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Enabling coastal blue carbon in Aotearoa New Zealand: opportunities and challenges

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Blue carbon is the carbon sequestered by coastal and marine habitats such as mangroves, saltmarsh, and seagrasses. The carbon sequestration service provided by these habitats could help to mitigate climate change by reducing greenhouse gas (GHG) emissions, as well as providing other important ecosystem services. Restoration of coastal habitats for the purpose of sequestering blue carbon can generate carbon credits, potentially offsetting the costs of restoration and any lost revenue for landowners. Coastal blue carbon projects have been successfully implemented overseas, but a blue carbon market has not yet been established in Aotearoa New Zealand (ANZ). Here we identify key data gaps that will be necessary to fill to develop a blue carbon market in ANZ. Calculation of carbon abatement through development of a standardised method is the first step and will allow economic assessment of potential restoration sites. Economic assessment will determine if the carbon credits generated will cover restoration costs and lost revenue from restored lands. Once economically feasible potential restoration sites have been identified, prioritisation of sites could be determined by the value of co-benefits produced (i.e., biodiversity). There are also legal uncertainties in ANZ and ownership of the foreshore has been a contentious topic. Current legislation provides that neither the Crown nor any other person owns or can own the common marine and coastal area, although Māori may apply for recognition of customary rights, interests, and title in the area. The legal status of property rights will have significant implications for privately owned land, as it is unclear whether land will be considered foreshore when inundated in future with sea level rise. Here, we discuss further policy enablers including the role of government and the insurance industry that could encourage uptake of carbon projects by private landowners. Filling these gaps in market assessments and recognising the key role of Indigenous owners and customary rights holders to coastal land can facilitate operationalising of coastal blue carbon opportunities in Aotearoa New Zealand.

KEYWORDS

blue carbon, nature-based solution, coastal rewilding, coastal marine restoration, coastal land tenure, coastal management, climate change

1 Introduction

Blue carbon refers to carbon sequestered and stored by coastal habitats such as mangroves, saltmarsh, and seagrasses (McCarthy, 2001). Carbon is stored in above and below-ground biomass and in captured sediments, often at much higher rates than terrestrial ecosystems (Chmura et al., 2003; Donato et al., 2011). The long-term carbon sequestration provided by these habitats makes them important carbon sinks, mitigating climate change by reducing overall greenhouse gas (GHG) emissions (Mcleod et al., 2011; Duarte et al., 2013). Restoration of coastal blue carbon ecosystems (not including conservation) has the global potential to sequester 0.06 to 2.1 Gt CO_2 per year (0.02 to 6.6% of 2020 CO_2 emissions) depending on the estimate (Williamson and Gattuso, 2022). In addition to carbon storage, these habitats provide other co-benefits for biodiversity, water filtration, and coastal protection (Short, 2003; Spalding et al., 2014). Despite the importance of coastal habitats for global biodiversity and climate mitigation goals, they are some of the most degraded habitats and are under threat from coastal development and land use changes, pollution, and climate change (Lovelock and Reef, 2020; Singh et al., 2022). Restoration and conservation of coastal habitats is essential to increase carbon sequestration and provision of co-benefits (Hejnowicz et al., 2015; Hilmi et al., 2021).

Ecologically, facilitating migration of blue carbon habitats inland with sea level rise maintains the important ecosystem functions and services these habitats provide and is likely to have wider consequences for estuarine and coastal health. If landowners are instead encouraged to prevent such migration (e.g., through sea walls or pumping) the total intertidal area available for blue carbon habitats will constrict through time, reducing their extent within estuaries and their important ecosystem functions and services. Mechanisms that encourage blue carbon restoration/protection are therefore critical for maintaining estuarine health in the face of impacts such as sea level rise. However, it is important to consider wider ecological and societal implications of blue carbon restoration not only to maximize co-benefits, but to avoid potential negative consequences of restoration. For example, a blue carbon restoration project which facilitates mangrove or saltmarsh restoration over mudflats or marginal lowland farm (with minimal current usage by the public) is likely to maximise ecological and societal benefits. Conversely, negative perceptions could result from facilitating blue carbon restoration when potential restoration sites overlap with abundant shellfish bed habitat or terrestrial fringing land of cultural or spiritual significance with high value to the community in its present form.

