecosystems and connectivity while advancing job creation, food security and addressing climate change. Restoration and the rise of more large-scale rewilding approaches give hope that fragmentation and its impacts can be reversed both on land and in the ocean.

Then in September 2020, political leaders participating in the United Nations Summit on Biodiversity, representing 78 countries from all regions and the European Union, committed to reversing biodiversity loss by 2030. The Leaders Pledge for Nature[5] commits them to develop and fully implement the Post 2020 Global Biodiversity Framework to be approved in next year's COP 15 and "*in particular to significantly increase the protection of biodiversity through representative, well connected and effectively managed systems of Protected Areas and Other Effective Area Based Conservation Measures, and to restore a significant share of degraded ecosystems*". By doing so, these leaders are sending a united signal to step-up global ambition and encourage others to match their collective ambition for nature, climate and people with the scale of the crisis at hand.

Thus, even from this brief touch on international frameworks and policies signed up to by most countries throughout the world, it can be clearly seen that there is a strong foundation from which to encourage greater action across international and regional policy instruments.

[5] https://www.leaderspledgefornature.org/

We simply don't need yet more statements – what is needed is practical, joined-up, refined and meaningful implementation at scale in the ocean.

Much good work is already underway through the UNFCCC in line with many of the policy statements made above and elsewhere. This should be strongly supported and continued. There are, however, limitations on what can be done, and how quickly, under the UNFCCC route, but many more opportunities to act on blue carbon exist under the CBD, other conventions such as Ramsar, and agreements that have yet to be properly realised. So, the world should not look only to the UNFCCC to secure the protection and management of blue carbon alone but should complement such measures with effective protection and management of blue carbon under the CBD, as well as other wider seascape measures regions and countries can take. Working synergistically must be key to future success, as is already being recognised by the 2020 UNFCCC ocean dialogues – an ideal which needs to be held and acted upon much more widely.

A recent study (Beeston, Cuyvers & Vermily, 2020) explored what form these limitations on UNFCCC actions can take for mangrove blue carbon, and identified 78 issues ranging across political, social, economic and scientific disciplines that are currently holding back implementation of mangrove-focused blue carbon projects. They found a high level of consensus as to which were the most urgent issues to address regardless of geographical locations, and that 47% of factors constraining operation and expansion of blue carbon projects are financial in nature.

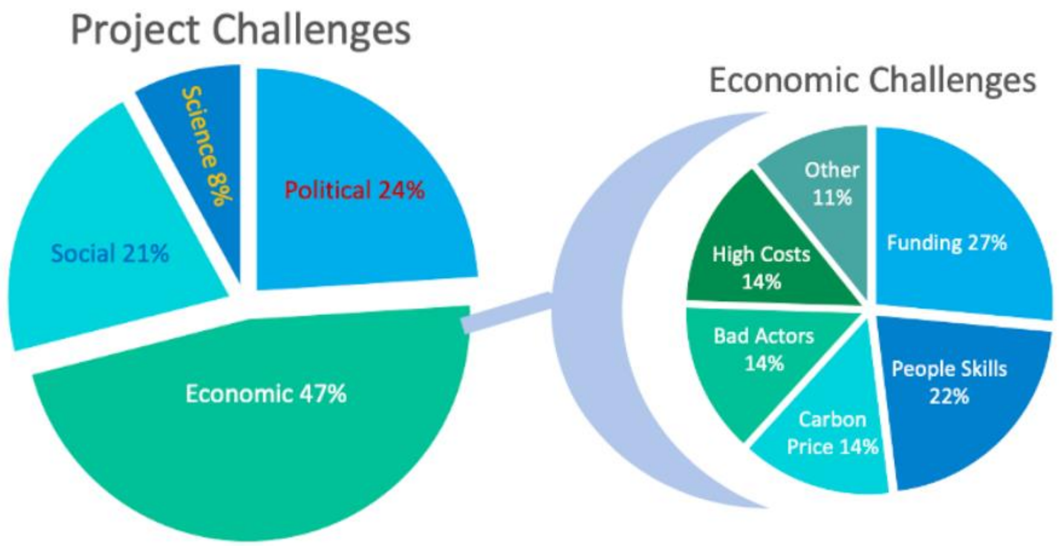

Figure 11. Analysis of issues limiting progress on blue carbon under the UNFCCC. Blue carbon projects are complex because they do not rely on any single factor. Political will and clarity cannot succeed without the underlying science necessary to design a credible project. Available financing alone will not make a successful project without the engagement of the community and competent leadership – the social aspect (Beeston, Cuyvers & Vermily, 2020).

