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Developing a national dataset for coastal wetland blue carbon in Aotearoa New Zealand

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Developing a national dataset for coastal wetland blue carbon in Aotearoa New Zealand

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Prepared for Ministry for the Environment and The Nature Conservancy Aotearoa New Zealand

Glossary

Term	Definition
Above-ground biomass (AGB)	Biomass of living vegetation above the soil. Different carbon abatement methods may have their own specific definition.
Aotearoa New Zealand national dataset for coastal wetland blue carbon	The dataset developed as an output from this report. Also shortened to 'Aotearoa New Zealand national dataset' in this report.
Below-ground biomass (BGB)	Biomass of live roots. Different carbon abatement methods may have their own specific definition.
Blue carbon accounting model (BlueCAM)	A tool for tidal restoration projects established under the Tidal Restoration for Blue Carbon method (2022) of the Australian voluntary carbon market.
Carbon abatement	A reduction in atmospheric greenhouse gases through emissions avoidance or removal and sequestration of carbon from the atmosphere.
Carbon credits	Measurable, verifiable emission reductions from certified climate action projects. These projects reduce, avoid or remove greenhouse gas emissions.
Carbon dioxide (CO_2)	A clear gas composed of one atom of carbon (C) and two atoms of oxygen (O).
Carbon inventory (or GHG Inventory)	An account of the emissions of carbon dioxide equivalents (CO_2eq) to the atmosphere for a defined system (such as political, territorial [per location], or other).
Carbon pool	A reservoir of carbon that has the capacity to accumulate or release carbon. Carbon pools include above-ground biomass, below-ground biomass, litter, dead material and soils.
Carbon sequestration	The process of capturing and storing atmospheric carbon dioxide.
Carbon stock	The total amount of organic carbon stored in a blue carbon ecosystem of a known size. A carbon stock is the sum of one or more carbon pools.
Cawthron	Cawthron Institute.
Default value	A pre-established, standardised value that is used when project- or site-specific data are unavailable or impractical to obtain (also see Tier 1). These default values are typically derived from peer-reviewed literature, expert judgement or global datasets.
GHG	Greenhouse gas.
Intergovernmental Panel on Climate Change (IPCC)	The leading international body for assessment of climate change. It is a key source of scientific information and technical guidance to the United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement.
Methane (CH_4)	A greenhouse gas contributing to human-induced climate change.
Method (also Methodology)	A specific set of criteria and procedures that apply to specific project activities for quantifying net greenhouse gas emission reductions and / or removals (among other things).
Nanozostera muelleri	The taxonomic name for the species of seagrass found in Aotearoa New Zealand, as recently revised by Sullivan and Short (2023). Previous taxonomic names used include *Zostera muelleri*, *Z. capricorni* and *Z. novaezelandiae*.

Term	Definition
National greenhouse gas inventory (NGHGI)	A comprehensive record of the amount and types of greenhouse gases emitted or removed from the atmosphere by a country. It provides data on the sources and sinks of greenhouse gases within a nation and is used to track a country's progress toward reducing its emissions and meeting international climate commitments.
Nationally Determined Contributions (NDCs)	National climate action plans, under the Paris Agreement, that outline a country's commitments to reduce greenhouse gas emissions and adapt to the impacts of climate change.
Nature-based solution	A solution that addresses socio-environmental challenges through sustainable management and use of natural features and processes.
New Zealand Greenhouse Gas Inventory (NZGHGI)	A comprehensive record of the amount and types of greenhouse gases emitted or removed from the atmosphere by Aotearoa New Zealand. It provides data on the sources and sinks of greenhouse gases within the country and is used to track progress towards reducing its emissions and meeting international climate commitments. It is produced each year as part of Aotearoa New Zealand's obligations under the Paris Agreement and United Nations Framework Convention on Climate Change (UNFCCC).
NIWA	National Institute of Water and Atmospheric Research.
Project	A specific project for a carbon abatement method that is carried out to reduce emissions or store carbon (e.g. in soil and vegetation).
Soil organic carbon (SOC)	The carbon component of soil organic matter.
Soil organic carbon accumulation rate (CAR)	The rate at which organic carbon is accumulated within soil over time.
Tidal restoration	The process of reintroducing tidal flow to a coastal wetland by changing or removing a tidal restriction mechanism.
Tidal rewetting	The process of changing a drained soil into a wet soil (in the tidal environment). A rewetted soil is a soil that has formerly been a drained soil but as a result of human intervention has become a wet soil. Tidal rewetting is synonymous with tidal restoration.
Tiers 1–3 (IPCC)	Tiers of data are based on the system used by the International Panel for Climate Change (IPCC). The tier of data becomes more locally relevant as the data improve, so Tier 1 is lower quality and Tier 3 is the highest quality. For example, Tier 1 is the most basic and generalised level of data provided. Tier 1 values are globally applicable (or regionally broad) values typically derived from models and used when country- or site-specific data are unavailable. Tiers 2 and 3 have increasing amounts of locally sourced data and conversion rates.
TNC NZ	The Nature Conservancy Aotearoa New Zealand.
VM0033	Verified Carbon Standard methodology for tidal wetland and seagrass restoration.
VCS	Verified Carbon Standard.

Contents

Executive summary

Coastal wetlands play an important role in climate change mitigation through their ability to store and sequester carbon. In Aotearoa New Zealand, these ecosystems include saltmarsh, mangrove and seagrass habitats, although a high proportion of these coastal wetlands have been degraded or lost due to human activities. As such, the relatively large potential for restoration and conservation of coastal wetlands has led to increased interest in their inclusion in carbon credit schemes and in New Zealand's Greenhouse Gas Inventory (NZGHGI). To inform these schemes, data on carbon sequestration and emissions in coastal wetlands are needed. Development of default national-scale values can be used to inform carbon sequestration and emissions values for locations that lack site-specific data.

The Ministry for the Environment (MfE), in partnership with The Nature Conservancy Aotearoa New Zealand (TNC NZ), have commissioned the development of a quantitative dataset on coastal wetland blue carbon in Aotearoa New Zealand. The primary purpose of the dataset is to inform a framework for potential inclusion of coastal wetlands into compliance and voluntary carbon credit schemes. Dataset development will also facilitate identification of data gaps and guide future data collection. Ultimately, it will highlight the role of coastal wetlands as nature-based solutions to climate change and set goals for coastal restoration and conservation in Aotearoa New Zealand. A consortium (Cawthron Institute, Tidal Research Ltd, and National Institute Water Atmosphere [NIWA]) was contracted to develop the dataset. Our approach followed five sequential steps: (1) select carbon abatement methods and outline relevant data for quantifying carbon stocks and sequestration and GHG emissions; (2) review existing coastal wetland and estuarine blue carbon data and compile metadata; (3) run a workshop to obtain expert input to define data requirements and align with carbon abatement methods; (4) develop a national dataset for blue carbon in coastal wetlands for Aotearoa New Zealand and identify data gaps; and (5) create a research plan for addressing data gaps.

Key results

Five carbon abatement methods were selected to inform national dataset development, including IPCC (2014), BlueCAM, Verra VM0033, Plan Vivo and Gold Standard. Of the range of relevant data for quantification of carbon stocks and sequestration and GHG emissions under these abatement methods, five key data measurements were selected for the Aotearoa New Zealand national dataset compilation: soil carbon accumulation rate (CAR), soil organic carbon (SOC) stocks, above-ground biomass (AGB), below-ground biomass (BGB), and greenhouse gases (GHGs). Our review of existing coastal wetland blue carbon data for the country contained 85 individual records. We presented our study approach at a workshop attended by carbon credit scheme experts from a variety of organisations (both domestic and international). Overall, there was broad agreement on, and useful input provided for, our approach taken to date and plan for next steps.

The Aotearoa New Zealand national dataset for coastal wetland blue carbon (hereafter Aotearoa New Zealand national dataset) and accompanying metadata were compiled into Excel files. Data were provided by data holders for all key measurements where available, although some data could not be obtained due to reasons such as unpublished status. Summary statistics and the number of sampling locations

were compared with temperate Australian datasets (i.e. BlueCAM) given the similarities in climate and coastal wetland species. Limited data were available to inform GHG emissions from both the Australian and Aotearoa New Zealand national datasets (i.e. three sites or fewer per habitat type). In terms of sampling effort, the Australian datasets had higher sampling numbers for all key data measurements except for salt marsh. Data were highly variable between and within habitat types for both the Aotearoa New Zealand and Australian datasets.

The spatial and numerical spread of the Aotearoa New Zealand national dataset, as well as sampling effort in the Australian dataset, were used to inform our high-level guidance for a research plan to fill gaps in the Aotearoa New Zealand national dataset. We identified regional data gaps for CAR, SOC stock and AGB for saltmarsh, mangrove and seagrass habitats. At each sampling point, we recommend that multiple cores are collected to inform within-wetland variability. Given the limited GHG data currently present within the Aotearoa New Zealand national dataset, we also recommend the collection of GHG data at multiple sites and habitat types across the country. Data collection should follow a standardised and best practice approach to ensure alignment with the Aotearoa New Zealand national dataset. Our research plan outlines a robust approach to strategically fill key gaps in the national dataset while balancing considerations around potential funding constraints, as per our study scope. However, if resources allow, additional samples collected over known environmental gradients and habitat distributions could further improve data estimates. To avoid duplication of effort, previously unavailable but potentially suitable data, such as unpublished datasets, should be reconsidered for inclusion in the Aotearoa New Zealand national dataset if they become available. Furthermore, to increase credibility of the Aotearoa New Zealand national dataset, we recommend supporting the publication of data sourced from unpublished datasets, technical reports or student theses, if publication in peer-reviewed journals is not already planned.

Introduction and scope

Coastal wetlands (mangroves, salt marshes and seagrass meadows) play an important role in climate change mitigation through their ability to store and sequester carbon (Bulmer et al. 2020; Lovelock and Duarte 2019; Macreadie et al. 2021). These ‘blue carbon’ ecosystems store their carbon in various ‘pools’, including within underlying soils and within above- and below-ground biomass such as leaves, branches and stems, and roots, respectively. However, they can also release carbon as greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O), especially following habitat degradation (Bulmer et al. 2015; Emmer et al. 2015; McLeod et al. 2011). In addition to carbon sequestration, coastal wetlands can provide a range of other benefits (‘co-benefits’) or ecosystem services, including supporting biodiversity, improving water quality, protecting coastal areas from storm surge, and cultural and social benefits (Adams et al. 2021; Barbier 2013; Costanza et al. 1997).

Aotearoa New Zealand currently contains approximately 20,932 ha of saltmarsh, 30,533 ha of mangrove, and 61,340 ha of seagrass (Bulmer et al. 2024). However, a high proportion of coastal wetland habitats has been degraded or lost, largely due to human activities such as land reclamation for development of agricultural, urban, and coastal areas (Denyer and Peters 2020; Dymond et al. 2021; Haacks and Thannheiser 2003). The coastal wetland restoration potential for the nation, and each region, has recently been quantified, with an estimated 87,861 ha of land potentially suitable for blue carbon projects via tidal restoration (Bulmer et al. 2024). Coastal wetland habitats are already undergoing restoration (e.g. by active planting) in many parts of the country, led by iwi, local government, and community or environmental groups.[1] The restoration and conservation opportunities have also led to interest in the inclusion of coastal wetlands in carbon credit schemes and in New Zealand’s Greenhouse Gas Inventory (NZGHGI)[2] (Bulmer et al. 2024; Jacobs et al. 2024; Ross et al. 2024; Weaver et al. 2022).

