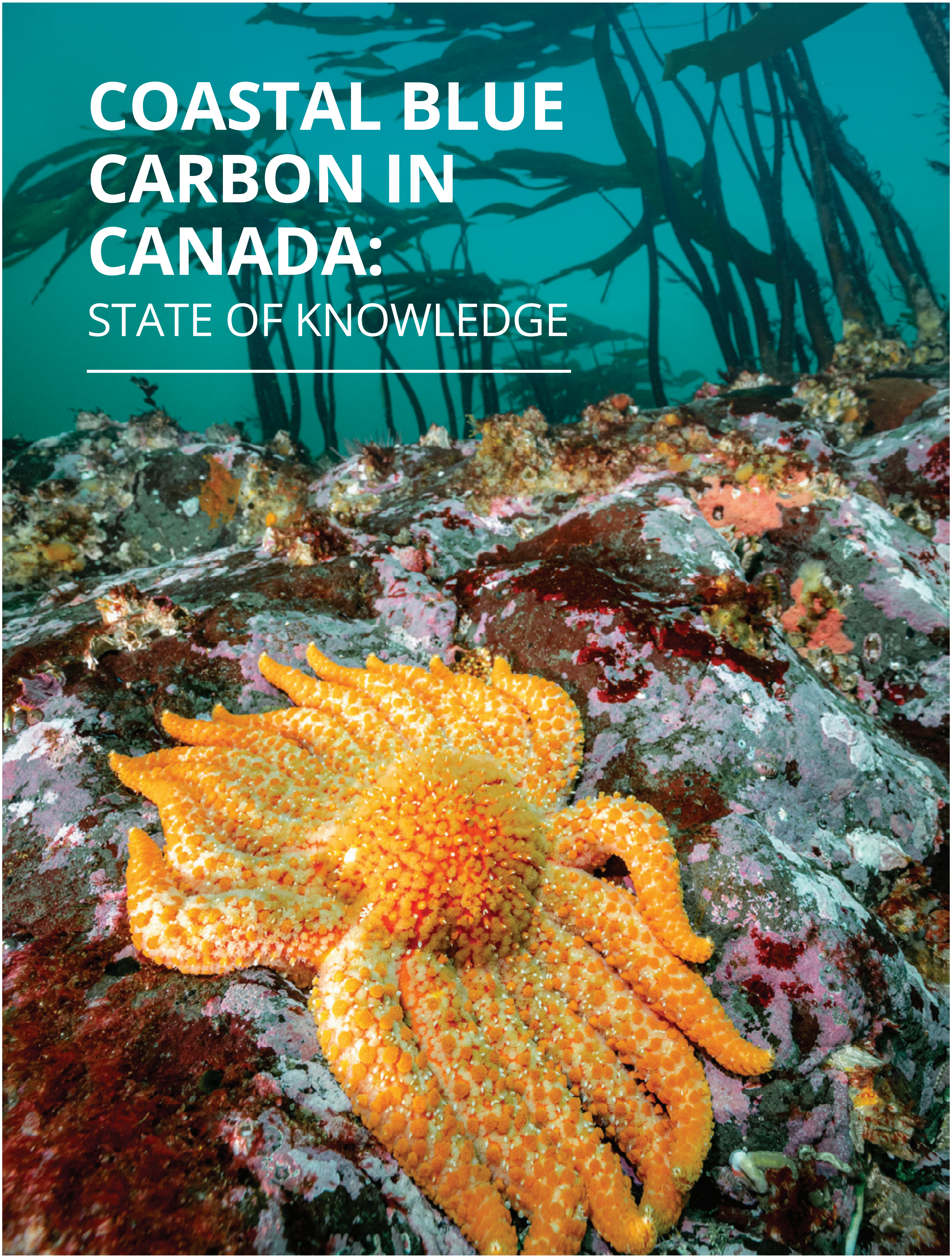
COASTAL BLUE CARBON IN CANADA:

STATE OF KNOWLEDGE



AUTHORS:

Alleway, Heidi The Nature Conservancy (Global), Virginia, USA

Baum, Julia University of Victoria, Department of Biology, Victoria, Canada

Beck, Allen Clean Foundation, Nova Scotia, Canada

Bullen, Cameron SciTech Environmental Consulting, Vancouver, Canada

Burt, Jenn Nature United (Canada), Vancouver, Canada

Carlson, Deborah West Coast Environmental Law, Vancouver, Canada

Currie, Jessica WWF-Canada, Toronto, Canada

Danyluk, Angela City of Vancouver, Vancouver, Canada

Darling, Kate Living Tree Law, Calgary, Canada

Dodge, Becky Simon Fraser University, Burnaby, Canada

Driscoll, John University of British Columbia, Vancouver, Canada

Dunn, Kim WWF-Canada, Toronto, Canada

Filbee-Dexter, Karen University of Western Australia, Western Australia, Australia; Université Laval, Québec City, Canada; Institute of Marine Research, His, Norway

Fish, Marianne WWF-Canada, Toronto, Canada

Gansworth, Leora York University, Toronto, Canada

Gold, Maya Meakin Consultants Inc., Kemptville, Canada

Gregr, Edward J SciTech Environmental Consulting, Vancouver, Canada

Hessing-Lewis, Margot Hakai Institute, British Columbia, Canada

Kanagasabesan, Thiviya WWF-Canada, Toronto, Canada

Kelly, Brianne WWF-Canada, Toronto, Canada

Kent, Sarah Simon Fraser University, Burnaby, Canada; British Columbia Institute of Technology, Burnaby, Canada

Kerr, Alex Meakin Consultants Inc., Kemptville, Canada

Kofahl, Mike East Coast Environmental Law, Halifax, Canada

McCarthy, Abby Simon Fraser University, Burnaby, Canada

McNeilly, Lauren Simon Fraser University, Burnaby, Canada

Meakin, Stephanie Meakin Consultants Inc., Kemptville, Canada

Metaxas, Anna Dalhousie University, Halifax, Canada

Northrup, Kostantina East Coast Environmental Law, Halifax, Canada

Pellatt, Marlow Parks Canada, Vancouver, Canada

Prystay, Tanya Fisheries and Marine Institute of Memorial University, St John's, Canada

Rindt, Cornelia Ostrom Climate Solutions (Canada) Inc., Vancouver, Canada

Saunders, Sarah Fisheries and Oceans Canada, Halifax, Canada (formerly WWF-Canada)

Seymour-Hourie, Rayanna West Coast Environmental Law, Vancouver, Canada

Thomson, Jordy Fisheries and Oceans Canada, Halifax, Canada (formerly Ecology Action Center)

Townsend, Justine Justine Townsend Consulting, K'ómoks Territory (Courtenay, Canada)

Wilson, Kelsey To Be Growing Strategies, New Brunswick, Canada

REVIEWERS:

Chmura, Gail McGill University, Montreal, Canada

Costa, Maycira University of Victoria, Victoria, Canada

Currie, Jessica WWF-Canada, Toronto, Canada

Eyzaguirre, Jimena ESSA Technologies Ltd., Vancouver, Canada

Gansworth, Leora York University, Toronto, Canada

Knox, Sara University of British Columbia, Vancouver, Canada

LeBris, Arnault Memorial University of Newfoundland, St. John's, Canada

McHenry, Jennifer University of Victoria, Victoria, Canada

Poppe, Katrina University of British Columbia, Vancouver, Canada

Reshitnyk, Luba Hakai Institute, Victoria, Canada

Rindt, Cornelia Ostrom Climate Solutions (Canada) Inc., Vancouver, Canada

Townsend, Justine Justine Townsend Consulting, K'ómoks Territory (Courtenay, Canada)

**Note that reviewers did not necessarily review the report in its entirety.*

Funding was generously provided by Donner Canadian Foundation, Fisheries and Oceans Canada – Oceans Management Contribution Program, Jess and Mark Pathy, Scotiabank and two anonymous donors. We recognize the in-kind contributions made by the institutions of participating authors, and financial support they received for this work, including from The Jordan and Andrea Lott Foundation. Special thanks for support to Caroline Martin.

Disclaimer: The opinions expressed in this report are those of the authors and do not necessarily reflect the views or positions of WWF-Canada.

Suggested Citation: Kelly B. Currie J. Fish M. Alleway H. Baum J. Beck A. Bullen C. Burt J. Carlson D. Danyluk A. Darling K. Dodge B. Driscoll J. Dunn K. Filbee-Dexter K. Gansworth L. Gold M. Gregr E. Hessing-Lewis M. Kanagasabesan T. Kent S. Kerr A. Kofahl M. McCarthy A. McNeilly L. Meakin S. Metaxas A. Northrup K. Pellatt M. Prystay T. Rindt C. Saunders S. Seymour-Hourie R. Thomson J. Townsend J. Wilson K. (2023). Coastal blue carbon in Canada: State of knowledge. Retrieved online from: wwf.ca/bluecarbon_stateofknowledge_report

Cover photo: © Eiko Jones Photography

FOREWORD

In the midst of the dual crises of biodiversity loss and climate change, we urgently need solutions that provide benefits for people, nature and climate. One such solution lies along our coastlines in the form of blue carbon.

Coastal communities globally understand the value of habitats such as seagrass beds, salt marshes and kelp forests — these ecosystems provide habitat for wildlife, support coastal livelihoods, regulate water quality and protect coastal lands. These same habitats hold potential as major carbon sinks: coastal ecosystems sequester two to four times more carbon than terrestrial systems per hectare.

The carbon sequestration potential of marine plants was recognized over forty years ago, but the term ”blue carbon” was only coined in 2009. As the science around the carbon removal of coastal ecosystems has evolved over the last decade, blue carbon has also attracted the attention of coastal communities, managers and policy makers seeking natural climate solutions.

In many respects, we are learning by doing when it comes to blue carbon work, and every country and community is working with their own set of unique circumstances. In Canada, coastal Indigenous Peoples have long-standing relationships with their lands and a deep understanding of the interconnected nature of the land and the sea. Such knowledge and experience are invaluable, and Indigenous-led initiatives for the protection, stewardship and restoration of blue carbon ecosystems should be prioritized.

To advance blue carbon work, we need to understand where we are, where we want to go and how to get there; this report represents the first step in that process. To complete it, WWF-Canada brought together authors from across the country to share their insights, knowledge and experience. The result is the first comprehensive report on the state of blue carbon in Canada. Importantly, the report also offers pathways to guide future work, including priority recommendations for future research, policy needs, financing arrangements and relationship development. Our hope is that the wealth of knowledge in this report will stand as a reference and guide for the broader community.

Answering outstanding questions and moving forward with effective action will require an all-hands-on-deck approach that embraces and facilitates collaboration and knowledge exchange at every level. Much work remains and time is of the essence. To this end, WWF-Canada has also been building a blue carbon Community of Practice to develop the connections and collaborations needed. Please join us as we work towards the effective protection, stewardship and restoration of blue carbon ecosystems across Canada.

James Snider

Vice-president, Science, Knowledge and Innovation
World Wildlife Fund Canada

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

BCMCA	British Columbia Marine Conservation Atlas
C:N	Carbon:Nitrogen
CAR	Carbon Accumulation Rate
CEC	Commission for Environmental Cooperation
CH_4	Methane
CO_2^{-3}	Carbonate
CO_2	Carbon Dioxide
C_{org}	Organic Carbon
CRF	Coastal Restoration Fund
DEM	Digital Elevation Model
DFO	Fisheries and Oceans Canada
EBM	Ecosystem-based Management
ECCC	Environment and Climate Change Canada
FPIC	Free Prior and Informed Consent
GHG	Greenhouse Gas
GSL	Gulf of St Lawrence
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LOI	Loss on Ignition
MaPP	Marine Plan Partnership
MESMA	Multiple Endmember Spectral Mixture Analysis
MPA	Marine Protected Area
N_2O	Nitrous Oxide
NbCS	Nature-based Climate Solution
NCS	Natural Climate Solution
NBIS	Nature-based Insurance Solutions
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
ROK	Roe-on-Kelp
RPAS	Remotely Piloted Aircraft Systems
SD	Standard Deviation
SE	Standard Error
TCFD	Task Force on Climate-related Financial Disclosures
UAV	Unmanned Aerial Vehicle
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
WCEL	West Coast Environmental Law

UNITS

CO_2e	carbon dioxide equivalents
g C	grams carbon
g C m^{-2}	grams carbon per metre squared
g C m^{-2} yr^{-1}	grams carbon per metre squared per year
g d^{-1}	grams per day
g L^{-1}	grams per litre
g m^{-2}	grams per metre squared
ha	hectare
kg C m^{-2}	kilogram carbon per metre squared
kg C m^{-2} yr^{-1}	kilogram carbon per metre squared per year
kg N ha^{-1} yr^{-1}	kilogram nitrogen per hectare per year
kg N t_{FW}^{-1}	kilogram nitrogen tonnes per fresh weight
m	metre
m^2	metre squared
Mt CO_2e	metric tonnes of carbon dioxide equivalent
Pg C	petagrams carbon
tCO_2e	tonnes of carbon dioxide equivalent
Tg CO_2e yr^{-1}	teragram carbon dioxide equivalent per year

INTRODUCTION

Marlow Pellatt and Brianne Kelly

Blue carbon is a term that recognizes the role of coastal ecosystems in the global carbon cycle. Ecosystems such as salt marshes and seagrasses sequester carbon dioxide from the atmosphere continuously over thousands of years, building stocks of carbon in organic-rich marine soils. Blue carbon ecosystems are recognized for their important role in climate-change mitigation, as well as their contribution to climate adaptation, ecosystem resilience and biodiversity conservation. In addition, these ecosystems provide multiple functions and services, among them regulating (e.g., shoreline stabilization), provisioning (e.g., food), supporting (e.g., nutrient cycling) and cultural services (Lau 2013; Barbier 2017).

Despite the growing recognition of blue carbon's importance, we still have a lot to learn about these ecosystems and coastal carbon dynamics broadly in Canada. Canada has over 200,000 km of coastline — the longest in the world — and there is thus a critical need to understand and explore blue carbon. To date, we have only scratched the surface of understanding. For example, despite the fact that seagrass is classified as a major habitat type in three quarters of Canada's marine biogeographic regions, only a fraction of seagrass has been mapped, and that mapping is coarse at best (McKenzie *et al.* 2020). We have only recently begun to explore how macroalgae (Macreadie *et al.* 2019) and unique Arctic ecosystems contribute to blue carbon. We need a distinctly Canadian focus on blue carbon, given large research gaps in mapping, carbon dynamics, threats and ecosystem specifics from coast to coast to coast.

For salt marshes in Canada, carbon stocks and carbon accumulation rates (CAR) are lower than the global average, but equivalent to other areas at similar latitudes (Chastain *et al.* 2018; Gailis *et al.* 2021; Douglas *et al.* 2022). In Canada, current research suggests that seagrass stocks and CAR appear to be considerably lower than the global average (Postlethwaite *et al.* 2018). Research often overlooks kelp (or macroalgae), a key component of Pacific coastal ecosystems whose blue carbon potential has only recently been recognized (e.g., Macreadie *et al.* 2019; Filbee-Dexter and Wernberg 2020). Carbon stocks and CAR data have been collected at relatively few sites along Canada's coastline. We need further research to bolster our understanding of coastal ecosystems at a national scale, including an evaluation of the lateral exchange of carbon among sites, greenhouse gas (GHG) fluxes and the permanence of carbon storage in these ecosystems.

We urgently need to better understand blue carbon ecosystems to further highlight their importance for climate-change mitigation and adaptation and ensure their conservation. **Quantifying total-ecosystem carbon dynamics for blue carbon ecosystems along Canada's coastline is critical to support the sustainable management, conservation and restoration of these valuable ecosystems that provide multiple socioeconomic and ecological benefits.** This quantification will support a more fulsome framework for international carbon reporting and accounting of blue carbon. It will also make it possible to include blue carbon stocks in Canada's Nationally Determined Contributions (NDCs)[1] and to enhance monitoring of blue carbon fluxes as part of Canada's emissions reporting. A better understanding of blue carbon dynamics will also be important at the local and regional level, as these ecosystems support conservation economies, and climate-change mitigation and adaptation.

This collaborative report aims to improve understanding of blue carbon ecosystems in Canada. The report outlines what is known about these ecosystems and highlights gaps in our understanding. It includes information on blue carbon science, legislation, policy and economics. The process used to develop this report is also noteworthy: it brought together authors and reviewers from along Canada's coastlines to share and exchange knowledge.

The objectives of the report are to

- present various perspectives on blue carbon in Canada and identify gaps in our knowledge and understanding
- produce a resource for people interested in, or currently working on, coastal blue carbon
- provide information to policy- and decision-makers to support the sustainable management, restoration and protection of blue carbon ecosystems
- highlight recommendations for future work in coastal blue carbon

Aspects of carbon dynamics along Canada's coastlines that we need to better understand:

- Carbon stocks: The amount of carbon stored in a reservoir or pool at a given time.
- Carbon Accumulation Rates (CAR): The rate at which carbon is added to a carbon stock.
- Greenhouse Gas (GHG) flux: The exchange of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) or nitrous oxide (N_2O) between carbon stocks/pools (e.g., soils, biomass).
- Lateral transfer of carbon: The transfer of organic carbon (C_{org}) between habitats or systems.
- Permanence: The ability to maintain carbon within a carbon stock for a significant period (generally over 100 years).

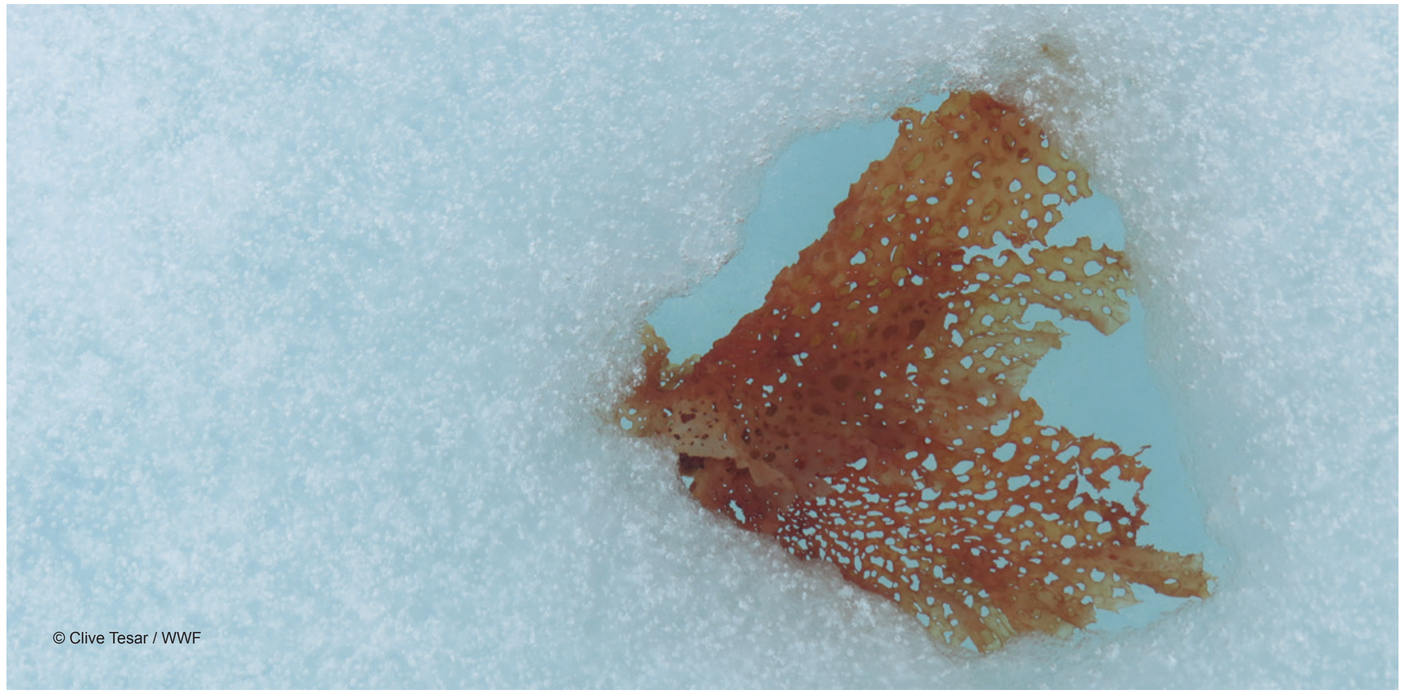
---

1. UNFCCC. "NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive Nationally Determined Contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions."