Challenges on the science side stem back in part to how action under the UNFCCC is predicated on the fact that carbon rich ecosystems sequester carbon from the atmosphere and if damaged or destroyed, release that stored carbon back into the air. Exploration of the emission pathways for the 'current' blue carbon ecosystems (mangroves, salt marshes and seagrass meadows) shows marked differences in emissions after such ecosystems are lost, which in broad terms is related as much to their degree of submergence as it is to local conditions.

What is clear is that the atmospheric emission link is far more immediate and direct for mangroves than for salt marshes and seagrass meadows (Figure 12 – note the markedly different scales of vertical axes). What is also evident is that many of these emission pathways are based on modelled data rather than direct observations (Kennedy, pers comm), especially for ecosystems such as seagrass meadows. For salt marshes and seagrasses, the global distributions are still incompletely mapped. For the latter the amount of carbon emitted is also highly dependent on the species of seagrass involved (Nordlund et al., 2016).

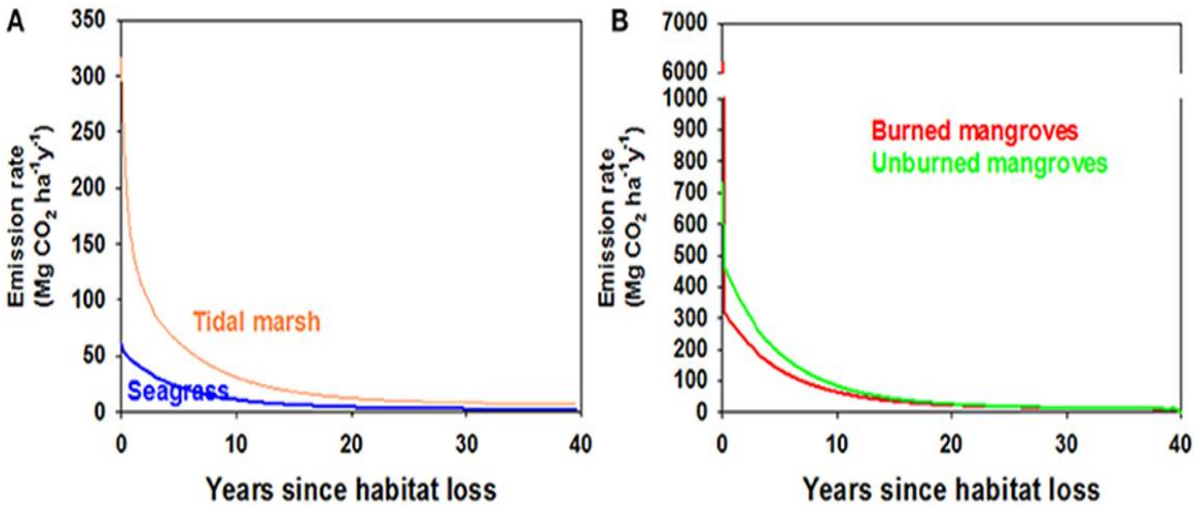

Figure 12. (A) Modelled CO_2 emission rates from disturbed seagrass beds (blue) and tidal marshes (orange), with the assumption that half of the organic carbon was deposited in oxic environments (i.e. α = 0.5). (B) Modelled CO_2 emission rates from disturbed mangroves where all above-ground biomass was burned (red) or the aboveground biomass was left to decompose *in situ* (green). The model was run with half of the sediment organic carbon deposited in an oxic environment (i.e. α = 0.5). Note the change of scale of the Y axis to accommodate high initial CO_2 emissions associated with burning of above-ground mangrove biomass (Lovelock, Fourqurean & Morris, 2017).