Aotearoa New Zealand has committed to transitioning to a low emissions economy, and this will involve both a reduction in GHG emissions and an increase in sequestration of carbon (Climate Change Response Act 2002). The NZGHGI (and Nationally Determined Contributions [NDC]) do not currently include coastal wetlands (Ministry for the Environment 2025; New Zealand Government 2025), although groundwork to incorporate the 2013 Intergovernmental Panel on Climate Change (IPCC) wetland supplement (IPCC 2014) into NZGHGI is already underway for other wetland types (e.g. freshwater; Pronger et al. 2022). Accounting for sequestration that existing coastal wetlands already provide, and for that additionality provided by restoration efforts, could reduce overall emissions in the NZGHGI, helping Aotearoa New Zealand meet international targets (UNFCC 2015). For example, Aotearoa New Zealand’s Nationally Determined Contributions (NDC2) aim to reduce emissions by 51–55% by 2035 (compared to 2005).

Another approach to support GHG reductions from the atmosphere is through carbon credit schemes, which facilitate habitat restoration and protection, and which can be part of the voluntary or compliance carbon market (Hilmi et al. 2021; Pendleton et al. 2012; Runting et al. 2016; Stewart-Sinclair et al. 2024). The voluntary carbon market typically involves a company or organisation buying carbon credits to

[1] https://www.doc.govt.nz/nature/habitats/estuaries/restoring-estuaries-map/
[2] https://environment.govt.nz/facts-and-science/climate-change/new-zealands-greenhouse-gas-inventory/

offset their own emissions, and buyers can be domestic or international emitters (Leining and White 2021; Ministry for the Environment 2022). In comparison, the compliance market operates under government-mandated emissions reduction targets, requiring domestic emitters in some industries to offset emissions by buying carbon credits. Internationally, interest in blue carbon credits is growing across both voluntary and compliance markets (Lovelock et al. 2023). However, Aotearoa New Zealand has not yet begun to participate in the blue carbon market domestically, although feasibility studies are underway at several locations (such as under The Nature Conservancy Aotearoa New Zealand [TNC NZ] Coastal Wetlands Blue Carbon Programme).

To inform carbon credit schemes and national inventories, data on carbon sequestration and emissions are needed. National-scale collection of data, such as soil carbon stock monitoring on agricultural land, is already set up to support the NZGHGI (Mudge 2022). Key data for coastal wetlands include the amount of carbon stored and / or accumulated within various carbon pools, such as in the soil and in vegetation biomass, as well as GHG emissions such as methane (CH_4) and nitrous oxide (N_2O) released from these ecosystems (Stewart-Sinclair et al. 2024). Furthermore, development of default national values can be used to inform carbon sequestration and emissions values where site-specific data are lacking (e.g. because they are difficult to obtain due to costs and logistical challenges). For Aotearoa New Zealand, a range of studies have collected, and / or are currently collecting, blue carbon–related data for coastal wetlands (outlined in Kettles et al. 2024). For example, Bulmer et al. (2024) recently summarised coastal wetland blue carbon data and estimated national-scale sequestration rates.

The Ministry for the Environment (MfE) and TNC NZ have commissioned the development of a quantitative dataset for coastal wetland blue carbon in Aotearoa New Zealand (as per the priority recommendations in Jacobs et al. [2024]). The primary purpose of the dataset is to inform a framework for potential inclusion of coastal wetlands into compliance and voluntary carbon credit schemes. More specifically, Jacobs et al. (2024) states that 'national approaches to data set development and maintenance will reduce the barriers to entry, facilitate investment in blue carbon and increase the integrity and consistency of blue carbon projects'. Dataset development will identify data gaps and guide future data collection. Ultimately, the dataset will help highlight the role of coastal wetlands as nature-based solutions to climate change and set goals for coastal restoration and conservation in Aotearoa New Zealand.

MfE, in partnership with TNC NZ, contracted a consortium (Cawthron Institute, Tidal Research Ltd and NIWA) to develop a dataset for blue carbon in coastal wetlands for Aotearoa New Zealand. Our approach followed five sequential steps:

1. Select carbon abatement methods and outline their relevant data for carbon and GHG quantification (to inform dataset development).
2. Review existing coastal wetland and estuarine blue carbon data and compile metadata.
3. Run a workshop to obtain expert input to define data requirements to align with carbon abatement methods.
4. Develop a national dataset for blue carbon in coastal wetlands for Aotearoa New Zealand and identify data gaps.
5. Create a research plan for addressing data gaps, including fieldwork and methods.

This report details the approach, results and discussion for the above steps.

Note that the scope of the national dataset for Aotearoa New Zealand was coastal wetland blue carbon habitats. As such, low-lying farmland that was formerly coastal wetland was excluded from our study due to differences in hydrology, species composition, and carbon sequestration and emissions between this land and coastal wetlands. However, we recognise that carbon-related data for former coastal wetlands can be useful for informing carbon inventories (e.g. based on land-use category) as well as site-specific carbon abatement restoration projects.

While we summarise some key carbon abatement methods and provide a high-level summary of select pros and cons in the context of our study, it was also outside of scope to recommend the use of a particular carbon abatement method for carbon credit schemes for Aotearoa New Zealand. This would require consideration of a range of factors, including (but not limited to) the type of coastal wetland-related restoration and / or conservation activities covered by the abatement method, the way the method considers risk (e.g. sea-level rise) and permanence (e.g. time frames), and the cost of implementing or using the method.

1. Selection of carbon abatement methods and identification of data

The first step for the study was to select carbon abatement methods and outline relevant data for quantification of carbon stocks and sequestration and GHG emissions. The purpose of this step was to inform which data were a priority for inclusion in the Aotearoa New Zealand national dataset for coastal wetland blue carbon (hereafter the Aotearoa New Zealand national dataset). Our approach and results for this step are outlined below.

1.1 Approach

Selection of carbon abatement methods

We selected carbon abatement methods that are used within compliance and voluntary carbon markets for coastal wetland blue carbon habitats. We also outlined additional information on the abatement methods relevant for informing the development of a national dataset. Relevant information included how well the abatement method aligned with the IPCC Wetlands Supplement (IPCC 2014), how developed the method was, how well known it was internationally, and the age and geographic region of the underpinning blue carbon data used to inform it.

Identification of relevant data under carbon abatement methods

The data relevant for quantification of carbon stocks and sequestration and GHG emissions[3] under each of the selected carbon abatement methods (Table 1) were identified and recorded in a standardised table (Appendix 1). For all relevant data, we outlined key details, where available, including measurement name and unit, measurement method including proxies, and any available default values and sources of data used to inform these. This approach was also applied to differing levels of data requirement, such as for Tiers 1–3 for IPCC data.

Given the complexity and level of details of some of the abatement methods (e.g. IPCC 2014; Verra 2023), it is possible that not all details for relevant data were identified. Furthermore, we did not include specific data requirements for project activities not considered relevant for Aotearoa New Zealand (e.g. construction of aquaculture ponds for shrimp / fish farming). For some carbon abatement methods, additional literature sources beyond the primary method document were used to assist with interpretation of data requirements. For VM0033 (2023), these sources included Needelman et al. (2018), Emmer et al. (2015) and Baldock et al. (2019). For BlueCAM, these sources included Serrano et al. (2019) and Lovelock et al. (2023). To the best of our ability, the information was checked to ensure

[3] Consideration of data requirements for the following under the carbon abatement methods was outside of our study scope: project restoration activities (e.g. fuel emissions), applicability, feasibility and risk assessment. It was also outside our scope to consider temporal requirements for relevant data under the carbon abatement methods, e.g. in relation to timing of project activities.

accuracy against the most recent version of the methods documents (if the method had more than one version).

Identification of key data for the Aotearoa New Zealand national dataset

We identified key data measurements to target for the Aotearoa New Zealand national dataset compilation, selected from the list of relevant data for quantification of carbon stocks and sequestration and GHG emissions for the carbon abatement methods (see Appendix 1). When identifying key data measurements, we considered the ultimate purpose of the Aotearoa New Zealand national dataset, which was to inform the potential inclusion of coastal wetlands in compliance and voluntary carbon markets. Therefore, we anticipate that the Aotearoa New Zealand national dataset (output of our study) will be useful for site-level restoration or conservation projects under the carbon abatement methods, but that additional context-specific data may be required depending on the carbon abatement methodology. Our selection of key data measurements for the Aotearoa New Zealand national dataset was guided by the following considerations:

- The measurement is relevant under multiple selected carbon abatement methods (Table 1), including Tier 1 under IPCC 2013 wetlands supplement, chapter 4 (IPCC 2014).
- The measurement can inform default values for carbon abatement methods or a key carbon pool. Therefore, data are applicable across coastal wetland restoration or conservation project sites.

The rationale for selection (or non-selection) of measurements as key data was recorded.

1.2 Results

Selection of carbon abatement methods

Five carbon abatement methods were selected to inform the development of the Aotearoa New Zealand national dataset (see Table 1). These methods were IPCC (2014), BlueCAM (Lovelock et al. 2023), Verra VM0033, v2.1 (Verra 2023), Plan Vivo (Plan Vivo 2024) and Gold Standard (GS4GG 2024). We also investigated the NZGHGI, but at the time of this research it did not encompass coastal wetlands and so was not considered further.

Table 1. The carbon abatement methods selected for consideration, and additional information relevant for informing our study (i.e. development of the Aotearoa New Zealand national dataset for coastal wetland blue carbon).

Carbon abatement method	Purpose	Additional information relevant for informing our study
IPCC 2013 wetlands supplement, chapter 4 (IPCC 2014) (Tier 1)	Provides specific guidance for quantifying carbon abatement from a range of management activities (forest management in mangroves, extraction, drainage, rewetting / revegetation and creation) and associated approach for quantification.	Well known internationally. Applicable globally. Guidelines used to inform national inventories and site-scale management actions. Default values are tropical / subtropical focused rather than temperate. Underpinning data are more than 10 years old.
Blue carbon abatement method (BlueCAM) (Lovelock et al. 2023)	Used to inform carbon abatement calculations for tidal restoration actions under Australia's voluntary carbon market scheme (Emissions Reduction Fund). Underpinning data inform Australia's national blue carbon inventory – data summarised in BlueCAM (2022).	Developed for Australia. Designed to conform to IPCC requirements for the relevant activities. Informs Australia's national blue carbon inventory. Default values informed by an extensive Australasian-focused temperate dataset, with comparable, or the same, species as Aotearoa New Zealand. Age of temperate data not disclosed.
VM0033, v2.1 (Verra 2023)[4]	A verified carbon standard (VCS) methodology for tidal wetland and seagrass restoration under the voluntary carbon market. It outlines procedures to estimate net GHG emission reductions and removals resulting from a range of project activities implemented to restore tidal wetlands.	Well known internationally. Applicable globally. Offers more options to quantify emission reductions than IPCC or BlueCAM; a sub-set of the options in VM0033 are consistent with IPCC. No evidence found of use for informing national inventories. Default values generally informed by published data, but with an international focus and not those from Aotearoa New Zealand. Underpinning data are more than 10 years old (noting that the method is currently under revision to ensure it reflects the most up-to-date science).
Plan Vivo (Plan Vivo 2024)	Currently at the concept stage. At this stage, applicable only to mangrove restoration and conservation. The plan is to prioritise the development of the mangrove components, followed by	Information not provided here given it is still at proof-of-concept stage – thus far, only one project is using this methodology.