Aotearoa New Zealand has a long coastline with corresponding significant opportunities for coastal blue carbon. However, a blue carbon market has not yet been established, and there is not currently a methodology accepted by the ANZ government for incorporation of blue carbon projects into the New Zealand Emissions Trading Scheme (ETS). For landowners, blue carbon projects could generate revenue on marginal coastal land via tidal restoration on land that is currently drained or on land that is predicted to be tidally influenced under sea level rise. In ANZ, iwi (tribes) and hapū (clans or family groups) of the Indigenous Māori own or have customary rights to large stretches of coastal land, so blue carbon projects could lead to positive outcomes by maintaining revenue from coastal land. Blue carbon restoration projects may also provide an opportunity to better support the customary rights of Māori within the coastal and marine area, through mechanisms such as financial support for iwi and hapū to lead and engage with current and future management activities in these areas. Funding mechanisms may also offer a pathway for iwi and hapū members to restore access and authority with respect to the taiao (environment) which has routinely been obstructed or undermined as a result of colonisation.

Here we discuss how a blue carbon accounting methodology could be established in ANZ, and how this could be incorporated into the government's emissions trading scheme or the voluntary carbon market. We identify key barriers and potential solutions to paving a pathway to a blue carbon market in ANZ (Figure 1). Establishing blue carbon markets may be more complicated from a legal perspective than terrestrial carbon markets, because of the relative complexity of property rights in the coastal marine area (Bell-James, 2016). It is critical that lack of clarity in policy does not become a reason to avoid decisions to enhance and maintain the ecological functioning of estuaries and coastal zones.

2 Establishing a blue carbon methodology for ANZ

From an economic and carbon accounting perspective, inclusion of blue carbon into the ETS could be facilitated by development of a standardized methodology for quantifying sequestration and GHG emission data of blue carbon ecosystems (i.e., an ANZ Blue Carbon Method). This methodology will allow for calculation of the net carbon abatement of blue carbon projects, which is the difference in sequestration between the current land use and the coastal habitat expected to replace it after restoration. Calculating the net sequestration of a blue carbon project will provide estimates used to generate carbon credits, and the economic feasibility of potential projects can then be assessed. Cost-benefit analyses can be used to determine if the financial benefits (carbon credits) outweigh the costs (cost to restore, maintenance, lost revenue) of a project and can be used to prioritize potential project sites. While economic viability is one approach to decision making, there is debate among environmentalists as to whether valuing natural capital is a practical path to leverage markets for environmental gain versus ethical and social concerns about commodifying nature (Kallis et al., 2013; Dehm and Natarajan, 2022). As such, other factors should also be considered when prioritizing areas to restore, such as the ability of the site to also provide important co-benefits (i.e., biodiversity, coastal protection services, recreational access, and cultural values).

The implementation of a blue carbon methodology requires carbon sequestration data from blue carbon habitats, ideally gathered from ANZ estuaries/coasts. Much of the data required

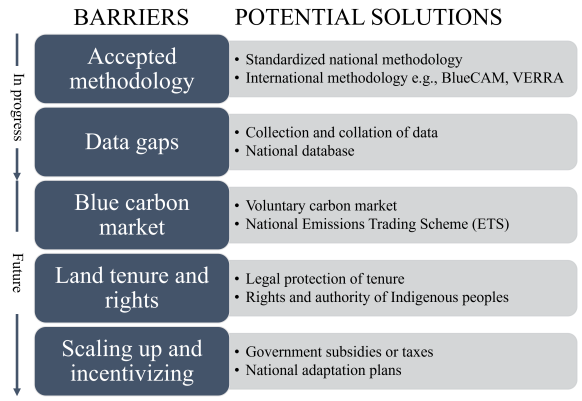

FIGURE 1
Key barriers to and potential solutions for establishing a blue carbon market in Aotearoa New Zealand.