As part of impressive ongoing work to support blue carbon action under the UNFCCC significant attention is now being applied to identifying and addressing such research challenges (Macreadie et al., 2019). Work by Oreska et al. (2020) has helped to start to close an important gap for seagrass identified above, by doing the first full in-the-field accounting of greenhouse gas offset potential for seagrass, and so replacing modelling with direct observation. Similarly, Luisetti et al. (2020) in recognising the need to expand the scope of blue carbon ecosystems to subtidal sediments explored the issues involved with expanding carbon accounting guidelines for the recording of carbon flows in terrestrial and coastal ecosystems to include shelf sea sediments. They examined the complexities of carbon transport and fate in shelf seas, and the geopolitical challenges of carbon accounting in climate governance, because of the transboundary nature of carbon flows in the marine environment. They concluded that new international accounting guidance and governance frameworks are needed to prompt climate action under the UNFCCC. Also, in 2020 Verra released the first blue carbon conservation methodology approved under any major GHG programme[6]. The methodology, which is a revision to the VCS REDD+ Methodology Framework (VM0007), adds blue carbon conservation and restoration activities as an eligible project type and is expected to unlock new sources of finance for tidal wetland conservation and restoration activities.

Whilst the conservation community will continue to grapple with closing critical gaps on information and policy needs, there is nevertheless good evidence in such carbon rich ecosystems that currently poorly regulated human activities are causing sediments to be destabilised, eroded, and ultimately the carbon sinks to be lost. Whether the sediment subsequently becomes oxidised, resulting in an emission back to the atmosphere is not proven in all cases, but clearly this lack of understanding must not delay the need for action now across UN Conventions and agreements to protect such important ecosystems.

It would be wise to rapidly diversify, accelerate and develop action under the full array of already-established policy mechanisms at the disposal of governments, and indeed it seems odd why this has not already happened, despite earlier recognition of the need for this to happen (e.g. Herr et al., 2017). If the global policy aim as defined through SDGs is to retain resilience in marine ecosystems and restore them where degraded, then understanding that there are such linkages and acting on them more comprehensively than at present, via global and regional conventions and initiatives, becomes key. Whilst engagement with mangrove carbon is likely to be achieved more quickly through the UNFCCC, because the science and understanding is more advanced and similar to 'forest' carbon with its established methodologies, it will take far longer to see equivalent actions for salt marshes and seagrasses. The CBD and other conventions such as Ramsar provide ideal complementary routes through which to take action to support the Paris Agreement and stop further degradation and loss of such blue carbon ecosystems.

6. Developing and implementing a practical blue carbon 'action plan' under the CBD

For the current well-known blue carbon ecosystems such as mangroves, seagrass meadows and salt marshes, as well as the wider array of submerged coastal marine ecosystems now known to be rich in carbon, the priority now must be to protect the resilience and functioning of the natural carbon stores and processes. This is no different to what has happened on land, but it is just that we have not yet done enough to achieve this in the ocean. Unlocking how management regimes can be altered to benefit and protect carbon functioning in such a wide array of ecosystems is the key to engaging with measures that should be taken under Conventions such as the CBD. To do this there needs to be in place an understanding on how human activities in the ocean interact with biogeochemical mechanisms in such ecosystems (i.e. the process of, and around, carbon sequestration).

When such linkages are explored, some complementary management measures become obvious. For example, cutting, burning, dumping, and coastal developments are clearly incompatible with maintaining healthy natural mangroves and salt marshes. Seagrass meadows and the wider suite of blue carbon ecosystems defined from the work in Scotland (biogenic reefs consisting of mussels, oysters, corals, coralline algae (e.g. maerl), brittlestars and flame shells (see Table 5)), are highly vulnerable to human activities that abrade, remove, or smother such ecosystems. Table 8 explores this relationship between blue carbon ecosystems and operations likely to cause deterioration or disturbance to the structure and

[6] https://verra.org/first-blue-carbon-conservation-methodology-expected-to-scale-up-finance-for-coastal-restoration-conservation-activities/

functioning of such ecosystems and associated biogeochemical cycling processes. Table 8 does not provide an exhaustive list, but it gives an illustrative picture of expected interactions. The degree to which management action is required will be a function of the present activities that cause such effects, and the extent and intensity at which they are undertaken. This table is based on the original approach I helped create for Regulation 33 advice under the UK Habitats Regulations for European Marine Sites in the seas around England.

Activities likely to cause deterioration or disturbance through abrasion, removal, or smothering predominantly involve bottom trawling and other seabed contact fisheries, and other operation such as existing (and new plans for) fish farms, capital dredging, dumping of dredge spoil, seabed mining, and some renewable energy developments. For biogenic reefs once the living surface part of the feature is damaged the sequestration ability linked to the overall physical biogenic structure and the underlying organic and inorganic stores is lost – quickly in some instances but nevertheless declining and disappearing over time. Historical losses of biogenic reefs are well documented and so stemming further losses is now urgent. Such measure taken in the ocean can complement actions to protect carbon on land. Indeed, as was demonstrated in the Burrows et al. (2014) and subsequent work arising from that report (Baxter, pers comms), some blue carbon sinks in Scotland are capturing appreciable carbon lost from deteriorating carbon sinks on land (e.g. peat bogs), so there is a connectivity aspect that also needs to be addressed to complement carbon management measures on land, with protecting adjacent sinks in the sea.