[4] Note that Verra is currently in the process of revising the VM0033 methodology to include conservation activities (e.g. those currently covered in VM0007 REDD+ Methodology, v1.8 [Verra 2024]) and to ensure that the methodology reflects the most up-to-date science. https://verra.org/verra-revises-blue-carbon-methodology/

Carbon abatement method	Purpose	Additional information relevant for informing our study
	seagrass, with the scope to add saltmarsh components at a later stage. This methodology is being developed by Leah Glass (Blue Ventures), with input from a network of blue carbon experts.	
Gold Standard (GS4GG, 2024)	A methodology for sustainable management (restoration and conservation) of mangroves applicable under the Blue Carbon & Freshwater Wetlands Activity Requirements.	No additional information is provided here given it was published at the end of 2024 and has not yet been used for any projects.

Identification of relevant data under carbon abatement methods

The identified relevant data for quantification of carbon stocks and sequestration and GHG emissions for each of the selected carbon abatement methods are outlined in Appendix 1.

Identification of key data for the Aotearoa New Zealand national dataset

The key data identified for inclusion in the Aotearoa New Zealand national dataset are outlined in Table 2, along with their relevance to specific carbon abatement methods. The rationale for excluding some of the data from the list of key data for the Aotearoa New Zealand national dataset compilation is included in Appendix 2.

Table 2. Key data measurements for inclusion in the Aotearoa New Zealand national dataset for coastal wetland blue carbon. The relevance of the measurements to the carbon abatement methods is also indicated. Y = yes (i.e. relevant) and N = no (i.e. not relevant).

Data measurements targeted for national dataset compilation	Carbon abatement method				
	IPCC (2014) Tier 1	BlueCAM	Verra VM0033, v2.1	Plan Vivo	Gold standard
Soil organic carbon stocks	Y	Y	Y	Y	Y
Soil organic carbon accumulation rate (CAR)	Y	Y	Y	Y	Not specified
Greenhouse gases (methane, nitrous oxide, carbon dioxide)	Y	Y	Y	Y	Y
Above-ground biomass (AGB) (carbon)	Y	Y	Y	Y	Y
Below-ground biomass (BGB) (carbon)	Y	Y	Y	Y	Y

2. Review of existing data

The second step our study was to carry out a review of existing data relevant to the development of the Aotearoa New Zealand national dataset. Our approach and results for this step are outlined below.

2.1 Approach

Metadata were obtained on existing data for blue carbon coastal wetland and estuarine ecosystems in Aotearoa New Zealand, focusing on data relevant to carbon and GHG quantification for the selected carbon abatement methods in Table 1. Both coastal wetland habitat (i.e. salt marsh, mangrove, seagrass) and unvegetated estuarine ecosystems (i.e. intertidal unvegetated sediments) were considered for metadata compilation. We identified sources of information, from which the metadata were obtained, using two main approaches:

- Search the published and grey literature (e.g. technical reports) following a targeted approach. As part of this approach, we leveraged previous work that compiled relevant information for Aotearoa New Zealand, such as Kettles et al. (2024), who provided a summary of recent blue carbon research in Aotearoa New Zealand.
- Contact key researchers in the blue carbon research space to obtain information on any additional unpublished data (including for ongoing projects that will produce relevant data in the immediate future) for Aotearoa New Zealand. This included communication through the Coastal Blue Carbon Network.[5]
- Expert elicitation on remaining metadata gaps (see Section 3).

Metadata obtained from the information sources followed a standardised template and, where available, included: study title, habitat type(s), measurement type, measurement method, authors, published status, publication / report citation or link (Appendix 2).

For completeness, we compiled all potentially relevant data, not only those that met specific measurement requirements under the carbon abatement methods. However, we did not compile metadata for measurements considered niche or site-specific, such as suspended sediment for VM0033. Furthermore, for salinity, we limited metadata collation to pore-water salinity measurements that were paired with coastal vegetation. Metadata for pore-water salinity in unvegetated sediments were excluded for two reasons: (1) many discrete datasets likely exist that were collected for unrelated purposes, and (2) such data are not considered valuable for the purposes of the Aotearoa New Zealand national dataset compilation. For seagrass biomass (presented as grams per dry weight rather than carbon stocks), we generally did not compile metadata for older studies (i.e. prior to 2010).

[5] We emailed the Coastal Blue Carbon Network in February 2025 to request information on any coastal blue carbon data additional to that summarised in Kettles et al. (2024).

2.2 Results

The metadata compiled for blue carbon in coastal wetlands and estuaries for Aotearoa New Zealand are shown in Appendix 2. Overall, metadata from 85 individual entries were compiled. Each entry (row) typically represents a different study, although some double-up occurred where data from individual studies were also encompassed under a wider review or analysis. The content of the underpinning datasets was not explored at this step. Types of information sources from which metadata were obtained were primarily scientific publications, technical reports, student theses and unpublished data from scientific researchers. Focusing on the key data identified for the Aotearoa New Zealand national dataset, eight entries / rows contained potentially relevant soil carbon accumulation rate (CAR) data, 19 studies contained soil organic carbon (SOC) stock data, 16 studies contained above-ground biomass (AGB) data, and two studies contained GHG data.

A range of other data that may be relevant for informing blue carbon management were also identified (yet deemed outside of the scope of this study for inclusion in the Aotearoa New Zealand national dataset), including 14 studies / datasets containing spatial layers (e.g. habitat maps) and 14 studies containing sediment accumulation rates (see Appendix 2 for further information). We expect that at least some of these data will be relevant for site-specific blue carbon projects. However, confirmation of their usefulness would require additional assessment and would vary based on factors such as the site-specific activity of interest and the carbon abatement method.

3. Workshop to obtain expert input

The next step was to obtain input from other experts in blue carbon and carbon trading schemes to define data requirements aligned with relevant carbon abatement methods. The purpose of this was to inform the subsequent steps for our study. Our approach and results for this step are outlined below.

3.1 Approach

We ran a joint workshop (co-facilitated with MfE and TNC NZ), inviting experts in blue carbon and carbon trading schemes. The experts were both domestic (i.e. from Aotearoa New Zealand) and international. During the workshop, we first gave an overview of the study and outlined our approach and results for the first steps of our study (Sections 1 and 2 above). To inform the next steps of our study, which was to compile the quantitative dataset and develop a research plan (Sections 4 and 5), we collectively addressed the following key considerations:

- Discuss the approach taken for the identification and review of existing data, including how data broadly relate to available carbon abatement methods and the impact this could have on data compilation for a national dataset.
- Clarify the carbon abatement methods to be used and implications for the final report.
- Determine the scope of the data collection required, including the level of data availability and rigour required to inform potential credit schemes (e.g. IPCC Tier 1, Tier 2, Tier 3).
- The next steps regarding data gathering and the associated report, including metadata status, data accessibility and publication status.
- Any other considerations that become apparent based on the study results to date.

Key workshop outputs were recorded and used to inform our approach taken for next steps for our study.

3.2 Results

The workshop was held on 21 March 2025, with 13 attendees overall (including the study team). External attendees (beyond the study team) were from the following organisations: TNC NZ, MfE, Verra, TerraCarbon, Toitū Envirocare and Manaaki Whenua – Landcare Research. Overall, there was broad support and agreement, and useful input, from workshop participants on our approach taken to date and our plan for next steps.

Specifically, participants agreed that:

- The approach that was taken to review the existing data was appropriate and no further datasets were identified.

- The high-level summary of the carbon abatement methods was appropriate in the context of this study.
- The focus of data collection towards default (Tier 1) values that could be used to inform national greenhouse gas inventory (NGHGI) and carbon credit schemes was appropriate.
- The next steps, including the proposed approach to the gap analysis, were appropriate. These steps include identifying data gaps by comparing the Aotearoa New Zealand national dataset with underpinning data from Australia used to inform default values from BlueCAM. The rationale was that the Australian dataset contained data from a comparable climate and similar species to those found in Aotearoa New Zealand, and that the dataset was deemed suitably rigorous to inform inclusion of coastal wetland habitats into Australia's NGHGI and to align with IPCC standards (for further details, see Section 4.1).

Examples of feedback given during the workshop included:

- *The dataset being compiled for New Zealand under this study is foundational. I think it's useful to have a dataset that can be utilised for many purposes, for voluntary carbon market and greenhouse gas inventories. It's having a Jack of all trades, rather than something that's super specific.*
- *One of the things that's been most important in Australia, is having a modelled approach which has been incredibly powerful for actual project development. So just bear that in mind if you're having to do a whole stack of sampling as part of your projects, which you may want to do anyway, just to improve your datasets just generally. But having a model approach is pretty powerful for project development.*
- *To some degree, if you're collating the New Zealand data, you can compare directly to the BlueCAM data. If the New Zealand data aligns well with the BlueCAM dataset – meaning there are no significant statistical differences – then that indicates there is a whole bunch of values you don't have to collect for New Zealand. So basically, that would allow you to say we've covered off on 80% of the values, synonymous with the Australian setting. Then you could collect data for which there is clearly glaring absences or gaps. And that way you would probably have a much more cost-effective approach for the gap analysis by utilising a big dataset that you can have as a reference in the first place.*
- *Under Verra, they're happy to consider regionally specific values, rather than the default. In practice, while VM0033 does allow for the application of local data, it does have to exist, and it is often very expensive for projects to generate that if it doesn't exist. And so most projects, especially for setting the baseline, will choose to use the default values, and specifically the ones about soil carbon sequestration and the salinity relationships from methane. Most projects do choose to use the default values just because if the local science doesn't exist, it's very expensive to get that local information.*
- *Sometimes reports or things like that don't always have as high of standards as publications. Anything that's of that sufficient quality, they try to get out into the peer-reviewed literature. For unpublished data, I guess it just puts a little bit more challenge back on everyone to have to do their own level of quality control.*

4. Dataset development and identification of gaps

The next step was to develop the Aotearoa New Zealand national dataset, which first required the key data to be obtained. A gap analysis process was then carried out (to inform the research plan to complete the dataset – Section 5). Our approach and results for this step are outlined below.

4.1 Approach

Collection of target data

To develop the Aotearoa New Zealand national dataset, we targeted the key data outlined in our review of existing data (see Section 2). We then obtained published data from online sources and / or communicated with data holders to ask if they would provide their data for a national dataset. Communications included outlining the purpose and intended future use of the dataset. To facilitate this process, we also created and provided the data holders with an example data template into which they could input their data and associated metadata. If data were not already publicly available, permissions to use the data were obtained along with key contact and citation details.

Development of the Aotearoa New Zealand national dataset

We developed the Aotearoa New Zealand national dataset in Excel format in a standardised template for each of the five key data measurements (Table 2). The target data provided by data holders were collated into the Excel files (a separate worksheet for each key data measurement). Metadata to accompany the target data were also included.

Identification of gaps

Data gaps in the Aotearoa New Zealand national dataset were identified by comparing it against datasets used to inform default values from carbon abatement methods. We concluded that the most relevant comparison datasets for identifying gaps were those from Australia used to inform BlueCAM. These Australian datasets were published by Serrano et al. (2019) and Lovelock et al. (2023) and contain data from temperate ecosystems that have many similar coastal wetland species to those found in Aotearoa New Zealand. For example, seagrass and mangrove habitats in Aotearoa New Zealand each consist of one species (*Nanozostera muelleri* and *Avicennia marina* subsp. *australasica*), both of which are also found in Australia, and salt marshes in Aotearoa New Zealand and Australia have some of the same species, such as *Salicornia quinqueflora* and *Juncus kraussii*. As indicated in Table 1, BlueCAM (and therefore its underpinning dataset) is designed to conform to IPCC requirements for the relevant activities covered by this abatement method (i.e. tidal restoration) and has been used in an Australian government framework to inform Australia's NGHGI. Carbon credits generated from this abatement method can also be sold on the voluntary carbon market.