already exists for ANZ, including the distribution of blue carbon habitats (Townsend and Wadwha, 2017; Lundquist et al., 2018; Suyadi, 2018; Suyadi et al., 2019; Ha et al., 2020; Martin et al., 2020; Ha et al., 2021; Ha et al., 2023), their rates of above- and below-ground carbon sequestration (Swales et al., 2007; Lovelock et al., 2010; Swales et al., 2015, Bulmer et al., 2016a; Bulmer et al., 2016b, Bulmer et al., 2020), as well as emissions of each habitat type (Pratt et al., 2014a; Pratt et al., 2014b; Bulmer et al., 2015; Pratt et al., 2015; Bulmer et al., 2017; Pérez et al., 2017; Bulmer et al., 2018; Drylie et al., 2018; Hamilton et al., 2020; Mangan et al., 2020; Thrush et al., 2021). Many projects are currently underway to further enhance this dataset, however, sufficient data exists now to inform a blue carbon methodology. Future research and monitoring will help to improve our management of these ecosystems, including improving our understanding of how carbon sequestration varies between and within blue carbon habitats, as well as assessing the vulnerability of these habitats to impacts such as sea level rise and climate change.

3 Blue carbon markets in ANZ

To support blue carbon restoration and enhancement in ANZ, the government could incorporate blue carbon habitats into the ETS. At present, carbon projects allowed under the ETS are limited and there is no allowance for wetlands (either freshwater or marine), in part due to a perceived lack of data on the carbon sequestration potential of wetland habitats in ANZ (but see Bulmer et al., 2020; Suyadi et al., 2020). Blue carbon was listed as an area of interest in the climate change emergency fund and in the review of the ETS, but further progress has not occurred. As such, there is momentum for development of a pathway to blue carbon, as ANZ is committed to reducing emissions in line with international targets (i.e., COP26).

The ETS is administered by the Ministry for the Environment and is responsible for making sure that ANZ meets domestic and international climate change targets, including the target set to reach net-zero emissions by 2050 under the Climate Change Response Act 2002. The ETS puts a price on emissions [i.e., a carbon price measured in tonnes of carbon dioxide equivalent (CO2-e)]. Each sector within the economy pays for their emissions, with the exception of agricultural emissions which are proposed to enter the ETS by 2025. To meet emissions targets, businesses can reduce their emissions or offset their emissions by buying units (NZUs) at the current carbon price from other sectors/businesses.

In Australia, the Clean Energy Regulator announced the Blue Carbon Method in January 2022, which allows landowners to generate Australian Carbon Credit Units (ACCU) through tidal restoration. These blue carbon credits are verified and sold through the Australian Government's ACCU Scheme (formerly known as the Emissions Reduction Fund) (Lovelock et al., 2022). However, in ANZ, the ETS only provides scope for native and pine plantations in its current framework. This forestry framework is unlikely to be applicable to coastal wetlands; rather a coastal wetland framework will need to be developed. Data on carbon and how these metrics changes over time are required to parameterize a blue carbon framework. There are several regional and national scale projects that are currently collecting relevant data (see Section 3.1 above). Once data has been collected and validated, the process for incorporating coastal blue carbon into national accounts would need to be clarified with government. Conversations surrounding this process should be initiated between researchers, government, and landholder and stakeholder communities, in ways that reflect and uphold the legal rights, political authority, and place-based knowledge of iwi and hapū.

Blue carbon projects in ANZ could also be incorporated into voluntary carbon markets. The voluntary carbon market also allows businesses to purchase and sell carbon credits, but they cannot be counted in the ANZ emissions budget (unless credits are bought by the government), so it may be less preferable from a government perspective. The voluntary market may also have lower compliance and oversight than non-voluntary mechanisms, which may increase the likelihood of adverse outcomes (e.g., greenwashing). Government regulation of the blue carbon market in ANZ would reduce the likelihood of adverse outcomes and increase the integrity of any carbon credits generated. For landowners however, the voluntary carbon market may be more profitable depending on the carbon price offered on the open market and may reduce the risk of political interference (e.g., Lawyers for Climate Action NZ Inc v Minister of Climate Change [2023] NZHC 1835). Landowners must also consider costs of different restoration actions, long term maintenance, and legal status of inundated land during and after project completion (see 'land tenure' below). Integration of blue carbon projects into aligned national policies such as the Climate Adaptation Act (see 'scaling up and incentivizing' below) could increase uptake of restoration and reduce reliance on the market value of carbon credits generated by blue carbon projects.