The report begins with an exploration of **Natural Climate Solutions and Blue Carbon**. This is followed by an exploration of **Legislation and Policy** in relation to blue carbon in Canada, including a discussion of Aboriginal law, Indigenous law, and federal, provincial/territorial and municipal legislation and policy. We then discuss **Blue Carbon Ecosystems**, with a focus on the ecosystems for which we have the most data in Canada: **Seagrass**, **Salt Marsh**, and **Kelp**. The discussion of each blue carbon ecosystem includes information on the regional context, carbon stocks and CARs, GHG fluxes, threats, and restoration potential. Also included is a chapter on an emerging area of interest, **The Arctic: A Unique Blue Carbon Region**.

We explore **The Blue Economy** with a discussion of carbon markets and other finance tools that may be relevant to blue carbon work. Within the blue economy, we dive into the details of one opportunity in particular: **Kelp Aquaculture and its Potential to Support Blue Carbon**. We explore the potential for seaweed farming to offset carbon emissions and support healthy marine ecosystems. Finally, the **Moving Forward** chapter ties together information presented throughout the report. Each chapter of the report contains recommendations, and a full list of these **Recommendations** is collated at the end of the report.

We have made a concerted effort to include as much information as possible on blue carbon in Canada across a broad scope of topics. However, this report is not exhaustive and does not include all voices or perspectives from across the country. We acknowledge that Indigenous perspectives, approaches and leadership are critical to effective knowledge exchange and the ethical implementation of solutions. In addition to being a valuable resource, this report may spur future connections, collaborations, research and implementation of blue carbon-related work across Canada.



© Clive Tesar / WWF

NATURAL CLIMATE SOLUTIONS AND BLUE CARBON

Jessica Currie and Kelsey Wilson

Nature is under threat. Disturbed ecosystems, the loss of wildlife (IPBES 2019; WWF-Canada 2020) and accelerating climate change (IPCC 2019a) are eroding and decreasing the reliability of the many ecological functions and ecosystem services that we collectively rely upon. The complexity, severity and scope of these environmental crises require multifaceted solutions. Natural climate solutions (NCS) — also known as nature-based climate solutions (NbCS) — are actions that harness the power of nature to sequester and store atmospheric carbon (Griscom *et al.* 2017; Seddon *et al.* 2021). These same conservation actions can also provide vital habitats for wildlife — helping to simultaneously address both climate change and biodiversity loss (Cohen-Shacham *et al.* 2019; Seddon *et al.* 2021). As a result, NCS have been recognized for their ability to support multiple United Nations Sustainable Development Goals (SDGs; Gómez Martín *et al.* 2020) — including climate and biodiversity targets (e.g., goal 13: climate action, goal 14: life below water) — and have gained momentum and uptake in the international research and policy spheres (e.g., COP27 and the Kunming-Montreal Global Biodiversity Framework).

In 2016, the Paris Climate Agreement came into effect with the goal of limiting global average warming to well below 2°C — and ideally to 1.5°C — compared to pre-industrial levels. Despite additional evidence on the impacts of global warming of 1.5°C above pre-industrial levels (IPCC 2018) and international efforts to mitigate climate change, anthropogenic global surface temperature has already increased by 1.1°C (IPCC 2021). It is anticipated that the 1.5°C goal will be exceeded by 2040 (IPCC 2021). The change in global surface temperature and the resulting impacts stemming from a warming climate (e.g., ocean acidification, rising sea levels, extreme weather events) can have profound consequences on the ecosystems that both humans and wildlife rely on. The rate of change is particularly noteworthy in Canada, where the observed and projected increases in mean temperature are about twice the global rate (Bush and Lemmen 2019). Climate change has been increasingly listed as a threat to species at risk in Canada (Currie and Marconi 2020) — a threat that often exacerbates other drivers of extinction risk (IPBES 2019). The interactions among climate, ecosystems and human society are widespread and complex (IPCC 2022), resulting in compounding risks from climate change and biodiversity loss. However, this very interconnectedness offers opportunities to effectively address multiple environmental crises simultaneously (IPCC 2019a; Turney *et al.* 2020; IPCC 2022).

Generally, NCS are actions to protect, sustainably manage and restore ecosystems to safeguard or increase carbon storage and minimize greenhouse gas emissions (Griscom *et al.* 2017). These same actions may also deliver benefits for biodiversity and human well-being (Seddon *et al.* 2021). Specific to context and location, NCS can vary widely in terms of mitigation potential, time horizon, co-benefits and cost effectiveness (Cook-Patton *et al.* 2021). NCS that aim to protect (i.e., via protected and conserved areas) are often prioritized: since protective measures halt negative impacts to nature, their mitigation potential is significant and immediate. However, if we are to deliver a nature-positive future, we also need to minimize unavoidable impacts (i.e., via the sustainable management of working lands and seascapes) and remediate negative ecological impacts (i.e., via ecological restoration) (Cook-Patton *et al.* 2021). A recent analysis of NCS pathways in Canada estimated that coastal and marine (i.e., blue carbon) NCS approaches have the potential to mitigate 1.7 million tonnes (Mt) CO_2e yr^{-1} by 2030 (Drever *et al.* 2021). Protecting and restoring blue carbon ecosystems make a relatively small contribution to potential mitigation compared to NCS of freshwater wetlands; this is to be expected, given the smaller spatial extent of these ecosystems (though only some pathways were considered; Drever *et al.* 2021). However, blue carbon NCS may deliver disproportionately large climate and biodiversity benefits per unit area (Macreadie *et al.* 2019).

NCS have the potential to meaningfully contribute to mitigating the biodiversity and climate crises (alongside rapid decarbonization of the economy; Seddon *et al.* 2021). However, it is important that NCS be developed in ways that support — rather than undermine — Indigenous governance, jurisdiction and authority. Supporting Indigenous-led conservation initiatives may result in better outcomes. Effective implementation of NCS must include — at a minimum — collaboration and consultation with Indigenous Peoples from the outset of projects to advance local priorities, objectives and values. It is imperative to recognize lessons and leadership from Indigenous Peoples, who have successfully stewarded healthy and resilient ecosystems for millennia. Their participation, consent and leadership are critical for advancing cross-sectoral transformative change to address the climate crisis (Townsend *et al.* 2020; IPCC 2018). Relationships and partnerships between Indigenous Nations and non-Indigenous stakeholders must be treated with respect, and we must uphold and surpass the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), including the right to free, prior, and informed (FPIC) consent.

To ethically and successfully implement NCS, we need equitable approaches to conservation that elevate Indigenous governance, rights and responsibilities (Townsend *et al.* 2020). This includes long-term funding to enable stewardship and sustainable conservation-based economies. NCS projects that leave decisions about carbon to project developers risk undermining Indigenous governance and perpetuating “carbon colonialism” (Osborne 2015).

To design a holistic approach to NCS in Canada, we need to look beyond carbon sequestration and storage, and consider such factors as cultural values, resilience and climate-change adaptation. For instance, in addition to naturally sequestering and storing carbon, blue carbon ecosystems support climate adaptation through shoreline stabilization and flood mitigation (Lovelock and Duarte 2019). These ecosystems also provide a host of other benefits; for example, they support nutrient cycling and cross-ecosystem nutrient transfers, bolster coastal livelihoods and communities (e.g., fisheries, tourism), provide erosion and pollution control and so maintain property values and public health, and contribute to recreation and water purification (Hun and Chmura 2006; Barbier *et al.* 2011; Macreadie *et al.* 2019). To safeguard these many ecosystem services, we need management plans that acknowledge blue carbon environments as part of the land-sea connection.

Importantly, while NCS can mitigate climate change, they are also vulnerable to its impacts, and so should be implemented alongside rapid decarbonization of the global economy (Seddon *et al.* 2021). A multitude of climate-related impacts — such as sea-level rise, storm intensity/frequency, and heatwaves — may result in widespread destruction and loss of blue carbon ecosystems (Macreadie *et al.* 2019). Many anthropogenic activities and impacts on blue carbon ecosystems have been individually studied (e.g., oil spills, seasonal wrack deposition, aquaculture, eutrophication, altered tidal flows, harvesting of fisheries resources). However, we need more research to understand the cascading and compounding effects of multiple threats — including climate change — to appropriately guide policy and management decisions (Macreadie *et al.* 2019). In brief, while the conservation and restoration of marine ecosystems serve as NCS, blue carbon ecosystems themselves are vulnerable to anthropogenic and climate impacts that can ultimately result in the release of carbon stocks, thereby accelerating the climate crisis. Despite this vulnerability, the multiple environmental, societal, and economic benefits that NCS provide underscore their value for implementation.


© Claudi Nir / WWF

INTERSECTIONS OF BLUE CARBON, INDIGENOUS-LED CONSERVATION AND RECONCILIATION

Justine Townsend

Often thought of as a public good, blue carbon exists in the territories of coastal Indigenous (First Nations, Inuit and Métis) Nations and communities throughout Canada.[2] For millennia, Indigenous Peoples have cultivated respectful relationships with their lands and waters. Indigenous Peoples' legal, governance, and knowledge systems have contributed to successful environmental stewardship practices in Canada and around the world (Artelle *et al.* 2018; Berkes 1999; Turner 2014; Artelle *et al.* 2018). Indeed, these long-standing practices have often shaped the blue carbon ecosystems that scientists, conservationists and governments increasingly wish to manage and protect. Because of this long-standing expertise that is rooted in place, Indigenous Peoples are well positioned to lead blue carbon conservation. Yet Indigenous Peoples are often excluded from both domestic and international decisions about climate (Tormos-Aponte 2021), despite being disproportionally affected by climate change (Havemann 2009; Ford 2012; Williams 2012; Lynn *et al.* 2013).

Though critical to the success of natural climate solutions (NCS), Indigenous Peoples face constraints that may limit their participation (Townsend *et al.* 2020). Framings of NCS often lack discussion about how NCS can support or limit Indigenous self-determination, and often lack acknowledgement of Indigenous jurisdiction (Reed *et al.* 2022). Given this, NCS can maintain "climate colonialism" and dispossess Indigenous Peoples of their lands and waters (Reed *et al.* 2022). Like mainstream conservation efforts more broadly, NCS can be enhanced by Indigenous worldviews that emphasize reciprocity and relationships between people and ecosystems. This framing is different from the market-based approaches to climate-change mitigation typical of NCS. A recent literature review on the extent to which Indigenous Peoples influence global climate governance (Tormos-Aponte 2021) suggested that:

> "decolonization might be a necessary condition for addressing the ecological crisis."[3]

Even the Intergovernmental Panel on Climate Change now recognizes Indigenous rights as critical to solving the climate crisis — a fact that Indigenous Peoples "have always known" (Rights and Resources Initiative 2019).

Blue carbon and associated NCS present a sea of opportunities that must be engaged with thoughtfully and respectfully. Although blue carbon and other natural assets of interest to NCS can appear depoliticized (e.g., salt marshes, kelp forests, and seagrass ecosystems), these ecosystems often include or support cultural keystone species.[4] Further, many of these ecosystems are under the governance and jurisdiction of Indigenous Peoples. Various laws, policies and frameworks in Canada affirm the rights of Indigenous Peoples and offer guidance about how to proceed respectfully when seeking to advance projects in Indigenous territories. These include Section 35 of the Canadian Constitution, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), the final report of the Truth and Reconciliation Commission (TRC) of Canada, and many court decisions that recognize or affirm Indigenous rights and title.[5] In addition to these important signposts, the Government of Canada has committed to a transformative process of reconciliation with Indigenous Peoples for the intergenerational trauma inflicted through residential schools. The impacts of the schools — and the broader effects of colonialism — echo throughout Canadian society, including climate governance and conservation through laws, policies, institutions and cultural norms (TRC 2015; Whyte 2017; Finegan 2018).

In Canada, the political climate around conservation is changing in exciting ways. It is no longer morally or socially acceptable for Crown governments and environmental non-governmental organizations (ENGOs) to establish parks and protected areas in Indigenous territories without the consent and partnership of Indigenous Peoples. While there are still many issues with existing parks and protected areas and conservation approaches, the tide is turning. There are now dozens of Indigenous Protected and Conserved Areas (IPCAs) at various stages of establishment in Canada. All of these have been initiated and declared by Indigenous Nations and communities — sometimes with Crown partners and support, but often without. IPCAs are "holistic and integrated approaches to stewardship" that can take many forms on land or water[6] (ICE 2018). IPCAs reflect the laws, priorities and visions that Indigenous Nations and communities have for their territories. Given this, they offer promising governance pathways for many Indigenous Nations and communities with coastal territories.

---

[2] In Canada, the term "Indigenous," which now commonly replaces the term "Aboriginal," encompasses three distinct groups of Indigenous Peoples in Canada: First Nations, Inuit and Métis. There are over 630 First Nations communities in Canada representing more than 50 First Nations and 50 Indigenous languages (CIRNAC, 2021a). Throughout Inuit Nunangat, or northern Canada, there are more than 53 Inuit communities and Inuktitut is the Indigenous language spoken (CIRNAC, 2021b). There are over 600,000 Métis people residing throughout Canada, and the Indigenous population in Canada is growing at a faster rate than the non-Indigenous population (Statistics Canada, 2022b). These statistics emphasize the diversity of Indigenous Peoples in Canada.

[3] This is not surprising given that colonialism, conjoined with capitalism, has given rise to environmental crises like climate change (Whyte, 2017).

[4] Garibaldi and Turner (2004) define cultural keystone species as the species that hold tremendous significance to a culture, whether for sustenance or for practical, ceremonial, social and intellectual reasons.

[5] The Government of Canada adopted the TRC's overarching recommendation to adopt UNDRIP as Canada's framework for reconciliation. UNDRIP contains various articles pertinent to conservation (Articles 25–29, 32), as well as to decision-making (Article 18), including granting or withholding free, prior and informed consent, and to the recognition of Indigenous laws (Articles 27 and 40). The Province of British Columbia (B.C.) adopted legislation to implement UNDRIP in 2019 and the Government of Canada adopted federal legislation in 2020. Other important frameworks include the Government of Canada's (2021) Principles Respecting the Government of Canada's Relationship with Indigenous Peoples and the Recognition and Reconciliation of Rights Policy (CIRNAC 2019).

[6] In 2018, the Indigenous Circle of Experts published their watershed report, *We Rise Together*. ICE defined IPCAs as being Indigenous-led, representing a long-term commitment to conservation, and elevating Indigenous responsibilities as well as rights (2018, p. 36). The Indigenous Circle of Experts was an Indigenous-led advisory group that made recommendations to primarily Crown (i.e., federal, provincial, and territorial) governments about how to simultaneously advance IPCAs and reconciliation with Indigenous Peoples in Canada.

When restoring and protecting blue carbon and marine ecosystems, Canadians can build on the incredible examples of Indigenous leadership in conservation in coastal regions throughout the country. The past five years have seen a surge of interest in Indigenous-led conservation, IPCAs and Indigenous Guardians. Crown governments are increasingly supporting IPCAs to advance their domestic and international conservation targets (ECCC 2020b 2022). But their importance goes beyond contributing to targets: IPCAs centre Indigenous self-determination in diverse conservation approaches across the country (Townsend 2022; Tran *et al.* 2020). For example, in 2022, Kitasoo Xai'xais Nation declared an Indigenous-led Marine Protected Area in a culturally significant area of their territory that they consider their "breadbasket" (Townsend 2022). Gitdisdzu Lugyeks (Kitasu Bay) is a 33.5 km^2 marine protected area off the central coast of B.C. in the Great Bear Rainforest. It is not protected under federal or provincial laws. Kitasoo Xai'xais Nation will continue to care for Gitdisdzu Lugyeks according to Indigenous knowledge and laws combined with an ecosystem-based management approach (Kitasoo Xai'xais Stewardship Authority 2022).

Indigenous-led conservation offers insight into how to care for blue carbon and coastal ecosystems in ways that honour the interconnections of the land, the sea and the people who live there. In contrast, splitting environmental jurisdiction between federal and provincial governments creates a false fragmentation of integrated coastal environments. For the most part, reserve lands, marine ecosystems and navigable waters are the responsibility of federal governments, while most terrestrial ecosystems, inland waters and shorelines are primarily the responsibility of provincial and territorial governments. This siloing perpetuates a "paradigm of disconnectedness" that continues to harm biodiversity and alienate Indigenous Peoples (ICE 2018). Indigenous worldviews understand the land and water as inseparable; this leads to more holistic decision-making that spans the land-sea interface (ICE 2018). With their rich insights and associated practices, Indigenous worldviews and knowledge systems have much to contribute to the development of blue carbon initiatives and policies. However, Indigenous knowledge systems must not be decontextualized, commodified or instrumentalized. Relationships, built over time and sustained by goodwill and accountability, are critical.

Crown (i.e., federal, provincial, territorial and municipal) governments and environmentalists may position Indigenous Peoples and their knowledge as a panacea for environmental ills. This position is troubling for several reasons. First, it can unfairly assume that Indigenous Peoples are obligated to share their knowledge, even if they haven't received assurances about how or under what conditions this knowledge will be used. Second, the tendency to treat Indigenous knowledge as supplemental to western environmental management approaches can miss the deeper understandings, values and contexts inherent in Indigenous knowledge systems. Missing this bigger picture, proponents of NCS may also miss opportunities to approach blue carbon solutions from a place of collaboration rooted in principles of respect and reciprocity. As Reed *et al.* (2022) suggest, it is essential

> "not only to advance the self-determination of Indigenous Peoples, but also to create the ceremonial ground for Indigenous visions of nature-based solutions."

NCS can reinforce relations of commodification with the natural world or reorient climate action towards reciprocal and ethical relationships in line with Indigenous values and worldviews (Reed *et al.* 2022). As the Indigenous Circle of Experts (2018) describes, reconciliation is essential not only among Crown and Indigenous governments and Peoples. We must also reconcile our relationships with all of our relations in the natural world. Blue carbon exists in animate ecosystems in the territories of coastal Indigenous Peoples. By restoring and protecting blue carbon and marine ecosystems, we create opportunities not only to mitigate climate change, but also to support Indigenous self-determination and Indigenous-led conservation efforts. Blue carbon initiatives are more likely to be just and effective if we support Indigenous-led initiatives and co-develop new initiatives with Indigenous Nations and communities.

© Mike Ambach / WWF

RECOMMENDATIONS FOR BLUE CARBON NATURAL CLIMATE SOLUTIONS

- ✓ Work collaboratively with Indigenous Peoples and local communities to design solutions to protect, manage and restore blue carbon ecosystems that prioritize multiple benefits and values, including carbon stocks. Current knowledge gaps must not delay critical on-the-ground action.
- ✓ When designing NCS, adopt an equitable approach that respects Indigenous rights, responsibilities and self-determination (e.g., fulfil and surpass the principles and minimum standards outlined in the United Nations Declaration on the Rights of Indigenous Peoples). Work collaboratively with Indigenous Peoples from the outset to ensure their values and needs are accounted for.
- ✓ Respond proactively and affirmatively to the needs, requests and concerns of Indigenous partners and the Indigenous Peoples whose territories encompass blue carbon resources and ecosystems.
- ✓ Invite meaningful collaboration with Indigenous Nations and communities early in the development of NCS projects and provide support to enable this capacity where desired.
- ✓ Build NCS holistically to include cultural values, increase resilience, and support climate-change adaptation across the land-sea interface.
- ✓ Support Indigenous-led NCS and marine conservation projects in ways identified by the lead Indigenous Nations and communities (e.g., through funding, information sharing, advocacy and collaboration).
- ✓ Prioritize the protection of blue carbon ecosystems to address habitat loss, the release of greenhouse gas emissions, and the need for future restoration.
- ✓ Ensure that current knowledge gaps do not delay action on the ground. No regret actions, such as protected and conserved areas, can meaningfully benefit biodiversity and climate, regardless of the magnitude of the benefit.
- ✓ Secure long-term investments and incentivize NCS to protect, sustainably manage and restore blue carbon ecosystems across Canada.
- ✓ Uphold Indigenous knowledge, legal and governance systems to at least the same degree as western climate and conservation science and policy when working collaboratively or partnering with Indigenous Nations and communities.
- ✓ Support research to address knowledge gaps in carbon dynamics, cumulative threats, and climate feedback loops in coastal ecosystems to inform decision-making on conservation prioritization, to improve the design of NCS, and to facilitate GHG reporting and targets.

