BLUE CARBON – THE NEW GREEN? AN OPPORTUNITY TOWARDS NET ZERO EMISSIONS

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ABSTRACT (500 WORDS MAXIMUM)

The risk of climate-related disasters is increasing and strategies to mitigate climate change are needed. Coastal ecosystems, including mangroves, tidal marshes and seagrasses, sequester and store "blue" carbon and are an essential piece of the climate change solution.

83% of global carbon is circulated through the ocean. Coastal habitats cover less than 2% of the ocean area, yet account for approximately half of the total carbon sequestered in ocean sediments. When protected or restored, blue carbon ecosystems sequester and store carbon. When degraded or destroyed, they emit the carbon they have stored for centuries. Experts estimate 1 billion tons of carbon dioxide being released annually from degraded coastal ecosystems. Coastal wetland habitats—through the build-up of sediment and vegetation—trap and bury carbon at a greater rate per area than terrestrial habitats such as forests or peatlands.

The potential for carbon captured by coastal ecosystems to contribute to net zero ambitions is attracting significant interest. Jacobs developed the world's first carbon code for coastal wetlands in 2014 and has extensive experience with coastal ecosystem restoration and climate change adaptation and mitigation. We are designing nature-based solutions that restore coastal ecosystems and developing and trialling a carbon code for U.K. saltmarshes.

Supported by the U.K. Government's Natural Environment Investment Readiness Fund, the carbon code for saltmarshes project is developing scientific and revenue models, which will demonstrate the carbon benefits of restoring saltmarshes. The need for restoration is pressing since significant areas of coastal saltmarsh have been lost due to land claim and concerns remain over potential losses caused by sea level rise and the presence of coastal defences.

This project is paving the way for investment in restoring the U.K.'s saltmarshes, which will help mitigate climate change, support biodiversity and reduce flood risk. The project has the potential to help attract up to $1.9 billion (£1 billion) of private investment in restoration projects over 25 years, creating up to 22,000 hectares (54,363 acres) of habitat.

A growing number of organizations in New Zealand, Australia and across the globe are committed to achieving net zero by reducing their carbon emissions and offsetting the impacts of essential activities. Closer to home, the Australian

Government is consulting on a Blue Carbon Strategy: a proposed new method under the Emissions Reduction Fund.

This paper outlines what blue carbon is and the importance of coastal ecosystems to sequester carbon and mitigate climate change. It draws on the extensive data Jacobs has access to around the potential benefits of restoring mangrove habitats, and the consequences of their decline. It summarises key elements of the carbon code project in the UK to demonstrate its direct relevance to a New Zealand context. It describes how a similar approach could be applied in New Zealand to assess the potential sustainability, scientific and financial opportunities that can be realised through blue carbon sequestration and coastal ecosystem restoration, and the subsequent carbon credits. This paper also outlines the barriers to blue carbon project implementation and options to mitigate these.

KEYWORDS

Blue carbon, sustainability, decarbonisation, greenhouse gas, coastal

PRESENTER PROFILE

Rebecca Phyland is an experienced ecologist with a passion for coastal and wetland restoration. She has designed and managed ecological restoration projects throughout Australia. Rebecca has been involved in environmental consulting projects relating to nature-based solutions for climate change adaptation with partners across Asia-Pacific, including Kiribati and Fiji.

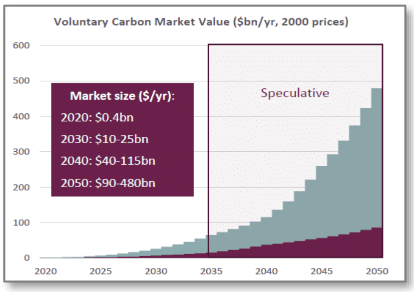
Nigel Pontee has >26 years' experience in coastal geomorphology and management. He has contributed to creating >1700ha of new wetland habitat and appraised >150 sites. He undertakes nature-based coastal defence projects globally and contributes to national and international guidance documents produced by World Bank, USACE, ASCE and UK Environment Agency. He is currently involved in a range of blue carbon projects in the UK.

Kate Simmonds is an environmental engineer with 20 years' experience in the water industry. Kate is passionate about strategic planning and innovation and is always looking for ways to improve the performance and benefits of our existing infrastructure, to achieve positive environmental, social and economic benefits for our communities.

INTRODUCTION

The risk of climate-related disasters is increasing and strategies to mitigate climate change are needed. Coastal ecosystems, including mangroves, tidal marshes and seagrasses, sequester and store "blue" carbon and are an essential piece of the climate change solution. The potential of blue carbon is being increasingly recognized globally. Over the next 30 years the value of globally traded carbon is projected to increase by up to $480bn (US dollars).

Blue carbon ecosystems remove significant amounts of carbon from the atmosphere, much more than land-based forests (Blue Carbon Initiative, 2016), and store it in their biomass and soil. The carbon sequestered in the soil can be stored for hundreds to thousands of years, helping to mitigate climate change. In addition, coastal wetlands provide adaptation and coastal protection benefits by absorbing incoming wave energy, providing coastal and storm surge protection, and preventing erosion. Coastal wetlands may keep pace with sea level rise and, in some instances, are more cost-effective than artificial infrastructure like seawalls and levees (Beck et al, 2015 and Narayan et al, 2016). Healthy coastal wetlands also support other benefits, including spawning grounds for commercial fish, water purification and local livelihoods. Thus, blue carbon ecosystems can be a nature-based solution with multiple co-benefits. When degraded, these co-benefits are greatly diminished along with the ecosystems' capacity to sequester carbon, consequently stored carbon can be released back to the atmosphere, along with other greenhouse gases.



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In addition to carbon sequestration potential there are other important benefits in coastal restoration projects including coastal defence, social value, biodiversity, and water quality improvements.

83% of global carbon is circulated through the ocean. Coastal habitats cover less than 2% of the ocean area, yet account for approximately half of the total carbon sequestered in ocean sediments. When protected or restored, blue carbon ecosystems sequester and store carbon. When degraded or destroyed, they emit the carbon they have stored for centuries. Experts estimate 1 billion tons of carbon dioxide being released annually from degraded coastal ecosystems, equivalent to 19% of emissions from tropical deforestation globally (Blue Carbon Initiative, 2016).