4 Policy barriers and enablers

There are several critical policy gaps that require further research to support and maximise opportunities for blue carbon markets in ANZ.

4.1 Land tenure arrangements

The law surrounding ownership of the foreshore and seabed has a turbulent history (Erueti, 2022). ANZ was settled by the British Crown after the signing of *Te Tiriti o Waitangi* between the Crown and Māori chiefs in 1840. *Te Tiriti* is the founding constitutional document in ANZ (Simon, 2016), and protects Māori rights to their lands and resources (including waters: Jones, 2016). Prior to the British acquisition of sovereignty, Māori tribes occupied and exercised sovereignty over all of ANZ pursuant to an intricate system of traditional laws and customs known as *tikanga* Māori (Jones, 2016). Upon colonisation, the British brought their common law from England, with its rules about property rights in land, water, and sea (Joseph, 2014).

The common law regarding rights in the coastal marine area is incredibly complex. Prior to the foreshore and seabed controversy that arose in the 1990s, the Crown simply assumed that it owned the 'coastal marine area'; the area from 'mean high water springs' out to the 12 NM seaward boundary of the territorial sea (Makgill and Rennie, 2012). The Crown also variously issued grants to private freehold titles to lands abutting the foreshore, which may have fixed boundaries (which could end above or below mean high water springs) or be aligned to 'high-water mark at ordinary tides' (known as a 'water boundary'). In some places there are Crown reserves or marginal strips running along the foreshore. Other rules of the common law and statute about legal boundaries abutting estuaries and around the mouths of tidal and navigable rivers and around lakes may provide different boundaries to mean high water springs. This complexity means that there can be legal uncertainty around the precise boundaries of land abutting the foreshore if the high-tide mark changes (McMorland et al., 2018).

A recent feasibility study of blue carbon projects in ANZ suggests that land tenure arrangements for land-based blue carbon developments on land above high-water mark, or land below high-water mark with fixed boundaries, would be straightforward, although the legal feasibility of each project would need to be determined in its particular circumstances (Weaver et al., 2022). Fixed, registered property titles will not change because of sea level rise and can remain private freehold title covered by water. Where the title boundary is the high-water mark, common law has provided longstanding doctrines of accretion, erosion, and avulsion, which provide that ownership of land that has a water boundary can change because of changes in physical boundaries between land and water.

Current legislation under the Marine and Coastal Area (Takutai Moana) Act 2011 provides that neither the Crown nor any other person owns or can own the common marine and coastal area. The legislation provides for a process by which Māori can apply to the High Court for recognition of customary marine title or protected customary rights in the marine and coastal area (or obtain these rights in direct negotiations with the Crown). A customary marine title holder is provided with an inalienable 'interest in land', including an entitlement to 'use, benefit from, or develop a customary marine title area (including derive commercial benefit)' subject to requirements to obtain planning consent under resource management legislation (s60), which presumably would enable the holder to benefit from carbon credits. We note that this could also be achieved without the need to rely on carbon credits, for example for ecological and cultural benefits, representing an alternative approach to nature commodification. Significantly, section 13 of the Act preserves the common law of accretion and erosion, meaning that these natural changes would result in changes to the legal boundaries of the common marine and customary area. Customary marine title holders may be able to use their status as titleholders to impose area-based protections in the marine and coastal area as *wāhi tapu* (sacred places), including prohibitions or restrictions on access to the area (Urlich et al., 2022). However, the process may also introduce new uncertainties or inequities in terms of blue carbon restoration, including overlapping claims as to rights and interests and temporal discrepancies between groups in obtaining recognition and granting of interests and title (for example between tribal groups with overlapping spatial boundaries where one group obtains legal recognition or negotiated settlement of their coastal land claims in advance of others). Any uncertainties around land tenure will require careful management, noting that the IPCC has alerted to the potential for adverse impacts of blue carbon policy on the rights of Indigenous peoples, especially at large scales and where land tenure is insecure (Lee et al., 2023).