INTEGRATING SCIENCE AND INDIGENOUS KNOWLEDGE

Leora Gansworth

WATER

Water is life. Water holds, carries, takes, gives, supports, memorializes and generates life. Water has the power to create and to destroy and, thus, the self-determination of water must be respected. Indigenous societies and knowledge systems honour and respect water:

> "Water as a living entity, as is articulated through oral traditions… (is) an expression of Indigenous water law" (Wilson 2019).

Water is a sacred site of relationships, a reliable and low-emission travel route, a connector of biomes, a reflector of Earth's upper realms and the cosmos. Water is the seamless tie that flows in symbiosis with other natural forces, those which exist beyond human control.

Conditions for human, marine, avian, freshwater, plant, terrestrial and other forms of life are made possible through interconnected nodes in collective webs of biodiversity — all of which are surrounded, nourished and connected by water. Water is also a home and host to countless life forms that support human existence. In recent framings, some of these life forms are referred to as sources of "blue carbon," which is a blanket term for carbon stored by species in coastal, carbon-rich ecosystems. Blue carbon tends to refer to living plants but can also include carbon stores that come from decomposed plants that have drifted down to lower strata of the ocean and estuary floor. It has been suggested that marine species such as eelgrass constitute a "secret weapon"[7] to mitigating climate change in coastal zones. All aspects of the plant have benefits: the root system, the long fronds that provide shelter for fish, the dense beds that prevent coastline erosion. The photosynthetic process of eelgrass growth is a natural mechanism to absorb carbon and methane. Measuring and analyzing blue carbon and the health of related support species such as eelgrass is suggested to have great potential for rapid decarbonization on a large scale if implemented urgently with care, targeted knowledge and appropriate application of technical expertise and skills. These approaches often frame studies conducted in universities and through organizations with significant capacity and institutional standing.

---

[7] From CBC

This report integrates ideas from such organizations and other voices, offering multiple insights and methods of studying coastal species. The purpose of this chapter is to put some thought and context into a long-range view of climate change, land alteration and wider processes of global environmental change that began with Indigenous dispossession and the denial of jurisdiction and authority that simultaneously rose with the expansion of Canada over time. This structure of Canadian domination negatively affects ecological integrity lands claimed by Canada and across its borders and boundaries by suppressing and denying Indigenous jurisdiction and decision-making authority.

DIVERSE WORLDVIEWS AND BLUE CARBON

For Indigenous Peoples[8] in territories claimed by Canada and in similar settler colonial occupation regimes around the world, blue carbon may be an unfamiliar framing, typical of Western worldviews that suggest a "universe… compartmentalized in dualistic forms and reduced to progressively smaller conceptual parts" (Gordon *et al.* 2023). Relationships with coastal zones that include saltmarshes, mangroves and specific seagrasses may represent long-sustained webs of interconnection and ecosystem care when perceived through the lens of Indigenous worldviews and sensibilities. To separate individual species from the waters they live in without consideration of other interdependent life forms and relationships constitutes a worldview chasm. It may be challenging to assign a monetary, numeric or other value to holistic ecosystems by breaking carbon down into measurable units and in non-relational terms. These uncertainties represent key distinctions and foundational challenges that are known differences between Indigenous ways of knowing and other forms of valuation, analysis or measurement.

At the same time, some Indigenous Peoples in Canada who desire to assert leadership roles in land and water governance have expressed interest in developing different types of economies that may make use of such methods, such as conservation economies that respond to propositions of climate science (ICE 2018). These types of economic systems notably grow on smaller scales in localized settings, different from the large, centralized systems of capitalism and its excessive, centralized and uneven profit margins.

IDENTIFYING OPPORTUNITIES

Cohen *et al.* (2021) suggest that funding, decision-making and knowledge mobilization are important levers that will facilitate the integration of Indigenous worldviews. These are intimately affected by differing concentrations of power and influence.

> "Dominant knowledge systems — specifically those that underpin Western colonial governments and liberal, capitalist economies — shape the provisioning of funding for local programs and determine the significance of different types of community observations in shaping management decisions" (Cohen *et al.* 2021).

Their suggestion identifies knowledge hierarchies that work to the exclusion of local and Indigenous-based data collection methods and monitoring capacity. Those monitoring systems and strategies may have different aims, methods and outputs than extensive monitoring systems paid for by large actors and yet, they may yield important and necessary information not available through other means.

> "…(a) conservation economy is not meant to employ thousands or generate extreme financial wealth. It is meant to create long-term sustainable employment potential for local and regional residents by maximizing existing skills and knowledge, providing new skills and adequately supporting families now and into the future" (ICE 2018).

The call for conservation-based economies and locally focused economies stems from an intersectional formation of Indigenous environmental justice, or perhaps, "climate justice." Climate justice centering on Indigenous worldviews "does not reduce the climate crisis to a puzzle simply focused on counting carbon" (Dayanei *et al.* 2021). An integrative, effective response requires reform in multiple societal sectors: land and water governance, enforcement of ideas about jurisdiction, legal pluralism, policy making, relationship building — all of which constitute shifts in paradigm and practice. The stakes are high, and outcomes (as of yet unseen) are promising.

---

[8] Peoples here is used to refer to Indigenous communities generally understood as "the living descendants of pre-invasion inhabitants of lands now dominated by others" (Anaya 2004). In Canada, three distinct groups are classified as "Indigenous" under S. 35 of the Constitution Act, 1982. Those groups are First Nations, Métis and Inuit Peoples.

LEGAL FRAMING AND POLICY CONTEXT

The foundations of Canadian law and land occupation are underpinned by false assumptions of superiority, domination and European sovereignty, which have been identified as problematic by numerous inquiries, including the 1996 Final Report of the Federal Royal Commission on Aboriginal Peoples, as well as the 2015 Truth and Reconciliation Calls to Action. [9] All sectors of society operating in Canada have responsibilities to Indigenous Peoples as evidenced in constitutional and international rights framing, discussed in this report. Indeed, with respect to the "Duty to Consult and Accommodate" that is enshrined in Section 35 of the Constitution Act of 1982, common law obligations exist, which are typically thought to be exclusive considerations of provincial and/or federal Crown governments.

Yet, much of the landscape for conservation, private lands and other lands of interest to NGOs, universities, private corporations, land trusts and other groups in Canada have come into the hands of said organizations as a result of historical and ongoing dispossession of Indigenous Peoples. Innes, Attridge and Lawson suggest that there are "many social and ethical responsibilities to engage with Indigenous communities, particularly given the legacy of dispossession and denial of Indigenous rights that has resulted from establishing conservation areas in Canada" (Innes *et al.* 2021).

Land-based Indigenous knowledge systems[10] are intimately intertwined with conceptions of Indigenous law — which is distinct from legacy framings of "Aboriginal" Peoples controlled and dominated by settler colonial law (e.g., Aboriginal law, the Canadian Constitution and its many historic oppressions of and obligations to Indigenous Peoples and others). Generally, "despite aspirational language, current policies and policy processes in Canada fail to support Indigenous sustainable self-determination" (Reed *et al.* 2022), which can be attributed to a lack of understanding and respect regarding Indigenous laws and legal traditions.

The sharing and implementation of Indigenous legal traditions exists as a core activity of developing self-determined priorities that facilitates engagement with other environmental governance structures, as potential collaborators. These decisions and relationships must be determined by Indigenous Peoples themselves, many of whom carry intimate knowledge and firsthand experiences stemming from the realization that climate change is caused by "resource extraction at a pace exceeding the natural limits of the earth systems, carried out through colonial economies that provide profit for a few at a cost to many" (Arif *et al.* 2021). The development of an effective paradigm to meet climate-related challenges must address environmental degradation as it relates to Indigenous dispossession.

For decades, processes of ecosystem degradation have led to "increases in the gravity of economic damages, health harms, political conflicts, geographic displacements and cultural losses" (Whyte 2019) because of imposed, enforced governance structures and practices that originate outside Indigenous communities, many of which explicitly undermine Indigenous governance. It is important to state that "the [1876] Indian Act attempts to destroy all facets of traditional First Nations governance" (Poucette 2018). One purpose in doing so was to relieve settler anxieties about the ongoing presence of "Indians" and their kinship systems, ways of life, and presence on lands and waters, including coastal environments through targeted campaigns of removal and disruption.

While expressly aspirational, and unclear in its enforceability, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) is a contentious document with a long history [11] that includes several guiding articles that could apply broadly to practices that target blue carbon activities:

> **Article 10** Indigenous peoples shall not be forcibly removed from their lands or territories. No relocation shall take place without the free, prior and informed consent of the Indigenous Peoples concerned and after agreement on just and fair compensation and, where possible, with the option of return
>
> **Article 24** 1. Indigenous Peoples have the right to their traditional medicines and to maintain their health practices, including the conservation of their vital medicinal plants, animals and minerals. Indigenous individuals also have the right to access, without any discrimination, to all social and health services
>
> **Article 25** Indigenous Peoples have the right to maintain and strengthen their distinctive spiritual relationship with their traditionally owned or otherwise occupied and used lands, territories, waters and coastal seas and other resources and to uphold their responsibilities to future generations in this regard.

---

[9] CRC. Truth and Reconciliation Commission of Canada, 2015: We call upon the Government of Canada, on behalf of all Canadians, to jointly develop with Aboriginal peoples a Royal Proclamation of Reconciliation to be issued by the Crown. The proclamation would build on the Royal Proclamation of 1763 and the Treaty of Niagara of 1764 and reaffirm the nation-to-nation relationship between Aboriginal peoples and the Crown. The proclamation would include, but not be limited to, the following commitments:

1. Repudiate concepts used to justify European sovereignty over Indigenous lands and peoples such as the Doctrine of Discovery and terra nullius.
2. Adopt and implement the United Nations Declaration on the Rights of Indigenous Peoples as the framework for reconciliation.
3. Renew or establish Treaty relationships based on principles of mutual recognition, mutual respect, and shared responsibility for maintaining those relationships into the future.
4. Reconcile Aboriginal and Crown constitutional and legal orders to ensure that Aboriginal peoples are full partners in Confederation, including the recognition and integration of Indigenous laws and legal traditions in negotiation and implementation processes involving Treaties, land claims, and other constructive agreements.

[10] Littlechild and Sutherland (2021) suggest that the strengths of Indigenous knowledge systems flow from several attributes; key strengths of Indigenous knowledge systems include "lived knowledge, place-based, holistic, [being] connected to legal traditions, [an] extended oral archive."

[11] See White Face, 2013.

> **Article 26** 1. Indigenous Peoples have the right to the lands, territories and resources which they have traditionally owned, occupied or otherwise used or acquired. 2. Indigenous Peoples have the right to own, use, develop and control the lands, territories and resources that they possess by reason of traditional ownership or other traditional occupation or use, as well as those which they have otherwise acquired. 3. States shall give legal recognition and protection to these lands, territories and resources. Such recognition shall be conducted with due respect to the customs, traditions and land tenure systems of the Indigenous Peoples concerned.
>
> **Article 27** States shall establish and implement, in conjunction with Indigenous Peoples concerned, a fair, independent, impartial, open and transparent process, giving due recognition to Indigenous Peoples' laws, traditions, customs and land tenure systems, to recognize and adjudicate the rights of Indigenous Peoples pertaining to their lands, territories and resources, including those which were traditionally owned or otherwise occupied or used. Indigenous Peoples shall have the right to participate in this process.
>
> **Article 28** 1. Indigenous Peoples have the right to redress, by means that can include restitution or, when this is not possible, just, fair and equitable compensation, for the lands, territories and resources which they have traditionally owned or otherwise occupied or used, and which have been confiscated, taken, occupied, used or damaged without their free, prior and informed consent
>
> **Article 29** 1. Indigenous Peoples have the right to the conservation and protection of the environment and the productive capacity of their lands or territories and resources. States shall establish and implement assistance programmes for Indigenous Peoples for such conservation and protection, without discrimination.
>
> **Article 32** 1. Indigenous Peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources. 2. States shall consult and cooperate in good faith with the Indigenous Peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.
>
> **Article 39** Indigenous Peoples have the right to have access to financial and technical assistance from States and through international cooperation, for the enjoyment of the rights contained in this Declaration.

These articles can be read as potentially supportive of invigorating and upholding the practices and skills derived from Indigenous knowledge systems. Those systems are often composed of relationships that are passed from generation to generation and can include the application of dynamic land- and water-based content sometimes referred to as "traditional ecological knowledge," which has "qualitative, holistic and sustainable" attributes (Gordon *et al.* 2023). To implement these systems would require large-scale change and a fundamentally different way of doing things.

MOVING TOWARD JUSTICE

Kyle Whyte[12] suggests that colonialism, capitalism and industrialization are the root causes of these injustices, and that solutions to climate change must be built from consent, trust, accountability and reciprocity — internally for Indigenous communities and externally with those with whom they might develop "coordinated action" (Whyte 2019) through multi-scalar collaborations. Water governance is a potential site for coordinated action and integration of Western conceptual framings like blue carbon. Water governance is one expression within wider holistic "Indigenous knowledge systems" [13] (ICE 2018; Vogel *et al.* 2022). Indigenous knowledge systems are complemented by legal traditions and built from ecological, cultural and spiritual knowledge. Indigenous knowledge systems are inclusive of multiple philosophical, place-based and practical, lived principles and realities. Water governance in most colonial and/or state-based approaches is based on the notion of water as resource, known as "Modern Water" (Wilson 2019), which assumes that water is there for the taking and has no sentience, no ability to engage reciprocally, no agency.

However, in the knowledge systems of many Indigenous Peoples, waters are understood as self-determining and self-governing entities who only require respect and noninterference from human beings:

> "nibi [water] can manage itself, contrasting the colonial position that humans can manage nibi" (Craft *et al.* 2021).

For example, Anishinaabe researchers have, for decades, been collaborating to share knowledge about the sentient life of water and all that lives in water; researchers have insisted that they "resist compartmentalization" (Craft *et al.* 2021) when it comes to water and see both human health and environmental health as intertwined and related.

This is consistent with other framings of Indigenous knowledge systems and the dichotomies that exist when trying to work with and within colonial knowledge paradigms. Consider these contrasts: on one hand, the idea that the "human role is to participate in the orderly designs

---

[12] Potawatomi climate scientist and Indigenous environmental justice scholar.

[13] The ICE report, on page iii, reads: "The time has come for Indigenous knowledge systems, legal traditions, and customary and cultural practices to be appropriately recognized as equally valid and binding"; IKS are further defined on 56: "Indigenous knowledge systems, while defined by those who practice and are guided by them, are passed from generation to generation through culture, song, language, dance, ceremony and witnessing. They draw upon the ever-changing natural world. As such, they change over time, bringing forward new understandings regarding the Earth's ecology" (ICE 2018).

of nature," which is said to be affiliated with Indigenous conceptions of land responsibilities and relationships. For some Western relationships, the "human role is to dissect, analyze and manipulate nature for [its] own ends" (Gordon *et al.* 2023).

Contrasts have long dominated in discussions about whose voices and approaches are prioritized. For Canada, in 2021, the passage of Bill C-92 represented a cautious optimism among some Indigenous Peoples: the Royal Assent of a bill to recognize and align Canadian federal law with UNDRIP.

The longer history of UNDRIP is important. The original articles of UNDRIP were drafted in 1994 with input and collaboration from Indigenous Peoples. Later drafts were modified to the protest of some Indigenous Peoples as documented by White Face (2013). The version of UNDRIP which was eventually approved by the UN general assembly in 2007 was modified to alter specific language that affects core concepts such as citizenship, territoriality, property law, settler notions on the 'rule of law' and human rights considerations (Gover 2015). All of these concerns act as barriers to truly implementing Indigenous knowledge systems and legal orders; the underlying self-supremacy of Canada in law and policy remains entrenched. Canada initially disapproved of UNDRIP along with Australia, New Zealand and the United States (the so called CANZUS states). Canada issued major objections before adopting the UNDRIP in 2016.

BACK TO CANADA

The UNDRIP articles mentioned here (and potentially others in the declaration) can provide a pathway toward identifying space and resources to acknowledge historical displacement and degradation of Indigenous waters, lands and territories, including coastal environments.

A clear example emerges in salt marshes, which are highly significant to Indigenous understandings of place but are also historically considered unproductive according to settler colonial environmental logic dating back to "pioneer" days (Wysote and Morton 2019). Salt marshes and wetlands were often drained for farmland, contributing to today's ideas about what is naturalized in a lot of coastal environments.

The alteration of environments such as salt marshes has overwritten Indigenous governance including relationships, responsibilities and place-based practices for long-term interspecies conduct. That conduct benefitted the mutual thriving of human beings with the "more than human" life forms that composed their civilizations and surroundings (MacMillan and Prosper 2016). Mi'kmaq Peoples on the Eastern seaboard of Canada have demonstrated multiple forms of leadership in creating and engaging frameworks such as "Two Eyed Seeing,"[14] which is widely understood as a collaborative, integrative approach of "knowledge creation, mobilization and translation" (Harris 2022) coined by Elder Albert Marshall. Elder Marshall tirelessly and repeatedly shares his knowledge and vision for Two Eyed Seeing to be fully realized:

> "Etuaptmumk: Two-eyed seeing refers to learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of western knowledges and ways of knowing — and learning to use both of these eyes together for the benefit of all" (ICE 2018).

INTERNATIONAL MOMENTUM

There is growing momentum in local and international fora, such as the Intergovernmental Panel on Climate Change (IPCC) to recognize that "Indigenous knowledge and local knowledge are both crucial for understanding as well as evaluating climate adaptation processes and actions to reduce risks from human-induced climate change" (IPCC 2022). For some time, numerous Indigenous governments and communities have engaged in robust efforts to assert their knowledge and perspectives as essential and foundational toward better relations with the oceanic environments that sustained them for generations.

In Australia, the concept of *aqua nullius* appears in discourse and scholarship as a correlate to *terra nullius,* which is an example of European concepts of sovereignty. *Terra nullius* refers to "lands without a master" and *aqua nullius* refers to water in the same way (Butterly and Richardson 2016). According to the accumulative, possessive nature of colonial thought, lands and waters without a master are fit for seizure and dispossession. Despite decades of advocacy by Indigenous peoples, the realization of *aqua nullius* persists in approaches to land management regimes that do not prioritize or even consider Indigenous knowledge and jurisdictional assertions.

In Aotearoa (New Zealand), water governance that includes Indigenous leadership and perspectives presents complex challenges: "management tends to focus on narrow conceptualizations of and engagement with watercourses" (Harris 2022). To do the work of integrating knowledge systems is a global challenge with highly specific local applications and effects.

---

[14] Per MacMillan and Prosper, there are specific dimensions of two eyed seeing that involve Indigenous-specific community work: "Two centrally oriented recommendations, one is that traditional knowledge should be woven into all aspects of community life including economic development, fisheries, health, social, law, environment, education. The other main point is that each Indigenous community needs to encourage the use of traditional knowledge to inspire younger generations and to learn about and respect customary practices and laws and spiritual performances and the languages related to hunting, fishing and food gathering and medicines and ecology and sciences and arts" (MacMillan and Prosper 2016).

THE ROLE OF THIS REPORT

This report, compiled from a Western science approach, offers a specific glimpse into certain environments and species: seagrasses, salt marshes, kelp and Arctic environments. It also makes efforts to engage with Indigenous laws, Aboriginal laws and what might be called the shifting legal landscape in Canadian environmental governance. Integration of Indigenous knowledge brings with it the benefit of place-based Peoples who carry a much longer memory than the recent introduction of Canada and its environmental practices, many of which are based on extractivism and contamination, both of which facilitate ecocide and other disruptions to all of life, and to the wellbeing of water.

