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Evaluating the blue carbon benefits of aligning Canada's biodiversity conservation and climate change mitigation targets

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Abstract

Natural climate solutions (NCS) are increasingly recognized as important for combatting climate change, but ocean-based pathways remain underrepresented in national strategies for conservation and climate change mitigation. Here, we present a transferable national assessment framework for blue carbon, applied to Canada, that maps blue carbon ecosystem extents, quantifies national carbon stocks and sequestration potential, and evaluates the benefits of increasing their spatial protection. We estimated that 10,952.5 Tg C (95% CI: 7,035.7 – 16,098.7 Tg C) is stored in the top 30 cm of Canada's marine soils and sediments, with marine macrophytes, including kelp forests, additionally sequestering 7.7 Tg C yr^{-1} (95% CI: 5.6 – 25.1 Tg C yr^{-1}). Expanding protection of blue carbon ecosystems to 30% by 2030, in line with the Kunming-Montreal Post-2020 Global Biodiversity Framework, could provide a practical pathway for incorporating blue carbon into national NCS portfolios. If current rates of habitat loss and disturbances were effectively abated in these areas, this could provide 106.9 Tg CO_2e (95% CI: 94.1 – 234.9 Tg CO_2e) in cumulative climate mitigation benefits by 2050. Our approach provides a foundation for integrating blue carbon into national climate and conservation strategies.

Keywords

Blue carbon ▪ natural climate solutions ▪ nature-based solutions ▪ carbon sequestration ▪ national greenhouse gas inventories ▪ marine protected areas ▪ Kunming-Montreal Global Biodiversity Framework

Introduction

While fossil fuel emission reductions are the cornerstone of climate change mitigation, natural climate solutions (NCS) are increasingly recognized as playing a supporting role[1–3]. NCS, involving avoided emissions or enhanced carbon removals from protecting, managing or restoring natural carbon stores in the biosphere, have the potential to help limit the temperature peak of greenhouse-gas-induced global warming and are considered vital for the long-term stabilization of global temperatures once net-zero greenhouse gas emissions are reached[4,5]. Within this context, ocean-based pathways for blue carbon ecosystems (BCEs) remain underrepresented in NCS portfolios. Although most NCS focus to date has been on forests, soils and freshwater wetlands[3], recent studies suggest the carbon storage and sequestration potential of BCEs rivals that of terrestrial ecosystems[6–8].

Early blue carbon research focused on coastal vegetated ecosystems, including mangroves, tidal marshes, and seagrass meadows, that directly fix CO_2 and store large amounts of organic carbon per area locally within their soils and sediments[9–12]. Globally, these three habitats are estimated to hold between 9 – 30 Pg of organic carbon (C) within their top meter of soils and sequester up to an additional 48 Tg C per year [7,11,13]. More recently, the definition of blue carbon has expanded to consider additional ecosystems, including macroalgal forests and unvegetated seabed sediments[7]. Given their vast area, macroalgal forests are estimated globally to sequester ~173 Tg C per year through annual productivity and export to long-term carbon sinks[14,15,16] with bare sediments storing ~2,300 Pg C in their top meter[17] and accumulating an additional 126 – 350 Tg C per year globally [18–20].

As evidence has grown for the additional carbon sequestration pathways offered by BCEs, so too has interest in understanding their potential role in national climate change mitigation strategies. Recent global syntheses have advanced understanding of the carbon sequestration and storage potential of BCEs [16,17,21–25] and established their relevance to global climate change mitigation efforts [11,26,27]. However, the data gaps, uneven sampling, and generalized assumptions inherent to global scale analyses create substantial uncertainty in national-scale estimates, limiting their utility for national or subnational decision-making[28]. Identifying where management could deliver the greatest climate mitigation benefits requires more resolved data on the extent, carbon stocks, and expected carbon removal rates of blue carbon ecosystems. Yet this information remains sparse for many coastal nations, particularly those with temperate and polar coastlines, which have been underrepresented in recent blue carbon syntheses. Bridging this gap is critical for translating the global potential of blue carbon into actionable NCS pathways at national scales.

A parallel knowledge gap concerns how blue carbon can be most effectively integrated into the marine conservation policy landscape. One of the primary tools for marine conservation is the establishment of marine protected and conserved areas (hereafter referred to as MCAs)[32]. Historically, MCAs were established to enhance fisheries, halt biodiversity loss, or protect representative marine habitats[34,35]. In recent years, however, their scope has expanded to encompass a broader set of ecological and societal values, including representation of areas of cultural significance and other ecosystem goods and services (e.g., climate regulation)[36–40]. This shift has prompted increasing interest in the potential role of MCAs in climate change mitigation by protecting natural carbon stores and reducing the risk of carbon emissions associated with ecosystem degradation[41]. However, despite growing recognition of these potential co-benefits, application remains limited in practice, and it remains unclear whether explicitly incorporating blue carbon into MCA planning and design could deliver meaningful climate mitigation benefits at national scales.

Canada exemplifies the challenge facing many coastal nations seeking to incorporate blue carbon into national climate and conservation strategies. Despite its extensive coastline and blue carbon ecosystems, national estimates of their extent, carbon stocks, and sequestration potential remain incomplete. While recent studies have advanced understanding of individual systems and locations[29–31], these efforts have been spatially limited, ecosystem-specific, or not comparable in terms of their methodology, preventing a unified understanding of the overall capacity of Canada's BCEs to support natural climate solutions. Recent data collection and analyses, however, now offer a growing foundation for national-scale synthesis. Canada has also, like other parties to the United Nations Convention on Biological Diversity (CBD), committed to protecting at least 30% of its marine and coastal areas by 2030 under the Kunming-Montreal Global Biodiversity Framework[33] (hereafter called 30% by 2030 targets). As of July 2026, Canada's MCA network covered 17.6% of the country's marine area[42], with 128 designations under a variety of governing bodies and legislative acts including Marine Protected Areas, National Marine Conservation Areas, Marine Parks, National Parks with marine components, Marine National Wildlife Areas, Provincial Parks with marine components, Indigenous and Territorial Protected Areas, and fisheries-focused "Other Effective area-based Conservation Measures" (OECMs or Marine Refuges)[43]. Together, this growing evidence base and the planned expansion of Canada's MCA network create a timely opportunity to evaluate the benefit of incorporating blue carbon into national marine conservation planning.

Here, we present the first comprehensive national assessment of Canada's blue carbon ecosystems, designed to evaluate the climate mitigation benefits of expanding spatial protections for these ecosystems. Synthesizing the best available data, we produced national mapped ecosystem extents and eco-regional estimates of the carbon sequestration and storage potential of Canada's seagrass meadows, tidal marshes and seabed sediments. We also assessed ecoregional

donor flux potential from kelp forests as a critical, but often overlooked, blue carbon asset. Next, we considered the extent to which the most carbon rich areas are currently represented (i.e., protected) by Canada's MCA network and then estimated the avoided emissions value and the maintained carbon removal value that could result from meeting a 30% protection target for blue carbon ecosystems by 2030 (Table S1). In doing so, this study represents a significant advance over previous assessments, bringing together substantial new datasets, models, and estimates in the most extensive national collation of blue carbon information to date. More broadly, our study provides a transferable approach for identifying opportunities to simultaneously advance national biodiversity and climates mitigation goals through the protection of blue carbon.

Results

National carbon stocks, accumulation rates, and fluxes

We first combined national ecosystem extent estimates with ecoregion- and ecosystem-specific carbon densities and sequestration rates to quantify the magnitude and distribution of Canada's blue carbon. We found that Canada's blue carbon ecosystems collectively represent substantial carbon storage assets with an estimated 10,952.5 Tg C (7,035.7 – 16,098.7 Tg C) stored in the top 30 cm of marine soils and sediments of vegetated and bare seabed ecosystems (Figure 1; Table 1). Nearly all of this carbon (~99%) is contained within bare seabed sediments along the continental margins with much smaller shares (<1%) held in the soils and sediments of tidal marshes and seagrass meadows, respectively. Within the bare seabed pool, high-carbon seabed representing upper quartile sediment carbon densities account for roughly 5% of the national total (Figure 1a). Additionally, macrophytes sequester an estimated 7.7 Tg C yr^{-1} (95% CI: 5.6 – 25.1 Tg C yr^{-1}), with carbon donor fluxes from kelp forests accounting for the majority (79%) and accumulation in tidal marsh (19%) and seagrass (2%) sediments contributing the remainder (Figure 1b). Of the carbon fluxes from kelp forests, an estimated 29% of exported carbon is estimated to reache deep ocean sinks with the remaining 71% becoming refractory dissolved organic carbon (DOC). Although these fluxes do not constitute *in situ* storage, they provide distinct pathways through which kelp forests may contribute to long-term marine carbon sequestration[15].

Sensitivity analyses indicate that although national estimates for vegetated ecosystems vary with assumptions made when estimating ecosystem-specific carbon densities and extents, their relative contributions remain consistent across scenarios(Figure S2).

Regional variation in blue carbon sequestration and storage

We next evaluated how carbon stocks, accumulation rates, and donor fluxes were distributed across 13 marine ecoregions intersecting Canadian waters. These blue carbon assets varied considerably among ecoregions (Figure 2) due to differences in ecosystem extents and per area estimates. High-carbon seabed sediments were the most extensive along the Atlantic and Pacific continental margins, with the Gulf of Saint Lawrence-Eastern Scotian Shelf, the Scotian Shelf,

the North American Pacific Fjordlands and the Oregon Washington Vancouver Coast and Shelf together accounting for ~75% of the national total (Table S8-S9). Tidal marsh carbon stocks were overwhelmingly concentrated in the Hudson Bay Complex, representing ~85% of the national total, with much smaller contributions from Atlantic ecoregion (Table S8-S9). Seagrass carbon stocks were more evenly distributed among the top four ecoregions, including the Hudson Bay Complex (26%), Gulf of Saint Lawrence-Eastern Scotian Shelf (23%), the Scotian Shelf (15%), and the North American Pacific Fjordlands (14%) (Table S8-S9). Kelp derived carbon fluxes to long-term sinks also varied regionally, with the Hudson Bay Complex contributing substantially more (~48%) than any other ecoregion, followed by Northern Labrador (~14%), the Gulf of Saint Lawrence-Eastern Scotian Shelf (12%), and the North American Pacific Fjordlands (12%) (Table S9).

Protection gaps for blue carbon ecosystems

We then quantified the current representation of each blue carbon ecosystem within the most strictly protected and actively managed areas of Canada's MCA network. Only a fraction of Canada's most carbon-rich areas, including tidal marshes, seagrass meadows, kelp forests, and high-carbon seabed areas, falls within the strictest designations of the MCA network (Figure 3). Approximately 15% of tidal marsh, 3.0% of seagrass meadows, and <1% of high-carbon seabed sediments presently fall within areas designated as either IUCN categories (I-II) or OECMs (i.e., marine refuges) and that have active management plans in place that could be altered to mitigate blue carbon loss (Figure 3a). For kelp forests, 4.5% of kelp area is protected overall, including 18.0% of surface kelp forests (i.e., giant kelp, *Macrocystis pyrifera* and bull kelp, *Nereocystis luetkeanas* on the Pacific coast). Across 13 marine ecoregions, most ecosystems fell well short of 30% representation for each of these four ecosystems, with only a few marine ecoregions reaching adequate coverage (Figure 3b). For example, MCAs in the Bay of Fundy and Gulf of Saint Lawrence-Eastern Scotian Shelf ecoregions included adequate representative protection for tidal marshes (44.2 % and 31.7 %, respectively). As a result, the majority of Canada's blue carbon remains outside of these strictly protected and managed areas.