For a further array of blue carbon ecosystems which are far more widespread than just biogenic reefs, similar connections need to be made on the presence of damaging human activities in the MPA, geochemical cycling, and corresponding appropriate area-based management regimes. These more widespread ecosystems consist of sands and muds, although the degree to which they trap organic carbon is highly dependent on grain size, long-term stability and degree of shelter from waves and currents. Nevertheless, Luisetti et al. (2020) consider that on a global scale, the carbon sink in shelf systems is comparable to that in tropical forests. It is well documented that fishing gear such as trawls and dredges alter the distribution and abundance of marine species, impoverish seafood stocks, and result in benthic mortality and sediment resuspension. What has been less well recognised is how such fishing operations interact with the biogeochemical processes associated with carbon sequestration and storage, even though peer reviewed papers are published on this aspect. In highly dynamic shallow water sandy seabed ecosystems, where natural disturbance from waves and currents may continually change seabed contours and mix sediments, the link may be less evident. It has been shown in sandy sediments that such physical disturbance, and the mediation of macronutrient and carbon cycling, is increasingly affected due to the impacts on organisms and the impairment of the natural sediment sequestration processes (Hale et al., 2017). This is because animals at the sand - water interface, or deeper down in the sediment, that are impacted by bottom fishing, are the most important for sustaining the biogeochemical functioning of such ecosystems.

The case is even clearer for muddier seabed ecosystems, a point recognised and already included in the recent JNCC report (Flavell et al., 2020). Such blue carbon ecosystems are more vulnerable to disruption of the carbon sequestration processes due to their inherent greater stability, and indeed from a biodiversity perspective such vulnerabilities to seabed trawls and dredges are already understood and documented[7]. In muddier environments it is

[7] https://www.marlin.ac.uk/biodiversity_conservation

Table 8. Examples of operations likely to cause deterioration or disturbance to blue carbon ecosystems and associated biogeochemical cycling processes. Black shading indicates expected incompatibility, and lighter grey incompatibility in some cases. This table is based on the original approach developed for Regulation 33 advice under the UK Habitats Regulations for European Marine Sites in the seas around England.

Examples of categories of operations likely to cause deterioration or disturbance	Blue carbon ecosystem type							
	Mangroves	**Salt marshes**	**Seagrass meadows**	**Biogenic reefs**	**Maerl beds**	**Macroalgal forests**	**Thick muds**	**Semi-stable sediments**
Physical loss								
• Cutting and burning			Not applicable					
• Removal/substratum loss								
• Smothering								
Physical damage								
• Changes in suspended sediment								
• Abrasion/physical disturbance (of ecosystem)								
• Changes in grazing management			Not applicable					
Non-physical disturbance								
• Noise & visual presence								
Non-toxic contamination								
• Changes in nutrient loading								
• Changes in turbidity								
Biological disturbance								
• Introduction of non-native species								
• Selective extraction of species								

the impact of the trawls and dredges on the sediment, rather than the losses of biodiversity alone that affect the carbon sequestration potential. This is such that otter trawling, for example, may be affecting organic-matter remineralization and nutrient cycling through sediment resuspension and burial of organic matter to depth, rather than simply through the loss of bioturbation potential of the benthic community (Sciberras et al., 2016).

For deeper water sediment ecosystems on the coastal continental slope, removed from the effects of surface waves and currents, the situation is also clear. Trawling such blue carbon ecosystems significantly decreases the organic matter content in the surface layers (up to 52%), slows organic carbon turnover (by about 37%), and reduces meiofaunal abundance (80%), biodiversity (50%), and nematode species richness (25%) (Pusceddu et al., 2014). Pusceddu et al. (2014) estimated that the organic carbon removed daily by trawling in the region they studied (north-western Mediterranean) represented as much as 60 – 100% of the input flux. Exposing deeply buried sediments to oxygen triggers the aerobic microbial breakdown of ancient stored carbon, and there is some broader evidence on the relationship between other human actions and events and activities such as oil spills, seasonal wrack deposition, aquaculture, eutrophication, and altered tidal flows.