Importantly, understanding holistic factors, such as the diets of precolonial coastal Peoples, can shed light on additional sources of blue carbon that are only nascent considerations here. For example, regular abundance of “eels, cod, salmon, shellfish, sea vegetables, seals and whales” composed up to 90 per cent of the Mi’kmaw diet prior to European settlement (MacMillan and Prosper 2016). To overlook the interchange between species can miss wider connections and greater stores of carbon and, thus, more resilient and robust solutions to accelerated carbon emissions created by large industries and systems that allow grandiose forms of pollution with nearly no social, legal or financial repercussions.

Take for example the plight of the American eel, a historically significant species to Mi’kmaq and other Peoples further inland. Alyson Eberhardt and colleagues (2015) documented that American eels in salt marshes trap and store nutrients in their guts and then facilitate dispersal as they migrate out of and through estuaries, benefitting the salt marsh environment and plant species that live there. To separate that relationship is to discount the historic role of eels, and to misunderstand the impact of historical practices where salt marshes were altered by early settlers to dig ditches for agriculture (Wysote and Morton 2019).

Mi’kmaw Peoples have held a sustained focus on revitalizing relationships with American eels and improving their migration and habitat. This has been a priority for generations and is tied to a very significant series of disputes and court cases including the Marshall decision of 1999 (MacMillan and Prosper 2016). American eels are significant not only as a food source, but as an important contributor to Mi’kmaw notions of reciprocity, seasonal and ceremonial cycles, gifting, nourishment and medicine, which are part of Mi’kmaw knowledge systems and land/marine tenure.

The integration of Indigenous knowledge in an intentional, holistic way can offer tremendous benefit and is urgently needed in projects that seek to ameliorate, mitigate or propose solutions to climate change. Doing so is about learning to see and do differently:

> “Rather than focusing on the ocean and coast as a repository of resources, we need to celebrate and respect the gifts that we receive from ocean life through its diverse ecosystems” (Strand *et al.* 2022).

Efforts to mitigate and adapt to global environmental changes must be mindful of historic and ongoing “pervasive systemic discrimination that devalues Indigenous knowledge and favours assimilation” (MacMillan and Prosper 2016). The deep-time knowledge of communities from land and water-based societies offers a pathway for understanding the complex roles of individual species, the symbioses they engage in, and the multiple layers of consideration that go into decisions informed by Indigenous knowledge systems and traditional ecological knowledge.

If Indigenous-led climate justice is a framework to seriously consider, there are considerations of “ethical space” that can be addressed through recommendations made in 2018 by the Indigenous Circle of Experts (ICE). Ethical space is a form of pluralism that “is formed when two societies, with disparate worldviews, are poised to engage each other” (Ermine 2007). The ICE report suggests that developing Ethical Space is a practice that “includes the minimum standards set out in UNDRIP, the TRC Calls to Action, the Canadian Constitution and Canadian jurisprudence, treaties, agreements and other constructive arrangements” (61). Ethical space is also “about relationality and finding ways to engage in an ethical way…knowing your positionality and listening to others” (Littlechild and Sutherland 2021).

Toward a holistic Indigenous framing of blue carbon, more Indigenous involvement is needed through the lens and practice of ethical space, which involves an encounter “that creates and implements connectivity and linkages in order to make sense of the subject matter being addressed” (Littlechild and Sutherland 2021).

THE FUTURE

For too long, colonialism as a given and permanent structure is an underlying assumption of Canada’s existential and recently developed identity as a nation state project. For Indigenous Peoples, the scale of time is different. These challenges of integrating Indigenous law, governance, knowledge and continuity are not specific to Canada:

> “We have a long history and a long historical memory of a different way of living, a different way of building our society and our communities and our government structures that honor our responsibility to all the things that are around us — and that’s our natural laws. Nature-based solutions are a very inadequate reframing of all of that and everything that we hold in our worldviews and traditional knowledge systems” (Funes 2022).

> “Indigenous Peoples have ongoing, complex cultural and economic relationships with both fresh and salt water that are difficult to articulate in legal frameworks premised on artificial delimitation of property rights, narrow economic agendas or stilted, stereotyped representations of Indigenous livelihoods” (Butterly and Richardson 2016).

Collective human evolution and the reflective space of the current moment can promote what the late Dakota scholar Vine Deloria called a “science of wholeness” (Deloria 1999) that originates from Indigenous knowledge systems. For blue carbon to realize its true potential, it is necessary to engage in deconstructing *aqua nullius* (Butterly and Richardson 2016) to recognize the existing and persisting views and perspectives of Indigenous Peoples and communities who have managed blue carbon sources for generations.

Among those Peoples are those who wish to engage in water governance and assert their longstanding responsibilities to place. They have important contributions to complement and extend the frameworks and beginnings of blue carbon discourse, such as those outlined in this report.

A call for multiple forms of justice has been issued in legal and policy framings of Canadian jurisprudence and society, and Canadian organizations and institutions have the potential to demonstrate renewed leadership by supporting the protection and restoration of ethically reciprocal relationships for all that lives in the water, respecting the role and agency of marine water itself.

Theories on the benefits of blue carbon management require acknowledgement of the life-giving capacity of water and the ability of nature to both heal and regenerate with holistic benefits, supported by human activities.

> “Energy derived from sources like the sun, air and water…is imbued with immense liberatory potential” (Ghosh 2021).

Nature, including plant life and marine sediment, is not for the contamination, control or surveillance of profit-based governance regimes. Instead, the gifts and powers of water and its constituent residents must be nurtured and cultivated wisely, as Indigenous communities have done and will continue to do for future generations, toward supporting wellness and continuity of all life.

Methods to foster such relationships may not include the domination of others or the acquisition of property regimes that regiment and control all life forms, and may require new ways of thinking, engaging and being. The goals of renewal and integrated knowledge-sharing and collaborative systems may include the sustained ability to relate with life in mutually beneficial ways that travel well into an increasingly uncertain future: “Providing hope that we can collectively become good neighbors as we envision a new shared future” (Gordon *et al.* 2023). The wellbeing of future generations is worth the effort of tackling these current challenges.

LEGISLATION AND POLICY

ABORIGINAL LAW

Kostantina Northrup

INTRODUCTION TO ABORIGINAL LAW IN CANADA AND ITS IMPLICATIONS FOR BLUE CARBON ECOSYSTEMS

This chapter of the report introduces Aboriginal law and explores how it can influence governance in blue carbon ecosystems, including actions to protect or steward these ecosystems by managing human activities. Indigenous Peoples have their own pre-existing legal systems that inform and legitimate their governance of marine ecosystems and resources, regardless of Crown recognition. Indigenous governance and authority are recognized to some extent by Aboriginal law but are also constrained by Aboriginal law.

What is Aboriginal Law?

In Canada, the term “Aboriginal law” refers to Canadian laws that impact Indigenous Peoples across the country. Aboriginal law has been shaped primarily by the legal system that the British brought with them when they came to the territories that are now known as Canada. That legal system was imposed to facilitate the colonization of Indigenous territories and establish colonial control over Indigenous Peoples, lands and resources. Those colonial roots are still evident in Aboriginal law today, which is why the term “Aboriginal law” means something very different from “Indigenous law.” Whereas in Canada “Aboriginal law” refers to colonial laws that impact Indigenous Peoples, “Indigenous law” refers to the laws of Indigenous Peoples themselves.

Aboriginal law in Canada has been shaped to some extent by Indigenous laws and Crown relationships with Indigenous peoples, and, in practice, the implementation of Aboriginal law can intersect with the implementation of Indigenous laws. However, many of the laws that constitute Aboriginal law in Canada have been imposed without the consent of Indigenous Peoples, and Aboriginal law has significantly limited Indigenous Peoples’ autonomy and self-determination historically and in the present day. Not least for these reasons, it is important to recognize the differences between colonial and Indigenous legal systems in Canada and in particular, to recognize when Aboriginal law is being used to sideline or suppress Indigenous laws.

This chapter focuses on Aboriginal law’s implications for governance in blue carbon ecosystems in Canada. Developments in the revitalization and implementation of Indigenous laws are discussed in a separate chapter.

THE CONSTITUTIONAL FOUNDATIONS OF ABORIGINAL LAW IN CANADA

The constitutional foundations of Aboriginal law in Canada are found primarily in the division of powers set out in sections 91, 92 and 92A of the Constitution Act, 1867 and the recognition and affirmation of Aboriginal and treaty rights set out in Section 35 of the Constitution Act, 1982.

The Constitutional Division of Federal and Provincial Government Powers

Sections 91, 92 and 92A of the Constitution Act, 1867 divide governmental authority between Canada's federal and provincial governments. Within these sections, several "heads of power" (areas of legislative authority) are assigned to the federal and provincial governments, giving these governments exclusive authority to make laws in particular areas. Many of the assigned heads of power have significant implications for Indigenous Peoples in Canada, and the powers exercised by Canada's federal and provincial governments have, in many cases, restricted or fully excluded Indigenous jurisdiction in Indigenous territories.

Two Noteworthy Federal Heads of Power

Indigenous Peoples and Lands Reserved for Indigenous Peoples

The federal heads of power set out in Section 91 of the Constitution Act, 1867 include the exclusive power to make laws concerning Indigenous Peoples and lands reserved for Indigenous Peoples in Canada. Under this head of power, the Government of Canada maintains the Indian Act, along with corresponding legal regimes that define — from the federal government's perspective — Indigenous jurisdiction to govern activities in Indigenous territories.

The Indian Act is a striking example of Aboriginal law that has perpetrated significant harms against Indigenous Peoples in Canada since it was first established in 1876. Although Aboriginal law has evolved in some ways that may reduce the harms of the Indian Act and legal regimes connected to it, the Act continues to restrict Indigenous Nations' autonomy and self-determination today. One of the contemporary legal regimes that intersects with the Indian Act and affects Indigenous governance in Indigenous territories is the First Nations Land Management Act (FNLMA). Working together with the Framework Agreement on First Nation Land Management, the FNLMA structures the federal government's recognition of First Nation land management on reserve. Within the regime established by the FNLMA, First Nations can enact land codes for their reserve lands. Among other things, such land codes can address and impose environmental protection. When such land codes come into force, various sections of the Indian Act that empower the federal government to manage reserve lands cease to apply to the lands in question.

There are significant limitations on the extent to which the FNLMA recognizes First Nation jurisdiction over land management on reserve; however, the regime offers some opportunities to move beyond the Indian Act and toward better recognition of Indigenous rights to self-determination. For First Nation communities whose reserve lands include blue carbon ecosystems (salt marshes, for example), the FNLMA regime presents some opportunities to recognize Indigenous jurisdiction to govern activities in such ecosystems.

When considering potential opportunities presented by the FNLMA regime, it is important to bear in mind that reserve lands represent mere fractions of First Nations' traditional territories; moreover, reserve lands are not established for Inuit and Métis. Because the FNLMA regime applies specifically to reserve lands, it does not advance recognition of Indigenous jurisdiction outside of those lands, which is a further restriction on the opportunities it offers to Indigenous Peoples in Canada.

Sea Coast and Inland Fisheries

Another significant federal head of power is the exclusive power to make laws concerning Canada's sea coast and inland fisheries. This head of power is the source of the Government of Canada's asserted authority to manage the fisheries and protect fish habitats against harm throughout Canada, including fish habitats that are also blue carbon ecosystems (such as seagrass meadows). This asserted authority has significant implications for many Indigenous Nations across the country. Asserted and established Indigenous rights to access or restrict fisheries — along with corresponding rights and responsibilities to protect related ecosystems — have been the subjects of extensive litigation and negotiation across Canada.

Fisheries disputes and jurisdictional conflicts may have broader implications for the governance of blue carbon ecosystems. A West Coast example of this is the dispute that arose between the Haida Nation and the Government of Canada with respect to the commercial herring fishery. Since time immemorial, the Haida Nation has managed its traditional territory, Haida Gwaii, in accordance with Haida laws. In recent decades, the nation has worked successfully to protect the territory from unsustainable resource exploitation. Among other things, this process has involved entering into several agreements with the Government of Canada to implement co-management of jointly recognized protected areas in Haida Gwaii, including the Gwaii Haanas Agreement of 1993 and the Gwaii Haanas Marine Agreement of 2010.[15] In addition, the Haida Nation is also protecting Haida Heritage Sites. In 2015, the Haida Nation was forced to seek court intervention to prevent Fisheries and Oceans Canada (DFO) from reopening a commercial herring fishery in Haida Gwaii despite Haida concerns that the herring population was too diminished to support a sustainable fishery.[16] Herring are a culturally significant species for Haida, and the harvesting of herring spawn-on-kelp is a traditional Haida activity. The Haida Nation succeeded in securing a court injunction against the reopening of the commercial fishery. This success was, in large part, due to the court's recognition of the Haida's significant cultural interest in protecting the herring stocks, as well as the spirit and intent of the Gwaii Haanas co-management agreements, which the court agreed would be undermined by unilateral action by DFO.[17]

---

15. *Haida Nation v Canada (Fisheries and Oceans)*, 2015 FC 290 (CanLII) at paragraph 10.

16. *Haida Nation v Canada (Fisheries and Oceans)*, 2015 FC 290 (CanLII) at paragraph 10.

17. *Haida Nation v Canada (Fisheries and Oceans)*, 2015 FC 290 (CanLII) at paragraphs 50–56.

This dispute between the Haida Nation and the Government of Canada was not framed as one that concerned blue carbon ecosystem governance. However, coastal and marine governance were clearly at stake, as were the nation-to-nation relationships underpinning the unique ecosystem-management structures of the Gwaii Haanas protection regimes. This example therefore illustrates how Canadian assertions of jurisdiction with respect to fisheries and fish habitats can intersect with Indigenous jurisdiction and governance in coastal blue carbon ecosystems. This intersection makes clear the need for nation-to-nation relationships that respect the coexistence of Indigenous and Crown legal systems that give rise to various governance mandates.

Provincial Heads of Power

Many of the provincial heads of power set out in sections 92 and 92A of the Constitution Act, 1867 establish provincial powers to make laws concerning the use of lands and natural resources within provincial borders. All of the following are provincial heads of power: the management and sale of public lands belonging to the provinces, the sale of timber harvested from such lands, exploration for non-renewable natural resources, and the development, conservation, and management of forestry resources and non-renewable natural resources.

These provincial heads of power have significant implications for Indigenous Peoples in Canada. Provincial laws typically govern the use and exploitation of vast areas that fall within Indigenous Nations' traditional territories but are not managed federally as reserve lands or governed directly by Indigenous Nations that have established title under Canada's common law[18] or by treaty. For example, a salt marsh may fall within an Indigenous Nation's traditional territory, but outside the borders of the nation's reserve lands (which are under federal jurisdiction) or title lands.[19] Under Canada's constitutional structure, ownership of the salt marsh and jurisdiction over activities within it will therefore be governed mainly by provincial laws (assuming the lands and waters in question do not fall within areas that are controlled federally, such as national parks). Provincial governments may recognize Indigenous jurisdiction and facilitate Indigenous management or co-management of such ecosystems. However, when provinces are recalcitrant, Indigenous Peoples may be forced to take legal action to protect ecosystems and assert their rights and responsibilities to determine how such areas should be preserved and accessed.

THE CONSTITUTIONAL RECOGNITION AND AFFIRMATION OF ABORIGINAL AND TREATY RIGHTS

Section 35 of the Constitution Act, 1982 recognizes and affirms the existing Aboriginal and treaty rights of the Indigenous Peoples of Canada. In this context, "the Indigenous Peoples of Canada" include First Nations, Inuit, and Métis in Canada. The Aboriginal and treaty rights that are recognized and affirmed by Section 35 are unique and independent categories of Indigenous rights. As interpreted by Canada's courts, "Aboriginal rights" are rights that flow from the distinctive cultural practices that First Nation and Inuit communities engaged in before their contact with Europeans and that Métis communities engaged in before Europeans gained effective legal and political control in relevant territories. "Aboriginal title," a unique form of title to land that Canada's courts have recognized under the common law, is a subtype of Aboriginal right. "Treaty rights" flow from solemn treaty promises made to Indigenous Nations by the British Crown or, more recently, the Crown as represented by Canada's federal and provincial/territorial governments. Indigenous title to lands (and corresponding governance rights concerning such lands) can be recognized under treaties and need not take the form of "Aboriginal title" as that term is defined by the common law.

Aboriginal Rights and Ecological Governance

Canadian recognition of Aboriginal rights can support Indigenous governance of human activities in blue carbon ecosystems in at least two ways: through recognition of site-specific / activity-specific rights and through recognition of title.

Indigenous communities that have historically engaged in distinctive cultural practices in blue carbon ecosystems may be able to assert and establish Aboriginal rights to continue those practices. For example, if an Indigenous community historically had a distinctive cultural practice of harvesting medicines from a salt marsh within its traditional territory, Canadian law may recognize an ongoing right for members of the community to continue that cultural practice. If the salt marsh is under the jurisdiction of the federal government or a provincial/territorial government, recognition of Aboriginal rights may require the government to take steps to protect the ecosystem, such as by refusing to authorize activities that could infringe those rights. Crown conduct that could negatively affect an asserted or established right would also trigger a duty to consult (discussed in more detail below).

Canada's Aboriginal law typically defines Aboriginal rights as being site-specific and activity-specific. This means that the law might recognize an Aboriginal right to harvest species in a certain area but would not necessarily recognize broader Indigenous rights to exercise jurisdiction over the practice or over other activities that could affect the practice. Canadian recognition of Aboriginal title under the common law can support greater recognition of Indigenous jurisdiction to govern activities within Indigenous territories, but even under the Aboriginal title framework, Canadian law limits recognition of Indigenous jurisdiction. In particular, Aboriginal title, as Canada's courts have defined it, imposes an inherent restriction on Indigenous use of Aboriginal title lands, making it unlawful for Indigenous Nations to

---

[18] The common law is a body of law based on court decisions.

[19] As recognized under the common law or through treaty.

use their lands in ways that conflict with the Canadian rationale for recognizing the title. Moreover, the Canadian law of Aboriginal title reserves the right for Canadian governments to violate Indigenous rights to Aboriginal title lands when Canada's courts determine that such violation is justified.

For all of these reasons, although Canadian recognition of Aboriginal rights can potentially support Indigenous governance in blue carbon ecosystems, Canada's Aboriginal law imposes significant restrictions in that regard.

Treaty Rights and Ecological Governance

As with Aboriginal rights, Canadian recognition of treaty rights can potentially support Indigenous governance of human activities in blue carbon ecosystems. Under Canada's Aboriginal law, some treaty rights are defined as being site-specific and activity-specific, such as treaty rights to hunt, fish or collect medicines in certain areas. However, treaty rights can also be more expansive and can recognize Indigenous title to treaty territories and corresponding Indigenous jurisdiction to govern activities within those lands.

Consider an East Coast example of a treaty recognizing Indigenous title and corresponding jurisdiction in coastal areas. The Labrador Inuit Land Claims Agreement (LILCA) is a modern treaty established in 2005 between the Nunatsiavut Government, Government of Canada and Government of Newfoundland and Labrador. The treaty establishes a Labrador Inuit Settlement Area in which various Labrador Inuit rights are recognized. Within that settlement area are specific lands that the treaty recognizes as Labrador Inuit Lands. The treaty recognizes Labrador Inuit title (in fee simple) to the Labrador Inuit Lands, and it also recognizes extensive (but not unlimited) Labrador Inuit jurisdiction to govern Labrador Inuit Lands in accordance with Labrador Inuit governance structures and laws.

As much of the territory covered by the LILCA is coastal, the Labrador Inuit can potentially govern or co-govern activities in local blue carbon ecosystems. Labrador Inuit collaboration with the Government of Canada to establish the Imappivut Marine Plan is a noteworthy example of this. The Imappivut initiative is designed not only to implement Chapter 6 of the LILCA, which addresses Labrador Inuit and Canadian rights and responsibilities with respect to ocean management, but also to "represent the relationship that Labrador Inuit have with coastal and marine areas" and to enable coastal and marine planning that is informed by Labrador Inuit Indigenous knowledge and reflective of Labrador Inuit interests in protecting coastal and marine territories for future generations.[20]

Canadian recognition of treaty rights can potentially support Indigenous governance in blue carbon ecosystems. However, like Aboriginal rights, treaty rights are subject to significant restrictions under Canada's Aboriginal law. Canada's courts accept that Canadian governments can violate Indigenous Peoples' treaty rights when such violations are deemed to be justifiable, according to an analytical framework developed by the courts. In consequence, Canadian governments' approach to treaties often falls short of building and honouring true nation-to-nation relationships with Indigenous Peoples.