Blue carbon benefits of meeting 30% by 2030 conservation targets

Finally, we estimated the potential carbon storage and climate change mitigation benefit of increasing protection of the most carbon-rich areas for blue carbon to 30% by 2030, in line with the Kunming-Montreal Biodiversity targets. Under this scenario, we estimated that the amount of blue carbon stored within strictly protected and managed areas could be increased nearly 14-fold from 14.2 Tg C (95% CI: 12.8 – 15.9 Tg C) to 193.1 T g C (182.9 – 198.5 Tg C) (Figure 4). Assuming that Canada sets specific targets for blue carbon protections and that current rates of habitat loss and disturbance are appropriately abated by 2030, such an expansion could have a cumulative avoided emissions benefit of 59.9 Tg CO_2e (95% CI: 56.9 – 63.5 Tg CO_2e) by 2050 and a maintained carbon removal benefit of 47.1 Tg CO_2e (37.2 – 171.4 Tg CO_2e) of equivalent carbon dioxide (Figure 5). High-carbon seabed sediments and kelp forests account for the largest

absolute share of potential avoided emissions and maintained carbon removals, respectively, due to their extensive extents. However, tidal marshes and seagrass meadows could also deliver a measurable contribution because of their higher documented rates of decline and high per-area stocks and accumulation rates.

Discussion

This study provides the first comprehensive national assessment of Canada's blue carbon ecosystems, and the potential benefits of employing its BCEs to help meet national climate change mitigation and marine conservation targets. Together our analysis shows Canada's BCEs represent substantial natural climate solutions assets in comparison to terrestrial ecosystems and previous national and global estimates for ocean based pathways[11,44,44]. Accounting for all blue carbon, including lower carbon density seabed sediments (~11.0 Pg)[30], these carbon storage assets equate to roughly 20% of the amount of carbon held in Canada's forest soils and more nearly 60% of the carbon held in its forested biomass[47,49]. Given Canada's large coastline, its vegetated blue carbon ecosystems are also globally significant, representing ~5 – 29% of global carbon stocks in tidal marshes[7,11], ~1 – 8% of global carbon stocks in seagrass meadows[7,11], and ~5 – 7% of global sequestration for kelp forests[14,50].

Previously, Canada has been underrepresented in global blue carbon syntheses and assessments[23,24,27,51], due to significant data limitations and uncertainties pertaining to ecosystem extents, and the stocks, sequestration rates, and fates of blue carbon across all of its coastlines. As a result, past efforts to represent Canada in national and global evaluations of natural climate solutions pathways have necessarily relied on sparse datasets and extrapolations of assumptions and data from other regions and systems[11,44]. By assembling the most expansive and comprehensive datasets currently available, we move beyond first order stock-taking to explore how much of Canada's blue carbon stores could potentially be safeguarded through expansion of marine protection, providing first estimates of avoided emissions and maintained carbon removal value of doing so, provided that all current manageable rates of habitat loss are appropriately addressed. In doing so, this study provides a critical evidence base for aligning Canada's biodiversity conservation targets with national climate change mitigation commitments while providing a transferable approach for evaluating blue carbon conservation opportunities amidst persistent data limitations.

Despite the magnitude of Canada's blue carbon, we find that only a small fraction of the most carbon rich ecosystems—approximately 1– 18% depending on ecosystem type—fall within the most strictly protected and managed areas. This means that much of Canada's marine carbon is either under protected or outside of areas that are currently managed by federal, provincial and Indigenous governments where appropriate steps could most feasibly be taken to abate current rates of habitat loss and prevent possible carbon remineralization following disturbances. This is likely a consequence of historical marine conservation planning processes that did not include

marine carbon as a conservation objective. While a growing body of work seeks to advance the inclusion of blue carbon ecosystems into MCA design globally[40,41,52], its integration remains limited in practice. Even within existing MCAs, there is variation in protection standards and permitted activities that could compromise the integrity of protected blue carbon. Introducing standardized policies and regulations designed to limit disturbances to blue carbon within current and proposed protected areas will therefore be crucial for maintaining long-term carbon sequestration and storage benefits.

Our analysis shows that 30% representation targets for the most carbon-rich areas could secure a substantial amount of potentially irrecoverable marine carbon (sensu [53]), which could be managed to prevent future losses. We show that such action could have an estimated climate change mitigation benefit of ~106.9 Tg CO2e by 2050 in the form of cumulative avoided emissions and maintained carbon removal capacity. However, further research to better constrain current rates of habitat loss or conversion across Canada's coastline, including the role and importance of climate drivers (e.g., ocean warming, sea-level rise), will be important for refining these estimates. While modest relative to Canada's total annual greenhouse gas emissions, this estimated mitigation potential is larger than previous estimates for its blue carbon ecosystems, which suggested a lower potential for avoided emissions pathways only for seagrass meadows (i.e., 0.9 Tg CO_2e corrected for a comparable timeframe) and did not include estimates for tidal marshes, kelp forests, or seabed sediments because of prior data limitations and constraints[44]. Although blue carbon alone will not be able to deliver the scale of climate change mitigation required to meet national targets, our study shows it could make a measurable contribution alongside greenhouse gas emissions reductions, geological carbon storage, and other natural climate solutions while also delivering important biodiversity and ecosystem services[54].

An important caveat to this work is that protection alone cannot guarantee the permanence of these carbon stocks, nor the emissions avoidance benefits we estimated. Realizing the climate mitigation benefits from such actions will ultimately depend on whether appropriate policies and regulations are enacted within and outside of protected areas to limit the disturbances that drive habitat loss and carbon remineralization. The management action required to achieve these benefits may also vary among ecosystems. For bare sediments, appropriately targeted spatial protection could address some of the primary disturbances threatening their carbon stores. Bare seabed sediments account for the majority of Canada's estimated blue carbon stores and represent the largest pool of unprotected carbon, but their relevance to climate change mitigation depends on reducing their exposure to physical disturbances, like bottom trawl fishing[55]. While destructive bottom trawl fishing is estimated to directly affect a relatively small proportion (~1%) of Canada's seabed sediments[55], it remains a key mechanism of disturbance in carbon rich areas in Atlantic and Pacific regions and could expand in Arctic regions as sea ice continues to retreat with climate change[31]. Continued sea ice retreat may also open new Arctic shipping routes, increasing demand for dredging and other coastal modifications that impact the seabed[56].

Additionally, large swaths of the continental shelf may soon be opened for offshore energy development, which could lead to further bottom disturbances from seabed construction and cable laying. Identifying where these emerging pressures overlap with carbon-rich sediments will therefore be important for targeting future protection and management.

For tidal marshes and seagrass meadows, realizing climate change mitigation benefits will likely require further coordinated management of multiple stressors occurring within and beyond MCA boundaries[64]. Because these ecosystems occur in heavily utilized areas, important pressures to consider include coastal development, land-use change and conversion, fishing and other human activities[58,59,63]. Looking ahead, accelerating sea-level rise could pose an additional and growing threat that will require proactive planning[65]. Nevertheless, tidal marshes and seagrass meadows remain particularly valuable targets for protection and restoration because of their relatively high per-area stocks, accumulation rates, and estimated loss rates[71–74]. Their conservation and restoration could also provide substantial co-benefits through their provisioning (e.g., food production and security), regulating (e.g., water quality), cultural (e.g., recreation and eco-tourism), and supporting services (e.g., habitat provision for species of ecological, cultural, and economic importance)[54,61,62].

For kelp forests, the climate change mitigation benefits of spatial protection are more uncertain. Our study shows that kelp forests can facilitate substantial carbon fluxes that, if left vulnerable to disturbance, would represent a significant lost asset. However, there is uncertainty about the ultimate fate and permanence of sequestered carbon, which currently limit their incorporation into national NCS inventories [66]. Yet delaying kelp forest conservation action until full accounting is achieved may risk losses of vital carbon sequestration pathways that may not be readily recoverable through kelp forest restoration[67]. At the same time, an increasing share of kelp loss is being driven by marine heatwaves and gradual ocean warming[65], meaning spatial protection alone may become increasingly insufficient to safeguard these ecosystems. Complementary management interventions—including managing trophic dynamics and grazing pressures, invasive species controls, and improved water quality in coastal watersheds—may therefore be necessary to safeguard kelp forests and their carbon donor role[68]. Nevertheless, incorporating kelp forests into MCAs could improve monitoring capacity and enable more proactive management of these important ecosystems.

Uncertainties and future research needs

The uncertainties in our assessment reflect persistent gaps in the spatial coverage and resolution of blue carbon data more broadly. Although sampling, mapping, and modelling efforts have expanded rapidly across blue carbon ecosystems[69–71], national assessments still require combining heterogenous datasets that vary substantially in coverage and methodology. In Canada, our analysis necessarily relied on global remote sensing products for tidal marshes and

global distribution models for seagrass and kelp forests ecosystems to constrain plausible upper bounds on their extents. Because distribution models represent potential rather than realized habitat, they could overestimate true ecosystem extents. Conversely, estimates based on complication of currently mapped extents likely underestimate their distributions. Our approach therefore presents both to capture a plausible range of national values (see Figure S2). Improving spatially resolved maps of ecosystem extent, condition, and historical change remains an important priority for future research.

Other uncertainties arise from gaps in available blue carbon inventories. We quantified sedimentary carbon stocks only within the top 30cm, although sediment accretion and carbon accumulation often extend well beyond this depth in coastal BCEs[72]. We also could not account for DOC contributions from seagrass meadows and tidal marshes and considered only two of the three potential pathways for sequestration of kelp-derived carbon, excluding carbon burial potential in shelf sediments[15,66]. These omissions suggest that total carbon storage could be greater than estimated here. Expanding sediment core and GHG flux datasets and resolving currently unquantified sequestration pathways would therefore greatly improve the completeness and precision of national blue carbon estimates.

Looking forward, an equally important challenge will be understanding how the distribution and vulnerability of blue carbon assets change over time. Spatially explicit projections of emerging and intensifying human pressures and climate change will be needed to anticipate where existing protections may become ineffective and where conservation could provide the greatest benefit. This is particularly important in rapidly changing and data-poor regions, including Canada's Arctic and offshore waters. More broadly, coupling improved blue carbon inventories with improved mapping, standardized monitoring, and spatial assessments of future threats will be critical for moving national assessments from static estimates of carbon assets towards robust evaluations of their persistence and climate mitigation benefits under future conditions.