To compare the Aotearoa New Zealand national dataset to the Australian datasets, we extracted all relevant Australian measurements taken in a temperate climate (i.e. any data available from the states of

New South Wales, Victoria, Western Australia, South Australia and Tasmania) for mangroves, salt marsh and seagrass from Serrano et al. (2019) and Lovelock et al. (2023). To identify gaps in the Aotearoa New Zealand national dataset, we considered the scale and scope of the data and compared these against the Australian datasets. We considered the number of samples used to inform different measurements (i.e. CAR, SOC stock, ABG, below-ground biomass [BGB], GHG emissions) in each habitat. We also considered the spatial spread and representativeness of data across the Aotearoa New Zealand national dataset to determine whether the number of locations the data were derived from were proportional to the area of coastal wetland habitat at a regional scale. If regions with large extent of coastal wetland habitat had few or no samples, we identified these as a spatial gap. We compared this to the spatial spread of data in the two Australian datasets.

4.2 Results

Collection of target data

Data, both published and unpublished, for the Aotearoa New Zealand national dataset were obtained for all key measurements. Some data required additional adjustment from us to make them suitable for inclusion in the national dataset. For example, seagrass above-ground biomass data as grams/dry weight from the literature were converted to carbon stocks (i.e. AGB) using a conversion factor. Data were not included in the national dataset if they were unsuitable for compilation because the collection methods and / or laboratory analyses were not comparable. Additional reasons for not being able to compile some data included: data holder did not respond (even after follow-up), state of data formatting did not facilitate rapid compilation into the dataset, and permission to compile unpublished data was not granted.

Development of the Aotearoa New Zealand national dataset

Dataset overview

The key data obtained were compiled into the Aotearoa New Zealand national dataset (Bulmer et al. 2025; this report). The national dataset was in Excel file format, with a separate worksheet for each data measurement (Appendix 3 and see Table 3 for a summary). Note that all carbon-related data in the dataset are organic carbon. Metadata accompanying the data included: date of collection, sampling location, habitat type (e.g. saltmarsh, seagrass, mangrove), key species, measurement type, measurement unit, region, estuary, publication status, additional data notes including quality caveats, acknowledgements and key contact. Summaries of the dataset showing data measurement (and units), method and data resolution (e.g. core level vs site level) are shown in Table 3. The locations of dataset sampling points across the country and by measurement and habitat type are shown in Figures 1–3. Dataset summary values and number of sampling locations are shown below.

Where readily available, data for carbon stocks and CAR were compiled at the per-core level for carbon stocks (although some were available only at the site-average level). In contrast, data for ABG and BGB were compiled at the site-average level, as many datasets were available only in that format. For GHGs, few datasets were available, and these were averaged at sampling event and / or site level (Table 3). Site was defined based on the authors' / data holder's original study, and in some cases, site-level data were averaged across multiple saltmarsh species. Using site-averaged data reduces noise in the data because it allows a standardised approach and ensures that data from one site are not overrepresented compared to others (e.g. core-level vs site-level data). The number of sampling points per study varied widely (e.g. in one GHG study more than 100 samples were collected at one study site, whereas others had only three samples).

Most data within the Aotearoa New Zealand national dataset are already published, giving them the highest credibility as specified by the carbon abatement methods (e.g. IPCC, VERRA VM0033). However, some data were sourced from technical reports or student theses, or are unpublished. Technical reports and student theses are likely to have been put though a review process, giving some confidence, although this process is not necessarily as robust as that required for scientific publication. Unpublished data have the lowest confidence given they may not have undergone any review process.

Note that some data, such as habitat maps, did not meet our criteria for compilation into the national dataset. However, we document their existence in the compiled metadata and their potential importance for informing carbon abatement methods or inventories (Appendix 2).

Summary of dataset values

The mean, standard error, minimum, maximum, median and number of samples were summarised for each key measurement type in the Aotearoa New Zealand national dataset (Appendix 4, with default values for carbon abatement methods for comparison in Appendix 5). In addition, to facilitate gap analysis (see Section 5), comparable data were generated for the Australian datasets underpinning the BlueCAM, namely data from Lovelock et al. (2023) and Serrano et al. (2019). Here, we briefly summarise general trends in the datasets based on median values that were used to align with default values in BlueCAM (as per Lovelock et al. 2023).

Soil organic carbon accumulation rates (CARs) were highly variable between and within datasets, ranging from 0.16 Mg C $ha^{-1}·yr^{-1}$ to 2.89 Mg C $ha^{-1}·yr^{-1}$ in the Aotearoa New Zealand national dataset, and 0.03 Mg C $ha^{-1}·yr^{-1}$ to 4.26 Mg C $ha^{-1}·yr^{-1}$ in the Australian datasets.[6] Within the Aotearoa New Zealand national dataset, median saltmarsh CAR (0.59 Mg C $ha^{-1}·yr^{-1}$) was 1.5 times that of mangrove (0.39 Mg C $ha^{-1}·yr^{-1}$), while seagrass CAR was relatively low (noting that very few data were available for seagrass). Differences in the median CAR were observed between the Lovelock et al. (2023) and Serrano et al. (2019) datasets; however, mangrove had the highest mean CAR in both compilations (Figures 4–6). The IPCC default values for saltmarsh and mangrove CAR were higher than the Australian and Aotearoa New Zealand datasets (Appendix 5).

Soil organic carbon (SOC) stock was higher in the Australian dataset than in the Aotearoa New Zealand national dataset, likely in part due to differences in core depth, with the Australian cores being standardised to 1 m depth whereas the Aotearoa New Zealand cores were generally collected to 50 cm depth or less. In Aotearoa New Zealand, the highest soil carbon stocks were observed in saltmarsh (median of 54.1 Mg C ha^{-1}), followed by mangroves (35.6 Mg C ha^{-1}), then seagrass (17.3 Mg C ha^{-1}), noting that very few data were available for seagrass. In Australia, the highest median SOC stocks were

[6] Mg = megagram. Mg C $ha^{-1}·yr^{-1}$ is equivalent to tonnes per hectare per year.

observed in mangroves (234.9 Mg C ha^{-1}), followed by saltmarsh (141.0 Mg C ha^{-1}), then seagrass (82.4 Mg C ha^{-1}) (Figure 7).

For all datasets, above-ground biomass (AGB) was approximately 10-fold higher for mangroves than saltmarsh, while seagrass had minimal AGB (> 0.5 Mg C ha^{-1}). This was not unexpected given the volume of biomass and the presence of woody AGB in mangroves. AGB was consistently higher in the Australian dataset than in the Aotearoa New Zealand national dataset for all habitats (Figure 8). There were more mangrove sampling points in the Aotearoa New Zealand national dataset (*n* = 105) than the Australian dataset (*n* = 9) and high variability was observed within each dataset (e.g. AGB for mangrove in Aotearoa New Zealand ranged from > 0.1–84 Mg C ha^{-1} and in Australia from 7.1–128.4 Mg C ha^{-1}).

Limited data were available to inform GHG emissions (CH_4, N_2O) from both the Australian and Aotearoa New Zealand datasets (i.e. three sites or fewer per habitat type) and all datasets contain some unpublished data. No data on N_2O emissions were available to include in the Aotearoa New Zealand dataset. From the limited data available, CH_4 emissions for saltmarsh were higher in the Aotearoa New Zealand national dataset than the Australian datasets (Figure 9), noting there are some quality caveats for the Aotearoa New Zealand data. However, both of these CH_4 emissions values were much lower than the IPCC default values (Appendix 5).

Table 3. Overview of data measurements in the Aotearoa New Zealand national dataset for coastal wetland blue carbon. See Figures 4–9 for the number of sampling points for each measurement type per habitat type. Mg = megagram (Mg C ha^{-1} is equivalent to tonnes per hectare).

Measurement type (and unit)	Method	Data resolution
Soil organic carbon (SOC) stocks (Mg C ha^{-1})	Soil samples, treated and analysed by elemental analysis to determine organic carbon content.	Per core (but some data means per site)
Soil organic carbon accumulation rate (CAR) (Mg C ha^{-1}·yr^{-1})	Combination of soil ageing and organic carbon analysis of soil core. Various age–depth modelling approaches used. Soil CAR based on time frames ranging from 20 to 100 years.	Per core
Below-ground biomass (BGB) (Mg C ha^{-1})	Various methods, including soil cores with root mass extracted and converted to carbon stocks.	Mean per site
Above-ground biomass (ABG) (Mg C ha^{-1})	Plant abundance, height and / or percentage cover estimated from counts or from collected biomass (seagrass). Data converted to biomass or carbon based on allometric equations from published data (salt marsh, mangrove).	Mean per site
Greenhouse gas (GHG) (methane [CH_4], nitrous oxide [N_2O], carbon dioxide [CO_2]) (flux, mg·m^{-2}·day^{-1})	Various methods, including: • Small or large dark incubation chambers during tidal emergence. Measured using a GHG analyser. • A West Systems diffuse flux meter (dark chamber) used to measure CH_4 flux rates from the surface of the sample areas. A Tedlar® bag gas sampling rig used to take gas samples from the chamber.	Mean per site or per sampling event / site (depending on source data)

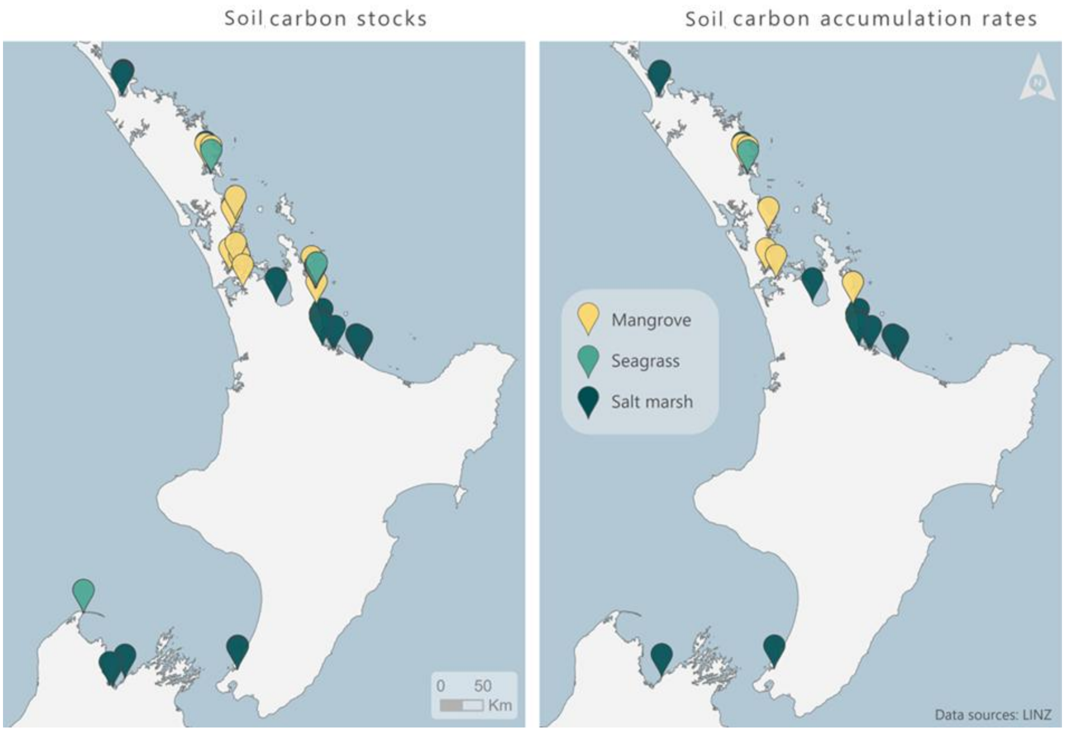

Figure 1. The sites and coastal wetland type for soil organic carbon (SOC) stocks and carbon accumulation rate (CAR) data (left and right, respectively) included within the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study).