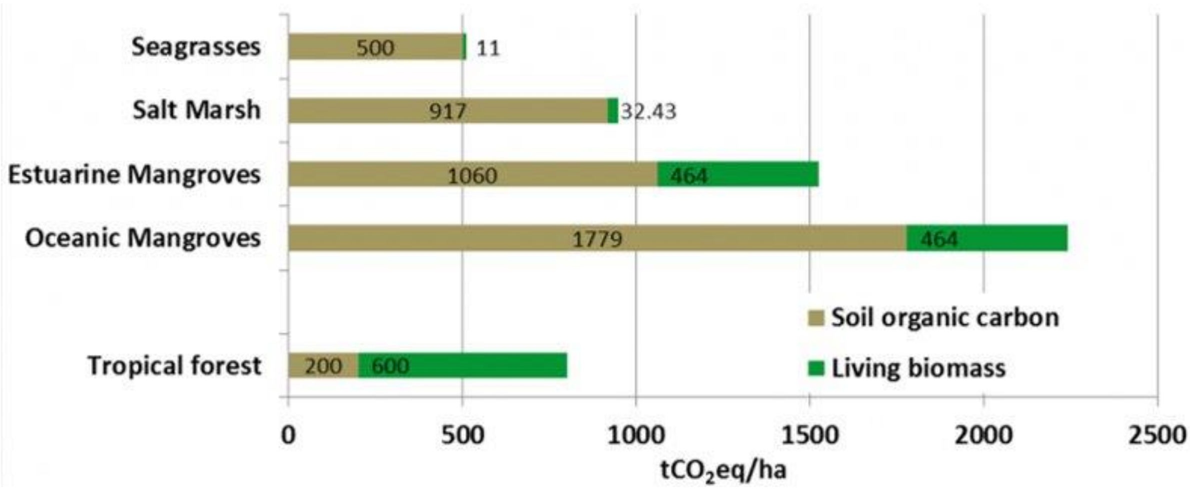

Figure 1: Carbon Sequestration potential from different habitats (Jacobs 2021)

Coastal wetland habitats—through the build-up of sediment and vegetation—trap and bury carbon at a greater rate per area than terrestrial habitats such as forests or peatlands (Figure 1). Their water-logged soils lack oxygen, meaning plant material decomposes in those soils far more slowly, and the carbon in the material gets locked away for long periods – unless disturbed. Ongoing sedimentation is another potential factor explaining high sequestration – including continuous burial.

This is important because release of carbon into the atmosphere is a major driver of climate change, yet these marine ecosystems are capable of storing up to 10 times the amount of carbon as the same area of land-based forests.

Some countries include blue carbon in their Nationally Determined Contributions (NDCs) – country action plans for reducing national emissions and adapting to climate change. In others, blue carbon credits have been awarded to groups funding restoration of coastal ecosystems. New Zealand is currently not represented in the Map of 28 countries that include a reference to coastal wetlands in terms of mitigation in their NDCs or in the map or 59 counties that include coastal ecosystems and the coastal zone in adaptation strategies in their NDCs (Figure 2, Martin et al, 2016)

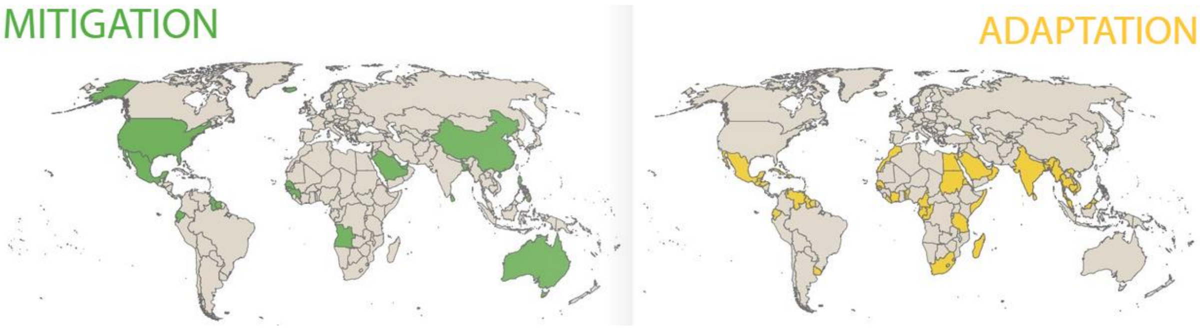

Figure 2: Map of 28 countries that include a reference to coast wetlands in terms of mitigation (left) and 59 countries that include coastal ecosystems and the coastal zone in adaptation strategies (right) in their NDCs

THE OPPORTUNITY FOR NEW ZEALAND

New Zealand's blue carbon potential is just starting to be realised. New Zealand has 15,000 kilometres of coastline making it the 9th longest in the world. This provides significant potential for blue carbon opportunities. The Blue Carbon Initiative have mapped potential geographies for blue carbon projects globally, and New Zealand shows promise in Mangrove, Salt Marsh and Seagrass (Figure 3).

Armstrong etc al (2020) produced a report which demonstrates a number of other carbon sink potential sources. This demonstrates that marine sediments are likely to be an important store for New Zealand (refer image inset).

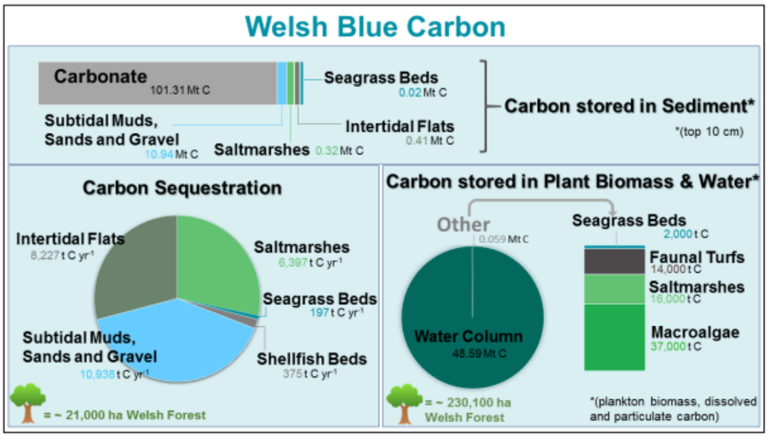

Image: Infographic on Welsh marine carbon storage and sequestration

Managing and restoring marine ecosystems or creating new habitats could protect existing carbon stores and enhance natural carbon uptake. These actions can also help build resilience to climate change impacts such as sea-level rise, improve water quality, and protect the habitats of birds, fish and other species.