Alignment of climate change mitigation and biodiversity protection mandates

Existing marine conservation commitments provide an important opportunity to better align biodiversity protection and climate change mitigation objectives. Canada is particularly well position to capitalize on this opportunity through explicit integration of blue carbon into the design and expansion of its marine conserved area network. Importantly, many of the management actions required to protect blue carbon are already in line with existing provincial, federal, and Indigenous conservation objectives and governance mechanisms. For example, seagrass meadows in Canada are already recognized for their biodiversity value and ecological importance as nursery habitat for culturally and economically important fish species[73] and they were targeted as a conservation priority in the Great Bear Sea marine protected areas network in Pacific Canada. Embedding blue carbon considerations into MCA expansion and management would therefore not require a fundamental rethinking of marine conservation policy, but rather a refinement of priorities to

ensure that climate change mitigation benefits are captured alongside other important benefits (i.e., biodiversity, cultural significance, fisheries production, etc.). Given the need to balance multiple objectives for marine conservation planning, including biodiversity representation, areas of cultural significance, and socio-economic considerations, future spatial prioritization analyses could help to identify locations where expanded protections simultaneously deliver blue carbon benefits while advancing other conservation and management goals[74].

The opportunity to leverage existing marine conservation commitments for climate mitigation extends well beyond Canada. Biodiversity loss and climate change constitute interconnected global crises[75], yet many coastal nations face similar challenges in accounting for marine carbon and translating rapidly advancing blue carbon science into actionable policy[11,15]. Indeed, the data gaps we document for Canada's blue carbon ecosystems are not unique; many other coastal nations face similar data limitations when estimating the blue carbon potential of their oceans[11,76]. By combining ecosystem mapping, ecoregional and ecosystem-specific carbon accounting, and explicit evaluation of current protection gaps, our study develops and demonstrates an approach that is readily adaptable to other coastal nations that share Canada's data limitations. More broadly, our study illustrates how marine conservation strategies can be leveraged to deliver complimentary benefits without displacing other objectives (i.e., biodiversity conservation). As countries work to implement the Kunming-Montreal Global Biodiversity Framework[33] and strengthen national climate commitments under their Nationally Determined Contributions, integrating blue carbon into marine conservation planning offers a pragmatic pathway to address both crises simultaneously.

Materials and Methods

Mapping the extents of Canada's blue carbon ecosystems

We focused our assessment on seagrass meadows, tidal marshes and bare seabed sediments on the continental margin, as well as kelp forests as donors of carbon rich material to long-term sinks. For each ecosystem, we collated spatial extent data across 13 marine ecoregions intersecting Canadian waters, excluding areas outside national jurisdictions[77]. To account for data gaps and uncertainties in available extent maps for coastal vegetated ecosystems, we compiled both (1) current mapped extents from various sources and (2) a plausible upper bound estimate based on modeled distributions and/or reasonable assumptions about their geophysical and/or ecological constraints.

For seagrass meadows, mapped extent data were obtained from multiple sources including the National Eelgrass Dataset For Canada (NETForce) (https://app.geo.ca/en-ca/map-browser/record/a733fb88-ddaf-47f8-95bb-e107630e8e62), Canadian Census of Environment (Statistics Division of Statistics Canada, Environmental Accounts, https://publications.gc.ca/site/eng/9.945402/publication.html), and regional distribution models [78,79]. Because these data are considered to be an underestimate of the true extent, we also derived

418 a plausible upper bound extent based on the predicted range of eelgrass meadows (*Zostera*
419 *marina*) in Canada from a published global model, masked to the 10m depth isobath and adjusted
420 for the fraction of soft sediments in each ecoregion[70]. For tidal marshes, current mapped extent
421 data was obtained from the Canadian Census of the Environment (Statistics Division of Statistics
422 Canada, Environmental Accounts, https://publications.gc.ca/site/eng/9.945402/publication.html),
423 with a corresponding upper bound estimate from published global maps of tidal marshes
424 classified from satellite imagery from 2020[69]. For surface canopy kelp forests, we acquired
425 mapped extents representing composite distribution maps developed by the British Columbia
426 Marine Conservation Analysis (BCMA; https://bcmca.ca/?s=kelp). To represent a plausible
427 upper bound for surface kelp forest, we also estimated the area of suitable habitat within the 10m
428 depth isobath, adjusted for the fraction of rocky coastline within each Pacific coast ecoregion
429 following previous approaches[29]. Because spatial data on subsurface kelp forests in Canada
430 remain extremely limited, we used two plausible extent scenarios. First, we estimated the area of
431 suitable habitats within the 20m depth isobath adjusted for the fraction of rocky coastline and
432 average kelp cover within each ecoregion[29]. Second, we estimated the area of suitable habitat for
433 subsurface kelps from the predictions of a published global model of the kelp forest biome,
434 masked to the 20m depth isobath and similarly constrained by the fraction of rocky coastline
435 within each ecoregion [71]. Finally, we acquired extent estimates for bare seabed sediments areas
436 from published maps and models[30,47].
437
438 ***Estimating the carbon storage and sequestration potential of Canada's BCEs***
439 For seagrass meadows and tidal marshes, we estimated the current carbon storage and
440 sequestration potential by combining our ecoregional extent maps with the best available data on
441 per-area sedimentary organic carbon stocks and accumulation rates. Measurements of per-area
442 sedimentary carbon density (g C cm^{-3}) and annual carbon accumulation (g C cm^{-2} yr^{-1}) were
443 compiled from a range of published and unpublished sources, including the peer-reviewed
444 literature, white papers, and master's thesis [23–25,27,80,81] (Table S2-5). Per-area carbon stocks were
445 derived from down-core measurements of carbon density for the top 30 cm, accounting for
446 differences in depth horizons with a weighted average similar to previous studies[25]. For cores
447 that did not reach the 30 cm threshold, we extended downcore measurements using the Blue
448 Carbon package in R[82]. We then applied a generalized linear mixed-effect model to estimate the
449 average per-area carbon stock (Mg C ha^{-1}) and accumulation rate (Mg C ha^{-1} yr^{-1}) for tidal
450 marshes and seagrass ecosystems in each of the 13 marine ecoregions, accounting for differences
451 between ecoregions as a fixed effect (Figure S1). From these models, we derived 95%
452 confidence intervals around the estimated mean per area carbon stocks and accumulation rates,
453 which were propagated through our analysis to quantify uncertainty in our national estimates.
454 The model intercept and confidence intervals around the grand mean were also used to
455 approximate carbon stocks and accumulation rates in ecoregions without data. These per-area
456 estimates (Figure S1) were then scaled by the estimated ecosystem extents (both mapped extent
457 and plausible upper bound scenarios) in each ecoregion to calculate the total carbon storage and

458 sequestration potential of each ecosystem, expressed in teragrams of carbon (Tg C) and
459 teragrams of carbon per year (Tg C yr^{-1}) respectively.
460
461 For kelp forests, we estimated carbon sequestration capacity as the lateral carbon flux capacity,
462 focusing on two of the three main pathways for kelp carbon sequestration: (1) export of
463 particulate organic carbon (POC) to the deep ocean was estimated and (2) flow and
464 transformation of dissolved organic carbon (DOC) into refractory DOC pools (rDOC)[15]. Per area
465 estimates of kelp species net primary productivity (g C m^{-2} yr^{-1}) were acquired and used to
466 estimate the per area annual carbon production of kelp communities in each ecoregion following
467 the same methodologies used in previous work[29]. Estimates of the annual rate of deep ocean
468 export (i.e., the amount of kelp-derived carbon per-area of kelp forests reaching the edge of the
469 continental shelf (>200 m isobath)) were then derived for Canada's 13 marine ecoregions by
470 multiplying per area carbon production estimates by the fraction of estimated export expected for
471 a given ecoregion from a global coastal residence time model[16,29]. We also estimated the annual
472 rate of rDOC export from kelp forests as 30.4% of annual carbon production (POC to DOC;
473 sensitivity of 18 – 45%) and then of that 37.5% of dissolved organic carbon production (DOC to
474 rDOC; sensitivity of 1.6 – 76%) [76]. These rates are conservative, as our annual carbon production
475 measures are largely from biomass accumulation studies, which underestimate the release of
476 DOC during growth[83]. These per-area values (Figure S1) were then summed by ecoregion and
477 scaled by the estimated extents (both mapped extent and plausible upper bound scenarios) of
478 surface and subsurface kelp forests, respectively, in each ecoregion to calculate the total carbon
479 flux potential of kelp forests, expressed in teragrams of carbon per year (Tg C yr^{-1}). Confidence
480 intervals were calculated by propagating uncertainty in annual carbon production estimates and
481 export estimates through both POC and rDOC pathways.
482
483 Finally, we estimated the carbon storage capacity of bare seabed sediments along Canada's
484 continental margin using a predictive model from [30], which produced fine-scale maps of the
485 estimated organic carbon density (kg C m^{-3}) of marine sediments along Canada's coastline
486 continental shelf. These data cover 4,449,235 km^2, which is 78.4% of the EEZ or 92.6% of the
487 seafloor area above 2500m. In this previous study, mean estimates and 95% confidence intervals
488 were derived at 200m resolution from random-forest predictive modeling, following a collation
489 of best available data on sediment organic carbon content, sediment composition, seafloor
490 morphology, hydrology, chemistry, and geographic setting[30]. Using these modeled outputs, we
491 first extracted and converted model estimates to per-area carbon stocks (Mg C ha^{-1}) within the
492 top 30 cm of sediment accretion for the entire model domain. For subsequent analyses, we
493 isolated the most carbon rich areas—hereafter called high-carbon seabed sediments—defined as
494 locations exceeding the upper quartile of sediment carbon densities (> 16.8 kg C m^{-3}), following
495 previous work [47,48]. We summed estimated carbon stocks within and across each ecoregion
496 (Figure S1) to estimate the total carbon (Tg C) stored in the top 30-cm of bare seabed sediments
497 broadly and within high-carbon areas of the seabed. Uncertainty in these estimates was

propagated from the modeled uncertainty in sediment organic carbon density maps in [31], with confidence intervals derived from the lower and upper bounds of the model predictions. Due to data limitations, we were unable to estimate the carbon sequestration capacity for these systems because of present data limitations, which is an essential area to resolve in future research.

Current protection gaps for blue carbon ecosystems

To evaluate the protection status of Canada's most carbon rich areas, we overlaid ecosystem extents and blue carbon estimates with the Canadian Protected and Conserved Areas Database (DFO, 2024, https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/protected-conserved-areas-database.html). From this database, we included federal, provincial, territorial, and Indigenous-led designations that meet the strictest protection criteria (i.e., IUCN categories 1a, 1b, and 2, and OECMs that have active management plans) under Canada's MCA network (Table S6). For provinces that have existing setback rules meant to prevent loss or conversion due to coastal development and land use changes within 100m of a tidal marsh (e.g., New Brunswick), we also included areas representing a 100m buffer around tidal marsh extents within those provincial jurisdictions. We then calculated the proportion of each ecosystem and associated blue carbon estimates (stock, accumulation, and flux) currently contained within MCA boundaries across ecoregions through spatial analysis using the *terra* library of R[84].