Determining the impact of land tenure arrangements will be important for landowners undertaking coastal blue carbon projects. At present, there are some reclaimed/drained areas of coastal property that would be suitable for blue carbon projects, as they are at an elevation below high tide, and would be tidally influenced once tidal barriers are removed (e.g., sea walls or tidal gates). If these areas were restored to being tidally influenced, it would be critical to understand the impact on land tenure in each given case, and whether law reform could improve legal certainty.

4.2 Scaling up and incentivizing

Once a pathway to successful blue carbon projects in ANZ has been developed, the next step is up-scaling to coordinated regional efforts with multiple landowners and potentially multiple local councils. Support from government would serve to streamline the permitting process for landowners and help to coordinate efforts between multiple landowners and therefore scale-up blue carbon within a region. Regional coastal plans, prepared by regional councils or other unitary authorities, are one potential mechanism for including blue carbon projects. Regional coastal plans could feed into national adaptation plans and goals such as ANZ's Climate Adaptation Act (CAA) and the Strategic Planning Act (SPA), or the Climate Emergency Response Fund (CERF). Other legal and policy mechanisms outside of the carbon market-based approach, such as public payments for ecosystem services, could represent an alternative pathway to uptake of blue carbon projects. These could include subsidies through reduced rates or taxes for landowners who are undertaking blue carbon restoration. There may be capacity to support this type of effort through the reform of the Resource Management Act (1991), for example blue carbon restoration could be included as activities within the Spatial Planning Bill. Regardless of the mechanism, it seems likely that to enable a thriving blue carbon scheme in Aotearoa, the government may need to enact policy to encourage widescale uptake of blue carbon projects.

The insurance industry could also play a role in the future of blue carbon projects in Aotearoa. Insurance costs for coastal areas are expected to increase as they become increasingly vulnerable to climate-related extreme weather events and sea level rise. It is also possible that insurance companies may choose not to renew insurance for high-risk areas, and managed retreat may be necessary. Flood risk has been an issue overseas, for example during the Australian NSW floods where some landowner insurance premiums had become prohibitively expensive, damage to property wasn't covered despite insurance, or insurers labelled properties as uninsurable (May and Knaus, 2022). In New Zealand, the EQC (Earthquake Commission) has increased the payout cap for customers from $150,000 to $300,000, reducing the responsibility of the insurance industry and reducing premiums for affected customers (EQC, 2022). A similar scheme could be enacted for coastal landowners vulnerable to inundation and storm surge. Coastal restoration can increase resilience to these threats; insurance companies could incorporate restoration into their policies and reduce insurance premiums where restoration is being undertaken (MfE, 2017).

5 Conclusion

Here we summarized some of the key considerations and steps required to take advantage of the opportunity for coastal blue carbon in Aotearoa New Zealand. While sufficient data has been collated to develop a blue carbon methodology, there remain questions surrounding the path forward through voluntary/non-voluntary funding mechanisms. There is a need for further research and development of policy and legal frameworks to support and underpin blue carbon initiatives that will enhance estuarine and coastal health and human wellbeing, and uphold the rights of Indigenous peoples, especially under increasing climate change pressures. It will be critical to undertake an informed adaptive management approach that facilitates active decision making now rather than delay action and risk the ecological functioning of estuaries and coastal zones.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

PS-S: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. RB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. EM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. CL: Conceptualization, Investigation, Methodology, Project administration, Writing – review & editing.

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Conflict of interest

Author PS-S and CL were employed by the company National Institute of Water and Atmospheric Research Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Bell-James, J. (2016). Developing a framework for 'blue carbon' in Australia: Legal and policy considerations. *The University of New South Wales Law Journal* 39 (4), 1583–1611.

Bulmer, R. H., Lundquist, C. J., and Schwendenmann, L. (2015). Sediment properties and CO_2 efflux from intact and cleared temperate mangrove forests. *Biogeosciences* 12 (20), 6169–6180. doi: 10.5194/bg-12-6169-2015

Bulmer, R. H., Schwendenmann, L., Lohrer, A. M., and Lundquist, C. J. (2017). Sediment carbon and nutrient fluxes from cleared and intact temperate mangrove ecosystems and adjacent sandflats. *Sci. Total Environ.* 599, 1874–1884. doi: 10.1016/j.scitotenv.2017.05.139