Whilst the exact responses to deeper water trawling and other human impacts may vary to a degree in sediment ecosystems in different parts of the world, it is clear that measures should be taken beyond the protection of the biodiversity present in MPAs to better manage and protect the resilience of the underlying biogeochemical services that such healthy ecosystems clearly can provide.

There is a strong and urgent case to respond to here, as the vast scale of such activities means that the overall impact on such processes is also vast. Thus, the presence of blue carbon ecosystems should therefore be connected in practice to providing high or full levels of protection via MPAs to prevent such losses from continuing. This is because high or full levels of protection in MPAs as a matter of course exclude the activities that cause damage and losses of blue carbon ecosystems.

So, if there is an urgent need to act on blue carbon under the CBD and other conventions in support of the Paris Agreement what would such an approach entail in practice? Drawing from the evidence presented in the previous pages there are five practical things signatories to the CBD can each do which, if carried out, can result in the implementation of real on-the-water measures to deliver and promote better protection and management of blue carbon (Table 9). The first three points in the table would be expected to be applied in the order given, but the latter two actions could be undertaken in parallel to ensure an even speedier management response.

None of the five actions require new global policies or statements – but they do require moving the MPA agenda forwards from viewing MPAs as simply a part of a % target, to delivering the on-the-water management that is effective, joined-up and achieves biodiversity and climate action. None of this is anything that countries have not already committed to deliver, but perhaps seeing it as five simple, practical steps may promote the join up and action now needed.

It is important that countries should also ensure that their MPAs meet the CBD/IUCN definition and MPA Standards - this includes that 'nature comes first', and rules and regulations are in place and are actively being used to secure effective management on the water. This report will help countries implement these five practical steps set out above, as it explores both the wide range of marine blue carbon ecosystems, as well as the relationship

Table 9. A five-point plan for improving the protection and effective management of blue carbon ecosystems in MPAs under the CBD in support of the Paris Agreement on climate change.

Key actions
• Recognise the full extent of blue carbon ecosystems present in MPAs (see Table 6 for examples).
• Act on operations likely to cause deterioration or disturbance (Table 8) and take the additional management measures needed now to secure the carbon values of well-documented blue carbon ecosystems.
• Map extent and quality of the carbon values of less well documented carbon ecosystems within current MPAs and implement relevant management measures.
• Designate new MPAs based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs, rather than just focusing on traditional biodiversity values alone.
• Take measures to complement the MPAs using tools such as marine spatial planning and fisheries management measures to recognise, protect and best manage blue carbon across seascapes.

Well documented blue carbon ecosystems	Mangroves, salt marsh and seagrasses, biogenic reefs, maerl beds, macroalgal forests, and thick muds. Such ecosystems are usually well known in MPAs, the carbon values have been defined, are often part of the conservation case to put the MPA in place, and management actions can be quickly tailored to ensure damaging activities are prohibited. Some mapping may be needed but known presence is sufficient to trigger appropriate management measures.
Less well documented blue carbon ecosystems	Stable to semi stable sediments including sand and muds. These blue carbon ecosystems are widespread and carbon values are increasingly understood, but boundaries and distribution are more likely to need mapping in MPAs before management actions are taken.

between their presence in MPAs and where management interventions are going to be needed. Well-documented blue carbon ecosystems whose presence is usually obvious in MPAs include mangroves, salt marsh and seagrasses, biogenic reefs, maerl beds, macroalgal forests, and thick muds, whilst ones that may need more mapping to define their 'boundaries' include stable to semi-stable sediments such as sand and muds.

Finally, considering everything already set out in the report there is a need to ensure that the definition attached to blue carbon is carefully handled to engender the greatest scope for action and meaningful outcomes under multiple UN Conventions. At present, and perhaps as a surprising by-product of the otherwise hugely welcome uptake to properly recognise blue carbon under the UNFCCC, the definition is now being increasingly tightly tied to that mechanism. If this is not handled carefully this could inadvertently and wrongly discourage others in governments from aggressive implementation of additional, complementary measures under the CBD and other agreements. A recent key publication on blue carbon (Crooks, Windham-Myers & Troxler, 2020) noted that from a practical standpoint and the need under the UNFCCC to link management, climate policies and finance opportunities associated with land-ownership, that the following conditions would need to be met for coastal and marine ecosystems to be fully recognised as 'blue carbon ecosystems' through the UNFCCC route:

- Rates of carbon sequestration and/ or prevention of emissions of greenhouse gases by the ecosystem is cumulatively at sufficient scales to influence climate.
- Major changes in stock and fluxes of greenhouse gases can be quantified spatially and temporally.
- Anthropogenic drivers are impacting carbon storage, stock change, or greenhouse gas emissions.
- Management of the ecosystem to improve sequestration or emission reductions is possible and practicable.
- Interventions can be achieved without causing social or environmental harm.
- Management actions can be aligned with existing or developing international policy and national commitments to address climate change

Crooks, Windham-Myers & Troxler (2020) add that other marine ecosystems that only meet some of these requirements should be considered as *potential* blue carbon ecosystems. It will be some time, if at all, that *all* the blue carbon ecosystems recognised in this report will be successfully acted upon under the UNFCCC.

Trying to integrate open-water potential blue carbon ecosystems will be at best challenging (Luiseetti et al., 2020). Crooks, Windham-Myers & Troxler (2020) suggest that establishing a separate Ocean Climate Framework may have significant climate and management merits. Clearly there is a need for clarity under the UNFCCC, but we must avoid at all costs unintended consequences that will by the very definition of blue carbon delay, discourage or mislead authorities away from taking complementary measures that are needed now under the CBD.

The practical steps set out in this section give ways for countries to help level the 'climate action' policy playing field across the land/sea divide, to recognise carbon in marine systems using a multi-convention approach, and to now act urgently to protect such blue carbon features in the ocean. This approach complements actions already in play under the UNFCCC to implement the Paris Agreement, and should also help form the centre of a 'grow back greener' no-regrets approach to tackling the climate and biodiversity crisis, that is long overdue.

7. The need to take urgent action

Blue carbon ecosystems are not immune from the changes that are now playing out due to the increasingly severe and apparently accelerating impacts being experienced from climate change and the disruptions it is causing on land and in the ocean. The longer it takes society to cut carbon dioxide emissions across the world, the greater the need for nature-based solutions, but also the greater the risk that such solutions will be increasingly compromised in the meantime, as climate change further undermines ocean health.

Changes in ocean physics and chemistry and impacts on organisms and ecosystem services according to stringent (RCP2.6) and high business-as-usual (RCP8.5) CO_2 emissions scenarios. From Gattuso *et al.*, 2015.