Currently the New Zealand Government is investigating how blue carbon research results will be used to inform policy development and initiatives to protect and restore coastal ecosystems in Aotearoa. Tangata whenua are kaitiaki of marine and estuary environments. In developing further actions to protect and enhance blue carbon in these environments, the Government is committed to working with its Te Tiriti partners.

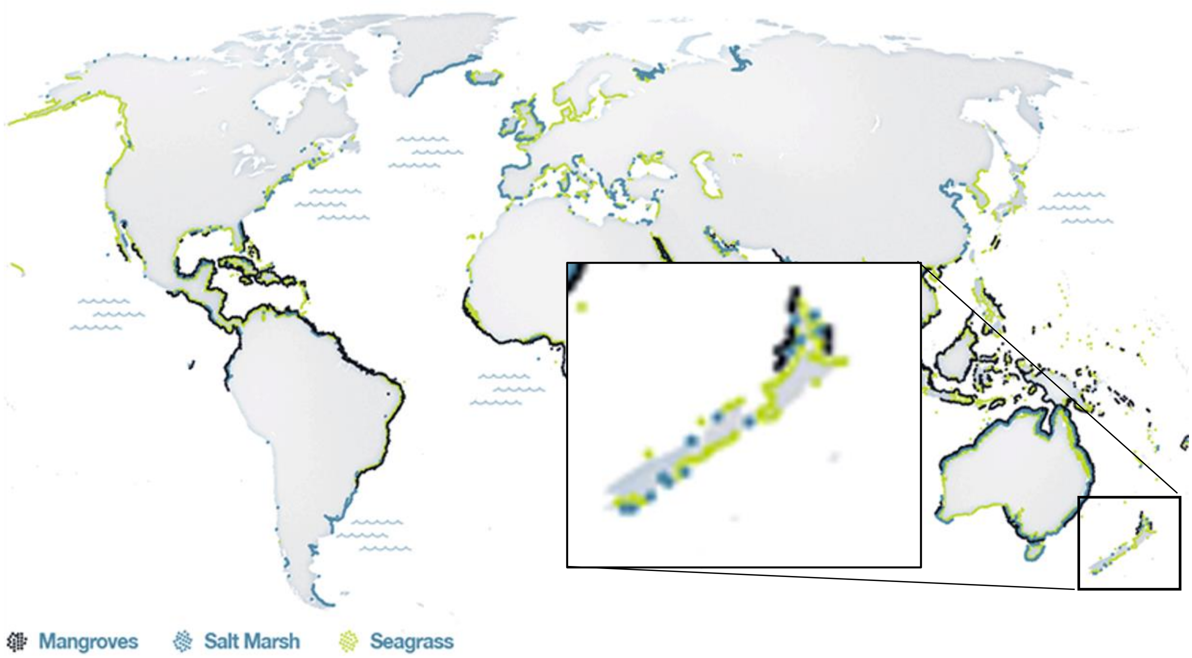

Figure 3: Potential geographies for blue carbon projects (Source: The Blue Carbon Initiative)

An assessment overseas of the coastal ecosystems ability to meet the Blue Carbon criteria for being effective has been completed (Figure 4).

	criteria for inclusion as actionable Blue Carbon ecosystems					
	scale of GHG removals or emissions are significant	long-term storage of fixed CO_2	undesirable anthropogenic impacts on the ecosystem	management is practical/possible to maintain/ enhance C stocks and reduce GHG emissions	interventions have no social or environmental harm	alignment with other policies: mitigation and adaptation
mangrove	yes[1,2]	yes[3]	yes[4,5]	yes[6,7]	?	yes[8]
tidal marsh	yes[1,9]	yes[9]	yes[10]	yes[11,12]	?	yes[13]
seagrass	yes[1,14]	yes[15]	yes[16]	yes[17]	yes	yes[18]
salt flats (sabkhas)	?	?	yes[19]	?	?	?
freshwater tidal forest	?	yes[20]	yes[21]	yes[22]	?	?
macroalgae	yes[23]	?[23]	yes[24]	yes[25]	?	yes[26]
phytoplankton	yes[27]	?[28]	?	?	?	no
coral reef	no[29]	no	yes[30]	no	?	yes[31]
marine fauna (fish)	no[29]	no	yes[32]	no	?	no
oyster reefs	no[29]	?	yes[33]	no	yes	yes[34]
mud flats	?[35]	?	yes[36]	?	yes	yes[36]

*Figure 4 Assessment of whether coastal ecosystems meet the Blue Carbon criteria [*indicate additional investigations needed] (Lovelock & Duarte, 2019).*

UK CARBON CODE

In the UK the need for saltmarsh restoration is pressing since significant areas of coastal saltmarsh have been lost due to land claim and concerns remain over potential losses caused by sea level rise and the presence of coastal defences. Some estimates suggest that that over 300,000 of new saltmarsh could be created around the coast of the UK. COP26 highlighted the potential for carbon captured by coastal ecosystems to contribute to net zero ambitions is attracting significant interest and this has led to renewed interest in the restoration of these habitats in the UK to help fight climate change.

Carbon codes or methodologies provide standard accounting methods to determine the amount of carbon credits generated by different types of projects. Such codes are needed projects in order to market the climate benefits of projects such as tree planting, peatland restoration or wetland restoration. These codes or methodologies provide assurances to voluntary carbon market buyers that the climate benefits being sold are real, quantifiable, additional and permanent.

Jacobs developed the world’s first carbon code for coastal wetlands in 2014. This methodology was developed for Louisiana’s Coastal Protection and Restoration Authority (CPRA). Since then there have been a number of other methodologies developed for coastal wetlands (Figure 5).