The Duty to Consult

Section 35 of the Constitution Act, 1982 recognizes and affirms the Aboriginal and treaty rights of the Indigenous Peoples of Canada. Flowing from this recognition and affirmation, Canadian courts have recognized the duty to consult. The duty to consult means that the Crown (represented by federal, provincial, or territorial governments and agencies) must consult Indigenous Peoples in Canada when Crown activities could negatively affect asserted or established Aboriginal and treaty rights. In some cases, the duty to consult may include a corresponding duty to accommodate the right in question and take steps to prevent, minimize or compensate negative effects.

Consultations carried out to meet the Crown's duty to consult may present opportunities for Indigenous Peoples to contribute to decision-making that affects blue carbon ecosystems. However, Crown consultations are not ideal venues in this regard. Crown representatives often take a fragmented, site-specific and activity-specific approach to assessing negative effects on Aboriginal and treaty rights. This practice limits opportunities to assess potential impacts — including cumulative impacts — more holistically, using ecosystem approaches and cumulative-effects assessment. In addition, these consultations are often led by the Crown, with significant portions of the process delegated to project proponents. For these reasons, Crown consultations typically offer minimal opportunities for Canadian recognition of Indigenous jurisdiction to govern activities within the ecosystems under discussion.

HOW INTERNATIONAL LAW SHAPES ABORIGINAL LAW IN CANADA

Aboriginal law in Canada has been shaped to some extent by international law and should be expected to evolve progressively to meet or exceed the binding requirements and clear expectations of the global human rights regime. For instance, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) should lead to greater recognition of Indigenous jurisdiction and the need to obtain Indigenous Peoples' free, prior and informed consent to activities carried out within their territories. It remains to be seen how domestic laws such as Canada's United Nations Declaration on the Rights of Indigenous Peoples Act, British Columbia's Declaration on the Rights of Indigenous Peoples Act, and others that may follow will produce meaningful progress in this regard.

---

20. Nunatsiavut Government. (2020). Imappivut: Nunatsiavut Marine Plan.

CONCLUSION

Canada's Aboriginal law can affect governance in blue carbon ecosystems by recognizing, to varying extents, Indigenous jurisdiction and rights to govern human activities in such ecosystems, access such ecosystems for cultural purposes, and participate in decision-making that affects such ecosystems. However, as a fundamentally colonial legal system, Canada's Aboriginal law imposes significant restrictions on Indigenous jurisdiction and Indigenous rights. This is one of the reasons why many Indigenous Nations across Canada are working to revitalize and implement their own laws and legal orders beyond the limits of Canada's Aboriginal law regime. That topic is addressed in more detail in the following chapter.

INDIGENOUS LAW AND COASTAL ECOSYSTEMS: A RELATIONAL APPROACH TO BLUE CARBON

Rayanna Seymour Hourie and Deborah Carlson

INTRODUCTION: CLIMATE CHANGE IS HERE

We need to take care of our Earth's ecosystems to combat climate change and prepare for its continued impacts of droughts, floods, sea-level rise, warming climate, and the degradation of habitat leading to decreased biodiversity. Climate change is currently impacting the natural, political, economic and social landscapes in a variety of ways. The time to act is now, and our action must recognize the fast-changing reality we find ourselves in. We must not only restore the landscapes, but also proactively adapt and plan for more climate change impacts while lessening our impacts on the Earth's cycles.

This chapter argues that we can mitigate climate change by supporting Indigenous rights and focusing on protecting, restoring and conserving key areas, such as coastal ecosystems that store blue carbon. Protection must be place-based. To go beyond status quo decision-making and transform environmental governance, we need to elevate community, capacity building and relationship-making.

BLUE CARBON'S ROLE IN CLIMATE CHANGE

Water surrounds us and connects us. The fresh waters flow into the salt waters where the land meets the water, creating coastal ecosystems all over the world. Blue carbon is stored in coastal ecosystems "provid[ing] a range of ecosystem services that can help in the management of coastal erosion, flooding, and climate change adaptation through shoreline stabilization, wave attenuation, and storm surge and flood protection" (Carlson 2020).

Coastal ecosystems have dual potential. They can both combat climate change (i.e., by sequestering and storing carbon in their biomass and sediments) and contribute to it (i.e., by emitting GHGs when they are destroyed or degraded). The functioning of coastal ecosystems depends on decisions made by humans. If coastal ecosystems are degraded by erosion, development or other impacts, they release their stored carbon, adding to greenhouse gas emissions and contributing to climate change. If they are safeguarded from degradation, they hold and store carbon. Given this, coastal ecosystems must be carefully looked after.

INDIGENOUS-LED CONSERVATION

From coast to coast to coast, Indigenous Nations and communities are working to conserve areas that are important to them. Many intend to expand their scope as capacity, funding, research and data collection increase over time. Increasingly, Indigenous Nations and communities are advancing conservation initiatives in their territories through Indigenous Protected and Conserved Areas (IPCAs). A vehicle for a paradigm shift in conservation, IPCAs ensure that Indigenous expertise, science, and governance are equal parts of the conversation. According to the Indigenous Circle of Experts (ICE), IPCAs are Indigenous-led, represent a long-term commitment to conservation, and elevate Indigenous rights and responsibilities (ICE 2018). Originating in self-determination, IPCAs are expressions of Indigenous governance. IPCAs differ significantly from Crown-led or conventional protected areas such as national or provincial parks and marine protected areas.

IPCAs uphold Indigenous laws. Expressed through Indigenous knowledge, languages, stories and songs, these laws are grounded in the inherent connection Indigenous Peoples have with their lands and waters. IPCAs can influence how we act as human beings on certain landscapes, guided by the local Indigenous Peoples. "Indigenous law" is distinct from "Aboriginal law." Aboriginal law is made in the courtrooms with lawyers and judges through the Canadian legal system (i.e., in a colonizing context); it lacks input from and consent of Indigenous Peoples. Indigenous Nations have the authority to declare and establish IPCAs in their own territories and do not require the approval of Crown (i.e., federal, provincial, and territorial) governments. Some Indigenous Nations pursue co-governance arrangements with Crown partners and pursue complementary legal protection by layering on Crown-protected areas (e.g., Thaidene Nëné IPCA).

On the West Coast, some Indigenous Nations are seeking to protect their marine and coastal ecosystems in British Columbia (B.C.). The Muwačatḥ (Mowachaht/Muchalaht) and Nuchatlaht First Nations are creating Salmon Parks "to restore wild salmon by recovering key watersheds in Nootka Sound, on Vancouver Island's west coast" (Salmon Parks n.d.). In order to manage sustainably, they are following their own knowledge and guiding principles:

- *HISHUK-ISH-TSA'WALK* Everything is connected
- *ISAAK* Respect for all
- *UU-A-THLUK* Taking Care Of
- *STALTH* Together

On the East Coast, Mi’kmaq are establishing their Unama’ki (Cape Breton Island, Nova Scotia) IPCA, led by five First Nations, that would protect a significant territorial-coastal-marine area sacred to Mi’kmaq. Unama’ki Institute of Natural Resources represents the five First Nations on Cape Breton Island in Nova Scotia. The guiding principle is *Netukulimk*, based on a respectful relationship with the natural world.

We must always remember that all lands across Canada are Indigenous lands. When researching coastal ecosystems and supporting their resilience to climate change — whether through blue carbon initiatives or other processes — we must follow principles that support ethical, cross-cultural work. Elder Albert Marshall describes the Mi’kmaq concept of *Etuaptmumk* or two-eyed seeing as the ability “to see from one eye with the strengths of Indigenous ways of knowing, and to see from the other eye with the strengths of Western ways of knowing, and to use both of these eyes together” (Bartlett *et al.* 2012).

Blue carbon research can help identify the status of specific coastal ecosystems (coastal wetlands, seagrasses and kelp beds), risks to their persistence, opportunities to increase their spatial extent and carbon sequestration. It can also confirm historical trends and factors contributing to losses. This information could be relevant to other aspects of coastal ecosystem management aimed at protecting or enhancing overall ecosystem health, as well as the health of particular species. Salt marshes and seagrasses provide habitat for other species, protect water quality, and contain culturally important plants. Kelp management is relevant to Indigenous-led herring roe fisheries and can support sustainable harvest opportunities.

The ideal is to manage blue carbon ecosystems through strong environmental co-governance that draws on two-eyed seeing supported by Indigenous knowledge. By focusing on ecosystem-based management and strong environmental co-governance, we will accelerate carbon storage and climate resilience in natural ecosystems, and better prepare ourselves and the Earth for climate-change impacts.

TWO-EYED SEEING AND LEGAL PLURALISM

Coastal management and planning require shifting our political landscape, notably the way in which Crown governments interact, engage and build relationships with Indigenous governments, communities and organizations across this country. One noteworthy agreement is the Gwaii Haanas Agreement between the Haida Nation and the Government of Canada. This interjurisdictional governance arrangement for coastal and marine protection acknowledges that both the Haida Nation and the Crown assert sovereignty over Gwaii Haanas on Haida Gwaii.

Recognizing the Haida Heritage Site, the *Gwaii Haanas Agreement* establishes the federal National Marine Conservation Area (NMCA) and outlines shared objectives. The agreement states that:

> “all actions related to the planning, operation and management of the Archipelago will respect the protection and preservation of the environment, the Haida culture, and the maintenance of a benchmark for science and human understanding.”

The agreement incorporates a co-management and co-governance structure between the Haida Nation and the Government of Canada where each has equal decision-making authority. In addition, the NMCA management plan is grounded in Haida law, knowledge and values. The agreement and associated management plans encompass aspects of two-eyed seeing and legal pluralism, or the coexistence of two or more legal systems in the same field.

LEARNING FROM FOREST CARBON PROCESSES

Legal pluralism is the basis of some interjurisdictional arrangements between Indigenous and non-Indigenous governments regarding coastal management and planning in British Columbia. Blue carbon stewardship could fit within these types of arrangements if this is desired by Indigenous Nations who feel it aligns with their ecosystem-management objectives.

Currently there is a range of Indigenous-led coastal stewardship and restoration initiatives underway (such as those listed above) that could potentially be linked to blue carbon assessment and management. If Indigenous Nations express specific legal interests in blue carbon within B.C. arising from their unextinguished Aboriginal title, there are precedents for recognizing Indigenous ownership in provincial law, based on previous work on forest carbon.

Despite contextual differences, it is helpful to analyze forest carbon policy to set the course for blue carbon initiatives in Canada. Between 2011 and 2019, 14 First Nations entered into government-to-government Atmospheric Benefit Sharing Agreements with the Province of B.C. regarding ownership of forest carbon credits in the Great Bear Rainforest. The carbon credits were associated with increased carbon sequestration or avoided emissions from the creation of new protected areas and a shift to ecosystem-based management in forests on the central and north Pacific Coast.[21] These agreements empower First Nations signatories to sell carbon credits in local and international carbon markets and retain 80 per cent of the revenue from the sales (Coastal First Nations 2022a; Government of British Columbia 2023). This initiative demonstrates the potential economic benefits of Indigenous-led carbon offsets while simultaneously empowering Indigenous-led conservation off the B.C. coast.

---

[21] Seven Coastal First Nations have Atmospheric Benefit Sharing Agreements: Gwa’sala-‘Nakwaxda’xw Nations, Kitselas First Nation, Haida Nation, and four Nanwakolas First Nations. See Atmospheric Benefit Sharing Agreements.

PARTNERSHIPS AS A WAY FORWARD: THE MARINE PLAN PARTNERSHIP FOR THE NORTH PACIFIC COAST (MAPP)

As stated at the beginning of this chapter, supporting Indigenous rights and focusing on protecting, restoring and conserving key areas, such as coastal ecosystems that store blue carbon, can help to mitigate the impacts of climate change. One way this can be achieved is through collaboration and partnerships. For example, the Marine Plan Partnership for the North Pacific Coast (MaPP) is a partnership between 17 First Nations and the Province of British Columbia resulting in four marine plans and a regional action framework covering 102,000 km^2 of coastal and marine waters. MaPP has relied on both Indigenous knowledge and western science in creating these plans and frameworks. The Regional Action Framework (2016) developed for the MaPP includes Action 3.1(c):

> “Engage in the Province of British Columbia’s blue carbon assessment framework to estimate the potential for marine carbon sequestration in the MaPP region” (MaPP 2016).

The MaPP Indigenous-led marine-use plans provided a foundation of community priorities and strategic direction for the larger area plans. This facilitated wider ecosystem-based management and the articulation of ecological, social and economic objectives. These accomplishments were hard won in the face of at times challenging Crown-Indigenous relations. After leaving the table in 2011, the federal government is re-engaging with MaPP, creating the possibility of further planning and implementation related to marine protected areas and marine-spill preparedness (Diggon *et al.* 2020).

> “Ecosystem-based management can be more fully realized by weaving together Indigenous knowledge and western science. Blue carbon research, with its relatively broad spatial and temporal scope and its questions about ecosystem health and persistence, may also help direct western thinking towards appreciating and learning from the Indigenous management of the land and water, founded on precise observations, deep understandings of ecosystem relationships, and long timeframes” (Carlson 2020).

At the same time, a blue carbon lens does not in itself overcome the limitations of western approaches (e.g., “carbon colonialism”) to carbon management and governance in coastal regions. Limitations related to law, culture and worldview also exist (e.g., Daniel 2019), and were touched upon in this chapter. Also discussed were principles — like two-eyed seeing and legal pluralism — that can guide us forward.

FEDERAL BLUE CARBON POLICY IN CANADA

Kim Dunn, Thiviya Kanagasabesan and Sarah Saunders

In 2022, WWF-Canada undertook a content analysis of relevant federal policy frameworks, guidance documents, strategies and discussion papers to determine the extent to which blue carbon is covered in Canada’s federal policy regime (WWF-Canada 2022). As “blue carbon” is a relatively new term (coined in 2009; Lovelock and Duarte 2019), the reviewers recognized that it would not be explicitly included in many of the policies and frameworks they were analyzing. Accordingly, they also assessed the term’s relevance and/or implicit inclusion within federal policy.

The 2022 review had three goals:

- to understand the extent to which blue carbon is directly addressed in existing relevant federal policies
- to determine the extent to which each policy applies to the protection and management of blue carbon habitats and ecosystems
- to identify ways to better integrate blue carbon into each policy

In total, 34 documents were reviewed: 15 from Fisheries and Oceans Canada, 11 from Environment and Climate Change Canada, four from the Government of Canada more generally (or jointly with provinces and territories), and one each from the Indigenous Circle of Experts, Infrastructure Canada, Impact Assessment Agency of Canada and Transport Canada. An initial set of documents was identified by WWF-Canada staff with expertise in coastal and marine management. Additional documents were identified by experts in the blue carbon community of practice during both the early phases of analysis and the review phase. See Table 1 for a list of documents reviewed. A set of keywords was used to conduct a content analysis of documents, and in particular to identify document objectives, applicable jurisdiction, and mechanism(s) of policy or framework implementation (WWF-Canada 2022).

Though outside the scope of this analysis, law and policy from other governing bodies in Canada are equally important for blue carbon. Policy from these governing bodies — including Indigenous, provincial, territorial and municipal governments — can play an important role in managing and protecting blue carbon, in addition to new and improved policy at the federal level.

Table 1. Documents reviewed for Federal Blue Carbon Policy Review.

Document	Year Released
Fisheries and Oceans Canada	
Canada's Oceans Strategy	2002
Identification of Ecologically and Biologically Significant Areas	2004
Canada's Ocean Action Plan	2005
A New Ecosystem Science Framework in Support of Integrated Management	2007
A Fishery Decision-Making Framework Incorporating the Precautionary Approach	2009
Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas	2009
Ecologically and Biologically Significant Areas - Lessons Learned	2011
National Framework for Canada's Network of Marine Protected Areas	2011
Small Craft Harbours: Harbour Authority Manual/Environment	2012
Fish and Fish Habitat Protection Policy Statement	2019
Policy for Applying Measures to Offset Adverse Effects on Fish and Fish Habitat	2019
Discussion Paper: A Canadian Aquaculture Act	2020
Blue Economy Strategy Engagement Paper	2021
Engaging on Canada's Blue Economy Strategy, What We Heard	2022
Ecologically Significant Areas Framework	2022
Environment and Climate Change Canada	
Federal Policy for Wetland Conservation	1991
The Federal Policy on Wetland Conservation Implementation Guide for Federal Land Managers	1996
Pan-Canadian Approach to Transforming Species at Risk Conservation in Canada	2018
Carbon Pollution Pricing: Options for a federal GHG Offset System	2019
A Healthy Environment and a Healthy Economy. Canada's Strengthened Climate Plan to Create Jobs and Support People, Communities and the Planet	2020
Climate Science 2050: Advancing Science and Knowledge on Climate Change	2020
Adapting to the Impacts of Climate Change in Canada: An Update on the National Adaptation Strategy	2021
Guidelines to Reduce Risk to Migratory Birds	2021
Strategic Assessment of Climate Change	2021
Achieving a Sustainable Future Draft Federal Sustainable Development Strategy 2022 to 2026	2021
Canada's 2030 Emissions Reduction Plan	2022
Infrastructure Canada	
Building the Canada we want in 2050: Engagement on the National Infrastructure Assessment	2021
Transport Canada	
Ports Modernization Review Discussion Paper	2018
Impact Assessment Agency of Canada	
Practitioner's Guide to Federal Impact Assessment under the Impact Assessment Act	2021
Government of Canada	
Canada's Arctic and Northern Policy Framework	2016
Pan-Canadian Framework on Clean Growth and Climate Change	2016
Canada's Pathway to Target 1 Report: One with Nature - a Renewed Approach to Freshwater and Land Conservation in Canada	2018
Government of Canada Green Bond Framework	2022
Indigenous Circle of Experts	
We Rise Together: Achieving Pathway to Canada Target 1 Through the Creation of Indigenous Protected and Conserved Areas in the Spirit and Practice of Reconciliation	2018

APPLICABILITY OF FEDERAL POLICIES TO BLUE CARBON

The reviewers found all documents analyzed to be applicable to blue carbon in some way. However, there was a spectrum of relevance, from explicit inclusion of the term “blue carbon” or “blue carbon ecosystems” at one end to a tangential (albeit still relevant) connection (WWF-Canada 2022) at the other. None of the documents analyzed provided comprehensive consideration of, or guidance for, blue carbon ecosystems, reinforcing the existence of a policy gap for blue carbon in Canada’s national policy regime.

Of the 34 documents reviewed, only four (Blue Economy Strategy Engagement Paper, Blue Economy Strategy What We Heard, Climate Science 2050: Advancing Science and Knowledge on Climate Change, and Canada’s 2030 Emissions Reduction Plan) explicitly used the term “blue carbon.” This is not particularly surprising as this term was coined in 2009 (Lovelock and Duarte 2019) and has only been recognized and used over the past few years. Several of the documents reviewed pertain to blue carbon ecosystems — such as wetlands, coastal salt marshes, sea grasses and kelp forests — without explicitly using the term. Other documents note habitat more broadly, and thus could apply to blue carbon habitats. Several of the documents note the significance of carbon-rich habitats to climate change; while they may give only terrestrial examples, these documents do recognize the need to protect and restore carbon-rich ecosystems to mitigate and adapt to climate change.

TIMEFRAME OF POLICIES

The policies analyzed span over three decades, from 1991 to 2022 (WWF-Canada 2022). It was assumed that any policy available on the Government of Canada website was current and in active use. However, it was difficult to assess the extent to which older documents are still guiding decision-making in Canada. Government policies released within a similar timeframe referred to each other, but more recent policies rarely referred explicitly to older ones, even when discussing a closely related subject. In contrast to these older documents, some of the newer documents are still in the discussion phase; the reviewers assumed that there would be opportunity to include blue carbon as they are developed.