Blue carbon benefits of meeting 30% by 2030 marine conservation targets

We then estimated the additional blue carbon benefits that could be secured from expanding MCA coverage to 30% of each ecosystem by 2030 in each ecoregion, consistent with the Kungming-Montreal Post-2020 Global Biodiversity Framework and Canada's 30% by 2030 marine conservation targets. For each ecosystem, we estimated both the total protected blue carbon assets (in terms of total stocks, accumulation and fluxes) and the climate change mitigation potential of expanded protections. Mitigation potential from expanded protection was projected using an avoided habitat conversion / loss framework, modeled after *Drever et al.* (2021), where we assumed that the ecosystem area required to reach 30% protection for each ecosystem is fully protected by 2030, that ecosystems remain intact relative to baseline conditions, and that appropriate spatial protection measures and/or regulations are put in place to effectively prevent current rates of habitat loss and conversion between 2030 and 2050. Thus, this scenario estimates the potential mitigation achievable where expanded protection is accompanied by effective management of current rates of habitat loss and disturbance, rather than assuming that MCA designation alone prevents carbon loss. Habitat loss and disturbance rates (Table S7) were drawn from published, ecosystem-level estimates following the approach used in the most comparable NCS assessment for North America[1,44,85] and reflecting current data availability at the national scale.

For each sedimentary ecosystem (*e)* in each marine ecoregion (*r*), we projected the cumulative potential avoided emissions from preventing habitat loss and/or conversion over a two decadal period from 2030 to 2050 as:

Avoided Emissions (e,r) = Carbon stock (e,r) x Area protected (e,r) x Cumulative loss rate (e) x Emissions rate

Where:

Carbon stock is the per-hectare carbon stock for ecosystem *e* within ecoregion *r* subject to disturbance (standardized to 30 cm for soils and sediments);

Area protected is the area protected if MCA coverage reached 30% of the ecosystem's extent in ecoregion r;

Cumulative loss rate (e) is the proportion of habitat expected to be lost or converted between 2030 and 2050 under baseline conditions without any interventions. This value is calculated from published annual ecosystem-specific habitat loss or disturbance rates (Table S7) assuming a constant rate of decline over time and compounding annual loss across the 20-year period;

Emission rate is the fraction of disturbed carbon assumed to be remineralised and released as CO_2 assuming 50% for tidal marshes and seagrasses, and seabed sediments. This value is considered conservative relative to the IPCC Tier 1 default assumption that 100% of soil carbon is emitted as CO_2 in the years of disturbance [86].

For macrophytes ecosystems (*e)* in each marine ecoregion (*r*), we also calculated the amount of maintained carbon removal by macrophytes—tidal marshes, seagrass meadows and kelp forests—that would be preserved from preventing habitat loss and/or conversion over a two decadal period from 2030 to 2050 as:

Carbon Removal (e,r) = Area protected (e,r) x Carbon removal (e,r) x Cumulative loss rate (e) x Emissions rate

Where *Area protected*, *Cumulative loss rate,* and *Emissions rate* are calculated as above and:

Carbon removal is the per-hectare annual carbon removal for ecosystem *e* within ecoregion *r.* For tidal marshes and seagrass meadows this is the annual accumulation rate in soils and sediments, assuming accumulation remains constant over time and that burial processes would be lost if the associated habitat were degraded or converted. For kelp forests, this is the annual carbon flux to the deep ocean and recalcitrant dissolved organic carbon (rDOC) pools, assuming constant annual rates of productivity and export.

The combined estimates represent the cumulative avoided emissions and carbon removal pathways that would be maintained by preventing ecosystem loss under expanded protection from 2030 to 2050. Uncertainty in these estimates was propagated from the 95% confidence

intervals associated with earlier estimates of per area carbon stocks, accumulation rates, and kelp carbon fluxes, which were applied to represent the lower and upper bounds of the avoided emissions and maintained carbon removal.

Tables

Table 1. Estimated national total extents, soil C stocks, soil C accumulation rates, and C donor fluxes (mean; 95% CI) for traditional and donor blue carbon ecosystems (BCEs) in Canada, respectively, followed by the potential climate change mitigation benefit of expanding Canada's MCA network to meet 30% by 2030 targets with ecoregional representation for blue carbon ecosystems incorporated into the design. See methods for calculation details.

Traditional BCEs	**Areal Extents** (ha)	**National C Stocks-** Total (Tg C)	**National C Accumulation-** Total (Tg C yr^{-1})	**National C Stocks-** Current MCAs (Tg C)	**Avoided Conversion Benefit by 2050-** Current MCAs (Tg CO_2e)	**Avoided Conversion Benefit by 2050-** 30% by 2030 (Tg CO_2e)	**Avoided Conversion Benefit by 2050-** Drever et al. (Tg CO_2e)
Tidal marshes	360,318.8[1] – 843,650.6[2]	75.6 (67.8 – 83.4)	1.5 (1.0 – 2.0)	10.9 (9.8 – 12.2)	1.9‡† (1.6 – 2.4)	4.1‡† (3.3 – 5.1)	None
Seagrass meadows	161, 600[1,3-4] – 706,580.8*	9.0 (7.1 – 14.5)	0.1 (0.06 – 0.2)	0.06 (0.04 – 0.08)	0.3‡† (0.2 – 0.5)	2.6‡† (1.8 – 3.8)	1.4*
Bare sediments	44,892,350[5]	10,952.5 (7,035.7 – 16,098.7)	ND	2.9 (2.7 - 3.0)	1.0*‡† (0.9 – 1.1)	55.9‡† (53.5 – 58.3)	None
Donor BCEs	**Areal Extents** (ha)	**National Deep Ocean C Flux-** Total (Tg C yr^{-1})	**National RDOC C Flux-** Total (Tg C yr^{-1})	**National C Flux-** Current MCAs (Tg C yr^{-1})	**Avoided Conversion-** Current MCAs (Tg CO_2e)	**Avoided Conversion-** 30% by 2030 targets (Tg CO_2e)	
Kelp forests	3,998,182[6] - 5,566,927.5*	1.7 (1.1 – 6.4)	4.3 (3.7 – 16.5)	0.3 (0.2 – 0.9)	6.3† (5.2 – 22.2)	44.2† (35.5 – 167.3)	None

Sources: (1) CEC Statistics Canada 2024, (2) Worthington et al. 2024, (3) Nephlin et al. 2020, (4) NETForce, (5) Epstein et al. 2025, (6) McHenry et al. 2025, *derived by this study. ‡ Indicates estimates account for avoided carbon emissions. † Indicates estimates account for maintained carbon removal. *Indicates the value is adjusted to a comparable period of 2020-2050 to 2030-2050.

Figures

Figure 1. Estimated national C stocks and C sequestration rates (mean; 95% CI) for traditional and donor blue carbon ecosystems (BCEs) in Canada.

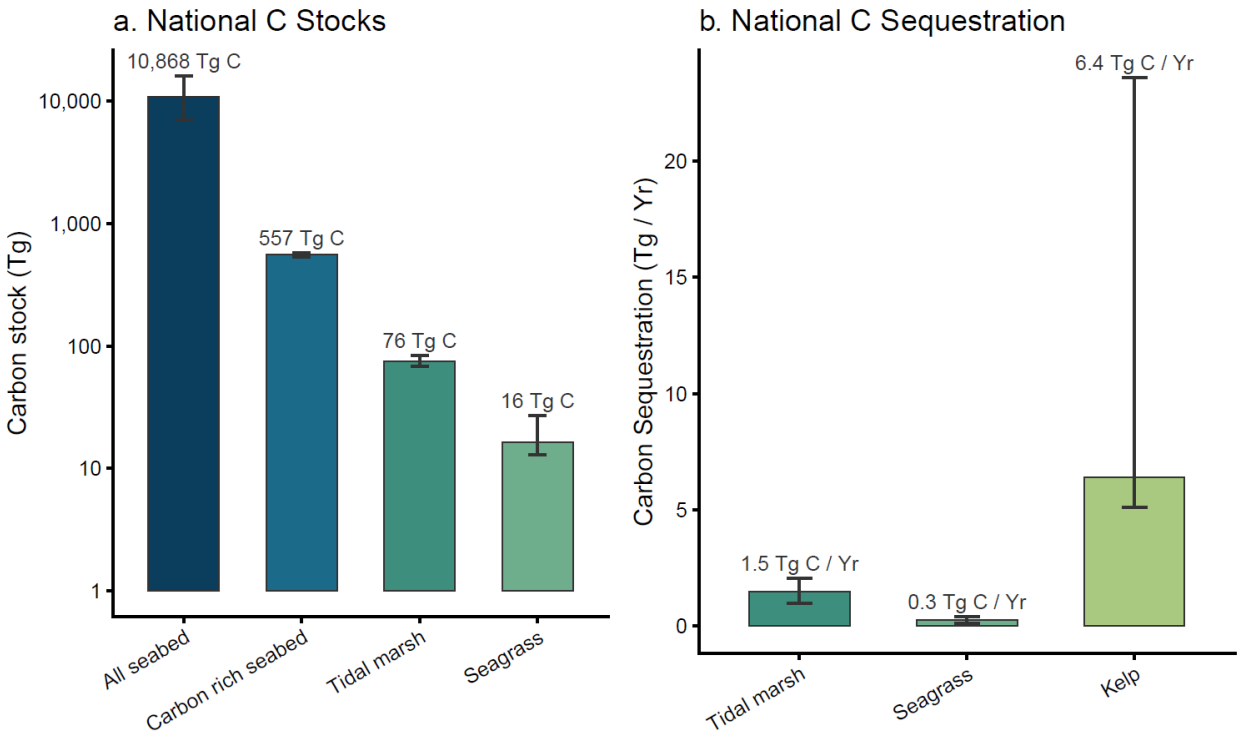


Figure 2. Regional variation in estimated (a) sedimentary carbon stocks (Tg C) and (b) carbon sequestration rates (Tg C yr^{-1}) associated with Canada's blue carbon ecosystems. Marine ecoregions include Baffin Bay - Davis Strait (BB-DS), Hudson Bay Complex (HC), Northern Labrador (NL), Northern Grand Banks - Southern Labrador (NGB-SL), Southern Grand Banks - South Newfoundland (SGB-SN), Gulf of St. Lawrence - Eastern Scotian Shelf (GoSL-ESS), Scotian Shelf (SS), Gulf of Maine/Bay of Fundy (BoF), Oregon, Washington, Vancouver Coast and Shelf (OWVCS), Puget Trough/Georgia Basin (PT/GB), North American Pacific Fijordland (NAPF), Beaufort-Amundsen-Viscount Melville-Queen Maud (B-A-V-M-QM), and Lancaster Sound (LS).