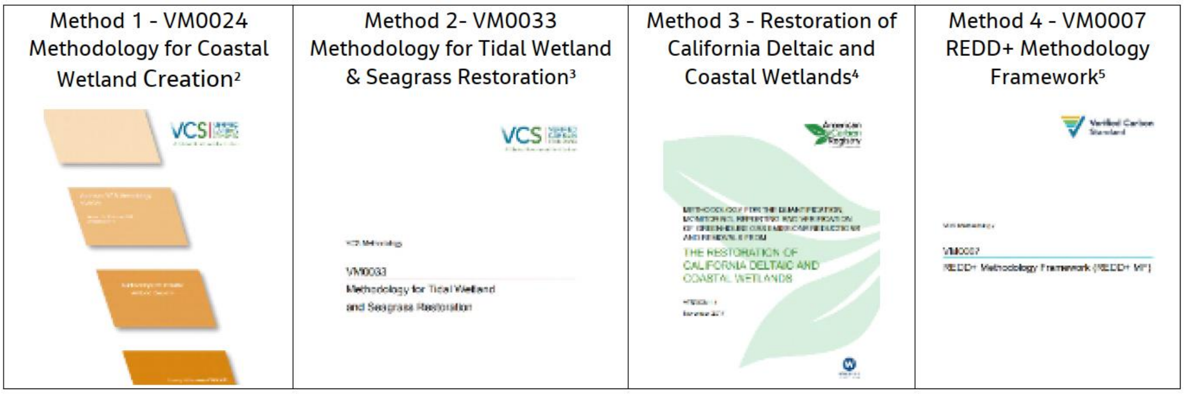

Figure 5: A selection of coastal wetland methodologies

As an initial step to developing a carbon code for UK saltmarshes Jacobs undertook a review of the four codes shown in Figure 5. Existing carbon methodologies for coastal wetlands have a number of technical steps/considerations. The main ones are: conditions of use, boundaries, baseline, permanence, leakage, additionality, greenhouse gas (GHG) emissions quantification and monitoring.

Potential challenges to be overcome in the development of carbon methodologies for coastal wetlands include: dealing with complex baseline environments, multiple landowners, methane emissions from projects, and high Monitoring, Reporting and Verification (MRV) costs (especially for small projects).

Jacobs is working with a consortia of organisations led by the UK Centre for Ecology and Hydrology on the project which is funded by the U.K. Government's Natural Environment Investment Readiness Fund. The carbon code for saltmarshes project is developing scientific and revenue models, which will demonstrate the carbon benefits of restoring saltmarshes.

The development of a viable carbon code for UK saltmarshes paves the way for new investment in restoring the U.K.'s saltmarshes, which will help mitigate climate change, support biodiversity and reduce flood risk. It has been estimated that a working code has the potential to help attract up to $1.9 billion (£1 billion) of private investment in restoration projects over 25 years, creating up to 22,000 hectares (54,363 acres) of habitat.

A growing number of organisations in New Zealand, Australia and across the globe are committed to achieving net zero by reducing their carbon emissions and offsetting the impacts of essential activities. Closer to home, the Australian Government is consulting on a Blue Carbon Strategy: a proposed new method under the Emissions Reduction Fund.

BLUE CARBON POTENTIAL IN NEW ZEALAND

New Zealand can realise blue carbon opportunities by developing and implementing evidence-based policy, projects and research through partnerships and engagement with the New Zealand community, the coastal industries that rely on healthy blue carbon ecosystems, and national stakeholders. These opportunities can support a path to net zero for organisations and for broader Aotearoa.

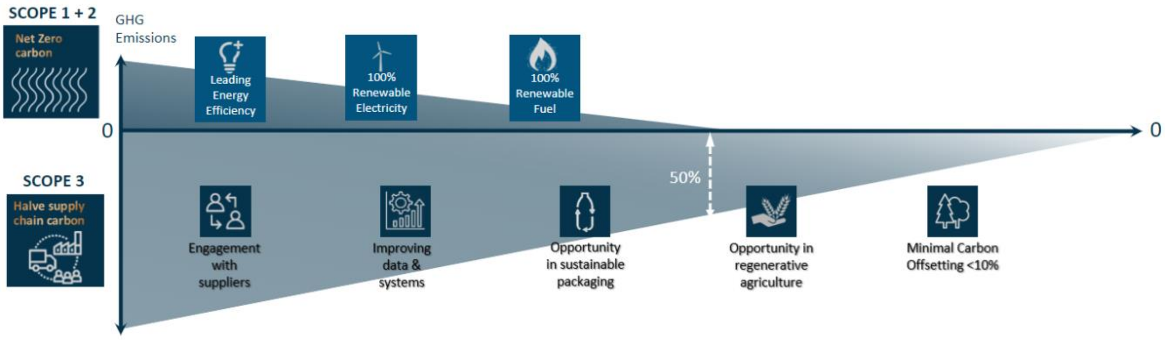

Figure 6: Example of pathway towards Net Zero Emissions

FUNDING THROUGH CARBON MARKETS

Future blue carbon projects in New Zealand could be supported by carbon financing from blue carbon credits, developed under an Emissions Reduction Fund. Australia have an Emissions Reduction Fund that has been operating since 2014, and has provided financial incentives for Australian businesses and natural resource managers to adopt new practices and technologies to reduce greenhouse gas emissions. Projects accredited under the Fund can receive carbon credits for each tonne of carbon reduction achieved. Carbon credits can then be sold to create a revenue stream. This type of carbon financing could potentially incentivise blue carbon projects in New Zealand.

Other innovative mechanisms to finance carbon sequestration projects are being developed and trialled throughout the world. Green bonds (and more recently, blue bonds), carbon in-setting, payment for ecosystem services and private-public partnerships of various kinds, are increasingly used to finance carbon sequestration and climate-resilience activities. For example, the green bond market is only a decade old and is already well established with over US$500 billion labelled green bonds, issued by over 600 financiers (IUCN, 2019). The various financing models can be assessed and trialled for applicability to blue carbon demonstration projects in New Zealand.

Longer term a blue carbon market could be established, through which organisations, and perhaps individuals, could buy credits to offset their carbon emissions. The generated money through this market could be utilised to fund restoration projects. Globally there is a corporate interest for blue carbon, not only due to the carbon sequestration potential, but due to the diverse habitat restoration providing other benefits in our climate change response.

PROJECT OPPORTUNITIES

There is an opportunity to set up blue carbon pilot trials to use as demonstration projects. The outcomes of these projects can be used to determine whether the theory is appliable in practice, and if carbon codes applied globally are relevant to our context and setting. These projects can also be utilised to grow our scientific and technical knowledge of blue carbon and the opportunity for blue carbon sequestration in New Zealand.

These projects also present an opportunity in terms of community partnerships and collaboration. In New Zealand, there are opportunities to protect, restore and enhance blue carbon ecosystems by implementing coastal restoration projects that re-establish natural tidal flows to enable wetland restoration, or by modifying infrastructure to allow for landward movement of saltmarsh and mangroves as sea level rises. In addition, reducing discharges of pollutants to coastal waters can prevent further degradation of seagrass meadows.

