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Beyond Blue Carbon: Estimating the Value of Ecosystem Services Provided by Coastal Wetlands in Aotearoa New Zealand

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ABSTRACT

Blue carbon ecosystems (BCE), including mangroves, saltmarshes, and seagrasses, provide essential functions and services globally but are increasingly challenged by climate change and other anthropogenic activities. In Aotearoa New Zealand (Aotearoa NZ), there is mounting interest in blue carbon as a nature-based solution to climate change. Quantifying the monetary co-benefits of BCE, in addition to carbon sequestration, can help illustrate the relative contribution of ecosystem services provided by existing habitats, as well as the potential additional value associated with restoration. Here, we estimated the value of provisioning, regulating, and cultural ecosystem services provided by BCE in Aotearoa NZ. We found that the most valuable ecosystem service provided by mangroves was carbon sequestration, while in saltmarsh and seagrass, the most valuable ecosystem services were waste treatment and existence, bequest values, respectively. Unit monetary valuations of ecosystem services range from NZD 3 ha^{-1} yr^{-1} (water flow regulation) to NZD 32,590 ha^{-1} yr^{-1} (climate regulation) for mangroves, NZD 8 ha^{-1} yr^{-1} (spiritual experience) to NZD 23,045 ha^{-1} yr^{-1} (waste treatment) for saltmarshes, and NZD 3 ha^{-1} yr^{-1} (water regulation) to NZD 14,512 ha^{-1} yr^{-1} (existence, bequest values) for seagrasses. The estimated national potential monetary value of ecosystem services provided by current habitats ranges from NZD 0.8–995 million yr^{-1} for mangroves (30,533 ha nationally), NZD 0.2–482 million yr^{-1} for saltmarshes (20,932 ha nationally), and NZD 0.2–216 million yr^{-1} for seagrasses (61,340 ha nationally). If drained areas were restored from drained agricultural use, values would increase accordingly. These results apply the benefit transfer approach (applying monetary values from analogous temperate ecosystems globally to estimate values in Aotearoa NZ) to generate indicative monetary benchmarks, which can help inform discussions around investment in BCE and long-term coastal climate change adaptation decision-making in Aotearoa NZ.

1 | Introduction

Blue carbon ecosystems (BCE) such as mangroves, saltmarshes, and seagrasses are widely distributed along global coasts and provide significant ecosystem services and functions globally (Araya-López et al. 2024). BCE act as carbon sinks by sequestering carbon in their above- and below-ground biomass (Chen et al. 2024) to remove anthropogenic CO_2 emissions, and as such are recognised as nature-based solutions for mitigating climate change (Erwin 2009; Duarte et al. 2013; Serrano et al. 2019; Doelle et al. 2023). BCE also provide other ecosystem services (i.e., co-benefits) in addition to carbon sequestration, including

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coastal protection, supporting biodiversity via providing food for species, nursery functions for other species, and water purification services (Drius et al. 2016, Díaz et al. 2019).

BCE are increasingly under pressure from environmental stressors (e.g., land use change, agricultural and grazing expansion, altered hydrology, and declining water quality (e.g., Boon et al. 2015, Davidson et al. 2018, Fluet-Chouinard et al. 2023) and exacerbated by climate-related factors (e.g., sea level rise and warming: Harley et al. 2006, Lu et al. 2018, Araya-López et al. 2024). These pressures have led to BCE degradation, biodiversity loss, and a decline in their ability to provide crucial ecosystem functions (Araya-López et al. 2024). Worldwide, an estimated 25%–50% of coastal BCE extent has been lost or degraded (Duarte et al. 2013). A similar trend occurs in Aotearoa New Zealand (hereafter Aotearoa NZ), where only 18.4% of saline wetland habitats remain compared to their historic pre-human extent (Ausseil et al. 2011). In Aotearoa NZ, historic losses are mostly due to drainage and land use changes for agricultural purposes (McGlone 2009, Marden et al. 2012, Julian et al. 2017, Curran-Cournane et al. 2024).

BCE restoration has the potential to be an important nature-based solution to climate change by creating buffer zones for coastal erosion, providing storm protection, and carbon sequestration. Therefore, establishing a framework to encourage the behaviour of funding BCE restoration is essential for designing climate change adaptation strategies (Jones et al. 2012, Wainger et al. 2017, Leo et al. 2019, Xu et al. 2024). Despite growing interest in conserving and restoring BCE for climate change mitigation (Ministry for the Environment 2022), Aotearoa NZ currently lacks a market for BCE or a policy framework for the ecosystem services market. The existing carbon market remains limited to terrestrial forestry, primarily non-native pine plantations (Bertram et al. 2021), and at present, the price of carbon credits is not high enough to offset the opportunity cost of restoring coastal wetlands (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024).

Unlike pine forestry, blue carbon projects are typically associated with positive impacts (co-benefits) and assigning monetary value to these co-benefits can help support incentives and decision-making by landowners to restore and protect coastal ecosystems. Quantifying ecosystem services in monetary terms may help support the development of blue carbon and other emerging ecosystem service markets, diversify funding, and encourage large-scale restoration and conservation of BCE in Aotearoa NZ. One possible approach is to 'stack' or 'add-on' ecosystem service values (i.e., combining the carbon value with other ecosystem service values per unit area) to increase payments for the restoration and conservation of BCE (Robertson et al. 2014). At present, there is limited research into the monetary value of ecosystem services in BCE in Aotearoa NZ; however, there is some research that quantifies the role of BCE in some ecosystem services, for example, as nursery habitats and sources of food (Parsons et al. 2016, Parsons et al. 2020).

In this research, we aimed to deliver the first step towards assessing indicative monetary estimates of the ecosystem services provided by BCE, including carbon sequestration, for mangrove, saltmarsh, and seagrass in Aotearoa NZ. This research is especially important in the context of global goals for reducing greenhouse gas emissions (Paris Agreement) and reversing biodiversity loss (The Kunming-Montreal Global Biodiversity Framework).

2 | Method

We used an interdisciplinary approach to link biophysical habitat mapping with the monetary valuation of ecosystem services (Figure 1). To assess the value of the co-benefits provided by BCE in Aotearoa NZ, we followed three steps:

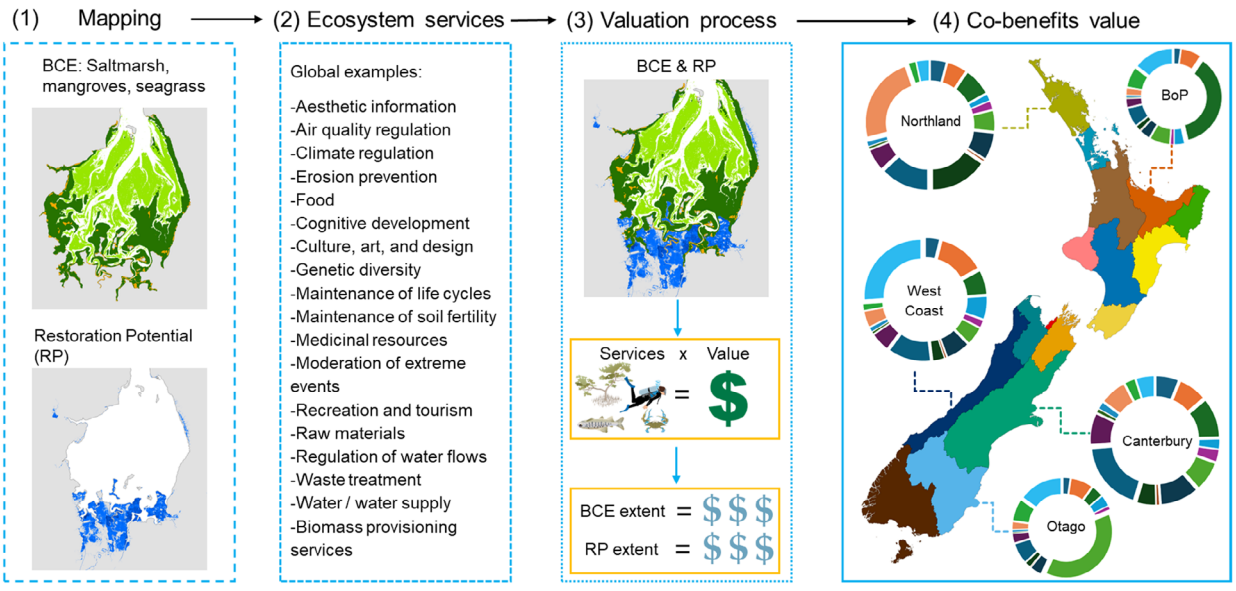


FIGURE 1 | Schematic of the four steps used in the Blue Carbon Ecosystem services monetisation framework. (1) spatial mapping of BCE habitat (current BCE habitat (top) and potentially restored BCE habitat (bottom); (2) evaluation of ecosystem services provided by each BCE habitat; (3) the valuation process; and (4) co-benefit value summaries (e.g., for different regions in Aotearoa NZ; BoP: Bay of Plenty). The different colours in the regional circle plots represent the different ecosystem service valuations.

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1. Extracted data on the extent of current BCE areas (mangroves, saltmarsh, and seagrass) and potential areas for future restoration.
2. Extracted data on ecosystem services for each BCE, calculated a global average monetary value per unit area for each ecosystem service for each BCE, and used the benefit transfer method to apply to Aotearoa NZ.
3. Calculated the total current and potential (via restoration) value of the BCE regionally and nationally for each ecosystem service.

2.1 | Spatial Extent of BCE

To determine (1) the current spatial distribution and (2) potential areas for future restoration of BCE co-benefits in Aotearoa NZ, we extracted extent data from recently published maps of the current distribution of BCE in Aotearoa NZ (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024). These spatial data layers included a breakdown of habitat distributions at a regional scale ($n = 16$). Significant variation exists in the extent of different BCE between regions due to the presence or absence of large estuarine areas.

Current spatial distributions and potential areas for future restoration of BCE were identified from remote sensing using machine learning approaches (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024). Potential restoration areas were split into tidal zones to determine the BCE ecosystem type suitable for restoration at each site (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024). Future sea level rise scenarios were not factored in when identifying the potential restoration areas.

2.2 | Value of Ecosystem Services in BCE

To estimate ecosystem service values using a benefit transfer approach (applying monetary values from analogous temperate ecosystems globally to estimate values in Aotearoa NZ), we extracted international data from the Ecosystem Services Valuation Dataset (ESVD: https://www.esvd.net/) for each BCE due to a lack of locally available data. The ESVD is a global database containing 10,874 ecosystem service value records from over 1100 studies distributed across all biomes, ecosystem services, and geographic regions.

We have identified relevant types of ecosystem services (23 services across four categories; Table 1) from the ESVD database that are appropriate for New Zealand's temperate climate and applicable to Aotearoa New Zealand's BCE habitats, ecosystems, and species. As this is a published international database containing ecosystem services that are identified or potentially implemented in other contexts, some services may not be applicable to Aotearoa NZ or may not be currently realised (e.g., medicinal resources derived from mangroves are not presently utilised in Aotearoa NZ and therefore remain a potential service). Consequently, our ecosystem service valuation estimates may be overstated. We applied the benefit transfer method to estimate the value of Aotearoa NZ's BCE as a benchmark, with the aim of assigning indicative monetary values rather than implying that these ecosystems are intrinsically worth those amounts.

The monetary value of ecosystem services was estimated in the ESVD using various methods, such as willingness to pay for water quality (Duijndam et al. 2020) and recreational experiences (Rojas et al. 2019), storm protection values (Duijndam et al. 2020), carbon sequestration calculated by multiplying carbon measurements by carbon prices (Guarderas et al. 2008), and annual indirect costs of ecosystem services, such as water monitoring and purification (Dewsbury et al. 2016; Kuwayama et al. 2022).

For each BCE (mangroves, saltmarsh, and seagrass), we extracted all ecosystem service valuation data available from temperate BCE globally to transfer to habitats. We excluded data from other climates (e.g., tropical climate) as these data were not applicable to habitats in Aotearoa NZ.

2.3 | Total Current and Potential Value of BCE

Using the data extracted from the ESVD, we calculated a global average value per unit ($ha^{-1}\ yr^{-1}$) area for each ecosystem service available for each BCE. We then used the value transfer method and converted into New Zealand dollars (NZD) using exchange rates as of December 2024 (see Supporting Information). This produced an average value in NZ$ $ha^{-1}\ yr^{-1}$ for each ecosystem service ($n = 23$) in each blue carbon ecosystem.

We then multiplied the total extent (in ha) of current and potential (via restoration) BCE area by the estimated value (in NZD $ha^{-1}\ yr^{-1}$) for each ecosystem service at the regional ($n = 16$, except mangroves, which are only present in four regions) and national scale. This produced estimates of the total current and potential restoration value (in NZD yr^{-1}) for each ecosystem service in each BCE in Aotearoa NZ.

3 | Results

3.1 | Spatial Extent of BCE

Currently, Aotearoa NZ has a total of 30,533 ha of mangrove, 20,932 ha of saltmarsh, and 61,340 ha of seagrass (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024) across all 16 regions. In addition, drained (mostly agricultural) areas with potential for BCE restoration totalled 17,291 ha of mangrove, 56,484 ha of saltmarsh, and 14,088 ha of seagrass (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024) across all regions (see Supporting Information).

3.2 | Value of Ecosystem Services in BCE

In general, there were more ecosystem services identified from the ESVD database for mangroves ($n = 19$) and saltmarsh ($n = 18$ ecosystem service types) than for seagrass ($n = 10$). The total number of value estimates was highest for mangroves ($n = 739$), followed by saltmarsh ($n = 241$), with very few

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TABLE 1 | Ecosystem services classification based on the TEEB (The Economics of Ecosystems and Biodiversity) framework $n = 23$ ecosystem services in four main groups, which align with the MA (Millennium Ecosystem Assessment) classification (Van der Ploeg et al. 2010).

Ecosystem service	Definition
Provisioning	
Food	Tangible food products, like crops, fish, and seafood, that ecosystems provide and that humans directly utilise for sustenance.
Water	The benefits humans derive from healthy ecosystems related to water include provisioning (water supply), regulating (flood control, water quality), and cultural (recreation, aesthetics) aspects.
Raw materials	Raw materials such as timber, fibres, and other biomass, which are directly used or processed by humans for various purposes.
Genetic resources	Genetic diversity within species and ecosystems allows populations to adapt to changing environments and maintain resilience to disturbances.
Medicinal resources	Natural resources, often plants or other organisms, are used for medicinal purposes, including the development of pharmaceuticals and traditional medicines.
Ornamental resources	Ornamental resources, such as decorative plants, pets, and fashion items that are derived from ecosystems.
Biomass	The tangible products and materials that ecosystems supply for human use, including food (crops, livestock, fish), fibre (cotton, wool), raw materials (timber, fuel), and genetic resources (for new breeds/medicines), represent nature's direct contribution to human sustenance and industry, from cultivated farms to wild harvests like fisheries.
Regulating	
Air quality regulation	The natural processes by which ecosystems maintain and improve air quality include filtering pollutants and regulating atmospheric composition.
Climate regulation	This specifically refers to the role of ecosystems in moderating climate conditions, including: Carbon Sequestration: The process by which ecosystems absorb and store atmospheric carbon dioxide. Local Climate Regulation: The influence of ecosystems on local weather patterns, such as temperature and precipitation, through processes like evapotranspiration and shading.
Moderation of extreme events	The ability of ecosystems to reduce the impact of natural disasters like floods, storms, landslides, and droughts.
Regulation of water flows	The benefits ecosystems provide in moderating water quantity and quality include flood control, drought prevention, and maintaining water cycle features.
Waste treatment	The natural processes by which ecosystems break down organic matter, remove pollutants from water and soil, and otherwise manage waste materials.
Erosion prevention	The capacity of an ecosystem to prevent and mitigate soil erosion and landslides.
Maintenance of soil fertility	The natural processes that sustain the capacity of soils to support plant growth and other ecosystem functions. This includes processes like nutrient cycling, soil formation, and the retention of organic matter.
Pollination	The transfer of pollen from the male to the female part of a flower, which maintains the health and productivity of ecosystems and is vital for food security.
Biological control	The natural regulation of pests and diseases by other organisms offers benefits like higher yields, reduced pesticide use, and improved human health
Habitat	
Maintenance of life cycles	The essential processes that support the reproduction, growth, and survival of species, including migratory species, and the habitats they rely on, such as nursery areas.