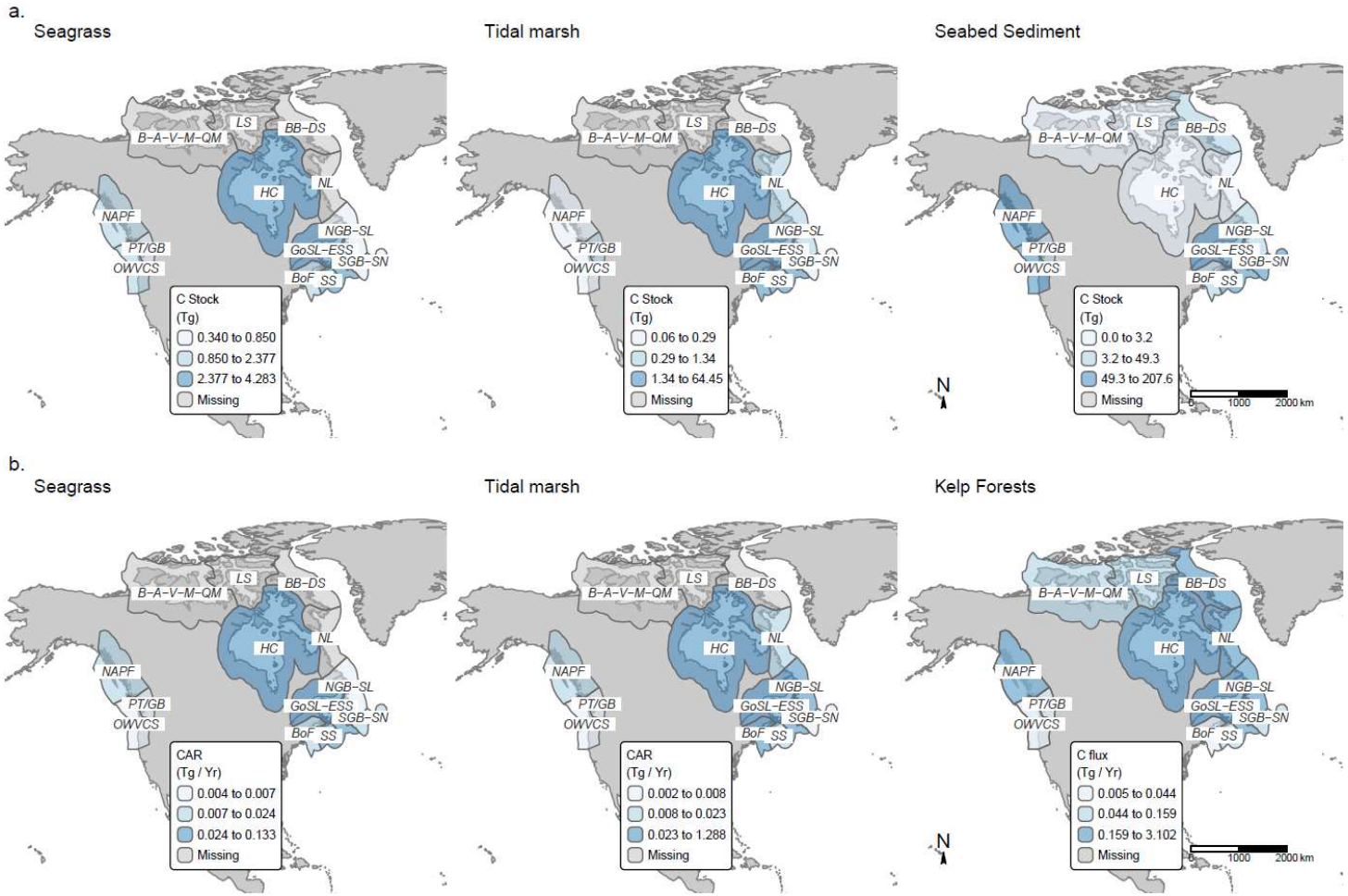


Figure 3. Current spatial protections of blue carbon ecosystems within Canadian waters by (a) habitat and (b) by marine ecoregions. Current protection is expressed as the percentage of seagrass, tidal marsh, kelp forests, and high-carbon seabed sediments that currently fall under strict protections within Canada's marine conserved areas (MCA) network. Protection level is categorized as: no protection (0 %; blank), inadequate protection (< 30%; orange), and adequate protection (>30%; blue). Marine ecoregions are as in Figure 2.

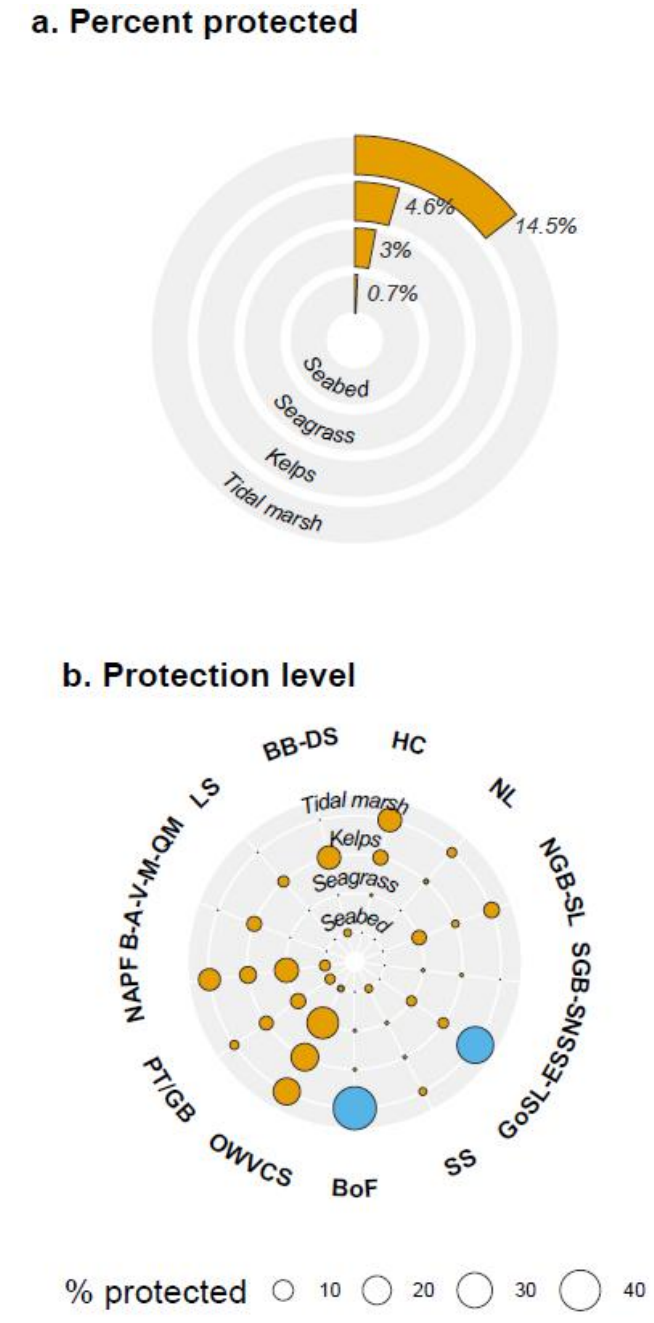


Figure 4. National blue carbon benefit of meeting Canada's 30% by 2030 conservation targets with representation targets for each of the four ecosystems.

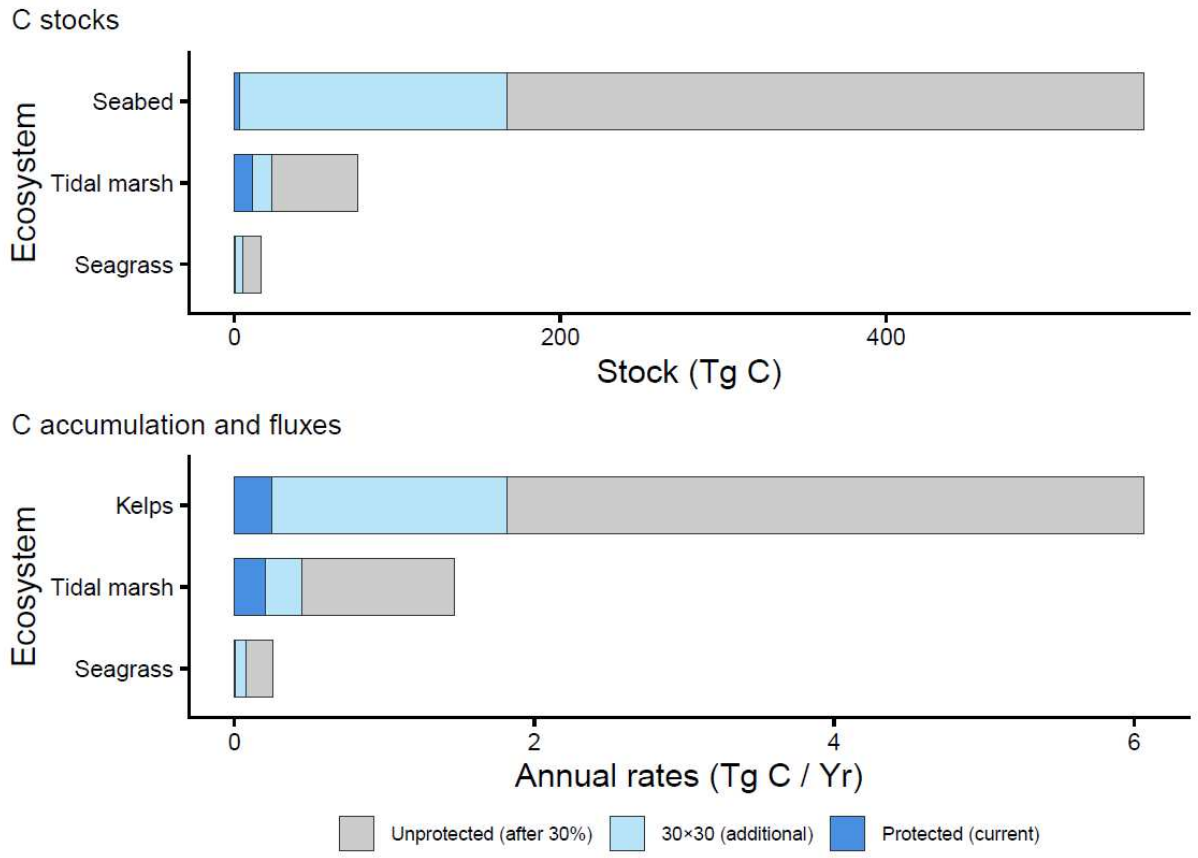
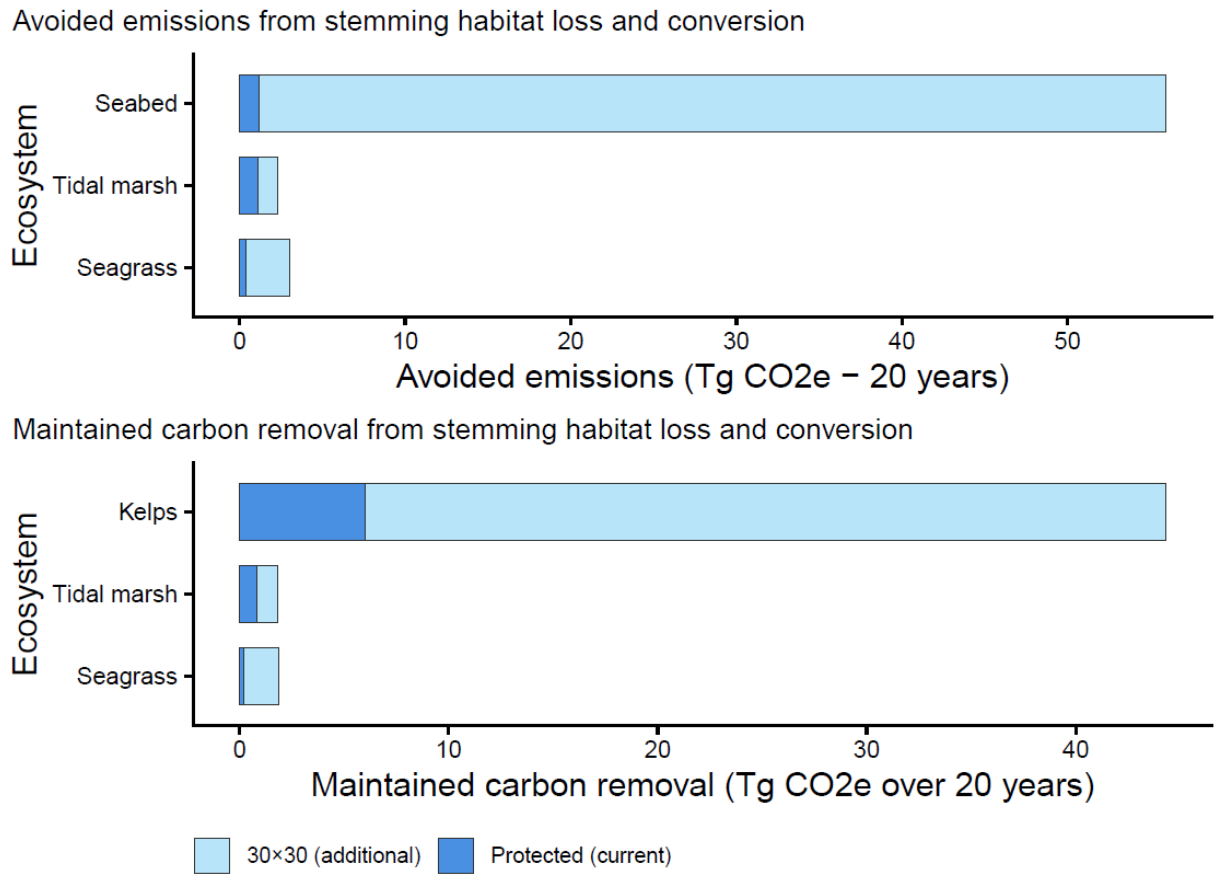