The good news is that some of this work is already underway and a handful of salt marshes and inter-tidal zones are already being assessed for their potential to help set up a market for blue carbon credit. American-based non-governmental organisation, The Nature Conservancy has initiated the assessment of six sites in Aotearoa, as part of various pilot projects around the world.

Three of the sites are in the top of the South Island; Waimea Inlet north-west of Nelson, Wairau Lagoon near Blenheim, and Farewell Spit, at the tip of Golden Bay. The others are at the top of the North Island; the Firth of Thames and in the Bay of Plenty (Jones, 2021). Further detailed project assessments will be needed in partnership with key stakeholders.

CASE STUDIES

A number of successful projects have been implemented globally demonstrating the potential for blue carbon in New Zealand. Some example case studies are presented in this section.

CASE STUDY 1 – PHILIPPINES

Current research into the importance of seagrass meadows in the Western Pacific, particularly the Philippines, is limited (Bujang et al. 2018). In 2015, Conservation International–Philippines (CI- Philippines), established a National Blue Carbon Technical Working Group which aims to consolidate research and implementation efforts related to Blue Carbon ecosystems. However, a key knowledge gap that remains is creating awareness for government and local communities on blue carbon ecosystems and its potential for climate change mitigation (Pangilinan 2015).

This study in the southern Philippines in 2020 aimed to comprehensively understand the impact of local environmental threats to seagrasses, and in turn identify the primary threat to target limited management resources. At the same time as investigating the extent and composition of seagrass around Danjugan Island, a second aim was to quantify their Blue Carbon potential. Methodology included extensive literature review, interviews with locals, field observations and data collection. This created a series of rapid assessment techniques that can assess the Blue Carbon potential in seagrass meadows with the intent that this could be replicated across the Asia-Pacific region.

The specific objectives were: 1. To map the extent of the three seagrass meadows; 2. To survey and observe the composition of the three seagrass meadows; 3. To calculate the Blue Carbon potential by using the extent and composition data obtained from the field site; 4. To identify the primary local environmental threat to the seagrass meadows

By identifying the primary environmental threat and ascertaining a Blue carbon value of the seagrass meadows, simultaneously, this research aimed to demonstrate options for improved environmental management in developing nations and provide the toolkit to do so. The recent study was conducted on Danjugan Island, a conservation island off Negros Occidental in the Philippines.

A measure of seagrass meadow perimeter and meadow composition was undertaken using Seagrass Watch methods across 6 replicates within 3 different meadow orientations. Using area, composition, biomass and sediment data the Blue Carbon potential of the seagrass meadows was calculated using the equations developed through the Blue Carbon Initiative (Chiscano and Duarte 1999; Gilpin et al. 2017; Howard et al. 2014)

A total of eight (8) species were identified. The dataset used to obtain the biomass of the identified seagrass species was made available by Chiscano and Duarte (1999), who consolidated the DW g/m2 of over 150 samples. This was used to calculate an average biomass of the identified species. There was no recorded data for two small species; *Halophila minor* and *Halodule pinifolia*, and therefore they were not included in the average calculation.

It was acknowledged that the biomass and carbon content of different species has temporal and spatial variability in productivity and hence the calculated values are estimates only. They are based on the carbon conversion factor of 0.34 which assumes that carbon constitutes 34% of the biomass (Howard et al. 2014). In this study it was estimated that the biomass accounts for 3% of the stored carbon in the seagrass meadow and that 97% of carbon is stored in the sediment (Gilpin et al. 2017). By combining the composition and extent data collected in this project, the total carbon stored in the biomass (above and belowground), was estimated to be 0.68 Mg C/ha. With global estimates averaging 2.52±0.48 Mg C/ha, the Western Pacific value calculated in this project is below the average but was expected due to the composition and geographical location of the species found (Gilpin et al. 2017).

The results of this project are promising as they were able to successfully calculate a Blue Carbon value for the Western Pacific (22.7 Mg C/ ha). Although it is important to identify potential variations within the dataset. Studies have found that the organic carbon in the biomass varies significantly between species, with the largest sequestration of carbon being found in the Mediterranean due to the dominance of Posidonia oceanica (Apostolaki et al. 2012). Due to constraints on sampling methods, Blue Carbon values could not be individually calculated at a species-specific level. It is believed that this did not have significant impact on the results but would be an insightful consideration for future research. The abundance of seagrass cover across the field site varied (32-63%), but was relatively low and as such contributed to the below average total of organic carbon.

Another factor to consider is that Blue Carbon can be stored in the epiphytic cover and litter of the seagrass, but calculations of these components were not estimated in this study. Other studies have also found that macroalgal detrital material has the potential to act as significant carbon donors to long-term sequestration habitats, such as seagrass meadows (Kogure and Pollard 1993). It is worth considering the contribution that epiphytic cover, litter and macroalgal make to the total organic carbon stock and therefore it can be assumed that the estimated value (22.7 Mg C/ha), is conservative.