(Continues)

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TABLE 1 | (Continued)

Ecosystem service	Definition
Maintenance of genetic diversity	The ability of ecosystems to support and preserve the variety of genes within species and between species is crucial for their long-term resilience and adaptability to changing environments.
Cultural	
Aesthetic information	The benefits humans derive from the sensory experience of ecosystems include the appreciation of beauty, inspiration for art and culture, and the enjoyment of natural landscapes.
Opportunities for recreation and tourism	Recreation: Natural landscapes and urban green spaces contribute to mental and physical health through recreational activities. Tourism: Nature tourism provides economic benefits and is a vital source of income for many countries.
Inspiration for culture, art and design	Natural landscapes, flora, fauna, and ecological processes have been incorporated into art, music, literature, and other cultural forms across various societies.
Spiritual experience	The spiritual and emotional values people or religions attach to local environments or landscapes are often rooted in religious and/or spiritual experiences.
Information for cognitive development	Exposure to nature and the benefits it provides can positively impact cognitive development, including attention, memory, and problem-solving skills.
Existence, bequest values	Existence value is the value people place on simply knowing that something exists, while bequest value is the value placed on ensuring that something is preserved for future generations.

estimates for values of ecosystem services in seagrass ($n = 38$). All ecosystem service valuations are standardised and reported on a per-hectare-per-year basis. There were no estimates within the database originating from Aotearoa NZ for BCE.

3.2.1 | *Mangrove Ecosystem Service Value Estimates*

From a total of $n = 739$ values for 19 ecosystem services in mangroves, the number of estimates used to calculate a global average value ranged from $n = 1$ for medicinal resources versus $n = 301$ for provision of food (see Supporting Information). The most valuable ecosystem service provided by mangroves was climate regulation (including carbon sequestration) at NZD$32,590 ha^{-1} yr^{-1}, while regulation of water flows was only worth NZD$3 ha^{-1} yr^{-1} (Figure 2).

3.2.2 | *Saltmarsh Ecosystem Service Value Estimates*

From the total of $n = 241$ values for 18 ecosystem services in saltmarsh, the number of estimates used to calculate a global average ranged from $n = 1$ (for genetic resources and regulation of water flows), to $n = 51$ (for provision of food) (see Supporting Information). The saltmarsh ecosystem services with the highest average values were waste treatment (NZD$23,045 ha^{-1} yr^{-1}) and moderation of extreme events (NZD$13,661 ha^{-1} yr^{-1}: Figure 2). These values are derived from avoided-cost methods in the ESVD and should be interpreted as indicative benchmarks rather than realised economic flows in Aotearoa New Zealand. Conversely, climate regulation, including carbon sequestration, was much less valuable at NZD$241 ha^{-1} yr^{-1} (Figure 3).

3.2.3 | *Seagrass Ecosystem Service Value Estimates*

From the total of $n = 38$ values extracted from the ESVD for 11 ecosystem services in seagrass, the number of estimates used to calculate a global average ranged from a minimum of $n = 1$ for erosion prevention and information for cognitive development, and a maximum of $n = 9$ for provision of food (see Supporting Information). In seagrass, the most valuable ecosystem services were existence, bequest values (NZD $14,512 ha^{-1} yr^{-1}) and moderation of extreme events (NZD $12,434 ha^{-1} yr^{-1}), while information for cognitive development was worth NZD$1 ha^{-1} yr^{-1} (Figure 4). Non-use values (existence, bequest values) reflect stated preference estimates from international studies and are included here as benchmarks, noting their high uncertainty and context dependence.

3.2.4 | *Mangrove Current and Potential Value*

At a national scale, the most valuable ecosystem service provided by current mangrove habitat (30,533 ha) was climate regulation (i.e., blue carbon) worth NZD$995 m yr^{-1} and moderation of extreme events worth NZD$373 m yr^{-1} (Table 2), highlighting the importance of mangroves for climate change mitigation and adaptation. If all areas with potential to be restored to mangroves (17,291 ha) were restored, the value of mangroves for climate regulation would increase by NZD$564 m, and NZD$211 m for the moderation of extreme events (including coastal protection) (Table 2).

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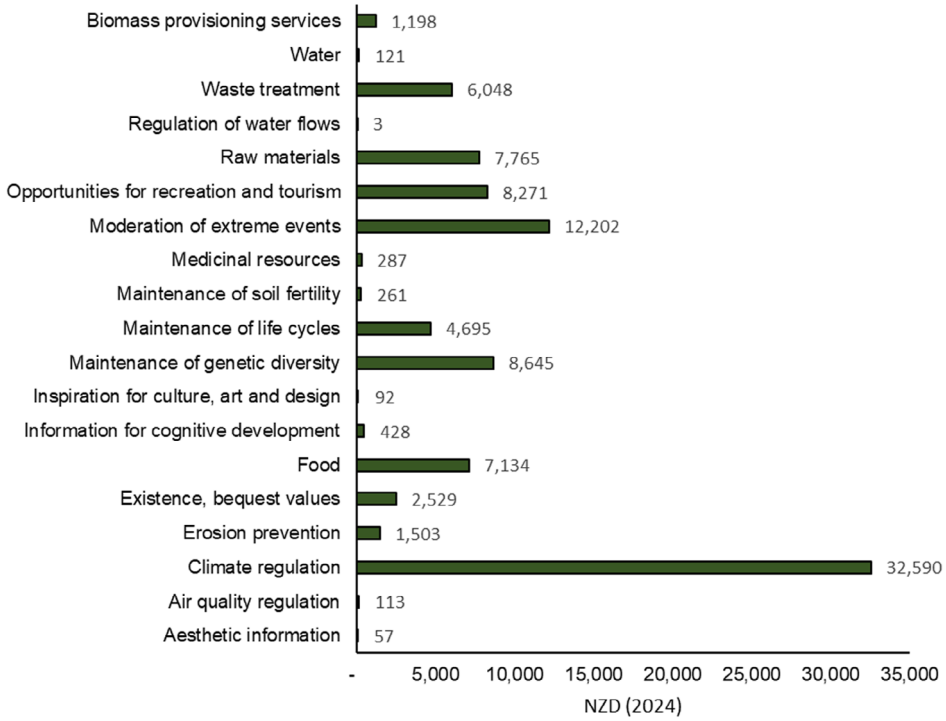


FIGURE 2 | Value of ecosystem services for temperate mangrove habitats in NZD (2024) per hectare per year, determined using global monetary values.