Figure 5. National estimated climate change mitigation potential projected from meeting Canada's 30% by 2030 conservation targets with representation targets for each of the four ecosystems.



Data availability:

Research outputs, including the collated and synthesized carbon datasets and the resulting national estimates, will be made publicly available at the time of publication through the Blue Carbon Canada Dataverse. To respect the data sovereignty of First Nations partners, certain cores data may be redacted in the publicly available dataset but may be available upon request. To request redacted data, the corresponding author can be contacted to arrange contact with appropriate groups to secure a data sharing agreement. Additionally, the R code supporting this study will be uploaded to a GitHub repository.

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Author Contributions:

J.M., G.E., M.I.O, S.H.K, P.A., S. F., K.K., K.F.D, M. H-L., M.W., T.R., E.R., L.S., V.V., and J.K.B conceptualized this study over a two day workshop, during breakout sessions led by J.M, G.E., and J.K.B. J.M. led the data acquisition and analyzed the data with contributions and input from G.E, V.V., L.S. , M.I.O, M.W., K.K., K.F.D., S.H.K., T.R., M. H-L, M.L., G.C., and J.K.B. J.M. wrote the original draft of the manuscript with significant contributions G.E. and revisions from M.I.O, S.H.K, P.A., K.K., and J.K.B. All co-authors contributed to the interpretation of the results, made substantive contributions through writing and feedback on the revised manuscript,

and approved the final manuscript for submission. J.K.B. supervised the research as the senior author and acquired the original funding with contributions from M.I.O, S.H.K., and P.A.

Declaration of interests:

The authors declare no competing interests.

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Supplementary information

Table S1. Ocean-based natural climate solutions pathways relevant to blue carbon ecosystems, summarizing definitions and primary climate change mitigation mechanisms considered in the context of Canada's marine conservation and 30% by 2030 commitments.

Solution Name	Definition	Climate impact mechanism
Tidal marsh protection	The legal protection of existing marsh ecosystems to prevent conversion, degradation, and disturbance, thereby safeguarding organic carbon stored in marsh soils and maintaining carbon sequestration.	Carbon avoided emissions; Maintained carbon removal
Seagrass protection	The legal protection of existing seagrass meadows to prevent physical disturbance, degradation or loss, thereby safeguarding organic carbon stored in marine sediments and maintaining carbon sequestration.	Carbon avoided emissions, Maintained carbon removal
Kelp forest protection	The legal protection of wild kelp forests to maintain their role as carbon donor systems, facilitating export of kelp-derived organic carbon to long-term sinks in the deep ocean and refractory dissolved organic carbon pools.	Maintained carbon removal
Carbon rich seabed sediment protection	The legal protection of high organic carbon density seabed sediments from disturbance, reducing resuspension and remineralization of stored sedimentary carbon on the continental shelf.	Carbon avoided emissions*

*Although maintained carbon removal is also possible from carbon rich seabed, the data to support estimation of this pathway remains limited in Canada and so is not included in this analysis.

898 **Table S2.** Collated and synthesized data sources used for estimating sedimentary organic carbon
899 stocks (Mg ha^{-1} of top 30 cm) associated with seagrass meadows by ecoregion. Samples
900 represent the number of values included in the analysis from each study.

Marine ecoregion	Data source	C stock-mean	C stock-SD	Samples
Gulf of St. Lawrence - Eastern Scotian Shelf	Christensen, M., Wong M.C., Guijarro-Sabaneil, J., Gerlinksy C., Henrichs, M., O'Connor, M.I., *in review.* Estuaries and Coasts	6.26	1.69	5
Scotian Shelf	Christensen, M., Wong M.C., Guijarro-Sabaneil, J., Gerlinksy C., Henrichs, M., O'Connor, M.I., *in review.* Estuaries and Coasts	19.27	16.60	20
North American Pacific Fijordland	Christensen, M., Wong M.C., Guijarro-Sabaneil, J., Gerlinksy C., Henrichs, M., O'Connor, M.I., *in review.* Estuaries and Coasts	22.19	1.52	2
	Prentice, C., Hessing-Lewis, M., Sanders-Smith, R., & Salomon, A. K. (2019). Reduced water motion enhances organic carbon stocks in temperate eelgrass meadows. Limnology and Oceanography, 64(6), 2389-2404.	18.73	11.65	6
Oregon, Washington, Vancouver Coast and Shelf	Kauffman, J. B., Giovanonni, L., Kelly, J., Dunstan, N., Borde, A., Diefenderfer, H., ... & Brophy, L. (2020). Total ecosystem carbon stocks at the marine-terrestrial interface: Blue carbon of the Pacific Northwest Coast, United States. Global Change Biology, 26(10), 5679-5692.	32.61	5.62	4
Puget Trough/Georgia Basin	Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., ... & Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature geoscience, 5(7), 505-509.	26.39		1
	Kauffman, J. B., Giovanonni, L., Kelly, J., Dunstan, N., Borde, A., Diefenderfer, H., ... & Brophy, L. (2020). Total ecosystem carbon stocks at the marine-terrestrial interface: Blue carbon of the Pacific Northwest Coast, United States. Global Change Biology, 26(10), 5679-5692.	13.51	2.14	2

	Christensen, M., Wong M.C., Guijarro-Sabaneil, J., Gerlinksy C., Henrichs, M., O'Connor, M.I., *in review.* Estuaries and Coasts	10.25	8.11	20
	Douglas, T. J., Schuerholz, G., & Juniper, S. K. (2022). Blue carbon storage in a northern temperate estuary subject to habitat loss and chronic habitat disturbance: Cowichan estuary, British Columbia, Canada. Frontiers in Marine Science, 9, 857586.	25.33	3.56	3

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904 **Table S3.** Collated and synthesized data sources used for estimating soil organic carbon stocks
905 (Mg C ha^{-1} in the top 30 cm) associated with tidal marshes by ecoregion. Samples represent the
906 number of values included in the analysis from each study.

Marine ecoregion	Data source	C stock-mean	C stock-SD	Samples
Gulf of Maine/Bay of Fundy	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	124.7	34.3	3
	Connor, R. F., Chmura, G. L., & Beecher, C. B. (2001). Carbon accumulation in bay of fundy salt marshes: Implications for restoration of reclaimed marshes. Global Biogeochemical Cycles, 15(4), 943–954. https://doi.org/10.1029/2000gb001346	104.7	15.9	6
Scotian Shelf	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	100.3	14.8	6
Gulf of St. Lawrence - Eastern Scotian Shelf	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	93.8	10.0	5
	Gu, J., van Ardenne, L. B., & Chmura, G. L. (2020). Invasive Phragmites increases blue carbon stock and soil volume in a St. Lawrence estuary marsh. Journal of Geophysical Research Biogeosciences, 125(8), e2019JG005473. https://doi.org/10.1029/2019jg005473	80.8	7.8	12
	van Ardenne, L. B., Jolicoeur, S., Bérubé, D., Burdick, D., & Chmura, G. L. (2018). High resolution carbon stock and soil data for three salt marshes along the northeastern coast of North America. Data in Brief, 19, 2438–2441. https://doi.org/10.1016/j.dib.2018.07.037	73.9	24.9	32
	Yu, O. T., & Chmura, G. L. (2009). Soil carbon may be maintained under grazing in a St Lawrence estuary tidal marsh. Environmental Conservation, 36(4), 312–320. https://doi.org/10.1017/s0376892910000184	92.1	7.2	2
North American Pacific Fijordland	Tom Reid, Nature Trust BC, unpublished data	114.4	56.6	21
	Sanborn, Paul; Coxson, Darwyn S. (2020): Dataset: Carbon data for intertidal soils and sediments, Skeena River estuary, British Columbia. The Smithsonian Institution. Dataset.	62.5	35.6	33
Oregon, Washington, Vancouver Coast and Shelf	Chastain, S. G., Kohfeld, K. E., Pellatt, M. G., Olid, C., & Gailis, M. (2022). Quantification of blue carbon in salt marshes of the Pacific coast of Canada. Biogeosciences, 19(24), 5751-5777.	67.4	33.8	19
	Kauffman, J. B., Giovanonni, L., Kelly, J., Dunstan, N., Borde, A., Diefenderfer, H., ... & Brophy, L. (2020). Total ecosystem carbon stocks at the marine-terrestrial interface:	96.9	6.9	2

	Blue carbon of the Pacific Northwest Coast, United States. Global Change Biology, 26(10), 5679-5692.			
	Tom Reid, Nature Trust BC, unpublished data	115.1	15.7	4
Puget Trough/Georgia Basin	Gailis, M., Kohfeld, K. E., Pellatt, M. G., & Carlson, D. (2021). Quantifying blue carbon for the largest salt marsh in southern British Columbia: implications for regional coastal management. Coastal Engineering Journal, 63(3), 275-309.	51.7	14.1	3
	Douglas, T. J., Schuerholz, G., & Juniper, S. K. (2022). Blue carbon storage in a northern temperate estuary subject to habitat loss and chronic habitat disturbance: Cowichan estuary, British Columbia, Canada. Frontiers in Marine Science, 9, 857586.	97.4	105.6	4
	Tom Reid, Nature Trust BC, unpublished data	113.1	61.5	14
	Poppe, Katrina; Bridgham, Scott D.; Janousek, Christopher; Williams, Trevor; Cornu, Craig; Perillat, Heather; et al. (2024). Dataset: Soil carbon stocks and long-term accretion rates in tidal marshes, tidal swamps, and former tidal wetlands in eight estuaries in the Pacific Northwest, USA. Smithsonian Environmental Research Center. Dataset.	59.5	12.4	8
	Poppe, Katrina, University of British Columbia, unpublished data	72.25	21.23	4

909 **Table S4.** Collated and synthesized data sources used for estimating sedimentary organic carbon
910 accumulation (Mg C ha^{-1} yr^{-1}) associated with seagrass meadows by ecoregion. Samples
911 represent the number of values included in the analysis from each study.