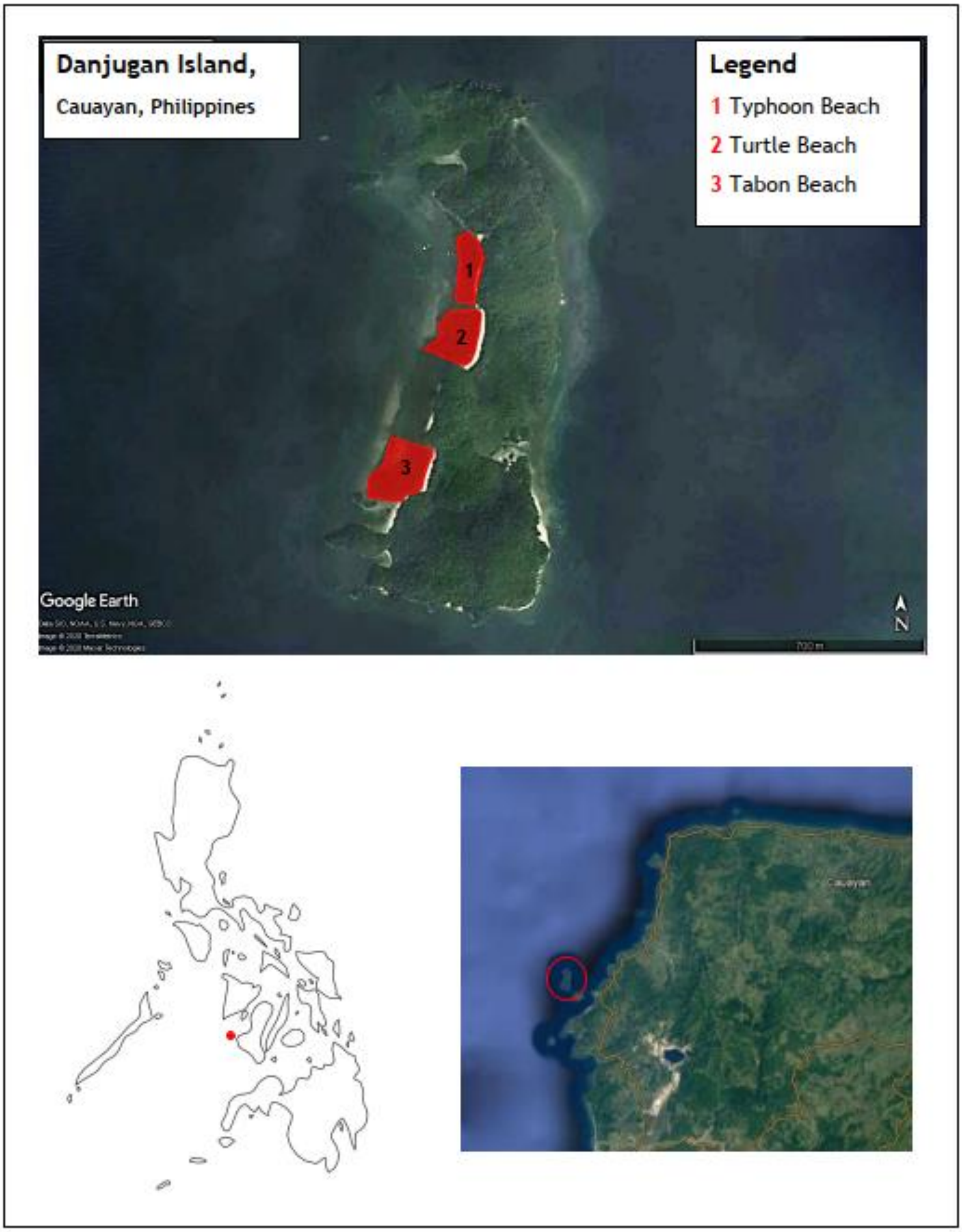

Figure 7: Extent of seagrass meadows sampled in Danjugan Island Blue Carbon Assessment, Philippines.

CASE STUDY 2 – AUSTRALIA EXAMPLE

Profiling of saltmarsh communities across the Eyre Peninsula in South Australia is nearly at the half-way mark, recording exactly what species are in the saltmarsh, analysing changes to sites over time and shedding new light on organic Blue Carbon stocks.

A recent saltmarsh profile survey was completed at Acraman Creek – between Streaky Bay and Ceduna– as part of a baseline data comparison of the condition of saltmarsh at 11 sites across the Eyre Peninsula. Acraman Creek is the fifth profile survey to be completed as part of the Saltmarsh Threat Abatement and Recovery Project supported by the local landscape board and the National Landcare Program.

Multiple agencies the local landscape board staff, university researchers, consultants and state government coastal specialists were involved in the field sampling.

Results from the five surveys undertaken so far are still being analysed, however early indications reveal some sites have changed very little in approximately 25 years since they were previously surveyed while others are showing more significant changes (Jones & Russell 2021).

Soil cores from different types of saltmarsh vegetation communities were taken at different height along the profile. Blue Carbon analysis is currently being undertaken on these sediment samples and will inform investigations on the influence of tides, sea level, vegetation type and disturbance on Blue Carbon storage in southeast Australian saltmarshes.

In late 2020, the Minister for Industry, Energy and Emissions Reduction (Australia) tasked the Clean Energy Regulator with developing a blue carbon methodology under the Emissions Reduction Fund (ERF) (Australian Government, 2022). The Emissions Reduction Assurance Committee has sought feedback on the proposed methodology. The proposed method aims to support projects that store carbon in biomass and soils and mitigate emissions, with projects able to earn carbon credits for the emissions captured within their project.

Eligible projects under this method will introduce tidal flows to completely or partially drained coastal wetland ecosystems. This is done by removing or modifying part of a tidal restriction mechanism such as a sea wall, bund, drain or tidal gate.

The project aims to abate carbon by:

- Increasing the carbon stored in soil and vegetation
- Avoiding emissions from soils as they are rewetted
- Avoiding emissions as freshwater wetlands are returned to saline wetlands.

To register a blue carbon project under Australia's ERF, proponents must describe the management activity undertaken to increase carbon storage and reduce GHG emissions from restoration of tidal flows (i.e. tidal restoration activity that removes or modifies structures that restricts tidal flows), and estimate and verify how much carbon has been accumulated in soils and biomass, and GHG emissions reduced over time in a manner consistent with the ERF offset integrity standards (Lovelock et al 2022; Kelleway et al. 2020).

The net abatement in BlueCAM is estimated based on the difference in carbon stocks and GHG emissions between the existing land use (the business-as-usual baseline) compared to the carbon sequestered and stored in the vegetation (living aboveground and belowground biomass) and the soil, and GHG emissions that occur after tidal introduction. In BlueCAM, all carbon pools or GHG emission sources are estimated for baseline (i.e. existing land uses) and as a consequence of project activities using equations that are consistent with Intergovernmental Panel on Climate Change (IPCC) guidance (Kennedy et al. 2014).

Studies such as the one we were involved in on the Eyre Penisula form a baseline for assessing the Blue Carbon potential of project sites utilising the Blue CAM methodology.

BARRIERS TO BLUE CARBON IMPLEMENTATION AND SUGGESTED MITIGATIONS

With all of this interest and clear potential for blue carbon sequestration, why are blue carbon projects not more prevalent globally? A recent paper by Phillip Williamson[1] and Jean Pierre Gattuso[2,3,4] has presented seven issues that affect the reliability of carbon accounting, and present barriers to blue carbon project uptake. These factors are summarized below including proposed mitigations to these barriers.