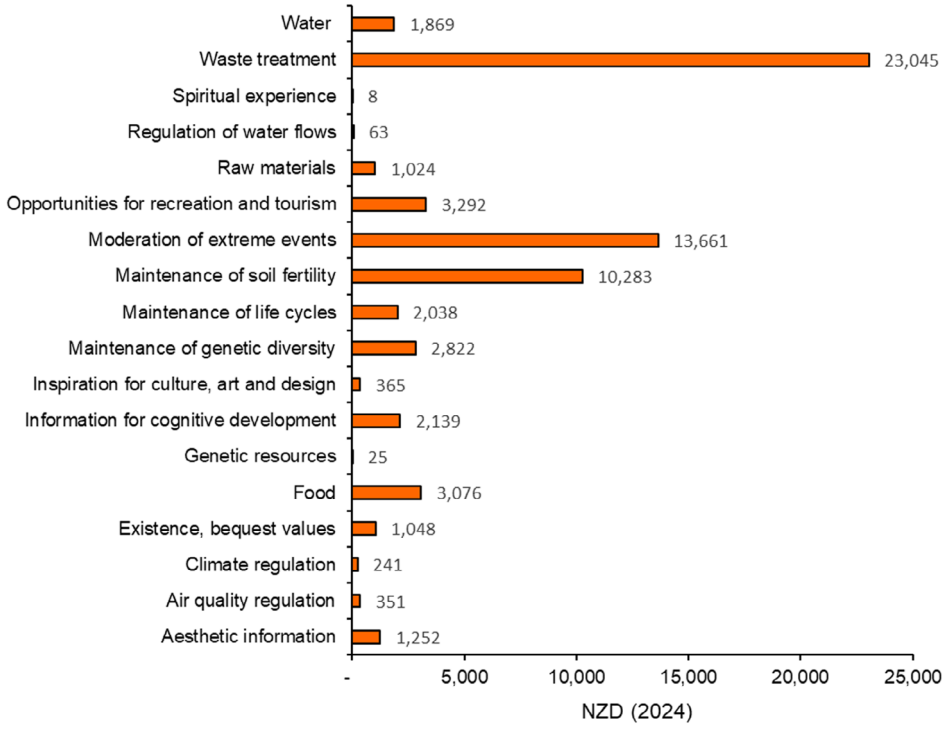


FIGURE 3 | Value of ecosystem services for temperate saltmarsh habitats in NZD (2024) per hectare per year, determined using global monetary values.

Regionally, Northland (16,073 ha current mangrove habitat) and Auckland (9237 ha) were valued at NZD$524 m and NZD$301 m for climate regulation and NZD$196 m and NZD$113 m for moderation of extreme events, respectively (Figure 5). Waikato (7298 ha) could add NZD$238 m for climate regulation and NZD$89 m of moderation of extreme events if all areas were restored (Supporting Information and Figure 5).

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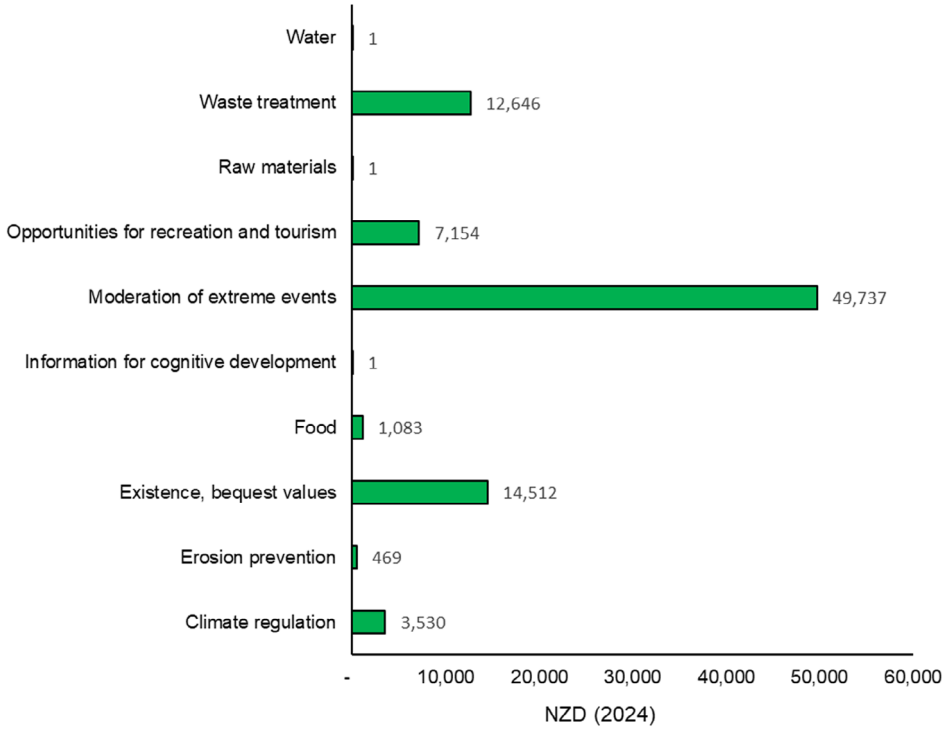


FIGURE 4 | Value of ecosystem services for temperate seagrass habitats in NZD (2024) per hectare per year, determined using global monetary values.

TABLE 2 | Value of ecosystem services (NZD yr^{-1}) provided by mangroves at a national scale in Aotearoa New Zealand.

Mangroves NZD yr^{-1}	Unit value ha^{-1} yr^{-1}	Current value, in millions	Restoration potential value, in millions
Climate regulation	$32,590	$995	$564
Moderation of extreme events	$12,202	$373	$211
Maintenance of genetic diversity[a]	$8645	$264	$150
Opportunities for recreation and tourism	$8271	$253	$143
Raw materials[a]	$7765	$237	$134
Food	$7134	$218	$123
Waste treatment	$6048	$185	$105
Maintenance of life cycles	$4695	$143	$81
Existence, bequest values	$2529	$77	$44
Erosion prevention	$1503	$46	$26
Biomass provisioning services[a]	$1198	$37	$21
Information for cognitive development	$428	$13	$7
Medicinal resources[a]	$287	$9	$5
Maintenance of soil fertility[a]	$261	$8	$5
Water	$121	$4	$2
Air quality regulation	$113	$4	$2
Inspiration for culture, art and design[a]	$92	$3	$2
Aesthetic information	$57	$2	$1
Regulation of water flows	$3	$0.08	$0.05
Total (sum across all services)	$93,942	$2871	$1624

Note: Summing across services risks double-counting (see Limitations); this total is indicative only.
[a]Category likely has limited current realisation in Aotearoa NZ (see Limitations). Values retained for international framework comparability.

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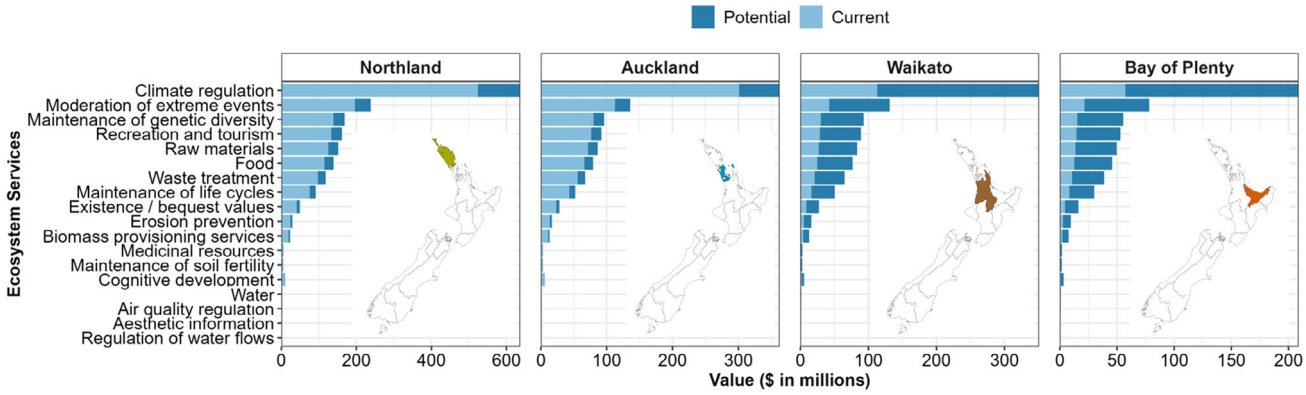


FIGURE 5 | Current (based on current existing habitat) and potential (based on potential future restoration opportunity) value of mangrove co-benefits (ecosystem services) across 4 regions in Aotearoa NZ. Value is expressed in million NZ dollars. Note *x*-axis is different for each region.