Marine ecoregion	Data source	CAR - mean	CAR - SD	Samples
North American Pacific Fijordland	Prentice, C., Poppe, K. L., Lutz, M., Murray, E., Stephens, T. A., Spooner, A., ... & Klinger, T. (2020). A synthesis of blue carbon stocks, sources, and accumulation rates in eelgrass (Zostera marina) meadows in the Northeast Pacific. Global Biogeochemical Cycles, 34(2), e2019GB006345.	0.19	0.13	5
Oregon, Washington, Vancouver Coast and Shelf	Prentice, C., Poppe, K. L., Lutz, M., Murray, E., Stephens, T. A., Spooner, A., ... & Klinger, T. (2020). A synthesis of blue carbon stocks, sources, and accumulation rates in eelgrass (Zostera marina) meadows in the Northeast Pacific. Global Biogeochemical Cycles, 34(2), e2019GB006345.	0.23	0.09	2
FgPuget Trough/Georgia Basin	Poppe, K. L., & Rybczyk, J. M. (2018). Carbon sequestration in a pacific northwest eelgrass (Zostera marina) meadow. Northwest Science, 92(2), 80-91.	0.10	0.05	12
	Prentice, C., Poppe, K. L., Lutz, M., Murray, E., Stephens, T. A., Spooner, A., ... & Klinger, T. (2020). A synthesis of blue carbon stocks, sources, and accumulation rates in eelgrass (Zostera marina) meadows in the Northeast Pacific. Global Biogeochemical Cycles, 34(2), e2019GB006345.	0.34	0.24	4

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914 **Table S5.** Collated and synthesized data sources used for estimating soil organic carbon
915 accumulation (Mg C ha^{-1} yr^{-1}) associated with tidal marshes by ecoregion. Samples represent the
916 number of values included in the analysis from each study.

Marine ecoregion	Data source	CAR - mean	CAR - SD	Samples
Gulf of Maine/Bay of Fundy	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	2.8	2.3	16
	Connor, R. F., Chmura, G. L., & Beecher, C. B. (2001). Carbon accumulation in bay of fundy salt marshes: Implications for restoration of reclaimed marshes. Global Biogeochemical Cycles, 15(4), 943–954. https://doi.org/10.1029/2000gb001346	1.2	0.8	4
Gulf of Saint Lawrence-Eastern Scotian Shelf	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	0.9	0.25	5
Scotian Shelf	Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. Global biogeochemical cycles, 17(4).	1.4	0.9	6
Oregon, Washington, Vancouver Coast and Shelf	Chastain, S. G., Kohfeld, K. E., Pellatt, M. G., Olid, C., & Gailis, M. (2022). Quantification of blue carbon in salt marshes of the Pacific coast of Canada. Biogeosciences, 19(24), 5751-5777.	1.9	1.3	8
Puget Trough/Georgia Basin	Drexler, J. Z., Woo, I., Fuller, C. C., & Nakai, G. (2019). Carbon accumulation and vertical accretion in a restored versus historic salt marsh in southern Puget Sound, Washington, United States. Restoration Ecology, 27(5), 1117-1127.	1.3	NA	1
	Gailis, M., Kohfeld, K. E., Pellatt, M. G., & Carlson, D. (2021). Quantifying blue carbon for the largest salt marsh in southern British Columbia: implications for regional coastal management. Coastal Engineering Journal, 63(3), 275-309.	1.6	0.4	2
	Poppe, Katrina; Bridgham, Scott D.; Janousek, Christopher; Williams, Trevor; Cornu, Craig; Perillat, Heather; et al. (2024). Dataset: Soil carbon stocks and long-term accretion rates in tidal marshes, tidal swamps, and former tidal wetlands in eight estuaries in the Pacific Northwest, USA. Smithsonian Environmental Research Center. Dataset.	1.6	1.1	8

917 **Table S6.** Marine conserved areas that have active management plans dictating the scope of
918 activities permitted (a) by designation type and (b) IUCN category that were selected for further
919 analysis.
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a) Designation Type	Area (ha)
Biodiversity Reserve	533153.2
Biological Refuge	492.6
Conservancy	827526.5
Ecological Reserve	497174.0
Marine Park	124723.4
Marine Reserve	181.0
Migratory Bird Sanctuary	11289082.7
National Park	33257312.9
National Wildlife Area	898219.1
Other Effective Area-Based Conservation Measure	4882.6
Protected Area	209841.4
Provincial Park	20040412.5
Quebec's National Park	5494576.4

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b) IUCN Category	Description
Ia	**Strict Nature Reserve:** Strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Ib	**Wilderness Area:** Protected areas that are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed to preserve their natural condition.
II	**National or Provincial Park:** Protected areas that are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
OECM	**Other Effective Area-Based Conservation Measures:** A non-IUCN designation for areas that deliver effective, long-term biodiversity conservation outcomes despite not being formally classified as protected areas.

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Table S7. Collated annual estimated habitat loss rates from published literature that are used to estimate the fraction of potentially avoidance emissions from strengthening protections for blue carbon under Canada's MCA network strategy.

Habitat	**Annual estimated net habitat loss rate (% per year)**	**Data source**
Tidal marshes	0.28 (net)	Campbell, A. D., Fatoyinbo, L., Goldberg, L., & Lagomasino, D. (2022). Global hotspots of salt marsh change and carbon emissions. Nature, 612(7941), 701-706.
Seagrass meadows	2.0 (net)	Dunic, J. C., Brown, C. J., Connolly, R. M., Turschwell, M. P., & Côté, I. M. (2021). Long-term declines and recovery of meadow area across the world's seagrass bioregions. Global Change Biology, 27(17), 4096-4109.
Kelp forests	2.0 (net)	Krumhansl, K. A., Okamoto, D. K., Rassweiler, A., Novak, M., Bolton, J. J., Cavanaugh, K. C., ... & Byrnes, J. E. (2016). Global patterns of kelp forest change over the past half-century. Proceedings of the National Academy of Sciences, 113(48), 13785-13790.
Habitat	**Annual estimated disturbance rate (% of area per year)**	**Data source**
Seabed sediments	1.0 per annum	Epstein, G., Fuller, S. D., Gullage, L., & Baum, J. K. (2025). Mobile bottom fishing in the Canadian Pacific and Atlantic causes disturbance and risk to remineralisation of seabed sediment carbon stocks. Canadian Journal of Fisheries and Aquatic Sciences, 82, 1-22.

932 **Table S8.** Per-area and ecoregional estimates of soil organic carbon stocks (mean; 95% CI)
933 stocks by blue carbon ecosystem in Canada.

Ecoregion	Abbreviation	Habitat	Per-area C stock (Mg ha^{-1})	Source	Ecoregional C stock (Tg C)
Baffin Bay - Davis Strait	BB-DS	Carbon rich seabed	48 (43.6 - 52.4)	Epstein et al. 2022	3.2 (2.9 - 3.5)
Lancaster Sound	LS		44.9 (41.1 - 48.7)	Epstein et al. 2022	0.5 (0.4 - 0.5)
Northern Grand Banks - Southern Labrador	NGB-SL		46.4 (44.7 - 48.1)	Epstein et al. 2022	40.8 (39.3 - 42.4)
Gulf of Maine/Bay of Fundy	BoF		47.8 (43.3 - 52.2)	Epstein et al. 2022	17.7 (16.1 - 19.4)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		47.2 (46.6 - 47.9)	Epstein et al. 2022	207.8 (204.8 - 210.8)
Scotian Shelf	SS		50.5 (48.3 - 52.6)	Epstein et al. 2022	74.3 (71.1 - 77.5)
Southern Grand Banks - South Newfoundland	SGB-SN		49.5 (46.9 - 52.1)	Epstein et al. 2022	64.8 (61.5 - 68.2)
North American Pacific Fijordland	NAPF		51.6 (48.7 - 54.4)	Epstein et al. 2022	69.2 (65.4 - 73.1)
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		57.3 (51.9 - 62.7)	Epstein et al. 2022	49.2 (44.6 - 53.8)
Puget Trough/Georgia Basin	PT/GB		49 (45.1 - 53)	Epstein et al. 2022	29.9 (27.5 - 32.3)
Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM		0 (0 - 0)	Epstein et al. 2022	0 (0 - 0)
Hudson Complex	HC		0 (0 - 0)	Epstein et al. 2022	0 (0 - 0)
Northern Labrador	NL		0 (0 - 0)	Epstein et al. 2022	0 (0 - 0)
Baffin Bay - Davis Strait	BB-DS	Tidal marsh	ND		ND
Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM		ND		ND
Gulf of Maine/Bay of Fundy	BoF		111.1 (88.2 - 134)	This study	2.4 (1.9 - 2.9)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		78.8 (67.3 - 90.2)	This study	4.8 (4.1 - 5.6)
Hudson Complex	HC		89.8 (81.6 - 97.9)	This study	64.5 (58.6 - 70.3)
Lancaster Sound	LS		ND		ND
North American Pacific Fijordland	NAPF		82.7 (71.5 - 93.9)	This study	0.3 (0.2 - 0.3)
Northern Grand Banks - Southern Labrador	NGB-SL		89.8 (81.6 - 97.9)	This study	1.2 (1.1 - 1.3)
Northern Labrador	NL		89.8 (81.6 - 97.9)	This study	0.7 (0.7 - 0.8)
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		77.4 (60.9 - 93.9)	This study	0.1 (0.1 - 0.1)
Puget Trough/Georgia Basin	PT/GB		88.3 (74.1 - 102.4)	This study	0.3 (0.2 - 0.3)
Scotian Shelf	SS		100.3 (66.6 - 134)	This study	1.3 (0.9 - 1.8)
Southern Grand Banks - South Newfoundland	SGB-SN		89.8 (81.6 - 97.9)	This study	0.1 (0.1 - 0.1)