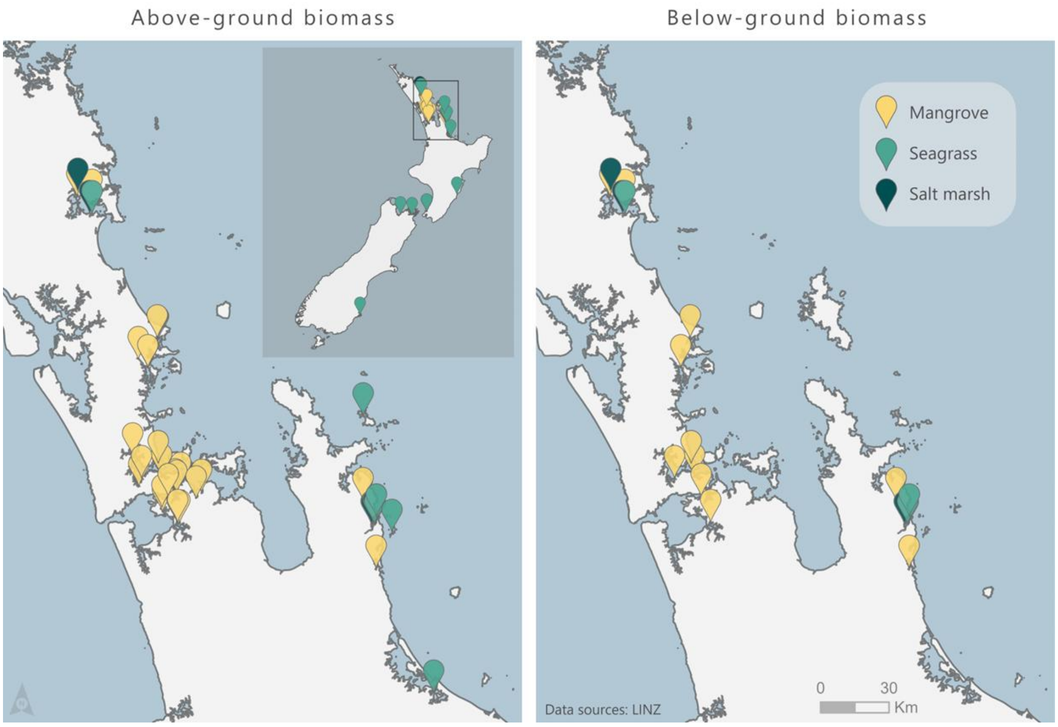

Figure 2. The sites and coastal wetland type for above-ground biomass (AGB) and below-ground (BGB) biomass data (left and right, respectively) included within the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study).

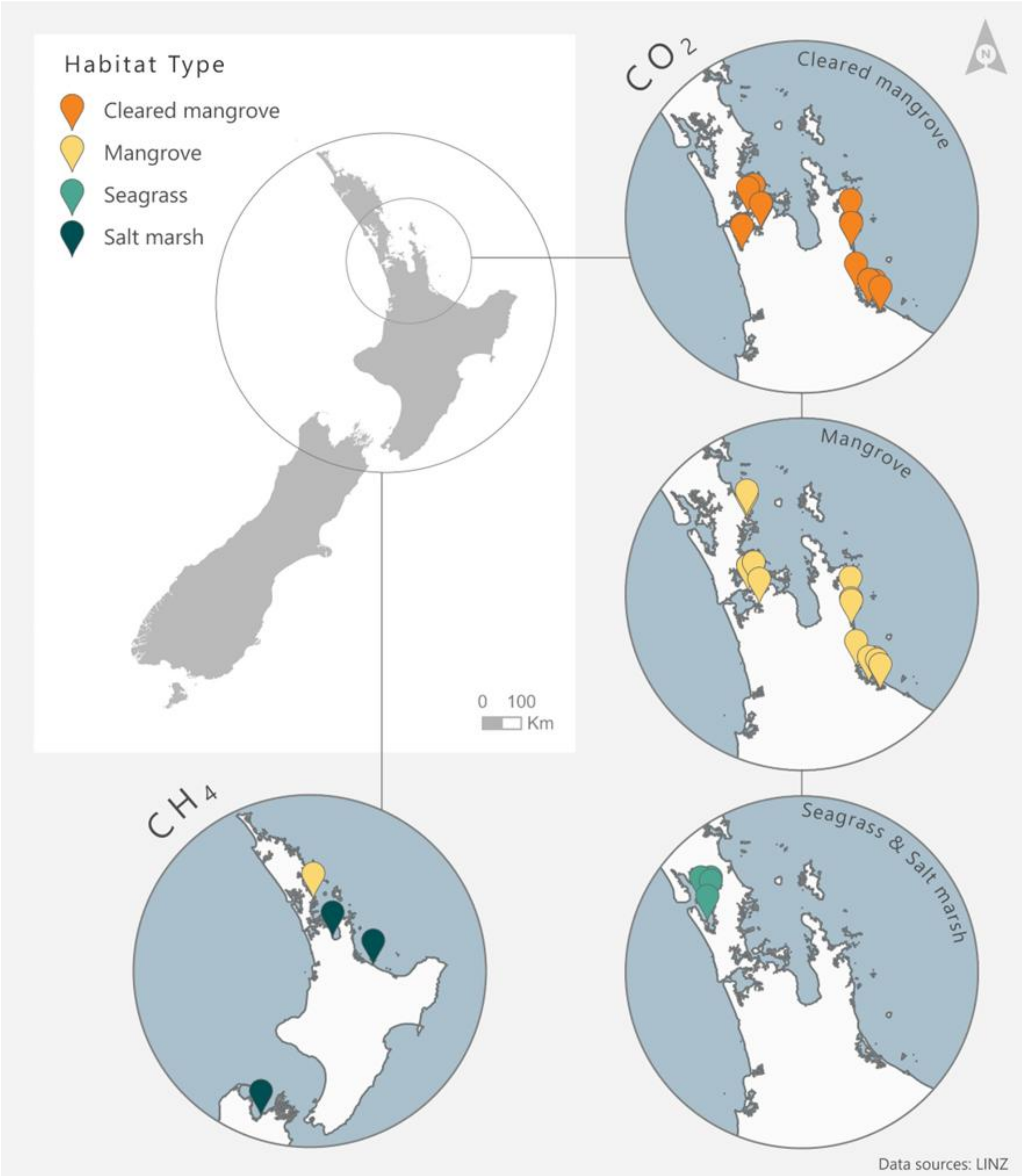

Figure 3. The sites and coastal wetland type for greenhouse gas (GHG) data (methane [CH_4] and carbon dioxide [CO_2]) within the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study).

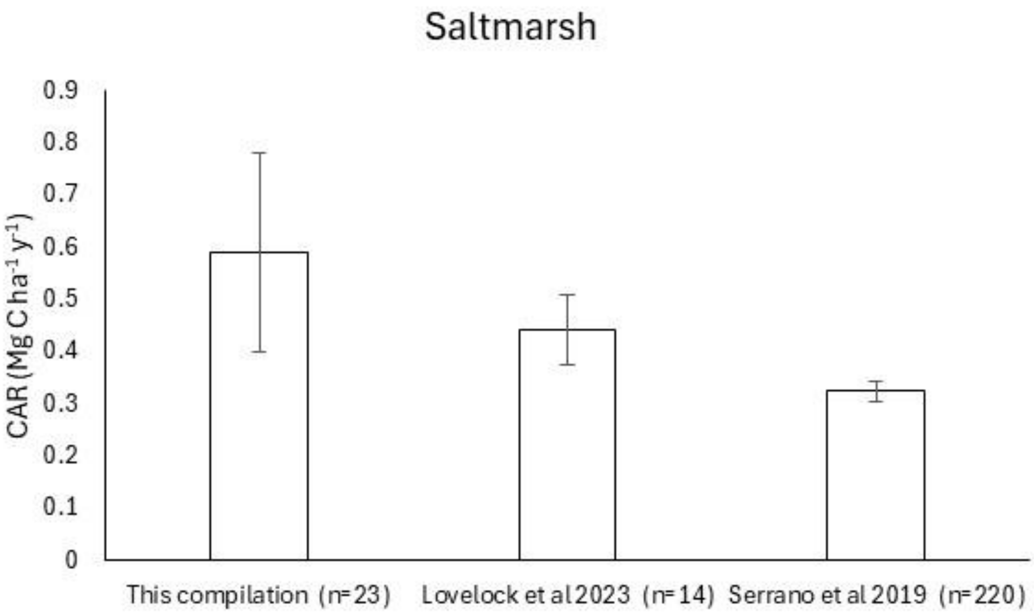

Figure 4. Median values (± SE) for soil organic carbon accumulation rate (CAR) for salt marsh. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and Australian datasets in Lovelock et al. (2023) and Serrano et al. (2019). n = number of sampling points.

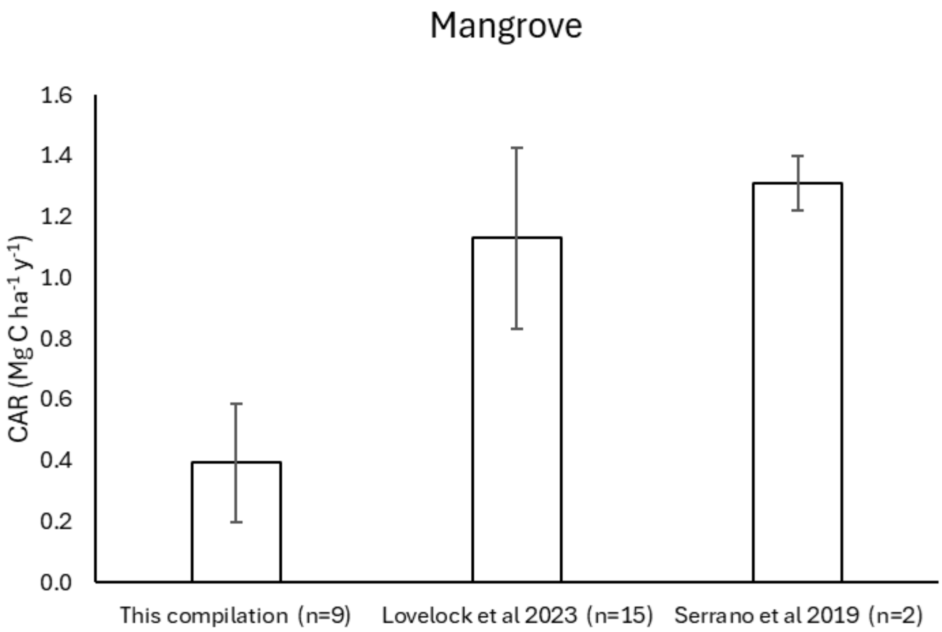

Figure 5. Median values (± SE) for soil organic carbon accumulation rate (CAR) for mangroves. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and Australian datasets in Lovelock et al. (2023) and Serrano et al. (2019). n = number of sampling points.