3.2.5 | *Saltmarsh Current and Potential Value*

At a national scale, the most valuable ecosystem services provided by current saltmarsh habitat (20,932 ha) were waste treatment (NZD$482 m yr^{-1}), moderation of extreme events (NZD$286 m yr^{-1}), and maintenance of soil fertility (NZD$215 m yr^{-1}), which could increase by NZD$1.3bn, NZD $772 m, and NZD$581 m if all potential areas (56,484 ha) were restored (Table 3). These ecosystem services are much more valuable in economic terms than the blue carbon services provided by saltmarsh (which falls under climate regulation), valued at NZD$5 m for current habitats and NZD$14 m if all potential areas were restored (Table 3).

At a regional scale, the value was determined by the total current area of saltmarsh habitat and potential area for restoration (see

TABLE 3 | The current and potential national-scale values (NZD yr^{-1}) of ecosystem services provided by saltmarsh in Aotearoa NZ.

Saltmarsh NZD yr^{-1}	Unit value ha^{-1} yr^{-1}	Current value, in millions	Restoration potential value, in millions
Waste treatment	$23,045	$482	$1302
Moderation of extreme events	$13,661	$286	$772
Maintenance of soil fertility[a]	$10,283	$215	$581
Opportunities for recreation and tourism	$3292	$69	$186
Food	$3076	$64	$174
Maintenance of genetic diversity[a]	$2822	$59	$160
Information for cognitive development[a]	$2139	$45	$121
Maintenance of life cycles	$2038	$43	$115
Water	$1869	$39	$106
Aesthetic information	$1252	$26	$0
Existence, bequest values	$1048	$22	$59
Raw materials[a]	$1024	$21	$58
Inspiration for culture, art and design[a]	$365	$8	$21
Air quality regulation	$351	$7	$20
Climate regulation	$241	$5	$14
Regulation of water flows	$63	$1	$4
Genetic resources[a]	$25	$0.50	$1.53
Spiritual experience	$8	$0.21	$0.52
Total (sum across all services)	$66,602	$1393	$3695

Note: summing across services risks double-counting (see Limitations); this total is indicative only.
[a]Category likely has limited current realisation in Aotearoa NZ (see Limitations). Values retained for international framework comparability.

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Supporting Information). Considering present areas, the value of waste treatment was NZD$93 m in Northland, NZD$72 m in Auckland, NZD$56 m in Southland, while the value of moderation of extreme events was NZD$55 m in Northland, NZD$43 m in Auckland, NZD$33 m in Southland (Figure 6). When considering areas that could be tidally restored, Waikato could provide $307 m of waste treatment services, Northland NZD$202 m, and Otago NZD$172 m (Figure 6). There was similar potential value for the moderation of extreme events in Waikato (NZD$182 m), Northland (NZD$120 m), and Otago (NZD$102 m) (Figure 6).

3.2.6 | *Seagrass Current and Potential Value*

Nationally, the most valuable ecosystem services provided by current seagrass habitat (61,340 ha) were not climate regulation but existence, bequest values (NZD$890 m yr^{-1}) and moderation of extreme events (NZD$763 m yr^{-1}), which could increase by NZD$205 m, and NZD$175 m if all potential areas (14,088 ha) were restored (Table 4). Existence, bequest values are cultural values placed on the existence of ecosystems for current and future generations (Table 4).

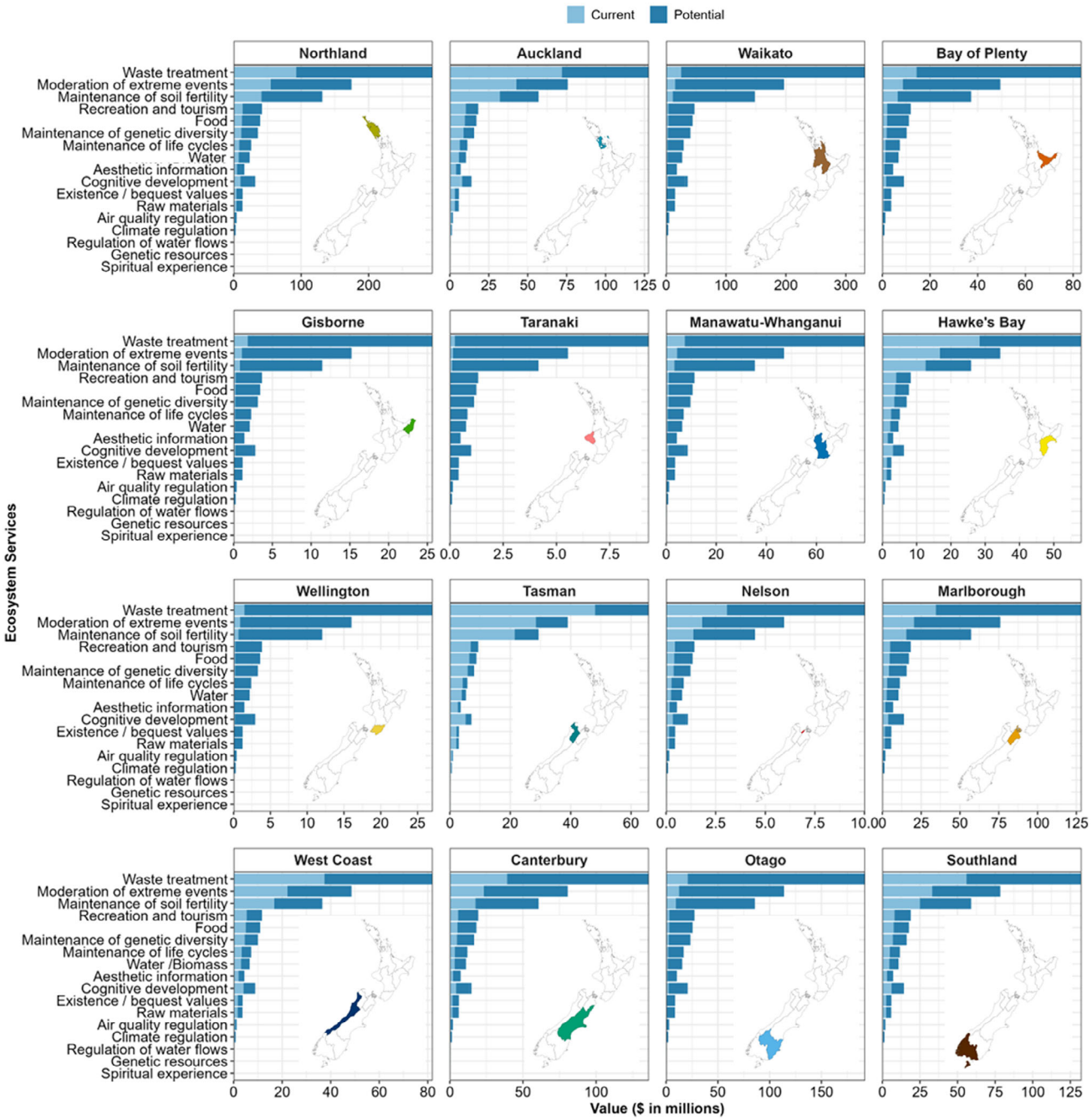


FIGURE 6 | Current (based on current existing habitat) and potential (based on potential future restoration opportunity) value of saltmarsh co-benefits (ecosystem services) across the 16 regions in northern Aotearoa NZ where mangroves are found. Value is expressed in million NZ dollars. *Note: x*-axis is different for each region.