Baffin Bay - Davis Strait	BB-DS	Seagrass	ND		ND
Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM		ND		ND
Gulf of Maine/Bay of Fundy	BoF		18.1 (14.3 - 22)	This study	1.3 (1 - 1.5)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		6.3 (6.3 - 16.8)	This study	4.3 (4.3 - 11.5)
Hudson Complex	HC		18.1 (14.3 - 22)	This study	3.7 (2.9 - 4.5)
Lancaster Sound	LS		ND		ND
North American Pacific Fijordland	NAPF		19.6 (11.2 - 28)	This study	2.3 (1.3 - 3.3)
Northern Grand Banks - Southern Labrador	NGB-SL		18.1 (14.3 - 22)	This study	0.3 (0.3 - 0.4)
Northern Labrador	NL		ND		ND
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		32.6 (20.8 - 44.4)	This study	1 (0.6 - 1.3)
Puget Trough/Georgia Basin	PT/GB		12.9 (8.2 - 17.5)	This study	0.4 (0.3 - 0.6)
Scotian Shelf	SS		19.3 (14 - 24.6)	This study	2.5 (1.8 - 3.2)
Southern Grand Banks - South Newfoundland	SGB-SN		18.1 (14.3 - 22)	This study	0.6 (0.5 - 0.8)

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938 **Table S9.** Per-area and ecoregional estimates of soil organic carbon accumulation and carbon
939 fluxes (mean; 95% CI) stocks by blue carbon ecosystem in Canada.
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Ecoregion	Abbreviation	Habitat	Per-area C Accumulation (Mg C ha^{-1})	Source	Ecoregional C Accumulation (Tg C Yr^{-1})
Baffin Bay - Davis Strait	BB-DS	Tidal marsh	ND		ND
Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM		ND		ND
Gulf of Maine/Bay of Fundy	BoF		2.5 (1.7 - 3.2)	This study	0.05 (0 - 0.1)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		0.9 (0.9 - 2.4)	This study	0.06 (0.1 - 0.1)
Hudson Complex	HC		1.8 (1.2 - 2.4)	This study	1.29 (0.9 - 1.7)
Lancaster Sound	LS		ND		ND
North American Pacific Fijordland	NAPF		2.6 (0.2 - 5)	This study	0.01 (0 - 0)
Northern Grand Banks - Southern Labrador	NGB-SL		1.8 (1.2 - 2.4)	This study	0.02 (0 - 0)
Northern Labrador	NL		1.8 (1.2 - 2.4)	This study	0.01 (0 - 0)
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		1.8 (0.6 - 3)	This study	0 (0 - 0)
Puget Trough/Georgia Basin	PT/GB		1.6 (0.6 - 2.6)	This study	0.01 (0 - 0)
Scotian Shelf	SS		1.4 (0 - 2.7)	This study	0.02 (0 - 0)
Southern Grand Banks - South Newfoundland	SGB-SN		1.8 (1.2 - 2.4)	This study	0 (0 - 0)
Baffin Bay - Davis Strait	BB-DS	Seagrass	ND		ND
Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM		ND		ND
Gulf of Maine/Bay of Fundy	BoF		0.2 (0.1 - 0.3)	This study	0.01 (0 - 0)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		0.2 (0.1 - 0.3)	This study	0.13 (0.1 - 0.2)
Hudson Complex	HC		0.2 (0.1 - 0.3)	This study	0.04 (0 - 0.1)
Lancaster Sound	LS		ND		ND
North American Pacific Fijordland	NAPF		0.2 (0.1 - 0.3)	This study	0.02 (0 - 0)
Northern Grand Banks - Southern Labrador	NGB-SL		0.2 (0.1 - 0.3)	This study	0 (0 - 0)
Northern Labrador	NL		ND		ND
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		0.2 (0 - 0.4)	This study	0.01 (0 - 0)
Puget Trough/Georgia Basin	PT/GB		0.2 (0.1 - 0.2)	This study	0.01 (0 - 0)
Scotian Shelf	SS		0.2 (0.1 - 0.3)	This study	0.03 (0 - 0)
Southern Grand Banks - South Newfoundland	SGB-SN		0.2 (0.1 - 0.3)	This study	0.01 (0 - 0)
Ecoregion	**Abbreviation**	**Habitat**	**Per-area C Fluxes (Mg C ha^{-1})**	**Source**	**Ecoregional C Fluxes (Tg C Yr^{-1})**
Baffin Bay - Davis Strait	BB-DS		1.4 (1.4 - 5.2)	This study	0.16 (0.2 - 0.6)

Beaufort-Amundsen-Viscount Melville-Queen Maud	B-A-V-M-QM	Subsurface kelp	1 (1 - 3.7)	This study	0.11 (0.1 - 0.4)
Gulf of Maine/Bay of Fundy	BoF		2 (1.1 - 9.1)	This study	0.02 (0 - 0.1)
Gulf of St. Lawrence - Eastern Scotian Shelf	GoSL-ESS		2.4 (1.5 - 9.7)	This study	0.77 (0.5 - 3)
Hudson Complex	HC		0.7 (0.7 - 2.7)	This study	3.1 (3.1 - 12)
Lancaster Sound	LS		1.1 (1.1 - 4.2)	This study	0.04 (0 - 0.2)
North American Pacific Fijordland	NAPF		4.7 (0.5 - 12.7)	This study	0.39 (0 - 1)
Northern Grand Banks - Southern Labrador	NGB-SL		2.5 (1.5 - 9.8)	This study	0.28 (0.2 - 1.1)
Northern Labrador	NL		3.4 (2.2 - 13.7)	This study	0.87 (0.5 - 3.5)
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		6.3 (0.7 - 16.9)	This study	0.04 (0 - 0.1)
Puget Trough/Georgia Basin	PT/GB		3 (0.3 - 8.1)	This study	0.01 (0 - 0)
Scotian Shelf	SS		2.1 (1.2 - 9.6)	This study	0.09 (0.1 - 0.4)
Southern Grand Banks - South Newfoundland	SGB-SN		3.2 (2 - 12.9)	This study	0.06 (0 - 0.2)
North American Pacific Fijordland	NAPF	Surface kelp	8.4 (5.9 - 15.5)	This study	0.38 (0.3 - 0.7)
Oregon, Washington, Vancouver Coast and Shelf	OWVCS		11.2 (7.8 - 20.7)	This study	0.08 (0.1 - 0.1)
Puget Trough/Georgia Basin	PT/GB		2.5 (2.5 - 5.5)	This study	0.01 (0 - 0)

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Figure S1. Regional variation in estimated (a) sedimentary carbon stocks (Mg C ha^{-1}) and (b) carbon sequestration rates (Mg C ha^{-1} yr^{1}) associated with Canada's coastal ocean ecosystems. Marine ecoregion are displayed as marine ecoregions including Baffin Bay - Davis Strait (BB-DS), Hudson Bay Complex (HC), Northern Labrador (NL), Northern Grand Banks - Southern Labrador (NGB-SL), Southern Grand Banks - South Newfoundland (SGB-SN), Gulf of St. Lawrence - Eastern Scotian Shelf (GoSL-ESS), Scotian Shelf (SS), Gulf of Maine/Bay of Fundy (BoF), Oregon, Washington, Vancouver Coast and Shelf (OWVCS), Puget Trough/Georgia Basin (PT/GB), North American Pacific Fijordland (NAPF), Beaufort-Amundsen-Viscount Melville-Queen Maud (B-A-V-M-QM), and Lancaster Sound (LS).

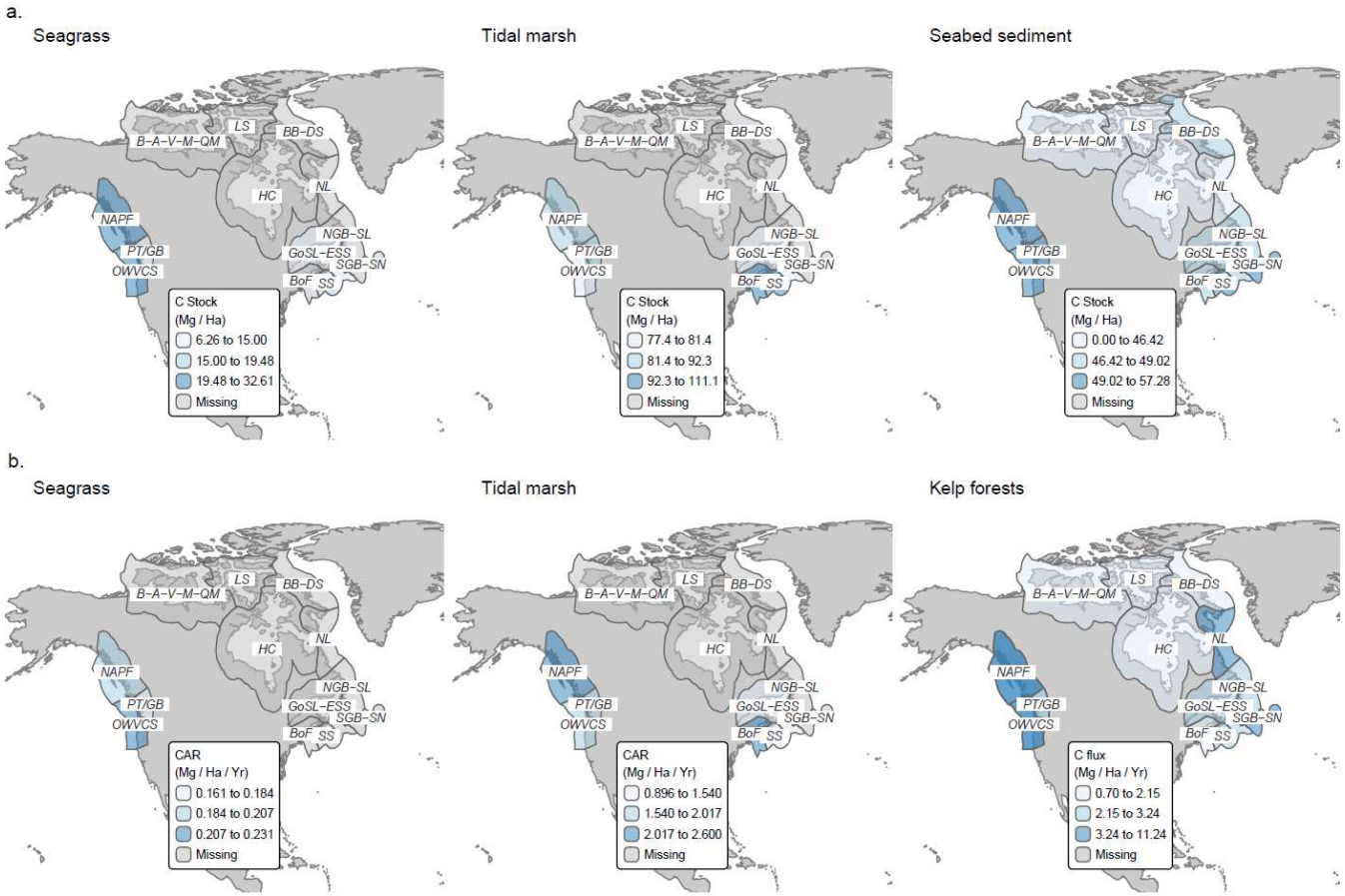


Figure S2. Sensitivity analysis of national estimates to assumptions about per area estimates (mean and 95% confidence intervals) and spatial extent estimates (upper and lower bounds) show variation with input values but consistent relative patterns overall. Bars show national estimates based on mean, upper, and lower bounds of per area estimates, with the range reflecting differences between the upper and lower extent estimates. Black circle represents the national estimates presented in the main figures.