JURISDICTION AND THE MARINE/TERRESTRIAL DIVIDE

Federal government departments divide responsibility for managing ecosystems, generally separating marine and terrestrial environments. As their policies generally follow suit, it is necessary to collaborate across jurisdictions to effectively manage blue carbon ecosystems. The administrative divide between federal government departments, and in particular the artificial divide in the management of coastal blue carbon habitats, complicate the discussion of how to better include blue carbon in Canada’s future policy landscape. Collaboration and coordination among multiple levels of government can improve policies and subsequent conservation of blue carbon ecosystems.

THEMES AND PRIORITIES COMMON TO NATIONAL POLICIES

The policy documents analyzed contained common themes and priorities relevant to blue carbon (WWF-Canada 2022). There was a recognition that we need the following:

- Indigenous perspectives on conservation efforts
- further understanding of critical ecosystems
- adaptation to and mitigation of climate-change impacts
- protection of critical habitats/ecosystems

These themes and priorities were found in multiple documents, but rarely did a single policy contain them all. For instance, many policies noted the need to protect important ecosystems, but did not discuss how ecosystem protection could support climate-change mitigation and/or adaptation. In fact, NCS more broadly were absent from most of the documents analyzed (WWF-Canada 2022).

OPPORTUNITIES TO BETTER INCORPORATE BLUE CARBON

Most of the policies reviewed by WWF-Canada (2022) referred to blue carbon ecosystems indirectly. Policies generally need to explicitly use specific terms for them to be considered fully in the decision-making process. Accordingly, relevant blue carbon policies should be updated to explicitly include the term “blue carbon” and identify its potential as an NCS.

The analysis raises several questions about how to move forward and ensure that blue carbon is adequately protected and managed. For instance, does Canada need a national policy framework specifically for blue carbon? Regardless of whether we have such a framework, how does Canada ensure that blue carbon is adequately considered across relevant policy frameworks and associated decision-making? How do mitigation measures to manage risks for blue carbon ecosystems link with efforts to accurately quantify and account for the spatial extent and carbon dynamics of these ecosystems? How can the Government of Canada and blue carbon practitioners meaningfully and respectfully incorporate Indigenous perspectives, knowledge, rights and leadership in blue carbon policy and management? These questions serve as the basis for additional research and collaboration that could inform a federal policy for blue carbon in Canada in the future.

RECOMMENDATIONS FOR FEDERAL POLICY

- ✓ In consultation and collaboration with Indigenous governments, federal agencies to review and potentially update relevant policies, regulations and legislation to include blue carbon.
- ✓ Implement principles of UNDRIP and the Truth and Reconciliation Commission's Calls to Action to support collaborative governance with Indigenous Nations and communities.
- ✓ Moving forward, ensure that all updated and novel relevant federal policies integrate considerations for blue carbon protection, climate-change mitigation and adaptation, and Indigenous-led conservation. All components are important.
- ✓ In the spirit of reciprocity, federal agencies to ensure that Indigenous Nations and communities can participate in government-to-government and nation-to-nation processes around blue carbon.
- ✓ Facilitate national-level and nation-to-nation discussions to determine federal policy needs and priorities for managing, protecting and restoring blue carbon.
- ✓ Add blue carbon to Canada's national GHG inventory once knowledge gaps are filled.
- ✓ Federal government to follow the Indigenous Circle of Experts' 2018 recommendations pertaining to Indigenous-led conservation and Indigenous Protected and Conserved Areas.
- ✓ Work effectively across jurisdictional divides with provincial, territorial and Indigenous governments to advance climate- and conservation-related initiatives (including blue carbon NCS) that span marine and terrestrial ecosystems.

SPATIAL PROTECTION TOOLS

Jessica Currie and Sarah Saunders

As blue carbon is a relatively new term, it rarely appears in federal legislation (WWF-Canada 2022). That said, several regulatory tools can be used to designate different types of protected and conserved areas in marine and coastal regions that contain blue carbon ecosystems (Table 2). Using the Oceans Act (1996), Fisheries and Oceans Canada (DFO) designates marine protected areas (MPAs) in estuarine, coastal and marine areas seaward of the low-water line. These MPAs can be created to protect fish habitat, habitat for at-risk species, unique habitats and areas of high biodiversity or biological productivity. Under the Fisheries Act (1985), DFO has powers to protect fish and fish habitat. Marine refuges have been created to protect fish habitat from the impacts of fishing in coastal and marine environments. An Ecologically Significant Areas (ESA) Framework (DFO 2022) is currently being developed to protect areas of fish and fish habitat that are sensitive, highly productive, rare, or unique by banning activities other than fishing. Productive coastal fish habitats often have high blue carbon value. Thus, while ESA designation may not be driven by climate considerations, this tool could have indirect benefits. Parks Canada has a mandate to protect and conserve representative examples of Canada's natural and cultural heritage. National Parks created through the Canada National Parks Act (2002) can sometimes include “submerged lands” that are underwater at high tide. The Canada National Marine Conservation Areas Act (2002) allows for the creation of National Marine Conservation Areas in any estuarine, coastal or marine environment. Environment and Climate Change Canada (ECCC) has the mandate to conserve and protect marine wildlife, especially migratory birds and species at risk and their habitat, and can create Migratory Bird Sanctuaries in both terrestrial and marine environments by virtue of the Migratory Birds Convention Act (1994). ECCC can also use the Canada Wildlife Act (1985) to create National Wildlife Areas on land and up to 12 nautical miles from shore, and marine National Wildlife Areas from 12 to 200 nautical miles from shore.

Table 2. Examples of regulatory tools and associated site types contributing to Canada's marine protected and conserved areas targets. Data retrieved from Fisheries and Oceans Canada (2023).

Act | Type	Count	Area (km²)	Coverage (% Protected)
Fisheries Act: Marine Refuge	35	327,340	5.62
Migratory Birds Convention Act: Migratory Bird Sanctuary	49	13,992	0.21
Canada National Marine Conservation Areas Act: National Marine Conservation Area	3	112,746	1.98
Canada National Parks Act: National Park	13	9,232	0.14
Canada Wildlife Act: National Wildlife Area	12	17,213	0.3
Oceans Act: Marine Protected Area	14	351,516	6.11

© Mike Ambach / WWF

INDIGENOUS MARINE PROTECTED AND CONSERVED AREAS

Historically in Canada, establishing protected areas has led to the violation of Indigenous rights, including the forced displacement of Indigenous Peoples and associated livelihood restrictions (Binnema and Niemi 2006; Sandlos 2008; Stevens 2014). However, there is growing recognition that Indigenous participation, leadership and consent is needed in establishing protected and conserved areas; these factors are essential to successful, ethical implementation and long-term management (ICE 2018). In fact, Canada is legally required to include Indigenous Peoples and respect Indigenous rights in Marine Protected and Conserved Area governance. This requirement stems from a number of sources: the recognition and affirmation of Indigenous rights set out in Section 35 of the Constitution Act, 1982; the recent federal legislation on implementing the United National Declaration for the Rights of Indigenous Peoples (UNDRIP 2021); and the Truth and Reconciliation Commission's Calls to Action. Additional reports, such as the Indigenous Circle of Experts' (2018) *We Rise Together*, reinforce the critical role of Indigenous Peoples in thoughtfully protecting and managing nature over time. Accordingly, the way marine protected and conserved areas are established needs to be rapidly transformed. A shift to collaborative decision-making and co-governance structures that elevate Indigenous rights, knowledge and priorities will be critical. The Final Report of the National Advisory Panel on Marine Protected Area Standards, submitted to the Minister of Fisheries, Oceans and the Canadian Coast Guard, includes similar recommendations, and expands upon the need for legislative changes and long-term funding to support Indigenous-led conservation. Despite this, transformation in the governance of protected areas is still in its infancy.

To effectively conserve ecosystem carbon and wildlife in Canada, we need to recognize lessons and leadership from Indigenous Peoples, who have been caring for healthy and resilient habitats, societies and interspecies relationships for millennia. Specifically, Indigenous Protected and Conserved Areas (IPCAs) have emerged as a means for Indigenous Peoples to advance their priorities in their territories. IPCAs comprise "lands and waters where Indigenous governments have the primary role in protecting and conserving ecosystems through Indigenous laws, governance and knowledge systems" (ICE 2018). They have the potential to simultaneously advance reconciliation and address environmental crises (Reed *et al.* 2021).

Indigenous governance and knowledge systems have emerged as an important issue for protected and conserved areas in Canada (Dietz *et al.* 2021), yet barriers to the establishment, recognition and governance of IPCAs remain. An analysis by Warrior, Fanning and Metaxas (2022) identifies the following barriers to MPA establishment in the Eastern Shore Islands, Nova Scotia: systemic challenges (i.e., pertaining to the organization of the governing system), and limited understanding and clarity of Mi'kmaq culture, governance and rights, including potential fisheries conflicts. It will be vital to address these and other barriers to advance marine IPCAs and to decolonize conservation approaches in Canada.

MUSQUASH ESTUARY MARINE PROTECTED AREA CASE STUDY

It has been estimated that since 1604, more than 85 per cent of the salt marshes in the Bay of Fundy have been lost through diking and causeway construction (Ganong 1903). The Musquash Estuary, located 20 km southwest of Saint John, New Brunswick — a heavily industrialized region — is the largest remaining intact salt marsh estuary in the Bay of Fundy. This productive habitat is home to a diversity of birds, mammals, fish, invertebrates and marine plants. Because of jurisdictional complexity, a variety of tools and agreements were needed to protect this ecologically important area. In 2006, the Musquash Estuary MPA was designated by DFO under the Oceans Act (DFO 2008; DFO 2019b). The 7 km^2 MPA aims to maintain biodiversity and safeguard habitat, including the physical and chemical properties of the ecosystem. As the Oceans Act applies only seaward of low tide, additional measures were needed to protect the intertidal zone — an important coastal salt marsh zone that is exposed to air at low tide and underwater at high tide. Accordingly, much of this area — referred to as the Administered Intertidal Area (AIA) — was transferred from the Province of New Brunswick to DFO via an agreement. The New Brunswick Coastal Areas Protection Policy, the New Brunswick Trespass Act and the Fisheries Act are collectively used to manage the AIA in a manner consistent with the MPA (DFO 2023). Protections also extend beyond the MPA and AIA through the establishment of conservation areas by non-government organizations such as the Nature Conservancy of Canada.

CHALLENGES TO APPLYING SPATIAL PROTECTION TOOLS

While we have tools that can protect blue carbon ecosystems, barriers to effective protection remain, such as a need to prioritize conservation values (Lemieux *et al.* 2019) and overlapping jurisdiction (i.e., competing priorities; Hewson *et al.* 2020). Given the variability in carbon sequestration within and among blue carbon habitats (Macreadie *et al.* 2019), it can be challenging to identify the most valuable sites for protection. In addition, protections often aim to safeguard biodiversity. This means that carbon sequestration is only a secondary benefit of establishing and managing protected areas. There are also limits to what protected areas can achieve. While they can reduce or eliminate local stressors on blue carbon ecosystems, they cannot necessarily protect against larger-scale threats, such as climate-change or water-quality issues that originate outside the boundaries of the protected area (Hoffman 2022). Despite these challenges, protected and conserved areas can be used to protect blue carbon ecosystems against specific threats and stressors and can also be deployed together as interconnected spaces to safeguard important habitats.

RECOMMENDATIONS FOR SPATIAL PROTECTION TOOLS

- ✓ Ensure that climate-change mitigation and adaptation are included in legislation and prioritization for spatial protection.
- ✓ Support Indigenous-led marine and coastal conservation initiatives, including Indigenous-led marine IPCAs or MPAs.
- ✓ Integrate the restoration and protection of blue carbon ecosystems in the prioritization, design and management of current and future MPAs.
- ✓ Support (e.g., provide funding and capacity where appropriate) Indigenous-led blue carbon mapping efforts.
- ✓ Support and build partnerships with coastal Indigenous Guardians programs in ways that advance their priorities and initiatives (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities).

© Lewis Jefferies / WWF-UK

PROVINCIAL POLICY AND LEGISLATION

BRITISH COLUMBIA

Brianne Kelly

In 2020, West Coast Environmental Law (WCEL) published an analysis of provincial policy and legislation in British Columbia through a blue carbon lens (Carlson 2020). The report explores current regulatory tools and evaluates their applicability to blue carbon ecosystems (Table 3). In general, Carlson (2020) found that **fragmentated planning at the provincial level leaves blue carbon ecosystems vulnerable to degradation.**

Table 3. Summary of the findings from the Carlson (2020) analysis of provincial legislation and its applicability to blue carbon management in British Columbia.

Provincial legal tool	Applicability to blue carbon management
Land Act, Land Title Act	No requirement to consider management of blue carbon on provincial Crown aquatic lands.
B.C. Wildlife Act	No direct mandate, but blue carbon management could fall under third-party activities included in management plans.
B.C. Park Act, Protected Areas of British Columbia Act, Ecological Reserve Act, Environment and Land Use Act	Do not include managing carbon sinks or sources.
B.C. Environmental Assessment Act	Blue carbon is not included in provincial environmental assessments. However, as carbon sinks, blue carbon ecosystems could be considered in the assessments.
Climate Change Accountability Act	Blue carbon is not included in the province's GHG reporting.

Carlson (2020) also discusses Indigenous law and jurisdiction in relation to blue carbon. Coastal ecosystems in British Columbia (and across Canada) are subject to Indigenous law, and the rights and title of Indigenous Peoples in Canada are constitutionally protected. With respect to blue carbon, Indigenous title and rights could be realized in a variety of ways. For example, Carlson (2020) highlights the possibility of Indigenous ownership of blue carbon rights, whereby Indigenous governments negotiate government-to-government with the province for carbon-credit ownership. This would be similar to the process that resulted in Atmospheric Benefit Sharing Agreements between the province of British Columbia and multiple First Nations for forest-based carbon credits in the Great Bear Rainforest. Blue carbon can also be integrated into Indigenous-led planning and management processes, such as the Marine Plan Partnership for the Pacific North Coast (MaPP) process. In Carlson's words (2020):

> "As illustrated through the MaPP process, ecosystem-based management can be more fully realized by weaving together Indigenous knowledge and western science. Blue carbon research, with its relatively broad spatial and temporal scope, and its questions about ecosystem health and persistence, may also help direct Western thinking towards appreciating and learning from the refined management of the land and water by Indigenous Peoples in BC, founded on precise observations, deep understanding of ecosystem relationships, and long timeframes."

RECOMMENDATIONS FOR BRITISH COLUMBIA

The following points summarize Carlson's key recommendations (2020):

- ✓ Increase provincial support for blue carbon research.
- ✓ Create a provincial framework for decision-making for coastal regions and ecosystems.
- ✓ Develop partnerships among governments to facilitate government-to-government agreements for sustainable blue carbon management.
- ✓ Integrate blue carbon management and monitoring into provincial strategies for mitigating and adapting to climate change.
- ✓ Incentivize NCS for coastal and land-use management while also respecting United Nations Declaration on the Rights of Indigenous Peoples.

ATLANTIC PROVINCES

Mike Kofahl

Blue carbon ecosystems, and the blue carbon sequestration function that they provide, are not explicitly recognized in the law and policy of any of the Atlantic provinces (New Brunswick, Newfoundland and Labrador, Nova Scotia and Prince Edward Island). Many of the environmental laws and policies in the Atlantic provinces that currently provide pathways to steward or protect specific types of blue carbon ecosystems (i.e., salt marshes or seagrass meadows) were not designed to recognize the carbon stock and sequestration function of these ecosystems. While carbon sequestration is recognized as a wetland function more broadly, it is not mentioned as a function of seagrass meadows in any provincial law or policy, despite recognition of seagrass as a blue carbon ecosystem by the IPCC.

Protected and Conserved Areas

Many provincial laws in the Atlantic region provide general opportunities to conserve, manage or protect habitats and ecosystems, and could be applied to blue carbon ecosystems. Legal mechanisms used to protect and conserve areas include provincial parks, nature or ecological reserves, wilderness areas, protected beaches and protected areas. However, the laws that enable these conservation mechanisms are generally focused on conserving species, habitats or ecosystems that are "threatened," "unique," "rare," "endangered," "uncommon" or "representative." For example, the New Brunswick Protected Natural Areas Act can be used to protect "unique" or "ecologically sensitive areas." The Newfoundland and Labrador Wilderness and Ecological Reserves Act is designed to set aside areas containing "representative" or "unique" ecosystems. The Nova Scotia Wilderness Areas Protection Act is meant to protect "unique," "rare" and "vulnerable" natural features. The Prince Edward Island Natural Areas Protection Act is used to preserve lands that contain "habitat of rare, endangered, or uncommon plants and animals." However, since these categories don't apply to blue carbon ecosystems, it is difficult to use these conservation mechanisms to steward blue carbon ecosystems. And because provincial policies currently do not explicitly recognize the carbon value of coastal ecosystems, blue carbon is not a conservation priority.

With the exception of Nova Scotia, the Atlantic provinces lack a coordinated intra-provincial approach to stewarding protected areas that may include blue carbon ecosystems. This is partially due to jurisdictional complexity along coastlines that results in siloed approaches taken by government departments (WWF-Canada 2022). Only Nova Scotia has attempted to coordinate conservation, stewardship, and protection priorities and management plans for existing and potential protected areas (e.g., Government of Nova Scotia 2013).

Provincial Policies and Regulations for Salt Marsh and Seagrass Protection

In Atlantic Canada, existing legislation provides greater protection to salt marshes than to seagrasses. In addition to the Federal Policy on Wetland Conservation, which is administered by Environment and Climate Change Canada and stresses the need for federal-provincial-territorial cooperation to conserve and restore wetlands, all four provinces have applicable wetland policies (Table 4).

Table 4. Atlantic Canadian Wetlands Policies[22]

Province	Wetlands Policy	Responsible Authority	Policy Objective(s)
New Brunswick	New Brunswick Wetlands Conservation Policy	Department of Environment and Local Government	To manage human activity on or near wetlands in a manner that will achieve no loss of Provincially Significant Wetland habitat and no net loss of wetland function for all other wetlands. To promote and facilitate the development of wetland stewardship, awareness and education through government initiatives and cooperative relationships with local citizens, private sector stakeholders, and municipal, provincial and federal governments.
Newfoundland and Labrador	Policy for Development in Wetlands	Department of Environment and Climate Change	This policy will establish the criteria for issuing a permit under Section 48 of the Water Resources Act, SNL 2002 cW-4.011, for all development activities in and affecting wetlands. The policy's objective is to permit developments in wetlands that do not adversely affect the water quantity, water quality, hydrologic characteristics or functions, and terrestrial and aquatic habitats of the wetlands.

---

[22] Table reproduced in part and modified from Emily Austen and Alan Hanson (2007), "An Analysis of Wetland Policy in Atlantic Canada," *Canadian Water Resources Journal*, 32:3, pages 168–69.

Province	Wetlands Policy	Responsible Authority	Policy Objective(s)
Nova Scotia	Nova Scotia Wetlands Conservation Policy	Department of Environment and Climate Change	To manage human activity in or near wetlands, with the goal of no loss in Wetlands of Special Significance and the goal of preventing net loss in area and function for other wetlands. To promote wetland protection and stewardship and to increase awareness of the importance of wetlands in the landscape. To promote a long-term net gain in wetland types that have experienced high historic losses, in order to restore beneficial ecosystem services and functions across the province. To encourage the use of buffers to protect the integrity of wetlands adjacent to development (i.e., residential, commercial, industrial) and agricultural, mining and forestry operations.
Prince Edward Island	A Wetland Conservation Policy for Prince Edward Island	Department of Environment, Energy, and Climate Action	To promote the conservation and protection of Prince Edward Island's wetlands to sustain their ecological and socioeconomic functions, now and in the future.

Three of the four provinces prohibit alteration or disturbance of wetlands without government approval and have provincial wetland-conservation policies. Newfoundland and Labrador is the outlier in this respect. Furthermore, all the provinces except Prince Edward Island require a project that will impact two or more hectares of wetland to undergo a provincial environmental assessment or environmental impact assessment. Provincial wetland-conservation policies (in Newfoundland, a development policy) dictate how government decision-makers should act when making decisions that affect wetlands; however, the policies afford discretion to decision-makers even where conservation of wetlands is a priority.