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TABLE 4 | Value of ecosystem services (NZD yr^{-1}) provided by seagrass at a national scale in Aotearoa New Zealand.

Seagrass NZD yr^{-1}	Unit value, ha^{-1} yr^{-1}	Current value, in millions	Restoration potential value, in millions
Existence, bequest values	$14,512	$890	$204.50
Moderation of extreme events	$12,434	$763	$175
Opportunities for recreation and tourism[a]	$5723	$351	$81
Waste treatment	$5058	$310	$71
Climate regulation	$3530	$216.50	$50
Food	$1083	$66.50	$15
Erosion prevention	$469	$29	$7
Water	$3	$0.20	$0.04
Raw materials[a]	$2	$0.10	$0.03
Information for cognitive development[a]	$1	$0.05	$0.01
Total (sum across all services)	$42,815	$2626	$604

Note: Summing across services risks double-counting (see Limitations); this total is indicative only.
[a]Category likely has limited current realisation in Aotearoa NZ (see Limitations). Values retained for international framework comparability.

Regionally, Auckland (20,631 ha), Northland (11,020 ha), and Tasman (9,458 ha) provide NZD$299 m, NZD$160 m and NZD $137 m of existence, bequest value, respectively, and NZD $257 m, NZD$137 m and NZD$118 m of moderation of extreme events (Figure 7). If all potential areas were restored, Otago (3494 ha) could provide NZD$51 m in existence value and NZD$43m in moderation of extreme events (Figure 7).

A summary of total ecosystem service values across all three BCE, including current habitat and restoration potential, is provided in Table 5.

4 | Discussion

In this research, we monetarized the benefits of BCE in Aotearoa New Zealand using a combination of national publicly available data (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024) and international datasets (ESVD; https://www.esvd.net/). We calculated the value of current BCE and of areas that could potentially be restored to BCE, at regional and national scales in Aotearoa NZ. We found that BCE provide highly valuable carbon sequestration services, but also provides valuable waste treatment, moderation of extreme events, coastal protection, and existence, bequest services, which in the case of saltmarsh and seagrass ecosystems, are more valuable than blue carbon. At present, mangroves provide the highest total benefit, but saltmarshes have the highest potential additional value through restoration. We highlight that these results should not be interpreted as estimates of current economic production, extractable revenue, or financial return from BCE in Aotearoa New Zealand. Ecosystem service benchmark values serve multiple policy purposes beyond return-on-investment analysis. They support conservation prioritisation, inform voluntary credit market design, and allow governments to compare the relative magnitude of services across habitats when designing incentive schemes (Barbier 2019). The purpose of this study is to generate the first such benchmarks for BCE in Aotearoa New Zealand, providing a foundation for future, more localised analyses.

Restoration and conservation of BCE are an important nature-based solution to climate change; however, at present, the cost of blue carbon projects outweighs the monetary benefit from carbon credits (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024). The break-even carbon credit value for blue carbon projects in Aotearoa NZ has been estimated to range from NZ$ 250–5000 per tonne of CO_2 (The Nature Conservancy Aotearoa New Zealand 2025), while the current carbon price sits at NZ$ 64 CO_2e t^{-1}.

We used global temperature average values converted to NZD as a benchmark in this research. Currently, Aotearoa NZ-specific ecosystem services valuation data are lacking. The only Aotearoa NZ -specific ecosystem services valuation data available is the climate regulation estimates generated from Aotearoa NZ Emission Trading Scheme on carbon sequestration market trading price (https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/ets/nz-ets-market/). Based on a carbon price of NZD 64 CO_2e t^{-1} for Aotearoa NZ emission units (NZUs; New Zealand Emission Trading Scheme), we compared the value of blue carbon based on national estimates of carbon sequestration rate in BCE using Bulmer's approach (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024) to contextualise global benchmark estimates against the only locally available ecosystem service price signal, rather than as an input to valuation.

To contextualise the climate regulation benchmark estimates against locally available data, we compared them with NZ ETS-based carbon values derived from national sequestration rates. Existing Aotearoa NZ mangrove habitats sequester carbon at a rate of 0.64 tC ha^{-1} yr^{-1} (Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024), equal to 2.35 CO_2e ha^{-1} yr^{-1}, which is worth NZD$150 ha^{-1} yr^{-1}. At an Aotearoa NZ national

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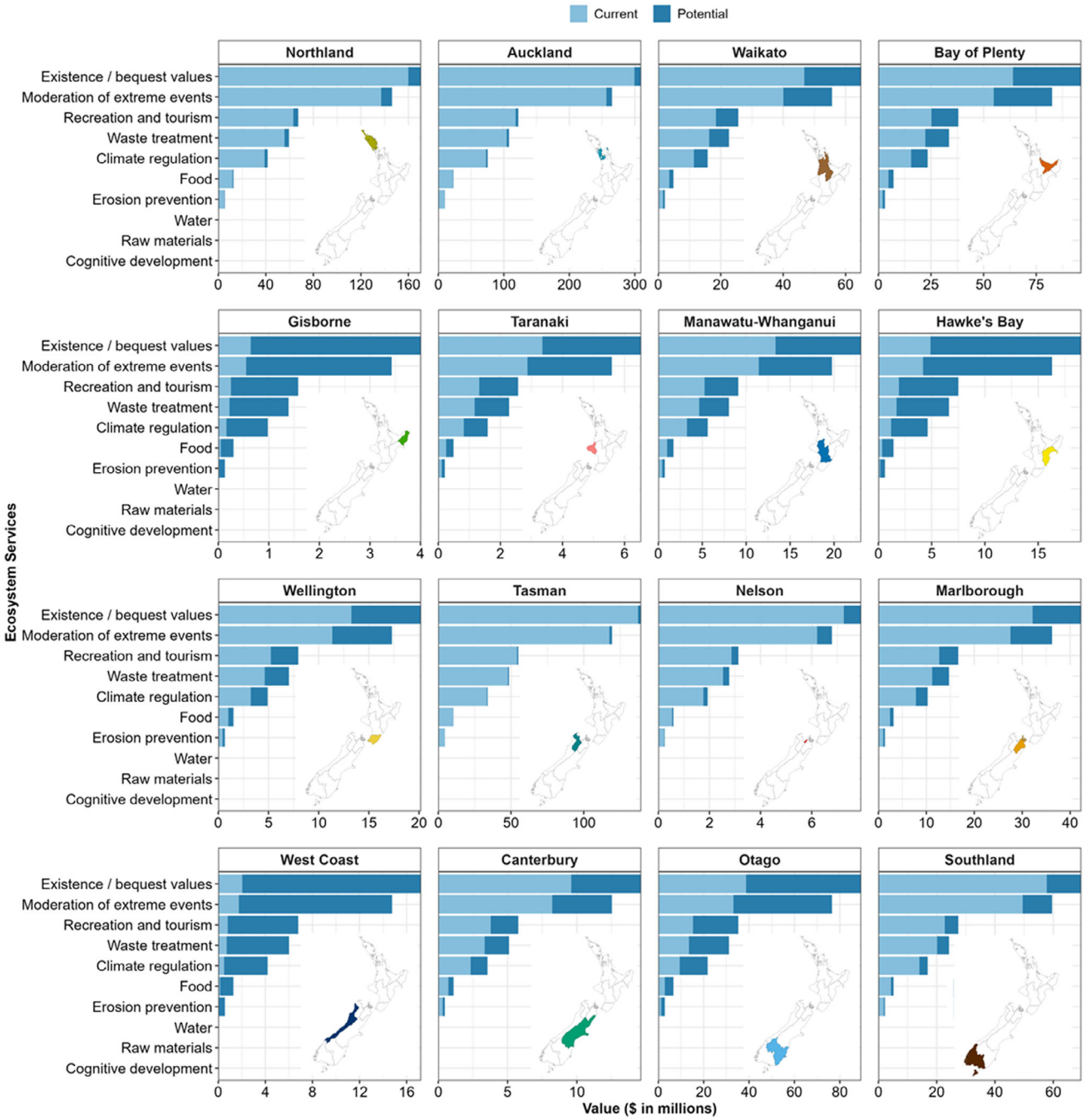