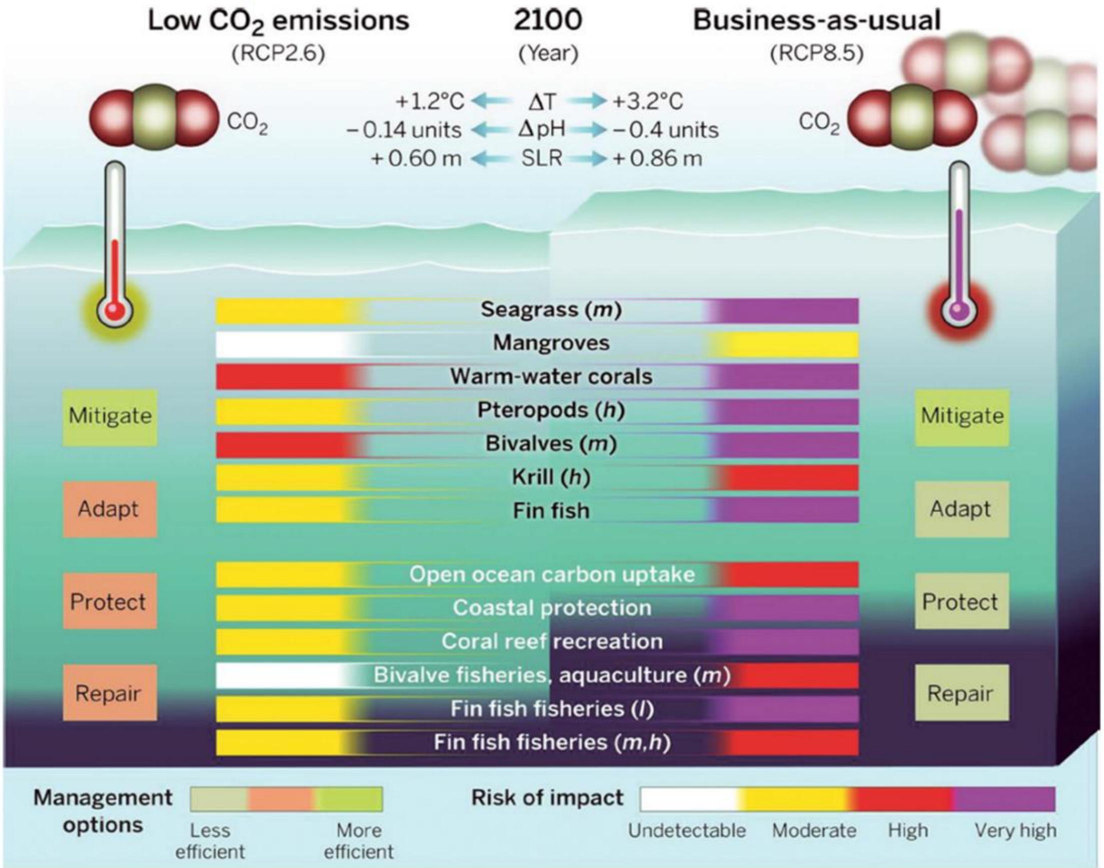

Figure 13. Contrasting futures for marine ecosystems under a low emission scenario (on the left) and business as usual on the right. In business as usual and high emissions, as is currently happening, the risks of impacts become much higher and the ability to adapt, protect and repair decreases as management options become less efficient (Gattuso et al., 2015).

The fear is that the accelerating downward decline in ocean health overtakes the ability of nature-based solutions to succeed as a key part of the much-needed solutions to our current planetary scale climate problems. In effect the longer we delay actions in cutting carbon dioxide emissions the more we compromise the scope and ability to successfully act in the future through natural solutions to the problems we face (Figure 13).

The detailed analysis by Gattuso et al. (2015) shows that the longer we wait to act, the less likely measures are to be successful. Mechanisms we have at our disposal to deliver adaptation, protection and recovery simply become less likely to succeed in the future due to the cumulated impact of human activities and climate change on such ecosystems. A joined-up approach and action now, removing the pigeon-hole of blue carbon as just a 'climate issues', in favour of broader synergistic policy action, clearly has the highest potential for success.

The challenges are brought into stark focus by the fact that, as is already being observed around the world, if mangroves are trapped by sea-level rise on the seaward side and by rising land or hard defences on the landward side – 'coastal squeeze' - then change will outpace adaptation. Indeed, in such circumstances mangrove species composition is already changing due to warming, as is their range, resulting in them invading coastal marsh land, as they alter their gross distributions to try and maintain optimal ecological location (Laffoley & Baxter, 2016). Unless we act in complementary ways on all fronts to put in place more widespread and rapid natural solutions – and this has at its core to include integrating the protection of blue carbon into business-as-usual - the problems that confront us will certainly grow in extent and amplitude in the coming decades, to a point that will become simply unmanageable. The timeline for things to become unmanageable seems to be accelerating and getting closer year-on-year; at the same time as science exposes more of the facts and impacts (see for example Cheng et al., 2019; Hu et al., 2020; Kappelle, 2020; Nerem et al., 2018).

It is particularly urgent to also act because of the interrelationship between the health of blue carbon ecosystems and the health of other ocean ecosystems that are also of considerable value for the ecosystem goods and services they provide. Take for example the plight of coral reefs. Many key coastal ecosystems rich in carbon such as mangroves and seagrass meadows benefit from the shelter of coastal fringing coral reefs in tropical parts of the world. The heating of the ocean is such that the very future viability of coral reefs is now being called into question due to increasingly frequent bleaching events. It is predicted that many coral reefs will die from an increased frequency of bleaching events in the coming decades (Hughes et al., 2018). This will then expose carbon-rich coastal ecosystems to rapid increased erosion as the reef is lost. Coastal erosion equivalent to the impact of several metres rise in sea level will occur as the reef structures deteriorate and ultimately collapse, thus closing off adaptation and mitigation pathways and dramatically impacting the livelihoods of many hundreds of millions of dependent people. This then is likely to trigger mass migration by people away from the areas of coast affected, as ecosystem services are disrupted or, at worst, lost (Laffoley & Baxter, 2018).