BARRIER 1 – HIGH VARIABILITY IN CARBON BURIAL RATES

Multiple biological, chemical and physical factors influence blue carbon sequestration rates through their interactions with primary production, sedimentation, decomposition and preservation. As a result there is high variability in the burial rates which can lead to uncertainty in commencing a blue carbon project. Suggested mitigations to this are to increase the data set, taking additional measurements. It is particularly beneficial if measurements can be taken over a time-span so that a carbon sequestration curve can be developed over time. This should be applied to both natural and restored marshes.

BARRIER 2 – ERRORS IN DETERMINING CARBON BURIAL RATES

Estimates of carbon sequestration rates to date have typically been indirect, based on the sediment carbon inventory (soil carbon stock) in near-surface layers (typically the top 1 m), rather than using direct flux measurements (Williamson and Gattuso, 2022). This can result in significant margins of error as these near-surface samples (often estuaries) are more significantly impacted by runoff, sedimentation, upstream lean use, and water quality changes.

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BARRIER 3 – LATERAL CARBON TRANSPORT

This barrier relates to understanding the source of carbon buried in coastal sediments. Allochthonous (non-local) carbon originates from terrestrial or atmospheric sources, or other marine ecosystems. The coastal blue carbon ecosystems may not have removed this carbon, and therefore need to be understood to enable determination of the proportion of carbon that is attributed to restoration. A counteracting consequence of lateral carbon transport (that would result in an underestimation of climatic benefits) is that there is also likely to be significant carbon export from coastal blue carbon ecosystems, a proportion of which may be subject to long-term storage, either as dissolved inorganic or organic carbon in deep ocean water, or as particulates that are buried in other depositional systems. The scale of these export processes may even exceed direct carbon burial (Maher et al., 2018; Santos et al., 2019, 2021).

BARRIER 4 – FLUXES OF METHANE AND NITROUS OXIDE

The anaerobic conditions in blue carbon sediments responsible for long-term carbon storage also have the potential to produce and emit two potent greenhouse gases of increasing climatic concern: methane (CH_4) and nitrous oxide (N_2O).

Long-term site-specific monitoring of both CH_4 and N_2O fluxes would help assess if the blue carbon system is a true carbon sink with a net environmental benefit. Sufficient baseline data to determine the changes arising from restoration is also required. Site-specific knowledge of previous land-use changes is also relevant to CH_4 emissions. It is also important to explore the applicability of international values to New Zealand's climate and conditions.

BARRIER 5 – CARBONATE FORMATION AND DISSOLUTION

Calcium carbonate ($CaCO_3$) precipitation (including the biological process of calcification by corals, many other benthic invertebrates and coralline algae) releases CO_2, whilst its dissolution has the opposite effect. Both these processes can occur in coastal blue carbon ecosystems. Calcium carbonate dissolution occurring within blue carbon sediments has the potential to significantly enhance their climate mitigation role. Studies have shown that the calcium carbonate dynamics can potentially override the climatic role of organic carbon burial in blue carbon ecosystems. Such effects have been neglected to date by standard blue carbon accounting, such as the VCS methodology (Verra, 2021). There is a need to determine their wider applicability and implications for blue carbon ecosystem restoration.

BARRIER 6 – VULNERABILITY TO FUTURE CLIMATE CHANGE

The implications of future changes in sea level rise, storm events, wave energy, and sea level rise for coastal blue carbon ecosystems are not well-understood, and are likely to show greater local and regional variability. Resilience will therefore be affected by sediment erodibility and sediment resupply, as well as by vegetation type, the frequency of extreme events, the rate of local sea level rise, and whether there is space for landward relocation (Williamson and Gattuso, 2022). The possibility of landward migration would seem inapplicable to most restoration projects, unless land suitable for such re-location is either initially included or can be added later; either option would have significant cost implications.

BARRIER 7 – VULNERABILITY TO NON-CLIMATIC FACTORS

Assuming that climate change impacts are mitigated, there are other non-climatic factors that can impact on the viability of blue carbon ecosystems. These depend on the behaviours and land uses in the area and are generally human dependent. It is therefore important that clear policy and direction from decision makes aligns with support coastal restoration and blue carbon ecosystems, excluding the use of coastal land from agriculture, aquaculture, industry and settlement. Other potential non-climatic issues include poor selection of flora species, resulting in poor survival and inefficient blue carbon sequestration. Therefore using local marine ecologists and undertaking pilot trials to determine appropriate flora selection is a critical part of a blue carbon project.

OPERATIONALISING BLUE CARBON

A key issue for blue carbon restoration is the ability to demonstrate net carbon removal that is considered valid and can be used as carbon credits or within carbon trading schemes. The system must demonstrate it can uptake and store carbon, and that the estimated benefit has a verifiable accuracy of ±10% (Williamson and Gattuso, 2022). A carbon balance is required to support this where the additional CO2 removal from the atmosphere needs to be estimated, coupled with climatic effects (e.g., changes in fluxes of non-CO2 greenhouse gases) and then reliably determined according to internationally agreed standards (IPCC, 2014; Needelman et al., 2019; Eger et al., 2022). The additional carbon sequestered should also be stored "permanently" (over 100 years) to be considered as part of long term climate mitigation action (Fearnside, 2002).

These requirements are extremely challenging for coastal blue carbon ecosystem restoration. To provide confidence that they are achievable, a Verified Carbon Standard (VCS) for Tidal Wetlands and Seagrass Restoration has been developed (Needelman et al., 2018; Verra, 2021), primarily in a US context. The VCS methodology is complex and technically demanding, with >30 parameters involved. The most reliable estimates for carbon removal are those directly derived from in situ measurements, ideally including comprehensive baseline data collected up to 4 years before the start of restoration (Verra, 2021). It may then take a further 10–20 years after the start of the restoration project before its carbon burial rates match those of mature ecosystems and the true carbon benefit can be realised.

Operationalizing marketable blue carbon is another key barrier. Macreadie et al (2022) summarise the key opportunities and barriers with this. The global carbon sequestration and avoided emissions potentially achieved via blue carbon is limited by multidisciplinary and interacting uncertainties spanning the social, governance, financial, and technological dimensions. Macreadie et al (2022) compiled a transdisciplinary team of experts to clarify these challenges and identify a way forward. Key actions identified to enhance blue carbon as a natural climate solution include "*improving policy and legal arrangements to ensure equitable sharing of benefits; improving stewardship by incorporating indigenous knowledge and values; clarifying property rights; improving financial approaches and accounting tools to incorporate co-benefits; developing technological solutions for measuring blue carbon sequestration at low cost; and resolving knowledge gaps regarding blue carbon cycles. Implementing these actions and operationalizing blue carbon will achieve measurable changes to atmospheric* *greenhouse gas concentrations, provide multiple co-benefits, and address national obligations associated with international agreements*".