Bulmer, R. H., Schwendenmann, L., and Lundquist, C. J. (2016a). Allometric models for estimating aboveground biomass, carbon and nitrogen stocks in temperate *Avicennia marina* forests. *Wetlands* 36, 1–8. doi: 10.1007/s13157-016-0793-0

Bulmer, R. H., Schwendenmann, L., and Lundquist, C. J. (2016b). Carbon and nitrogen stocks and below-ground allometry in temperate mangroves. *Front. Mar. Sci.* 3 (150). doi: 10.3389/fmars.2016.00150

Bulmer, R. H., Stephenson, F., Jones, H. F. E., Townsend, M., Hillman, J. R., Schwendenmann, L., et al. (2020). Blue carbon stocks and cross-habitat subsidies. *Front. Mar. Sci.* 7 (380). doi: 10.3389/fmars.2020.00380

Bulmer, R. H., Townsend, M., Drylie, T., and Lohrer, A. M. (2018). Elevated turbidity and the nutrient removal capacity of seagrass. *Front. Mar. Sci.* 5 (462). doi: 10.3389/fmars.2018.00462

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., and Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global biogeochemical cycles* 17 (4). doi: 10.1029/2002GB001917

Dehm, J., and Natarajan, U. (2022). Reconfiguring environmental governance in the green economy: extraction, stewardship and natural capital. *Locating Nature: Making Unmaking Int. Law*, 70–108. doi: 10.1017/9781108667289.006

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., and Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* 4 (5), 293–297. doi: 10.1038/ngeo1123

Drylie, T. P., Lohrer, A. M., Needham, H. R., Bulmer, R. H., and Pilditch, C. A. (2018). Benthic primary production in emerged intertidal habitats provides resilience to high water column turbidity. *J. Sea Res.* 142, 101–112. doi: 10.1016/j.seares.2018.09.015

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Climate Change* 3 (11), 961–968. doi: 10.1038/nclimate1970

EQC (2022) *EQCover building cap and premium changes*. Available at: https://www.eqc.govt.nz/what-we-do/what-youre-covered-for/building-cover/eqcover-building-cap-and-premium-changes/.

Erueti, A. (2022). *The UN declaration on the rights of indigenous peoples: A new interpretative approach* (New York, NY, USA: Oxford University Press).

Ha, N. T., Manley-Harris, M., Pham, T. D., and Hawes, I. (2020). A comparative assessment of ensemble-based machine learning and maximum likelihood methods for mapping seagrass using sentinel-2 imagery in Tauranga Harbor, New Zealand. *Remote Sens.* 12 (3), 355. doi: 10.3390/rs12030355

Ha, N. T., Manley-Harris, M., Pham, T. D., and Hawes, I. (2021). The use of radar and optical satellite imagery combined with advanced machine learning and metaheuristic optimization techniques to detect and quantify above ground biomass of intertidal seagrass in a New Zealand estuary. *Int. J. Remote Sens.* 42 (12), 4712–4738. doi: 10.1080/01431161.2021.1899335

Ha, N.-T., Pham, T.-D., Pham, H.-T., Tran, D.-A., and Hawes, I. (2023). Total organic carbon estimation in seagrass beds in Tauranga Harbour, New Zealand using multi-sensors imagery and grey wolf optimization. *Geocarto Int.* 38 (1), 2160832. doi: 10.1080/10106049.2022.2160832

Hamilton, D. J., Bulmer, R. H., Schwendenmann, L., and Lundquist, C. J. (2020). Nitrogen enrichment increases greenhouse gas emissions from emerged intertidal sandflats. *Sci. Rep.* 10 (1), 6686. doi: 10.1038/s41598-020-62215-4

Hejnowicz, A. P., Kennedy, H., Rudd, M. A., and Huxham, M. R. (2015). Harnessing the climate mitigation, conservation and poverty alleviation potential of seagrasses: prospects for developing blue carbon initiatives and payment for ecosystem service programmes. *Front. Mar. Sci.* 2, 32. doi: 10.3389/fmars.2015.00032

Hilmi, N., Chami, R., Sutherland, M. D., Hall-Spencer, J. M., Lebleu, L., Benitez, M. B., et al. (2021). The role of blue carbon in climate change mitigation and carbon stock conservation. *Front. Climate* 3. doi: 10.3389/fclim.2021.710546

Jones, C. (2016). *New treaty, new tradition: reconciling New Zealand and Maori law* (UBC Press).