FIGURE 7 | Current (based on current existing habitat) and potential (based on potential future restoration opportunity) value of seagrass co-benefits (ecosystem services) across 16 regions in Aotearoa NZ. Value is expressed in million NZ dollars. *Note: x*-axis is different for each region.

scale (30,533 ha of mangroves), this is valued at NZD$4.58 million annually. The large difference between this locally-grounded estimate and the international benchmark (NZD$995 m yr^{-1}) is itself a key finding of this study, illustrating the importance of locally-derived valuation data and the limitations of benefit transfer for carbon regulation services specifically. Saltmarsh habitats in Aotearoa NZ sequester 3.27 CO_2e ha^{-1} yr^{-1} (0.89 tC ha^{-1} yr^{-1} converted to CO_2; Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024), which is worth NZD$209 ha^{-1} yr^{-1} in carbon credit value. Nationally, this is equivalent to NZD$4.38 million annually (total area of 20,932 ha), which is in line with global estimates of climate regulation value (including carbon sequestration) of saltmarsh at NZD$5 million annually. Existing Aotearoa NZ seagrass beds sequester carbon at a rate of 1.17 CO_2e ha^{-1} yr^{-1} (0.32 tC ha^{-1} yr^{-1}; derived from Australian seagrass data reported in Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024 Table 2, following Lovelock et al. 2023; an Aotearoa NZ-specific rate of 0.04 tC ha^{-1} yr^{-1} is also reported in Bulmer, Stewart-Sinclair, Lam-Gordillo, Mangan, et al. 2024 but is based on limited sampling), which is worth NZD$75 ha^{-1} yr^{-1}. Nationally, this equates to 4.61 million NZD annually (61,340 ha of seagrass beds), which is again much lower than international estimates (NZD $217 m). These NZ ETS-based figures are presented here as contextual benchmarks using the only locally available price signal,

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TABLE 5 | Summary of total ecosystem service values for current and potential restoration areas of blue carbon ecosystems (BCE) in Aotearoa New Zealand. Totals are summed across all ecosystem services identified for each BCE from the Ecosystem Services Valuation Dataset (ESVD).

Ecosystem	Current habitat, ha	Potential restoration, ha	Total current value, NZD yr^{-1}	Total per-hectare value, NZD ha^{-1} yr^{-1}	Total restoration potential value, NZD yr^{-1}	Dominant service
Mangroves	30,533	17,291	$2871 m	$93,942	$1624 m	Climate regulation
Saltmarsh	20,932	56,484	$1393 m	$66,602	$3695 m	Waste treatment
Seagrass	61,340	14,088	$2626 m	$42,815	$604 m	Existence, bequest values

Note: Summing across services risks double-counting where services overlap (see Limitations); totals are indicative only. Services marked * in Tables 2–4 have limited evidence of current realisation in Aotearoa NZ.

rather than as replacements for the international estimates that form the primary outputs of this study. The international estimates are retained because they capture the full range of climate regulation services beyond carbon sequestration alone, and because the NZ ETS price reflects current market conditions rather than the social cost of carbon.

It is possible that BCE outside of Aotearoa NZ may provide different levels and capabilities of climate regulation services compared with Aotearoa NZ BCE species. For example, Aotearoa NZ only have one mangrove species (*Avicennia marina*), while the shading and evapotranspiration services *Avicennia marina* can provide would be different compared with *Rhizophora mangle*. Thus, this may lead to higher estimates of the ecosystem services valuations in monetary terms for *Rhizophora mangle* than for *Avicennia marina*. Therefore, establishing a dedicated dataset for ecosystem services valuation in Aotearoa NZ is necessary to increase confidence in the value of BCE.

The Aotearoa NZ Government is interested in emerging ecosystem service markets (Ministry for the Environment 2025), where credits of multiple ecosystem services, in addition to carbon sequestration, could be bundled or stacked on top of carbon credits to increase benefits to landowners and incentivise large-scale restoration (Landaverde 2023). For example, there are developing markets in biodiversity (included in existence, bequest value category) and coastal resilience (included in moderation of extreme events category), which, if stacked or bundled, would increase the net benefit generated by blue carbon projects.

Globally, in addition to carbon credit development, biodiversity credit development is the second most developed credit market with emerging markets in Australia (Nature Repair Market: Australia 2023), the UK (Biodiversity Credit Alliance 2023), and the international voluntary market (Nature Framework by Verra: SD VISta 2024). Domestically, there has been work on biodiversity credit methods in the terrestrial sphere (BioCredita: Ekos 2025), but the marine and coastal space has yet to be implemented in Aotearoa NZ.

Coastal resilience markets are of specific relevance for BCE and aim to reduce flooding in coastal areas through the conservation and restoration of BCE (Verra's SD VISta program: SD VISta 2010). Blue carbon pilot projects that could also generate resilience credits are currently underway in saltmarsh habitat in Aotearoa NZ (The Nature Conservancy 2025).

Other enablers for future expansion of restoration and conservation in the coastal space include a projected increase in the carbon price and industry mechanisms such as parametric insurance. Parametric insurance is a special type of insurance that pays out a pre-agreed amount automatically when a specific, measurable event (a 'parameter' or 'trigger') occurs, like an earthquake of a certain magnitude or wind speed above a threshold (Figueiredo et al. 2018). It is ideal for risks hard to insure traditionally, offering swift financial relief for events like natural disasters, crop failure, or lost revenue, often complementing standard policies (Figueiredo et al. 2018). The carbon price is expected to increase over time due to increased intensity of anthropogenic pressures, and revenues from carbon credits were over 100 billion USD in 2023 (World Bank 2024). New mechanisms for financing restoration through insurance are emerging - for example, 'resilience insurance' whereby reductions in insurance premiums are applied for nature-based solutions (such as coastal restoration that increases coastal protection: Reguero et al. 2020).

In addition to forecasted increasing benefits, it is also likely that the opportunity cost of restoration for blue carbon will decrease in future. With rising sea levels and groundwater tables, and the increasing frequency of coastal flooding and erosion, the availability of coastal land suitable for agriculture (including farming) is expected to decrease (Gould et al. 2020, Kantamaneni et al. 2020, Sudol et al. 2023). Furthermore, in some areas, inundated farmlands will transition into BCE as sea levels rise and BCE will migrate to those areas, increasing the benefits of blue carbon schemes for landowners (Linhoss et al. 2015, Brown 2019, Guimond et al. 2021).

4.1 | Limitations

While this research represents an important foundation for determining the full value of ecosystem services provided by BCE, there are a number of limitations related to the interconnectedness of ecosystem services (i.e., not independent), uncertainties in the

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value transfer of international data, and the cultural context of monetary valuations in Aotearoa NZ. Furthermore, the lack of Aotearoa NZ local data is a key limitation for this research.