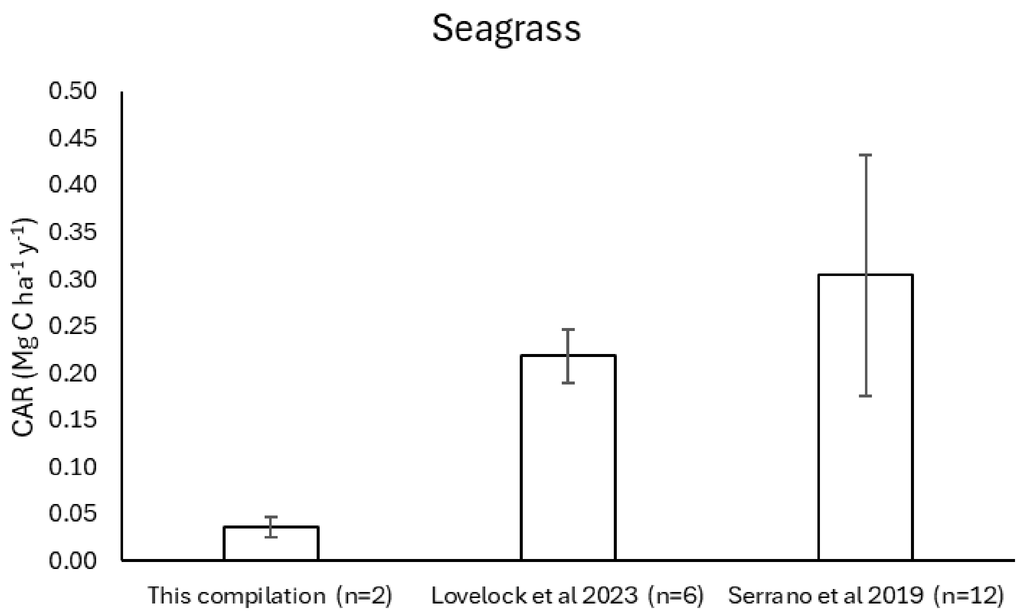

Figure 6. Median values (± SE) for soil organic carbon accumulation rate (CAR) for seagrass. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and Australian datasets in Lovelock et al. (2023) and Serrano et al. (2019). n = number of sampling points.

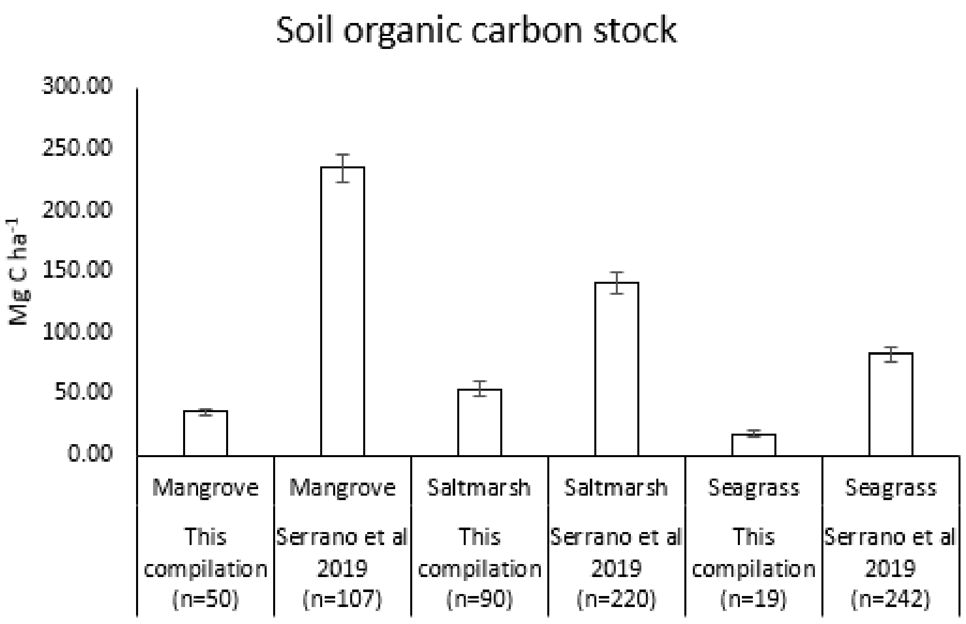

Figure 7. Median values (± SE) for soil organic carbon (SOC) stocks for mangrove, salt marsh and seagrass. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and the Australian dataset in Serrano et al. (2019). n = number of sampling points.

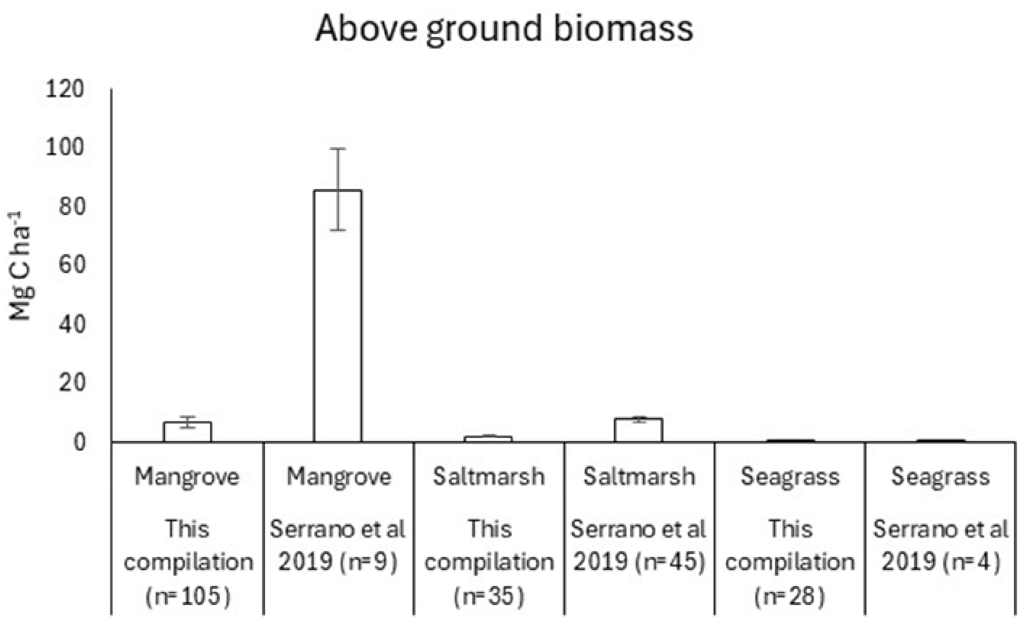

Figure 8. Median values (± SE) for above-ground biomass (AGB) for mangrove, salt marsh and seagrass. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and the Australian dataset in Serrano et al. (2019). n = number of sampling points.

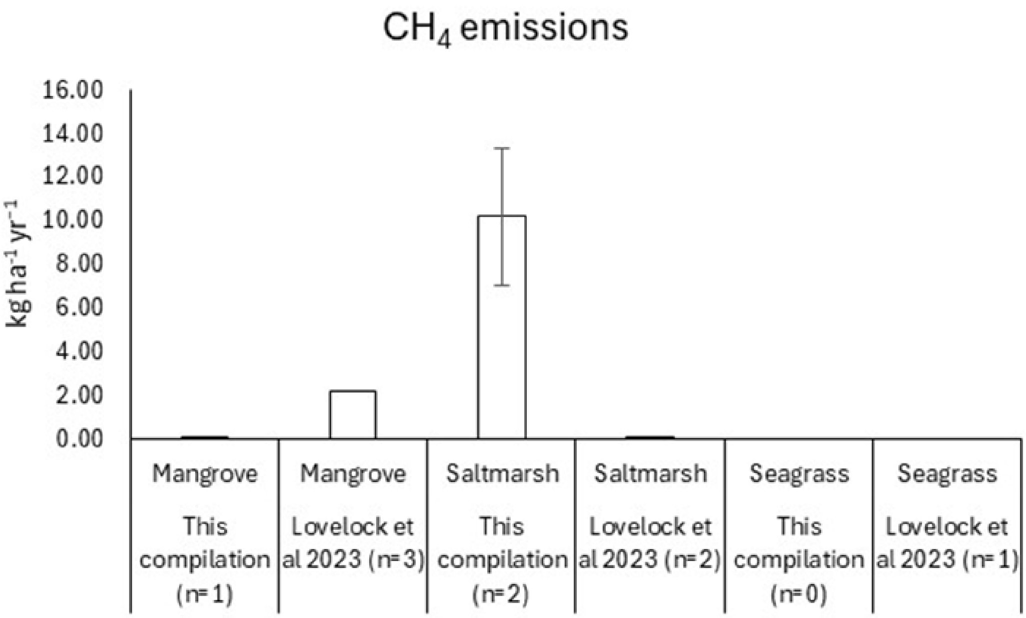

Figure 9. Median values (± SE) for methane (CH_4) emissions for mangrove, salt marsh and seagrass. Values are presented for the Aotearoa New Zealand national dataset for coastal wetland blue carbon (compiled in this study) and Australian datasets in Lovelock et al. (2023) and Serrano et al. (2019). n = number of sampling points. Note that there are some quality caveats for the Aotearoa New Zealand data.

Identification of gaps

Dataset sampling effort overall and across regions

The number of sampling points collected in the Aotearoa New Zealand national dataset versus the temperate Australian temperate datasets (Serrano et al. 2019 and Lovelock et al. 2023) were compared to identify data thresholds and gaps. These comparisons are detailed in the section above (including in Figures 4–9) and in Appendix 5. When the regional distributions of mangrove, salt marsh and seagrass were assessed against the current sample locations, key trends emerged (Table 4).

Overall, the Australian datasets had higher sampling numbers for all key data measurements except for salt marsh. For example, in Serrano et al. (2019), there were 234 CAR samples across habitats in temperate climates, while in Lovelock et al. (2023) there were 35 samples. In the Aotearoa New Zealand national dataset, we compiled 34 samples, although many of these were collected from salt marsh from only one region. For example, a total of 16 of the 21 CAR values for salt marsh were collected from the Bay of Plenty, despite this region containing only 624 ha of salt marsh (compared to a national extent of 20,932 ha), and only one measurement was collected from the South Island (despite the South Island containing 39.6% of all salt marsh extent). Similarly, mangroves are present only in the north of the North Island (a total of 30,533 ha), and the majority of mangroves occur in the Northland Region; however, only three CAR samples were available from the Northland Region (out of a total of nine mangrove samples, compared to the 15 samples included in Lovelock et al. [2023]). In addition, mangroves are found in the Bay of Plenty, yet no CAR samples were available from this region. Seagrass covers approximately 61,324 ha in Aotearoa New Zealand but was undersampled in the national dataset, with only two samples (both from the Northland Region) informing estimates of CAR.

Table 4. Information used to identify data gaps and prioritise data collection for soil carbon accumulation rate (CAR) to fill gaps in the Aotearoa New Zealand national dataset for coastal wetland blue carbon. The spatial extent of wetland type (mangrove, salt marsh, seagrass) from Bulmer et al. (2024) is shown as hectares (ha) per region. The number of cores for soil carbon accumulation rate (CAR) for which data are already compiled in the national dataset are presented in column 'CAR (*n*)'. In this column, the number of additional cores that would be needed to fill key gaps in the dataset are presented in brackets. Green boxes indicate under-represented / priority based on regional extent and current sampling effort. NI = North Island, SI = South Island.