Joseph, P. A. (2014). *Constitutional and administrative law in New Zealand* (Brookers Ltd. Wellington: Wellington).

Kallis, G., Gómez-Baggethun, E., and Zografos, C. (2013). To value or not to value? That is not the question. *Ecol. economics* 94, 97–105. doi: 10.1016/j.ecolecon.2013.07.002

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., et al. (2023). AR6 synthesis report: climate change 2023. *Summary Policymakers*. doi: 10.59327/IPCC/AR6-9789291691647.001

Lovelock, C. E., Adame, M. F., Bradley, J., Dittmann, S., Hagger, V., Hickey, S. M., et al. (2022). An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. *Restor. Ecol.* 31 (7), e13739. doi: 10.1111/rec.13739

Lovelock, C. E., and Reef, R. (2020). Variable impacts of climate change on blue carbon. *One Earth* 3 (2), 195–211. doi: 10.1016/j.oneear.2020.07.010

Lovelock, C. E., Sorrell, B. K., Hancock, N., Hua, Q., and Swales, A. (2010). Mangrove forest and soil development on a rapidly accreting shore in New Zealand. *Ecosystems* 13 (3), 437–451. doi: 10.1007/s10021-010-9329-2

Lundquist, C. J., Jones, T. C., Parkes, S. M., and Bulmer, R. H. (2018). Changes in benthic community structure and sediment characteristics after natural recolonisation of the seagrass Zostera muelleri. *Sci. Rep.* 8 (1), 13250. doi: 10.1038/s41598-018-31398-2

Makgill, R. A., and Rennie, H. G. (2012). A model for integrated coastal management legislation: A principled analysis of New Zealand's resource management act 19911. *Int. J. Mar. Coast. Law* 27 (1), 135–165. doi: 10.1163/157180812X620667

Mangan, S., Bryan, K. R., Thrush, S. F., Gladstone-Gallagher, R. V., Lohrer, A. M., and Pilditch, C. A. (2020). Shady business: the darkening of estuaries constrains benthic ecosystem function. *Mar. Ecol. Prog. Ser.* 647, 33–48. doi: 10.3354/meps13410

Martin, R., Ellis, J., Brabyn, L., and Campbell, M. (2020). Change-mapping of estuarine intertidal seagrass (Zostera muelleri) using multispectral imagery flown by remotely piloted aircraft (RPA) at Wharekawa Harbour, New Zealand. *Estuarine Coast. Shelf Sci.* 246, 107046. doi: 10.1016/j.ecss.2020.107046

May, N., and Knaus, C. (2022). *The Australian suburbs where more than half of properties will be uninsurable by 2030* (The Guardian).

McCarthy, J. J. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Cambridge, UK: Cambridge University Press).

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front. Ecol. Environ.* 9 (10), 552–560. doi: 10.1890/110004

McMorland, D. W., Campbell, N. R., Gibbons, T. N., Scott, S., Twist, P. L., Foster, J. L., et al. (2018). *Hinde mcMorland & Sim land law in New Zealand* (LexisNexis NZ).

MfE (2017). *Coastal Hazards and Climate Change: Guidance for local government* (Wellington, New Zealand: Ministry for the Environment).

Pérez, A., MaChado, W., Gutierrez, D., Stokes, D., Sanders, L., Smoak, J. M., et al. (2017). Changes in organic carbon accumulation driven by mangrove expansion and deforestation in a New Zealand estuary. *Estuarine Coast. Shelf Sci.* 192, 108–116. doi: 10.1016/j.ecss.2017.05.009

Pratt, D. R., Lohrer, A. M., Pilditch, C. A., and Thrush, S. F. (2014a). Changes in ecosystem function across sedimentary gradients in estuaries. *Ecosystems* 17 (1), 182–194. doi: 10.1007/s10021-013-9716-6

Pratt, D. R., Lohrer, A. M., Thrush, S. F., Hewitt, J. E., Townsend, M., Cartner, K., et al. (2015). Detecting subtle shifts in ecosystem functioning in a dynamic estuarine environment. *PloS One* 10 (7), e0133914. doi: 10.1371/journal.pone.0133914

Pratt, D. R., Pilditch, C. A., Lohrer, A. M., and Thrush, S. F. (2014b). The effects of short-term increases in turbidity on sandflat microphytobenthic productivity and nutrient fluxes. *J. Sea Res.* 92, 170–177. doi: 10.1016/j.seares.2013.07.009

Short, F. T. (2003). *World atlas of seagrasses* (Berkeley, USA: Univ of California Press).