Although the benefit transfer method has limitations and is frequently criticised, its practicality has made it an influential and widely used tool in the appraisal of transport impacts and other areas of government intervention (Waka Kotahi 2022). However, continued improvements in the quality, consistency, practicality, and accessibility of benefit transfer are among the most impactful and socially beneficial contributions economists can make, as benefit transfer is almost certain to remain a central component of transport policy analysis and investment appraisal worldwide (Johnston et al. 2017). Some impact of the benefit transfer approach can be disaggregated into distinct components, a subset of which may be suitable for valuation with broad applicability (Waka Kotahi 2022). For example, in the context of biodiversity, European approaches separate impacts related to air quality deterioration in proportion to traffic volumes, as these effects are ubiquitous and can be assigned values that are transferable across locations. In contrast, other biodiversity impacts, such as habitat loss or fragmentation, are more spatially heterogeneous and are therefore not well suited to generalised valuation. Australian guidance groups consider these latter impacts together with landscape effects, which are problematic (Waka Kotahi 2022). In the United Kingdom, earlier guidance included landscape values, but these have since been removed due to the risk of double-counting impacts that are already captured within other components of the valuation framework (Waka Kotahi 2022). In the absence of greater investment in primary valuation of transport impacts, higher-quality benefit transfer and a broader understanding of the method represent a second-best but necessary pathway to improving appraisal quality and decision-making support. This approach is urgently needed in Aotearoa NZ to establish benchmark monetary values for BCE and to support their consideration in policy implementation aimed at addressing climate change challenges. It is important to note that some ecosystem services provided by BCE overlap with one another (e.g., food-providing services may also include nursery functions and storm protection services for mangroves), and that there is high uncertainty in valuations (Cadotte et al. 2017; Hölting et al. 2019; Mouchet et al. 2017; O'Farrell et al. 2010). Therefore, there is a risk of double-counting when all monetary values are summed together, as currently done here when calculating total economic value. Further research is needed to explore how these ecosystem services interact on larger scales to enable quantification of the total economic value of conserving and restoring coastal wetlands (Barbier 2019).

We used the value transfer method, whereby we took equivalent values (i.e., from similar temperate ecosystems) and converted them into the local currency. While we have validated these estimates by using local current BCE habitat size and potential restoration habitat size data, where available. We were not able to ground-truth many of the estimates. For climate regulation, global estimates were in line with local estimates for saltmarsh but not for mangroves or seagrass. One likely reason for this discrepancy is that different species of seagrass have been shown to sequester different amounts of carbon. This highlights that local data are preferable to value transfer when available. Some ecosystem service categories are included for Aotearoa NZ, but other ecosystem service categories may not be applicable to Aotearoa NZ, for example, mangroves are likely to be more valuable for raw materials in other countries where they are used as fuelwood but not in Aotearoa NZ. Another example of an ecosystem service category not being as relevant to Aotearoa NZ could potentially be the moderation of extreme events by Aotearoa NZ seagrass. Given that Aotearoa NZ seagrass is relatively short and low in structure compared to some other seagrasses globally, potentially Aotearoa NZ seagrass does not provide the same level of extreme event moderation. Despite these uncertainties, our study is an important first step in indicative benchmark estimates for BCE in Aotearoa NZ. Future research should focus on the collection of locally specific data to reduce these uncertainties and increase confidence when incorporating data into ecosystem service market frameworks.

While monetary valuation is an important tool for incorporating ecosystem services into conventional economic frameworks, it is not the only way to value nature. In Aotearoa NZ, the indigenous Māori have an intricate, holistic, and interconnected relationship with nature, shaped by thousands of years of history and a knowledge base known as mātauranga Māori (Harmsworth and Awatere 2013). Māori cultural knowledge provides a dynamic understanding of the relationship between humans and nature that goes beyond monetary valuation and is a significant driving force for decision-making in Aotearoa NZ (Chan et al. 2012). While some cultural value is perhaps captured through the 'existence, bequest' ecosystem service category, valuing cultural and non-market ecosystem services is challenging and cultural valuation of BCE in Aotearoa NZ is beyond the scope of our study. Accordingly, monetary estimates presented here should be interpreted as complementary to, rather than substitutive of, Indigenous and non-market value systems.

4.2 | Policy Implications

This analysis provides the first estimates of all BCE benefits in addition to the carbon sequestration benefit in Aotearoa NZ, which can help to guide policy and decision making. Supporting the growth of the voluntary nature credits market is one of the key focus areas of the New Zealand Government (Ministry for the Environment 2025). Our results highlight the high-value of existing mangrove habitat, which could inform local conservation priorities, while drained coastal areas offer high value restoration gains in saltmarsh habitat. Regional differences in these results will be important in the spatial prioritisation of national conservation and restoration goals. The Aotearoa NZ Government is a signatory to the Paris Agreement, which aims to significantly reduce greenhouse gas emissions, as well as the Kunming-Montreal Global Biodiversity Framework (GBF), which includes goals to restore 30% of degraded ecosystems and conserve 30% of the area by 2030. Restoration and conservation of BCE help governments to meet their commitments under these international agreements.

4.3 | Conclusions

BCE provide significant carbon sequestration services that have been the focus of a rapidly expanding carbon market globally.

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Growing interest in environmental market-based mechanisms for financing conservation and restoration of BCE could enable higher payments for ecosystem services if the additional value of co-benefits is verified. The value of co-benefits provided by BCE has been understudied, so estimating the relative magnitude of ecosystem service values is important to support more informed policy discussion and consideration of conservation and restoration pathways at scale. Here, we estimate the value of BCE co-benefits in Aotearoa NZ, where frameworks for blue carbon and biodiversity markets are just being developed. These values could feed into credit schemes that could offset the opportunity cost of blue carbon projects. Increased conservation and restoration of BCE would be an important nature-based solution to mitigate climate change impacts to coastal communities, for example, creating buffer zones for flood water storage or coastal wave reduction to protect coastal assets (e.g., coastal properties), while also supporting progress toward international targets for climate mitigation and biodiversity restoration.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Exchange rates used to convert ecosystem service values to New Zealand dollars (NZD) as of December 2024. Exchange rates sourced from Google Currency Converter (https://www.google.com/search?q=currency+exchange). **Table S2:** Number of value estimates (n) and global average values (NZD ha^{-1} yr^{-1}) used to calculate ecosystem service benchmarks for mangroves, saltmarsh, and seagrass, derived from the Ecosystem Services Valuation Dataset (ESVD). Values converted to NZD using December 2024 exchange rates (Supplementary Table S1). Services are listed alphabetically within each habitat. †Maintenance of soil fertility for seagrass has a global average value of \$0 ha^{-1} yr^{-1} and is excluded from Table 4 in the main text. **Table S3:** Current and restoration potential value (NZD millions yr^{-1}) of ecosystem services provided by mangrove habitat across regions in Aotearoa New Zealand. Values calculated by multiplying regional habitat extent by global average unit values (Supplementary Table S2). Regions where mangroves are absent are not included. Note: summing across services risks double-counting where services overlap (see Limitations); row totals are indicative only. * Category likely has limited current realisation in Aotearoa NZ (see Limitations). Data provided as a separate CSV file (Mangrove_SuppTable_S3.csv) due to file size. **Table S4.** Current and restoration potential value (NZD millions yr^{-1}) of ecosystem services provided by saltmarsh habitat across all 16 regions in Aotearoa New Zealand. Values calculated by multiplying regional habitat extent by global average unit values (Supplementary Table S2). Note: summing across services risks double-counting where services overlap (see Limitations); row totals are indicative only. * Category likely has limited current realisation in Aotearoa NZ (see Limitations). Data provided as a separate CSV file (Saltmarsh_SuppTable_S4.csv) due to file size. **Table S5:** Current and restoration potential value (NZD millions yr^{-1}) of ecosystem services provided by seagrass habitat across regions in Aotearoa New Zealand. Values calculated by multiplying regional habitat extent by global average unit values (Supplementary Table S2). Note: summing across services risks double-counting where services overlap (see Limitations); row totals are indicative only. * Category likely has limited current realisation in Aotearoa NZ (see Limitations). Data provided as a separate CSV file (Seagrass_SuppTable_S5.csv) due to file size.

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