Region	Mangroves (ha)	CAR (*n*)	Saltmarsh (ha)	CAR (*n*)	Seagrass (ha)	CAR (*n*)	Total (ha)
Northland	16,073	3 (4)	4,020	4	11,020	2	31,113
Auckland	9,237	3	3,123	(2)	20,631	(4)	32,990
Waikato	3,466	3	1,095	1	3,221		7,781
Bay of Plenty	1,758	(2)	624	16	4,405	(2)	6,788
Taranaki			10		231		241
Gisborne			78		44		122
Hawke's Bay			1,228		337		1,564
Manawatū-Whanganui			322		920		1,242
Wellington			63	1	914		977
Marlborough			1,494		2,216		3,710
Nelson			133	1	499		633
Tasman			2,086	(2)	9,458	(2)	11,544
West Coast			1,624	(4)	140		1,764
Canterbury			1,694	(4)	661		2,355
Otago			909	(2)	2,665	(2)	3,573
Southland			2,428	(2)	3,979	(2)	6,407
Total	30,533	9 (15)	20,932	21 (33)	61,340	2 (14)	112,806
% habitat NI	100		60.4		68		
% habitat in SI	0		39.6		32		
% samples NI (currently)	100		95.2		100		
% samples SI (currently)	0		4.8		0		
% samples NI (including proposed)	100		59.5		57.1		
% samples SI (including proposed)	0		40.5		42.9		

Dataset variability

High variability in the underpinning Australian and Aotearoa New Zealand datasets was observed for all carbon and GHG measurements, likely driven by factors such as tidal elevation / salinity, hydrodynamics, sedimentation, climate, site histories (e.g. age of forest / marsh), and habitat type. In practice, this means that the collection of additional data for Aotearoa New Zealand may not reduce the variability in the underpinning dataset. However, additional data will provide greater understanding of the key drivers of variability in the rates of carbon sequestration and GHG emissions within coastal wetland habitats and may facilitate accounting for this variation in national estimates moving forward (e.g. through modelling approaches).

Underlying variability is not unique to the blue carbon habitats or to those in Aotearoa New Zealand. Notably, Australian datasets, despite exhibiting similar variability, are used to inform the BlueCAM and their NGHGI, highlighting that such variability should not be seen as a hurdle to prevent management actions. Our gap analysis has therefore focused on developing a research plan to create a dataset with a comparable or greater number of samples than those used to inform Australia's BlueCAM. This plan also aims to account for regional habitat distributions and is tailored to facilitate additional exploration of, and better account for, the drivers of variability in the underpinning data moving forward. Determination of where and what type of data should be collected in the future to fill current gaps in the Aotearoa New Zealand national dataset is outlined in our research plan below (Section 5).

5. Research plan to complete the dataset

The final step for our study was to outline a research plan to fill gaps identified in the Aotearoa New Zealand national dataset. Our approach and results for this step are outlined below.

5.1 Approach

To develop a research plan to fill gaps in the Aotearoa New Zealand national dataset, we focused on the data measurement CAR. CAR was prioritised due to its importance across multiple carbon abatement methods, including IPCC guidelines, and because below-ground carbon storage represents the largest carbon pool for coastal wetlands (McLeod et al. 2011). Additionally, CAR sampling often coincides with collection of other relevant data, such as carbon stocks and biomass. In terms of sampling effort, we decided that that, at a minimum, our research plan should aim to match the number of CAR data sampling points in Lovelock et al. (2023) used to underpin the BlueCAM method (although this dataset had fewer sampling points than the Serrano et al. [2019] dataset for saltmarsh CAR). For saltmarsh habitats specifically, we recommended a higher number of CAR sampling points than Australia to allow regional gaps for Aotearoa New Zealand to be filled.

Our approach then prioritised the locations, measurement types and habitats (including consideration of environmental gradients within habitats) for taking these samples to maximise the robustness of the dataset while minimising sampling costs (see following paragraph). The current extent of coastal wetland habitats throughout the country was used to weight proposed sampling effort to fill gaps in the underpinning datasets. There was an element of subjectiveness needed to prioritise between some sites / regions, as decisions were not always clear-cut based on available information and were influenced by consideration of resource constraints. To guide future sampling, we also provide high-level information on recommended sampling methods and laboratory analyses, to ensure that the data collected align with those already compiled within the national dataset.

Note that our study scope, as defined by MfE and TNC NZ, required us to consider potential future resource constraints (i.e. funding available for data collection) when developing the research plan. Therefore, while we consider our research plan a robust approach to filling data gaps, it does not represent a full scientific perspective. For example, a purely science-led approach would likely involve more extensive sampling within and across sites to better understand data variability than we have outlined here. In addition, we have not detailed the site-scale methodology, such as how to stratify sampling design or the specific methodology to be applied. However, any future sampling should adhere to established best practice standards (Bansal et al. 2023; Howard et al. 2014)

5.2 Results

Research plan

Here, we provide high-level guidance to fill gaps in the Aotearoa New Zealand national dataset, aiming to at least match the sampling effort of the temperate Australian BlueCAM dataset. For further detail on designing high-quality sampling plans, we recommend following a standardised approach for fieldwork and laboratory analysis to enable alignment with the national dataset (see Bansal et al. [2023] and Howard et al. [2014] for examples of standardised approaches). Further, study teams should ideally demonstrate experience collecting and analysing measurements (e.g. CAR, allometry, GHG fluxes) from a range of coastal wetland habitat types, noting that estuarine and coastal environments provide unique challenges to data collection that can impact data collection and quality (such as tidal submergence, inaccessibility, health and safety).

Our research plan was informed by the spatial extent of coastal wetland types across regions and the number of data sampling points in the Aotearoa New Zealand national dataset relative to the Australian dataset (Table 4). Based on the Aotearoa New Zealand dataset, we identified regional gaps to be prioritised for CAR future data collection (Table 4). For mangroves, this recommendation was Northland (four cores) and Bay of Plenty (two cores). For seagrass, this recommendation was Bay of Plenty, Tasman, Otago and Southland (two cores each), and Auckland (four cores). For salt marsh, this recommendation was Auckland, Tasman, Otago and Southland (two cores each), and Canterbury and West Coast (four cores each).

Many measurements underpinning datasets for the BlueCAM (Lovelock et al. 2023) and Verra VM0033 (Chmura et al. 2003) abatement methods are based on only one CAR measurement per site (likely due to the expense of data collection). However, if possible when filling data gaps, we recommend that a minimum of two cores be collected at each sampling site (i.e. habitat type within an estuary) to better understand and address site-scale variability in the Aotearoa New Zealand national dataset. For example, one core could be collected from a higher tidal elevation zone that may be receiving lower sediment input than closer to the edge of a forest or marsh, where the second core could be prioritised. The purpose of the two cores is to collect within-site data to help understand variability occurring across smaller spatial scales (e.g. variability in sediment supply, age of wetland, salinity, elevation). We note that further details to guide sampling locations can be found in Bansal et al. (2023) and Howard et al. (2014).

Besides the collection of CAR data, at each sampling location we recommend that SOC stock, BGB (both required for CAR) and AGB data are also be collected. We note that BGB is typically aggregated into SOC and used to calculate CAR (Lovelock et al. 2023; Serrano et al. 2019). While allometric equations for mangroves in Aotearoa New Zealand are relatively well developed (Bulmer et al. 2016), only preliminary saltmarsh allometric equations exist (Bulmer et al. 2020). It is therefore recommended that, at a sub-set of locations, saltmarsh blades are also collected and analysed to generate robust allometric equations for the most dominant species (e.g. *Juncus kraussii*). The number of above-ground samples used should be sufficient to generate reliable equations, comparable to international studies (e.g. Butler et al. 2025). However, it is important to note that AGB in saltmarsh in Aotearoa New Zealand contributes relatively low amounts of carbon to total carbon sequestration rates and therefore should not be prioritised over CAR measurements (Bulmer et al. 2024).

In addition, given there are a limited amount of GHG data currently compiled within the Aotearoa New Zealand national dataset, we also recommend the collection of GHG data at a minimum of two further regions across the country, one in Northland and one in Southland, across multiple habitat types. This will help to capture potential climatic or latitudinal drivers of variation, while also prioritising the regions with some of the largest coastal wetland extent and habitat diversity for the North Island and South Island, respectively. These data will also help determine whether GHG emissions are minor in size, consistent with observations in Australian systems (Lovelock et al. 2023).

Our research plan follows a robust approach to filling key gaps in the Aotearoa New Zealand national dataset, guided by sampling effort benchmarks in the temperate Australian BlueCAM dataset while balancing potential funding constraints as per our study scope. However, if resources allow, additional samples collected over known environmental gradients (e.g. elevation / distance from edge, sedimentation and nutrient inputs, climate) and habitat distributions will improve data estimates further. Future sampling should be guided by the relevant carbon abatement method requirements and analysis of the existing dataset (e.g. if GHG measurements demonstrate that emissions of CH_4 and N_2O are minor, additional GHG measurements may not be required and resourcing may prioritise CAR). As identified in best practice guidance, sampling could be prioritised following a randomised stratified sampling process or other methods that consider the spatial distribution and extent of habitats of interest. We also note that mangrove and seagrass habitats will remain undersampled compared to their national extent in Aotearoa New Zealand, even after key gaps are filled. Therefore, future sampling efforts (beyond the research plan) should continue to reflect regional habitat extents, while noting that seagrass CAR values may remain low or be difficult to obtain and therefore may be a lower priority for further sampling compared to mangrove despite the large national extent of seagrass habitat.

Use of existing data and improving data confidence

Alongside future field collection, one potential avenue for sourcing data to meet the goals of the research plan is to gain permission to include any currently unpublished and suitable data from previous studies (e.g. data we were not granted permission to compile for this study and that were collected following methods that align with the Aotearoa New Zealand national dataset; see Appendix 2). One approach is to wait until data are made publicly available through publication. Key studies for which target data were still unpublished include Future Coasts Aotearoa (NIWA) for saltmarsh and mangrove CAR, and Hokianga Harbour sedimentation (GNS and Te Rarawa) for mangrove CAR and SOC stocks. Furthermore, published or reported studies that may contain target data but for which timely communication was not received by us or data were not readily available in a suitable format included McMahon (2023) for salt marsh / seagrass sediment carbon stocks, Yang et al. (2013) for mangrove sediment carbon stocks, Wei (2023) and Wei et al. (2024a,b) for mangrove sediment carbon stocks, and Tran et al. (2016) for mangrove AGB. There are also some older studies (pre-2010) containing seagrass biomass data as grams per dry weight that could be collated and converted to carbon stock pending suitable data values (e.g. mean per site) being available (e.g. a list of studies containing seagrass biomass data is included in Clark and Crossett [2019]). There may also be some data collection already planned under existing studies, and those results, once available, could contribute to completing the research plan. At the time of developing the research plan, the scope and suitability of unpublished or planned data were unknown, as detailed metadata (e.g. on core sampling locations) were not available.

Furthermore, to increase credibility in the Aotearoa New Zealand national dataset, data that were sourced from unpublished sources, technical reports and student theses should be supported for publication if suitable and where publication in peer-reviewed journals is not already planned. This would subject the data to the rigorous peer-review process required by scientific journals, thereby increasing their reliability and ensuring they are viewed as highest-confidence data under the carbon abatement methods.