Figure 8 outlines the research and implementation priorities for the four main sources of uncertainty in blue carbon projects including the important dependencies.

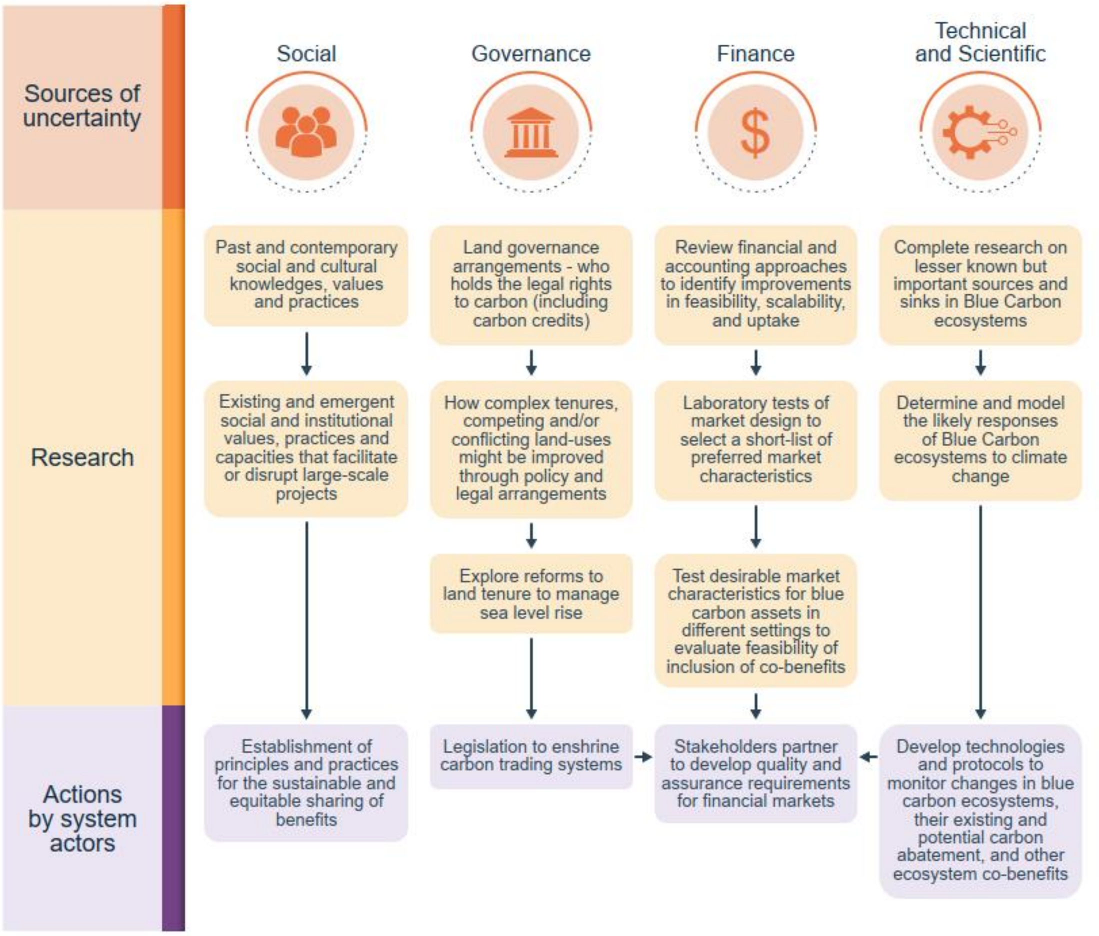

Figure 8: Framework for operationalizing marketable blue carbon.

Research and implementation priorities for the four main sources of uncertainty in blue carbon projects are shown. Arrows indicate important dependencies.

CONCLUSIONS

Innovative solutions to mitigate the impact of climate change are needed now more than ever. Coastal ecosystems sequester and store "blue" carbon more effectively than forestry and are an essential piece of the climate change solution. New Zealand's blue carbon potential is just starting to be realized.

COP26 The potential for carbon captured by coastal ecosystems to contribute to net zero ambitions is attracting significant global interest. Jacobs developed the world's first carbon code for coastal wetlands in 2014. The carbon code for saltmarshes project is developing scientific and revenue models, which will demonstrate the carbon benefits of restoring saltmarshes.

Case studies have been presented demonstrating promise in successfully calculating a Blue Carbon value for the Western Pacific, and also in demonstrating the potential for blue carbon projects to:

- Increase the carbon stored in soil and vegetation
- Avoid emissions from soils as they are rewetted
- Avoid emissions as freshwater wetlands are returned to saline wetlands.

A number of barriers to have been presented demonstrating that operationalizing marketable blue carbon is not without challenge. The global carbon sequestration and avoided emissions potentially achieved via blue carbon is limited by multidisciplinary and interacting uncertainties spanning the social, governance, financial, and technological dimensions. However there are a number of actions which will help to enhance blue carbon as a natural climate solution ranging from policy and legal directions, improving financial approaches and accounting tools to incorporate co-benefits; and developing technological solutions. Implementing these actions and operationalizing blue carbon will achieve measurable changes to atmospheric greenhouse gas concentrations, provide multiple co-benefits, and address national obligations associated with international agreements.

The importance of coastal ecosystems to sequester carbon and mitigate climate change is clear. The carbon code project in the UK is directly relevant to a New Zealand context. A similar approach could be applied in New Zealand to assess the potential sustainability, scientific and financial opportunities that can be realised through blue carbon sequestration and coastal ecosystem restoration, and the subsequent carbon credits.

Nature based solutions involving marine processes, such as coast blue carbon ecosystem restoration, are attractive not only for climate mitigation but also in the context of their other benefits, that include improved food security, reduced coastal erosion, and rebuilding marine biodiversity. They also enjoy strong community support.

There are undoubtably challenges with blue carbon however the wider benefits that protecting, enhancing and restoring our marine habits means that surely blue carbon in New Zealand is a ‘no brainer’?

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