Simon, H. (2016). Te arewhana kei roto i te ruma: an indigenous neo-disputatio on settler society, nullifying te tiriti, 'Natural resources' and our collective future in aotearoa New Zealand. *Te Kaharoa: e-Journal Pacific Indigenous Issues* 9 (1), 55–119. doi: 10.24135/tekaharoa.v9i1.6

Singh, M., Schwendenmann, L., Wang, G., Adame, M. F., and Mandlate, L. J. C. (2022). Changes in mangrove carbon stocks and exposure to sea level rise (SLR) under future climate scenarios. *Sustainability* 14 (7), 3873. doi: 10.3390/su14073873

Spalding, M. D., McIvor, A. L., Beck, M. W., Koch, E. W., Möller, I., Reed, D. J., et al. (2014). Coastal ecosystems: a critical element of risk reduction. *Conserv. Lett.* 7 (3), 293–301. doi: 10.1111/conl.12074

Suyadi, S. (2018). *Spatial distribution of mangroves in the Auckland Region, (1940-2014) and implications for aboveground carbon stocks* (Doctoral dissertation, The University of Auckland).

Suyadi,, Gao, J., Lundquist, C. J., and Schwendenmann, L. (2019). Land-based and climatic stressors of mangrove cover change in the Auckland Region, New Zealand. *Aquat. Conservation: Mar. Freshw. Ecosyst.* 29 (9), 1466–1483. doi: 10.1002/aqc.3146

Suyadi,, Gao, J., Lundquist, C. J., and Schwendenmann, L. (2020). Aboveground carbon stocks in rapidly expanding Mangroves in New Zealand: regional assessment and economic valuation of blue carbon. *Estuaries Coasts* 43, 1456–1469. doi: 10.1007/s12237-020-00736-x

Swales, A., Bentley, S. J., and Lovelock, C. E. (2015). Mangrove-forest evolution in a sediment-rich estuarine system: opportunists or agents of geomorphic change? *Earth Surface Processes Landforms* 40 (12), 1672–1687. doi: 10.1002/esp.3759

Swales, A., Bentley, S. J., Lovelock, C., and Bell, R. G. (2007). Sediment processes and mangrove-habitat expansion on a rapidly-prograding muddy coast, New Zealand. *Coast. Sediments'* 07, 1441–1454. doi: 10.1061/40926(239)111

Thrush, S. F., Hewitt, J. E., Gladstone-Gallagher, R. V., Savage, C., Lundquist, C., O'Meara, T., et al. (2021). Cumulative stressors reduce the self-regulating capacity of coastal ecosystems. *Ecol. Appl.* 31 (1), e02223. doi: 10.1002/eap.2223

Townsend, M., and Wadwha, S. (2017). Developing automated methods for mapping estuarine vegetation. *Interim Rep. prepared Waikato Regional Council.*

Urlich, S. C., White, F. R., and Rennie, H. G. (2022). Characterising the regulatory seascape in Aotearoa New Zealand: Bridging local, regional and national scales for marine ecosystem-based management. *Ocean Coast. Manage.* 224, 106193. doi: 10.1016/j.ocecoaman.2022.106193

Weaver, S. A., Berthelsen, A., Schattschneider, J., and Bennion, T. (2022). *Feasibility assessment: aotearoa New Zealand blue carbon resilience credit projects* (Report to The Nature Conservancy, Ekos, Cawthron Institute, and Bennion Law).

Williamson, P., and Gattuso, J.-P. (2022). Carbon removal using coastal blue carbon ecosystems is uncertain and unreliable, with questionable climatic cost-effectiveness. *Front. Climate* 4. doi: 10.3389/fclim.2022.853666