8. Conclusions

Healthy blue carbon ecosystems go hand-in-hand with a wide variety of associated goods and services. Even when taking a narrower carbon view of their benefits, healthy blue carbon ecosystems do more than just sequester carbon - they may export and feed carbon into nearby ecosystems, such as mangroves exporting carbon to support nearby shelf sea ecosystems, or degrading macroalgae detaching and being transported by currents, and deposited in seabed carbon sinks beyond the extent of macroalgae habitats. Whatever the situation such carbon sinks do not form or act in isolation from surrounding ecosystems, or for that matter in relation to human activities. Using the hook of blue carbon, as has been shown, can open the door to much greater political engagement and action under the UNFCCC, but there is now a need to help the Paris Agreement by taking effective, complementary and synergistic supporting actions across other UN Conventions and agreements as well.

This report has been born out of a frustration that whilst much good work has and is being done on blue carbon ecosystems we are simply now not acting fast enough and at sufficient scale to secure their health and survival into the future. The longer we dither and delay, the more damage is done, and the harder it will be to ensure success in tackling the biodiversity and climate crisis. What is evident is that there is a clear policy framework already in existence that would enable much more widespread measures to better protect and manage ALL marine and coastal carbon-rich and functionally important ecosystems. Why this has not occurred is probably less to do with the UNFCCC but more to do with a lack of awareness and communication of what else can and should be done in support of the Paris Agreement. This needs better communication of the evidence-base, compounded by the realisation that other parts of governments not charged with climate policy and action can and should urgently act as well in a more coordinated and determined manner.

From the analysis and information provided in this report there are several broad conclusions that can be drawn:

- We need to embrace and demonstrably act on current policy imperatives to protect the resilience and functioning of carbon in natural systems – and that this explicitly includes the ocean. Better policy join-up, refinement and implementation are now what is urgently needed. Whilst good progress is being made in this respect under the UNFCCC and must be sustained and further strengthened, far more must be done to protect marine carbon stores under the CBD and other relevant agreements.

- Delaying action on such complementary measures by the CBD and others is closing off future opportunities, as marine carbon stores continue to be lost or degraded right now because of the widespread absence in MPAs of effective management measures. The priority must be to join up the science with radical improvements in MPA management to stop further degradation of such carbon stores, and through more appropriate management foster their restoration and recovery.

- We must act now across the board to protect the full range of coastal and ocean ecosystems naturally rich in carbon, introducing and using as needed standardised units to document the values. Such widespread actions need to focus not just on understanding how they relate to Governments' existing responsibilities in EEZs, but also the High Seas, and ensure in the latter that effective protection and management of blue carbon is provided for in the new Treaty under negotiation at the United Nations.

- In light of the above we need to avoid inadvertently tying the policy definition of 'blue carbon' to just the minority of carbon rich ecosystems that currently may qualify under UNFCCC (as IS happening) or overplay the sequestration/atmospheric links (as seems to be happening). This can make the protection/restoration of blue carbon ecosystems appear too much of 'just a climate issue', where in fact it should now be the focus for urgent action under all relevant conventions and agreements.

- We must also not just focus on MPAs but better manage human activities in the wider seascape that disrupt, damage, or cause the loss of natural carbon sinks and sequestration processes. Science shows how current activities permitted in MPAs are destroying marine carbon stores, and the case is no different for the broader seascape. Bottom contact fisheries are by far and away the biggest contributor to damaging marine carbon sinks.

The five-point plan set out in this report provides a vision of how countries can use existing measures to make much greater progress on protecting blue carbon ecosystems to complement actions already taking place through the UNFCCC. This is not an 'either or situation', as supporting complementary measures delivered through other conventions are critically needed to stop deterioration and losses of blue carbon ecosystems that are now happening and continue to happen. There is no barrier to such broader ambition other than seeing the opportunity, seizing it, and putting more effective management measures in place. Now is the time to act to safeguard ocean carbon sinks. This is an ultimate no-regrets policy that can be part of 'growing back greener, but that in any case needs to be put into practice now.

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Dan is a well-respected world leader on Marine Protected Areas and ocean conservation. Scientist, communicator, explorer, and conservationist, at IUCN he is Marine Vice Chair for IUCN World Commission on Protected Areas, and Senior Advisor on Marine Science and Conservation in the Global Marine and Polar Programme. For nearly 35 years Dan has been responsible for the creation of many global, European and UK public and private sector partnerships, alliances and frameworks that underpin modern-day marine conservation. This work includes creating global conservation targets for the ocean, the concept behind blue carbon, scaling up action on ocean warming, acidification and deoxygenation, scaling up work on marine World Heritage and conservation of the High Seas, and various key global guidance on implementing Marine Protected Areas and Marine Spatial Planning. (Photo credit: John Baxter)