In some of the Atlantic provinces, wetland protection is limited by an approach to conservation that seems drawn from the Federal Wetlands Policy. The federal policy takes a three-tiered approach to wetlands conservation: avoidance of wetlands when possible, minimization of impacts when avoidance is not possible, and compensation for losses of existing wetland. The primary challenge with respect to the third option (compensation) is that salt marshes are not readily or quickly compensable: the carbon that is stored in the subsoil of these ecosystems accumulates over decades or centuries, and when disturbed, it can be permanently released. Although each of the Atlantic provinces has a wetlands inventory, these inventories are outdated. This makes it difficult to monitor goals for conserving wetlands, and therefore salt marshes.

The Atlantic provinces offer less protection to seagrass meadows than to salt marshes, given that provincial jurisdiction effectively ends at the low water mark.[23] Consequently, seagrass meadows generally fall under the purview of federal jurisdiction (see the Federal Blue Carbon Policy in Canada and Spatial Protection Tools chapters of this report). Nevertheless, they may also be protected indirectly under general provincial mechanisms to protect "coastal" species or habitat. For example, in New Brunswick, under the Clean Environment Act, the responsible minister can protect coastal areas, defined generally as the environment between the low-water mark and one kilometre to the landward side of the high-water mark. Similar protections are available in Newfoundland and Labrador for shore water zones, and will be available in Nova Scotia for that part of its coast that lies within a prescribed "Coastal Protection Zone" once its Coastal Protection Act comes into force.

Part of the difficulty of protecting seagrass meadows is that provincial jurisdiction ends at the low-water mark. Generally, marine areas seaward of that mark are under federal jurisdiction. This means that seagrass meadows in Atlantic Canada will likely need to be protected using federal law and policy.

---

23. Jurisdiction is connected to territory that provinces held at the time of Confederation. The boundaries of both Nova Scotia and New Brunswick at the time of Confederation are still unclear, and each province may have a claim to jurisdiction over parts of the Bay of Fundy. See Gerald V. La Forest, "Canadian Inland Waters of the Atlantic Provinces and the Bay of Fundy Incident" (1963) 1 Can. Y.B. Int'l Law 149 at pages 150-156; see also Meinhard Doelle *et al*, "The Regulation of Tidal Energy Development off Nova Scotia: Navigating Foggy Waters" UNB LJ volume 55 at pages 40–41.

Additional Tools for Blue Carbon Management and Protection

Protected and conserved areas and wetland-specific legislation are important tools for protecting blue carbon. Further review of legislation and policy in the four Atlantic Canadian provinces identifies three broad-scale legislative categories that we could potentially use to steward or protect blue carbon ecosystems: environmental assessments, aquaculture and wildlife.

Environmental Assessments

In Atlantic Canada, no project is required to undergo an environmental assessment (Newfoundland and Labrador and Nova Scotia) or an environmental impact assessment (New Brunswick and Prince Edward Island) for the sole reason that it impacts a blue carbon ecosystem. The same is true for impact assessments under the federal Impact Assessment Act. In their current forms, the assessment requirements for projects in each of the four Atlantic provinces do not require assessment of the impacts of activities on blue carbon or the ability of blue carbon ecosystems to sequester carbon.

Aquaculture

Provincial aquaculture legislation and policy in New Brunswick, Newfoundland and Labrador, and Nova Scotia (and federal legislation for Prince Edward Island) cannot be applied to steward or protect blue carbon ecosystems. The existing regimes deal primarily with aquaculture site leases and licensing, as well as fish health. They do not require assessment of aquaculture impacts on their ecosystems — such as excess waste and nutrient build-up that could harm the integrity and efficiency of blue carbon ecosystems.

Wildlife

Species-at-risk laws in Atlantic Canada are meant to protect species and their specific habitat rather than broad ecosystems. This prevents this type of legislation from being an effective tool to specifically manage and protect blue carbon ecosystems. The Atlantic provinces' "wildlife" legislation does not protect plant species present in salt marshes or seagrass meadows unless these are listed as "Species at Risk." Like species-at-risk legislation, wildlife-protection legislation is usually focused on individual species and their habitats rather than taking a broader ecosystem approach. Provincial parks are generally designed to be areas of the province that are protected, but still used by the public for recreational activities. In contrast, laws that create wilderness or nature areas are more focused on an ecosystem approach rather than on specific species or habitat.

Through its provincial protected areas policy, Nova Scotia coordinates species and habitat protections. This may be an effective way to establish stewardship and conservation priorities, especially since multiple government departments and agencies are often responsible for legislation or policy that may apply to blue carbon ecosystems. Provincial policy or strategy should take an ecosystem approach to conservation and set out priorities for types of ecosystems that should be protected.

RECOMMENDATIONS FOR THE ATLANTIC PROVINCES

The Atlantic provinces neither recognize the importance of blue carbon ecosystem function nor prioritize their explicit protection within relevant legislation and policies. Atlantic Canadian laws and policies should identify the unique ability of blue carbon ecosystems to sequester carbon and prioritize the stewardship of these ecosystems specifically.

- ✓ In collaboration with Indigenous Nations and communities, revise provincial impact-assessment legislation or policy to consider the implications for climate-change mitigation and adaptation if blue carbon ecosystems are disrupted, altered or destroyed.
- ✓ In collaboration with Indigenous Nations and communities, design blue carbon conservation policies or update existing policies relevant to blue carbon to include considerations and priorities for blue carbon for each province.
- ✓ Explicitly protect blue carbon ecosystems in applicable law or policy to recognize and elevate the importance of these ecosystems.

ARCTIC POLICY AND LEGISLATION

Kate Darling, Steph Meakin and Alex Kerr

This chapter contributes an Arctic perspective on the evolving science, laws, policies and strategies that may be employed to support blue carbon protection and sequestration in Canada. It draws on available literature and data to describe the characteristics of and conditions facing blue carbon ecosystems along Canada's northernmost coastlines, including federal, provincial and territorial laws, regulations and policy measures in Yukon, Northwest Territories, Nunavut, Quebec, Manitoba and Ontario. While in some cases these laws and policies reflect treaties and Indigenous rights, this chapter does not explicitly analyze how existing Indigenous rights, governance structures and environmental-management frameworks are being or could be used to support blue carbon ecosystems. A focused study of these frameworks is fundamental to any discussion about recognizing and supporting blue carbon ecosystems in this region. Local Inuit, First Nations and Métis communities are uniquely placed to understand the locations, status and holistic value of blue carbon ecosystems.

THE REGION

In the Arctic, marine and freshwater ecosystems across Inuit Nunangat and southern Hudson and James Bays represent a notable percentage of global blue carbon. Together, the Inuvialuit Settlement Region, Nunavut, Nunavik and Nunatsiavut make up more than 40 per cent of Canada's landmass and 72 per cent of Canada's coastline. Because of this extensive coastline and a number of other factors — knowledgeable Indigenous and other local communities, comparatively lower levels of coastal industrial development, and a distinctive regulatory and rights frameworks — the Arctic presents a unique opportunity to advance blue carbon sequestration.

Challenges are posed by the fact that blue carbon terminology is in its infancy, and blue carbon ecosystems cross boundaries. In addition, exploring the legislative tools applicable to Canada's Arctic requires inquiry into the intergovernmental, legislative and policy frameworks of 15 variously overlapping jurisdictions. These include the four Inuit regions of Inuit Nunangat recognized through the five Inuit-Crown treaties negotiated between 1975 and 2005: the Inuvialuit Final Agreement, the Nunavut Agreement, the James Bay and Northern Quebec Agreement, the Nunavik Inuit Land Claims Agreement, and the Labrador Inuit Land Claims Agreement, along with the much earlier Treaty 5 in Northern Manitoba and Treaty 9 in Northern Ontario. Finally, these include the political jurisdictions of Canada, Yukon, Northwest Territories, Nunavut, Manitoba, Ontario, Quebec, and Newfoundland and Labrador.

BLUE CARBON LEGISLATION AND POLICY

In Canada, blue carbon sequestration remains an underdeveloped aspect of national, provincial, territorial and municipal strategies to mitigate climate change. While regulatory tools exist to support blue carbon initiatives, protections rely heavily on safeguarding habitat for protected fish, migratory birds and species at risk (e.g., Fisheries Act, Migratory Bird Convention Act, Species at Risk Act). These indirect measures do not account for additional ecosystem services that blue carbon habitats provide, such as climate-change mitigation and adaptation, as well as food security. In other words, blue carbon ecosystems in the Arctic are not assigned explicit value and therefore lack safeguards for their climate-change contribution or mitigation potential (Darling *et al.* 2023; Table 5).

Thanks to early conservation efforts and long-term stewardship by Inuit communities, large parks, marine protected areas and migratory bird sanctuaries line Arctic coastlines and indirectly protect the blue carbon ecosystems they contain. Migratory bird sanctuaries in particular span the terrestrial-marine divide, reflecting the habitat on which migratory birds rely. Protected under law, these spaces present an opportunity to explicitly integrate blue carbon as a valued component and objective of conservation for both biodiversity and climate change.

Table 5. Applicable Arctic blue carbon legislation, policies and measures reviewed.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Federal	**21**	Canada Impact Assessment Act	This may provide an avenue to support Indigenous and other jurisdictions in preparing project-specific studies relating to impacts on blue carbon ecosystems that can then form part of an impact assessment. Strategic and regional assessments are tools that can be used to incorporate considerations about blue carbon ecosystems into impact assessment and other review processes.
		Canada Fisheries Act	At the federal level, due to its scope of application and purposes, the Canada Fisheries Act is central to any discussion about blue carbon sequestration. - The 2019 Policy Statement lists habitat degradation, including the impairment of ecological functions, and modification among interrelated factors that threaten fish habitat. This would present an opportunity to identify blue carbon sequestration as an ecological function, which could open the door for protecting marine plants uniquely for those functions. - Bill C-68 gave the Fisheries Act the authority to designate "ecologically significant areas"; however, regulations establishing such an area have not been promulgated. Additional steps may be required for this authority to prove effective in blue carbon protection.
		Fishery (General) Regulations and pursuant acts and regulations	Of limited utility for protecting blue carbon ecosystems as they do not refer to habitat, plants or blue carbon.
		Canada Aquatic Invasive Species Regulations	The regulatory framework for aquatic invasive species does not currently target aquatic plants, but this could be changed through legislative amendment and ministerial discretion.
		Arctic Waters Pollution Prevention Act	While this act may have a general positive impact on blue carbon ecosystems, it does not support them in a targeted way.
		Canada National Marine Conservation Areas Act	The NMCA Act authorizes the establishment of National Marine Conservation Areas by order of the Governor in Council. Located in Lancaster Sound, Nunavut, the Tallurutiup Imanga NMCA is the only NMCA discussed in this paper. In 2021, Canada committed to establishing 10 new marine and four new freshwater NMCAs over the next five years. This could be an opportune time to identify blue carbon ecosystems as areas worthy of designation as NMCAs.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Federal		Canada National Parks Act	The act does have potential for protecting blue carbon ecosystems, particularly in the larger park areas established in the Arctic and northern regions. A number of the National Parks listed in Schedule 1 of the act abut the Arctic coastline, beginning at the ordinary low-water mark and expanding inland. Through designation and regulation, these tidal areas could be subject to specific blue carbon protections.
		Canada Wildlife Act	As with other legislation, a link between a blue carbon ecosystem and habitat for a protected species must be established before protections can be activated.
		Oceans Act	One of the act's objectives is to promote the wide application of the precautionary approach to conserving, managing and exploiting marine resources in order to protect these resources and preserve the marine environment. MPAs are a key avenue for protecting blue carbon ecosystems for two reasons: they apply to marine environments where seaweed grows, and they don't require establishing a habitat link to a protected species.
		Species at Risk Act	SARA defines wildlife species as a "species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature." If a plant in a blue carbon ecosystem is listed in the Schedule, the act protects it directly rather than merely through its role as habitat provider. Under SARA, critical habitat that belongs to any listed endangered or threatened species is also protected from destruction on federal lands, within the Exclusive Economic Zone (EEZ) or on the continental shelf, where the species is listed as aquatic, or where it is a migratory bird sanctuary.
		Migratory Bird Convention Act	Migratory Bird Sanctuaries (MBS) offer a potential model for protecting blue carbon as habitat in intertidal and interjurisdictional areas in the Arctic.
		Blue Carbon in Canada: A Federal Policy Review	This review of blue carbon legislation and policy covers an extensive cross section of documents from Fisheries and Oceans Canada, Environment and Climate Change Canada, Infrastructure Canada, Transport Canada, Impact Assessment Agency of Canada, Government of Canada, and the Indigenous Circle of Experts.
		Inuit Nunangat Declaration, Inuit Nunangat Policy and Inuit-Crown Guidance	While not immediately relevant to blue carbon sequestration, the declaration encourages the joint development of policies, strategies and guidance in a range of spaces, including the marine environment. For any initiative relating to blue carbon ecosystems in Inuit Nunangat, Inuit will play a key role. It will be important to keep an eye open for further guidance documents and strategies from the ICPC in the coming years, particularly regarding the environment and climate change.
Federal		Government of Canada Guidance for Recognizing Marine Other Effective Area-Based Conservation Measures (2022)	As the 2022 OECM Guidance notes, "OECMs may be used to protect areas important for carbon sequestration and provide other adaptation and mitigation benefits as part of a nature-based solution to climate-change impacts." The guidance recognizes that support for climate-change adaptation and mitigation, including carbon sequestration, benefits biodiversity conservation. Blue carbon ecosystems could satisfy the "benefit for an important habitat" criterion.
Yukon	**19**	Yukon Environmental and Socio-economic Assessment Act	The categories evaluated do not exclude blue carbon ecosystems. However, neither these categories nor the regulations refer to climate-change mitigation or carbon sequestration specifically. Unless a decision-maker is already well versed in the potential of blue carbon sequestration, there is no guarantee that this factor would be considered. Two tools may be used to incorporate blue carbon ecosystems into impact assessment: regional land-use plans and mitigative measures.
		Yukon Act (Canada)	Most relevant to blue carbon ecosystems is the Yukon Legislature's power to make laws related to the conservation of wildlife and its habitat, as wells as waters, including the deposit of waste in those waters. However, this power does not extend to federal conservation areas. This exclusion does affect blue carbon initiatives as Ivvavik National Park, a federal conservation area under the Yukon Act, encompasses the western half of the Yukon coastline. Initiatives regarding blue carbon ecosystems in Yukon will require cooperation between the federal, territorial and Inuit governing organizations at minimum.
		Yukon Waters Act and Waters Regulation	The act and regulations provide for careful treatment of drainages into the Beaufort Sea, where blue carbon ecosystems are found. However, the protections afforded are general in nature and do not require specific evaluation of blue carbon impacts.
		Parks and Land Certainty Act	Like the National Parks Act, this statute provides protection tools that could be applied to blue carbon ecosystems. Blue carbon ecosystems could fit within the following categories: an ecological reserve, a natural environment park or a wilderness preserve. The Commissioner in Executive Council has broad authority to make regulations and could provide robust protections at least to the low-water mark on the coast of the Beaufort Sea.
		Herschel Island Park Regulations	The plan does not specifically refer to any key blue carbon concepts. However, it provides fairly broad protections benefitting the entire area of Herschel Island and all of the flora and fauna that live there. Though not specifically protected, blue carbon ecosystems could be characterized as incidental beneficiaries. Given the collaborative management-planning processes and research structures, Herschel Island may also provide opportunities for research and monitoring.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Yukon		Yukon Wildlife Act and Regulations	Under the regulations, Ts'alwnjik Chu - Nordenskiold Wetland Habitat Protection Area has been designated. However, no such areas have been established in a blue carbon ecosystem zone. As with the fishery and conservation statutes discussed above, protection under this act is limited to the role of blue carbon ecosystems as habitat or incidental residents of areas critical to protected species.
		Withdrawal from Disposition of Certain Yukon Oil and Gas Lands (Yukon North Slope) Order, Prohibition of Entry on Certain Lands (Yukon North Slope) Order, and Withdrawal of Certain Lands from Disposal (Yukon North Slope) Order	Provides general protection from industrial interference in this area.
		Draft Policy for the Stewardship of Yukon's Wetlands	The draft policy lists carbon storage and release as functions of wetlands, and notes that wetlands can address atmospheric carbon and climate change. These factors could result in special consideration for wetlands during planning processes and environmental assessments. However, the criteria used to assess a potential wetland do not include carbon-sequestration potential. This policy's priorities are to contribute to biodiversity and critical habitat, as well as to the social and cultural well-being of Yukon First Nations.
		Our Clean Future: A Yukon strategy for Climate Change, Energy and a Green Economy	Although the strategy does not currently mention blue carbon, an engagement process in the future would be an opportunity to incorporate key blue carbon concepts.
		Ecosystems of the Yukon Arctic Region: A Guide to Identification	Suggests the Yukon Arctic region is important data gap that may hinder blue carbon ecosystem knowledge and support initiatives. There are research opportunities in the region.
		Management Plan for Yukon Amphibians	This could overlap with efforts to protect blue carbon ecosystems through wetlands; initiatives could be used to manage blue carbon ecosystems as well.
Northwest Territories	23	NWT Wildlife Act	The act is centred around the conservation of wildlife. Blue carbon ecosystems are protected only indirectly, when their terrestrial or amphibian inhabitants receive protection.
		NWT Waters Act and NWT Waters Regulations	This act applies a system of thresholds, use types, licences and prohibitions to the use of waters and the deposit of waste in waters. This system could impact blue carbon ecosystems along the coasts of the Beaufort Sea and Arctic Oceans, and so they would be subject to the protections under the act.
		NWT Territorial Parks Act and NWT Territorial Parks Regulations	Most likely to be relevant to protecting blue carbon ecosystems, Cultural Conservation Areas "may be developed to protect the culturally significant site or landscape, and industrial activity may be prohibited." However, beyond establishing authorities for area-based protections, this act does not specifically address factors that may threaten blue carbon ecosystems, and does not refer to key blue carbon concepts.
		Anguniaqvia niqiqyuam Marine Protected Areas Regulations (ANMPA Regulations)	Not investigated, but relevant.
		NWT Migratory Bird Sanctuaries (Canada)	Sanctuaries protect blue carbon ecosystems indirectly by virtue of the migratory birds that use them.
		Statement of Environmental Values	The SEV incorporates the principles laid out in the NWT Environmental Rights Act (ERA), including those identified as relevant to blue carbon ecosystems (precautionary principle, polluter pay, intergenerational equity and ecological sustainability).
		Land Use Planning, Protected and Conserved Areas	There are currently no references to marine coasts, plants, habitat or any other key blue carbon concepts. As these new frameworks develop, it may be an opportune time to incorporate blue carbon concepts, which have been largely invisible to date in law and policy.
		2030 NWT Climate Change Strategic Framework & 2019–2023 Climate Change Action Plan (2019)	The Action Plan identifies the following as both a goal and an action item: determining the potential value of natural carbon sinks and undertaking work to estimate carbon stored in NWT ecosystems. However, the only reference to sequestration potential in the NWT Climate Change Strategy relates to forests.
		NWT Environmental Protection Act	The NWT EPA prohibits the discharge of contaminants into the "environment," subject to a list of exceptions. This would encompass any blue carbon ecosystem within NWT, arguably regardless of its onshore/offshore location. General protection is offered by actions taken under this act to deter the deposit of deleterious substances into locales where blue carbon ecosystems might be found. However, the broad exemption authority and lack of any reference to blue carbon ecosystems as a valued component of the NWT environment weaken even this amount of protection. The act does not directly refer to key blue carbon concepts.
		NWT Protected Areas Act	The act offers broad coverage of environmental components and systems thanks to inclusive terms. These terms are broad enough to include blue carbon ecosystems. Currently, none of protected areas covers blue carbon lands. However, the act's tools could be used, subject to the Inuvialuit Final Agreement, to create a layer of protection for these ecosystems.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Nunavut	**13**	Nunavut Territorial Parks Act and Nunavut Territorial Parks Regulations	Though centred on human experience, Natural Environment Recreation Parks are likely most relevant to blue carbon ecosystem protection. These parks are designed to preserve the natural environment in those parks for the benefit, education and enjoyment of the public. Beyond establishing authorities for area-based protections, the Nunavut TPA and the TP Regulations do not refer to key blue carbon concepts or specifically address factors that may threaten blue carbon ecosystems.
		Nunavut Wildlife Act	This act does not apply to marine plants, as defined in section 47 of the Fisheries Act (all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae and phytoplankton). This means that marine plants that form blue carbon ecosystems will be protected only by virtue of the habitats these ecosystems provide.
		Nunavut Conservation Areas Regulations	Where blue carbon ecosystems overlap with Conservation Areas — and perhaps form part of the habitat — they will receive protections that cover critical habitat.
		Nunavut Land Use Planning	There is no reference to blue carbon or sequestration. However, the Draft Land Use Plan indicates three land-use designations: Limited Use Areas, Conditional Use Areas and Mixed-Use Areas. The first two provide the kinds of protections that might benefit blue carbon ecosystems.
		Nunavut Migratory Bird Sanctuaries (Canada)	Sanctuaries protect blue carbon ecosystems indirectly by virtue of the migratory birds that use them.
		"Nunavut" Fisheries Regulations	Although the Nunavut Agreement came into effect in 1993 and Nunavut was established in 1999, Nunavut fisheries are still managed under the Northwest Territories Fishery Regulations. Though this engagement process is now closed, the "Nunavut" Fisheries Regulations may present an opportunity to incorporate some of the holistic elements seen in the Wildlife Act to marine plants as vital blue carbon resources.
		Nunavut Environmental Protection Act	The act does not refer directly to key blue carbon concepts. However, environment is defined broadly and encompasses any blue carbon ecosystem within Nunavut, arguably regardless of its onshore/offshore location. General protection is offered by actions taken under this act to deter the deposit of deleterious substances into locales where blue carbon ecosystems might be found. However, the broad exemption authority and lack of any reference to blue carbon ecosystems as a valued component of the Nunavut environment weaken even this amount of protection.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Manitoba	**11**	Manitoba Provincial Parks Act and Manitoba Park Parks Designation Regulations	Currently no provincial park borders Hudson Bay. However, the "wilderness park" designations with strategically placed wilderness land-use categories could be considered as a tool for blue carbon sequestration adjacent to the Wapusk National Park. Beyond environment and water, the act does not refer to key blue carbon concepts.
		Endangered Species and Ecosystems Act and Regulations	The orientation of this act aligns with efforts to protect blue carbon ecosystems: it aims to conserve and protect endangered and threatened ecosystems in the province and promote the recovery of those ecosystems. However, it does not list blue carbon resources among the endangered and threatened ecosystems.
		Manitoba Climate and Green Plan Act	This act provides for dedicated planning, monitoring, reporting and oversight of carbon as a driver of climate change. However, it prioritizes reducing greenhouse gas emissions and does not consider or assign value to naturally occurring carbon sinks within the province. The legislation does not indicate whether carbon released through the destruction of carbon sinks (blue or otherwise) would be measured. In any event, this act is likely most useful in terms of the dialogue it promotes through the planning and reporting processes.
		Made-in-Manitoba Climate and Green Plan 2017	While the planning promise could provide a live venue for discussions regarding the value and vulnerability of blue carbon ecosystems, Hudson Bay does not appear to be an integral part of the 2017 Plan. Data could encourage the Manitoba Government to include blue carbon concerns.
		Wapusk National Park (Canada)	This park includes tidal flats, which could encompass large areas of blue carbon ecosystems within the National Parks Act and National Parks Regulations.
		Manitoba Wildlife Act	While this act is wildlife-centric, its provisions are broad enough to include blue carbon ecosystems where a link with a species of wildlife can be established. However, establishing designated areas would require a great deal of legislative work. Beyond habitat, the act does not refer to key blue carbon concepts.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Ontario	**28**	Ontario Environmental Assessment Act	The act is not specifically relevant to blue carbon ecosystems as it applies to surface water and ground water, but not marine water. However, this act's processes for proposals on provincial lands would be relevant where coastal development is planned.
		Ontario Far North Act	One of the act's objectives is to protect ecological systems in the Far North by various means. One of these is the designation of protected areas in community-based land-use plans and the maintenance of biological diversity, ecological processes and ecological functions, including the storage and sequestration of carbon in the Far North. All plans must consider "the maintenance of biological diversity, ecological processes and ecological functions, including the storage and sequestration of carbon in the Far North." First Nations concerned about carbon sequestration could use the act's planning and designation processes to extend real protections — at least to the ordinary low-water mark — to blue carbon ecosystems in the Far North region.
		Ontario Planning Act	This act outlines a general planning process and does not specifically target blue carbon ecosystems. However, local councils could apply land-use planning tools to designate blue carbon ecosystem areas — at least to the low-water mark — for restricted activities.
		Ontario Fish and Wildlife Conservation Act, Ontario Fish Licensing Regulations	Both the act and the regulations are focused on kingdom Animalia. Ecosystems are only an object of protection through wildlife. Otherwise, there is no reference to habitat, plant species and other key blue carbon concepts.
		Ontario Endangered Species Act, Species at Risk in Ontario List, Habitat Regulations	If it could be established that a species of plant involved in a blue carbon ecosystem is rooted above the low-water mark and is extirpated, endangered or threatened, these instruments could be useful. A closer look at all of the listed species and their ranges would be a productive first step.
		Ontario Provincial Parks and Conservation Reserves Act	Wilderness Park and Natural Reserve Park classifications offer the greatest level of protection for blue carbon ecosystems. However, beyond general protections, there is no reference to key blue carbon concepts.
		Ontario Migratory Bird Sanctuaries (Canada)	Sanctuaries protect blue carbon ecosystems indirectly by virtue of the migratory birds that use them.
		2020 Provincial Policy Statement	Neither Hudson nor James Bay coastal wetlands are included in these descriptions. Perhaps with more awareness about the critical role blue carbon ecosystems and their lowland neighbours play, these areas could be incorporated into this policy scheme.
Ontario		A Wetland Conservation Strategy for Ontario (2017–2030)	This strategy provides helpful statistics for the blue carbon sequestration toolkit, such as the following: "in Ontario, the majority of wetlands are found in northern Ontario, with the Hudson Bay Lowlands Ecozone accounting for 20,000,000 hectares or about 57 per cent of Ontario's wetlands."
		Ontario Conservation Land Act	For this to work as a tool for conserving blue carbon ecosystems, such lands would need to be privately owned. Further research would be needed to determine whether any titles are registered for areas (or parts of areas) containing such ecosystems.
		Conservation Authorities Act	Jurisdiction appears to reach to the ordinary low-water mark along Hudson Bay and James Bay, which means that the act applies to some blue carbon assets. Unfortunately, no Conservation Authorities have been established adjacent to Hudson Bay or James Bay. However, the Indigenous Nations and communities along the coast of James Bay, for example, could consider establishing such an authority. This would allow them to receive funds and make certain decisions about the watersheds in their areas.
Quebec	**14**	Quebec Natural Heritage Conservation Act	Under the act, the government may designate any public land in the domain of the State as a protected area with sustainable use, a biodiversity reserve, an ecological reserve or a marine reserve. The most likely candidates for protecting blue carbon ecosystems are ecological reserves. While tools for protecting blue carbon ecosystems are available under this act, decision-makers aren't required to consider the sequestration value of these ecosystems.
		Quebec Migratory Bird Sanctuaries (Canada)	Sanctuaries protect blue carbon ecosystems indirectly by virtue of the migratory birds that use them.
		Plan Nord and Northern Action Plan 2020–2023	The NAP sets out its conservation target under the first element: "The 2020–2023 NAP is consolidating the commitment to designate by 2035 50% of the territory north of the 49th parallel for conservation purposes. A network of protected areas representing 20% of the northern territory will be strengthened and 30% of the territory will be devoted to environmental protection, safeguarding biodiversity, and the promotion of various types of development." Beyond this conservation objective, which could indirectly support blue carbon ecosystems, the NAP does not refer to key blue carbon concepts.
		2030 Plan for a Green Economy	The 2030 Plan views natural environments as a potential means to sequester carbon, and notes that they can be disrupted by human activity. The plan commits to valuing natural environments such as forests for their sequestration abilities. It appears that Quebec recognizes the marine region as a potential resource for carbon sequestration, though the means to conduct this accounting have not yet been thoroughly described, at least in this policy space.