6. Appendices

Appendix 1. Selected carbon abatement methods and relevant data

The carbon abatement methods for coastal wetlands selected in our study to inform development of the Aotearoa New Zealand national dataset for coastal wetland blue carbon. Data relevant for quantification of carbon stocks and sequestration and greenhouse gas (GHG) emissions are also outlined. This table is provided as a separate electronic file in Excel format.

Appendix 2. Compiled metadata on existing coastal wetland blue carbon data

Compiled metadata on existing data for coastal wetland and estuarine blue carbon in Aotearoa New Zealand. Metadata were sourced from Kettles et al. (2024) or collated during our study. This table is provided as a separate electronic file in Excel format.

Appendix 3. Aotearoa New Zealand national dataset for coastal wetland blue carbon

The Aotearoa New Zealand national dataset for coastal wetland blue carbon (Bulmer et al. 2025; this report). There is a separate worksheet for each of the five data measurements: soil carbon (SOC) stocks, soil carbon accumulation rate (CAR), above-ground biomass (AGB), below-ground biomass (BGB) and greenhouse gas (GHG, including methane [CH_4], nitrous oxide [N_2O] and carbon dioxide [CO_2]). Note that all carbon-related data in the dataset are organic carbon. The dataset is provided as separate electronic files in Excel format.

Appendix 4. Summary values for key carbon-related measurements from the Aotearoa New Zealand national dataset

Summary values for key carbon-related measurements from the Aotearoa New Zealand national dataset for coastal wetland blue carbon (this compilation) and Australian datasets informing BlueCAM (Lovelock et al. 2023; Serrano et al. 2019). SE = standard error, min = minimum, max = maximum, *N* = number of sampling points, NZ = New Zealand, C = carbon, CAR = soil organic carbon accumulation rate, SOC = soil organic carbon, AGB = above-ground biomass, BGB = below-ground biomass, Mg = megagrams, ha = hectares, y = year, kg = kilograms, CH_4 = methane, N_2O = nitrous oxide, CO_2 = carbon dioxide. Note that there are some quality caveats for the Aotearoa New Zealand GHG (for CH_4) data for salt marshes.

Country	Source	Measurement	Habitat	Mean	SE	Min	Max	Median	*N*	Method
Temperate Aotearoa NZ	This compilation	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Salt marsh	1.08	0.19	0.16	2.89	0.59	23	Radiometric dating
Temperate Aotearoa NZ	This compilation	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Mangrove	0.64	0.20	0.22	2.12	0.39	9	Radiometric dating
Temperate Aotearoa NZ	This compilation	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Seagrass	0.04	0.01	0.03	0.05	0.04	2	Radiometric dating
Temperate Australia	Lovelock et al. 2023	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Salt marsh	0.43	0.07	0.13	1.03	0.44	14	Radiometric dating
Temperate Australia	Lovelock et al. 2023	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Mangrove	1.49	0.30	0.26	4.26	1.13	15	Radiometric dating
Temperate Australia	Lovelock et al. 2023	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Seagrass	0.21	0.03	0.12	0.30	0.22	6	Radiometric dating
Temperate Australia	Serrano et al. 2019	CAR ($Mg\ C{\cdot}ha^{-1}\ y^{-1}$)	Salt marsh	0.40	0.02	0.03	1.34	0.32	220	Radiometric dating
Temperate Australia	Serrano et al. 2019	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Mangrove	1.31	0.09	1.22	1.40	1.31	2	Radiometric dating
Temperate Australia	Serrano et al. 2019	CAR ($Mg\ C{\cdot}ha^{-1}{\cdot}y^{-1}$)	Seagrass	0.50	0.13	0.12	1.41	0.30	12	Radiometric dating

Country	Source	Measurement	Habitat	Mean	SE	Min	Max	Median	*N*	Method
Temperate Aotearoa NZ	This compilation	AGB ($Mg\ C{\cdot}ha^{-1}$)	Salt marsh	2.36	0.26	0.88	8.78	2.07	35	Allometric equations
Temperate Aotearoa NZ	This compilation	AGB ($Mg\ C{\cdot}ha^{-1}$)	Mangrove	13.54	1.69	0.05	84.88	6.90	105	Allometric equations
Temperate Aotearoa NZ	This compilation	AGB ($Mg\ C{\cdot}ha^{-1}$)	Seagrass	0.13	0.02	0.01	0.50	0.11	28	Allometric equations
Temperate Australia	Serrano et al. 2019	AGB ($Mg\ C{\cdot}ha^{-1}$)	Salt marsh	8.41	0.90	0.43	23.66	7.78	45	Allometric equations
Temperate Australia	Serrano et al. 2019	AGB ($Mg\ C{\cdot}ha^{-1}$)	Mangrove	70.44	13.68	7.10	128.40	86.00	9	Allometric equations
Temperate Australia	Serrano et al. 2019	AGB ($Mg\ C{\cdot}ha^{-1}$)	Seagrass	0.27	0.10	0.09	0.53	0.23	4	Allometric equations
Temperate Aotearoa NZ	This compilation	SOC stock ($Mg\ C{\cdot}ha^{-1}$ variable depth)	Salt marsh	66.36	5.65	0.97	420.70	54.09	90	Soil organic carbon analyser
Temperate Aotearoa NZ	This compilation	SOC stock ($Mg\ C{\cdot}ha^{-1}$ variable depth)	Mangrove	40.55	2.78	9.75	85.85	35.56	50	Soil organic carbon analyser
Temperate Aotearoa NZ	This compilation	SOC stock ($Mg\ C{\cdot}ha^{-1}$ variable depth)	Seagrass	18.26	2.58	4.11	54.70	17.30	19	Soil organic carbon analyser
Temperate Australia	Serrano et al. 2019	SOC stock ($Mg\ C{\cdot}ha^{-1}$ in 1 m-thick soil)	Salt marsh	172.50	8.15	13.93	581.43	140.95	220	Soil organic carbon analyser
Temperate Australia	Serrano et al. 2019	SOC stock ($Mg\ C{\cdot}ha^{-1}$ in 1 m-thick soil)	Mangrove	247.25	11.18	26.66	571.75	234.94	107	Soil organic carbon analyser
Temperate Australia	Serrano et al. 2019	SOC stock ($Mg\ C{\cdot}ha^{-1}$ in 1 m-thick soil)	Seagrass	113.04	6.13	6.49	609.71	82.40	242	Soil organic carbon analyser

Country	Source	Measurement	Habitat	Mean	SE	Min	Max	Median	*N*	Method
Temperate Aotearoa NZ	This compilation	CH_4 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Salt marsh	15.759	3.13	-40.15	73.73	10.22	2	Greenhouse gas analyser and benthic flux chamber
Temperate Aotearoa NZ	This compilation	CH_4 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Mangrove	0.04	0.00	0.00	0.20	0.02	1	Greenhouse gas analyser and benthic flux chamber
Temperate Aotearoa NZ	This compilation	CH_4 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Seagrass							
Temperate Aotearoa NZ	This compilation	N_2O flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Salt marsh							
Temperate Aotearoa NZ	This compilation	N_2O flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Mangrove							
Temperate Aotearoa NZ	This compilation	N_2O flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Seagrass							
Temperate Aotearoa NZ	This compilation	CO_2 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Salt marsh							
Temperate Aotearoa NZ	This compilation	CO_2 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Mangrove	24,646.83	6,478.15	9.82	101,313.50	20,673.93	15	Greenhouse gas analyser and benthic flux chamber
Temperate Aotearoa NZ	This compilation	CO_2 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Seagrass	11,524.55	2,159.99	3,911.96	19,455.45	9,417.26	7	Greenhouse gas analyser and benthic flux chamber
Temperate Aotearoa NZ	This compilation	CO_2 flux ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Cleared mangrove	24,937.42	6,035.56	1,108.40	115,192.43	19,420.96	21	Greenhouse gas analyser and benthic flux chamber
Temperate Australia	Lovelock et al. 2023	Emissions CH_4 ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Salt marsh			-0.21	0.44	0.11	2	Greenhouse gas analyser and benthic flux chamber
Temperate Australia	Lovelock et al. 2023	Emissions CH_4 ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Mangroves			0.91	3.31	2.19	3	Greenhouse gas analyser and benthic flux chamber
Temperate Australia	Lovelock et al. 2023	Emissions CH_4 ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Seagrass					0.00	1	Greenhouse gas analyser and benthic flux chamber
Temperate Australia	Lovelock et al. 2023	Emissions N_2O ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Salt marsh			0.02	0.23	0.13	2	Greenhouse gas analyser and benthic flux chamber

Country	Source	Measurement	Habitat	Mean	SE	Min	Max	Median	*N*	Method
Temperate Australia	Lovelock et al. 2023	Emissions N_2O ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Mangrove			0.17	2.75	0.24	3	Greenhouse gas analyser and benthic flux chamber
Temperate Australia	Lovelock et al. 2023	Emissions N_2O ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Seagrass					0.00	1	Greenhouse gas analyser and benthic flux chamber
Temperate Aotearoa NZ	This compilation	BGB ($Mg\ C \cdot ha^{-1}$)	Salt marsh	34.42	0.59	33.39	35.45	34.42	4	Core sample analysis
Temperate Aotearoa NZ	This compilation	BGB ($Mg\ C \cdot ha^{-1}$)	Mangrove	18.19887	1.102634	1.539179	35.45	18.25633	66	Core sample analysis
Temperate Aotearoa NZ	This compilation	BGB ($Mg\ C \cdot ha^{-1}$)	Seagrass	2.995	0.561108	1.99	4.57	2.71	4	Core sample analysis

Appendix 5. Comparison with default values for soil carbon stocks and accumulation and greenhouse gas fluxes

Comparison of Aotearoa New Zealand (this compilation), Australian Tidal Introduction BlueCAM approach, and IPCC Tier 1 default values for soil carbon stocks and accumulation, and greenhouse gas (GHG) fluxes. Extract from BlueCAM technical overview https://cer.gov.au/document/blue-carbon-accounting-model-bluecam-technical-overview. Licensed from the Clean Energy Regulator, Commonwealth of Australia, under a Creative Commons Attribution 4.0 licence. All Australian BlueCAM and Aotearoa New Zealand national dataset values are medians, except for above-ground biomass values, which are means. C = carbon, ha = hectare, y = year, kg = kilogram, NA = not applicable.

	IPCC Approach / Tier 1 value Australia BlueCAM approach / emission factor	Australia BlueCAM approach / emission factor	Aotearoa New Zealand national dataset (this compilation)
Above-ground biomass (ABG; tonnes C·ha^{-1})			
Mangrove biomass	NA	70.4	13.54
Saltmarsh biomass	Use country-specific values	7.89	2.36
Seagrass biomass	Use country-specific values	0.57	0.13
Soil organic carbon accumulation rate (CAR; tonnes C·ha^{-1}·yr^{-1})			
Mangrove soil carbon accumulation	1.63	0.95	0.39
Saltmarsh soil carbon accumulation	0.91	0.48	0.59
Seagrass soil carbon accumulation	0.43	0.61	0.04
Greenhouse gas (GHG [methane, nitrous oxide]; kg·ha^{-1}·yr^{-1})			
Mangrove methane emissions	193.7	2.19	0.02
Saltmarsh methane emissions	193.7	0.11	10.22
Seagrass methane emissions	NA	0	No data
Mangrove nitrous oxide emissions	NA	0.24	No data
Saltmarsh nitrous oxide emissions	NA	0.13	No data
Seagrass nitrous oxide emissions	NA	0	No data

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