Jurisdiction	Number Reviewed	Titles	Notable Aspects
Quebec		Act to Affirm the Collective Nature of Water Resources and to Promote Better Governance of Water and Associated Environments	The act establishes a governance, research/knowledge and deterrence framework for water around four main principles: user/polluter pays, prevention, reparation and transparency. The regional county municipalities of Northern Quebec and Western Quebec would be relevant to blue carbon protection; however, neither of these municipalities appears to have a plan for wetlands and bodies of water.

RECOMMENDATIONS FOR ARCTIC POLICY AND LEGISLATION

- ✓ Explore treaty and Indigenous rights frameworks as a mechanism to protect blue carbon ecosystems, and vice versa.
- ✓ Integrate blue carbon into existing legislation and policy to better safeguard blue carbon ecosystems.
- ✓ Create forums for collaboration and integration among jurisdictions and Indigenous Nations and communities to facilitate holistic approaches to safeguarding blue carbon ecosystems.

MUNICIPAL POLICY AND LEGISLATION

Angela Danyluk

INTRODUCTION

Across Canada, local governments have the opportunity to both support and benefit from blue carbon systems. Most blue carbon systems exist in nearshore areas, which are typically under the jurisdiction of federal, provincial and Indigenous governments, and occasionally local governments. Local governments, including municipalities and regional districts, may influence, and sometimes regulate, the protection, restoration or creation of blue carbon systems directly or indirectly through their powers and interests related to land-use planning, infrastructure, climate action, environmental planning and other aspects of municipal service delivery (e.g., financial planning, partnerships and advocacy).

BACKGROUND

Carbon sequestration via blue carbon ecosystems is a relatively new concept for local government practitioners and best aligns with local government interests related to climate action. For most local governments in Canada, formal climate-action work began in the early 2000s. Since then, most local governments have been measuring and reporting on their greenhouse gas inventories, working to reduce their emissions, and investing in approaches to climate-change adaptation. Science and lived experience have improved our understanding of the climate crisis since those early days, and we now find ourselves in the midst of a climate emergency where leadership and action are urgently needed to avoid warming above 1.5°C (IPCC 2018). If we are to achieve our goals, natural climate solutions (NCS) will need to be part of climate-action work at all levels of government.

LAND USE

One of local government’s primary services is planning and regulating land use, typically above the high-water mark. Usually, this authority does not extend below this point or to the water column where most blue carbon ecosystems are located, unless the local government has formal tenure through an agreement with the province or federal government. Still, local governments can use their authority to manage and regulate land use to the benefit of nearshore blue carbon ecosystems.

Local governments can make community plans that take a medium-term (e.g., 30–50 years) and holistic view of a community’s aspirations, goals and values. Aligning community plans with climate and environmental goals can improve efficiency and effectiveness. For example, in British Columbia, most local governments are required to include GHG mitigation targets and policies within their community plans. This overlap in land-use planning and environmental goals provides an opportunity for local governments to develop and implement blue carbon policy and NCS as a part of long-term strategies.

Local governments can protect and conserve coastal ecosystems by using and leveraging zoning regulations and bylaws (Carlson 2020). For example, through the development process, local governments can negotiate the location and size of park designations, an opportunity to protect and conserve shoreline areas. Likewise, in British Columbia, local governments can support the implementation of “Environmental Stewardship Restrictive” covenants on private property through a voluntary process using Section 219 of the Land Title Act (British Columbia Ministry of Environment 2023). Some local governments in British Columbia also use their authority to create “Development Permit Areas” or “Environmentally Sensitive Areas.” These require developers to protect ecosystems or design and construct specific forms of development that mitigate impacts on ecosystems and ecosystem services (City of Surrey 2023; District of North Vancouver 2023). Development Permit Areas and Environmental Sensitive Areas can be created along the shoreline or anywhere else within a local government’s jurisdiction.

Local governments can apply zoning regulations and bylaws along and landward of the shoreline to ensure that ecosystems and ecosystem processes on the land that support nearshore ecosystems are healthy and functioning. Some of these approaches can be used to restrict development and degradation in sensitive habitat areas (e.g., by requiring (i) the retention of soil to enhance on-site rainwater management, (ii) hook-up to sanitary sewerage, (iii) setbacks from streams and plant native vegetation, etc.). Across Canada, there are many examples of local governments leveraging zoning regulations and bylaws for “environmental benefits,” but few if any examples of local governments deliberately taking these actions to safeguard the health of blue carbon ecosystems.

Some local governments may have the authority to manage coastal areas and services related to marine traffic, docks, businesses, facilities and other infrastructure that have the potential to destroy or damage sensitive nearshore ecosystems. In British Columbia, Islands Trust has examined ways to regulate and encourage investment in community docks in island communities to reduce the number of waterfront structures and conserve sensitive habitat (e.g., Youmans 2013; Islands Trust 2022). Local governments can use their Official Community Plan to make policy statements about community docks and regulate dock structures and use via Land Use Bylaws. This type of tool could be used to protect blue carbon ecosystems found in the nearshore.

In both the public and private realm, it is possible to craft design guidelines and setbacks to mitigate the negative effects of stormwater and erosion, and to support processes and systems beneficial to blue carbon ecosystems. The City of Surrey has a range of biodiversity guidelines for various forms of development and infrastructure to mitigate the impacts of development and preserve the city’s biodiversity (City of Surrey 2021). These guidelines were created in collaboration with biologists, engineers, landscape architects and planners.

INFRASTRUCTURE AND SERVICE DELIVERY

Local governments deliver services like clean water, drainage, sanitary sewage and transportation. Quite often these projects are large and influence blue carbon ecosystems indirectly through non-point source pollution or directly through physical damage or destruction. To minimize damage and disruption to blue carbon systems, local governments can implement policies and regulations when planning, constructing and delivering infrastructure projects.

Stormwater is a significant source of non-point source pollution in Canada’s coastal areas. Delivering a mix of metals, nutrients, bacteria, pesticides, sediments and other contaminants, stormwater can cause significant harm to blue carbon ecosystems. To mitigate this harm, local governments can manage their stormwater to reduce water volumes and improve water quality to meet aquatic life standards. In Metro Vancouver, British Columbia, municipalities are required to use Integrated Stormwater Management Plans (ISMPs) to ensure that member municipalities meet regulations and receiving waters are kept healthy. Metro Vancouver supports local governments by facilitating the sharing of information, helping develop tools and resources, and acting as a liaison between local governments and the province of British Columbia.

Coastal local governments are typically responsible for planning, building and maintaining coastal-flood infrastructure, such as dikes and foreshore protection. These infrastructure typologies can harm coastal ecosystems directly by destroying them, or indirectly by restricting their natural dynamics and expansion. Alternatives to “hard infrastructure” are being considered and implemented across Canada, but are not yet mainstream (Eyquem 2021). From 2021 to 2022, the City of Vancouver investigated the use of nature-based climate solutions as an element of flood protection during the Sea2City Design Challenge in False Creek (City of Vancouver 2023). The design concepts crafted as part of the project tested a combination of “hard” and “soft” infrastructure to provide not only flood protection, but also benefits related to reconciliation, recreation, environmental restoration and carbon sequestration (City of Vancouver 2023).

MUNICIPAL CLIMATE ACTION AND BLUE CARBON

Most local governments have targets related to reducing community and corporate greenhouse gases and their risk to climate-change impacts (i.e., adaptation). Blue carbon NCS can help local governments achieve a variety of climate-action deliverables. This sub-chapter includes examples of how to integrate blue carbon NCS into municipal climate-action work.

Local governments’ plans for mitigating climate change include targets for reducing carbon pollution and can also include targets or milestones for carbon sequestration. In 2020, the City of Vancouver became one of the first cities in Canada to set a carbon-sequestration target as part of its Climate Emergency Action Plan (CEAP). In this CEAP, the section called

"Big Move 6: Natural Climate Solutions" commits to an interim sequestration target within the city boundaries of 21,000 tonnes of CO_2e per year (City of Vancouver 2021). NCS in the city currently sequester approximately 16,000 tonnes of CO_2e annually (City of Vancouver 2021). The City of Vancouver aims to achieve its target by conserving and planting trees on both private and public property. The City of Vancouver examined NCS in other ecosystems, such as agricultural lands, wetlands and blue carbon systems, but determined that tree planting was more feasible (City of Vancouver 2021). Several factors made blue carbon solutions seem less feasible, such as gaps in our understanding of blue carbon dynamics in the Fraser River basin, the complexity of blue carbon governance, and the lack of a clear framework for carbon accounting.

Plans for mitigating climate change can also include funding and resources to support research, relationship building, and the implementation of blue carbon projects. Examples of funding and resources provided by local governments are staff capacity (including in-kind), project funding, facility use (to support research and convene blue carbon experts and practitioners), and/or designation of land for the protection, restoration or study of blue carbon ecosystems.

Where appropriate, blue carbon projects can be integrated into municipal plans to adapt to climate change. For example, many coastal communities are responding to, or are planning to respond to, the impacts of sea-level rise and extreme storm events. In Canada, coastal NCS include vegetation plantings, land terracing, beach nourishment, and protection of subtidal ecosystems and/or barrier islands to mitigate erosion and flooding (Eyquem 2021; City of Vancouver 2023). Few projects harness salt marshes, seagrasses or kelp forests exclusively and at scale for the purpose of coastal adaptation; instead, blue carbon NCS are integrated into and used in conjunction with a variety of other adaptation measures (Eyquem 2021; City of Vancouver 2023). Still, blue carbon NCS can support flood reduction and shoreline retention, while simultaneously contributing to climate-change mitigation.

PUBLIC LANDS

Local governments are responsible for a range of public lands and assets that they have built, purchased or received through donation. Public lands include a variety of ecosystems within the broader land-sea interface. Consequently, by protecting and sustainably managing public lands, we can contribute to the health of blue carbon ecosystems and the potential success of blue carbon NCS. Local governments can leverage current public lands or invest in acquiring additional areas to further these conservation goals. In addition, they could use existing lands and assets as "living labs" to resolve knowledge gaps pertaining to blue carbon ecosystems. Local governments may also support collaboration and integration among jurisdictions to address the complexity of jurisdictional authority along the coastline.

As previously discussed, local governments' primary authority is managing land use within municipalities or regional districts. Through that authority, local governments may zone public and private lands as parks. For instance, the City of Richmond purchased the last remaining privately held bog forest (15 acres) in north Richmond in 2011 (Campbell 2011) and 127 acres of marine wetlands along Sturgeon Bank in 2012 (City of Richmond 2012). In both cases, environmental benefits guided land purchases, with carbon storage and sequestration factoring into the rationale (note that a carbon-credit or emission reduction-credit scheme has yet to be created).

Local governments can directly support research, measurement and monitoring of blue carbon projects to address gaps in our current understanding of blue carbon ecosystems (see Seagrass, Salt Marsh, Kelp, the Arctic). Local governments and other agencies can partner with researchers, Indigenous Nations and communities, and others to support research and knowledge exchange, including mapping of blue carbon ecosystems. An example of an Indigenous-led project to map blue carbon ecosystems is the eelgrass mapping by Tsleil-Waututh First Nation (2015–2020). The project was completed in collaboration with multiple partners, including the City of Vancouver. As part of this project, the City of Vancouver provided financial support to eelgrass-mapping efforts. The data collected will be used by Tsleil-Waututh First Nation to advance community goals, and could potentially serve as baseline information for future blue carbon credit schemes.

Local governments can help break down jurisdictional barriers if they own lands that contain blue carbon ecosystems, have zoning authority over them, or support collaboration and integration among jurisdictions and Indigenous Nations and communities. Blue carbon NCS and associated potential carbon-credit schemes are relatively new to local governments, and much remains unknown about how these systems work. The lack of information about ecosystem function and about the governance of carbon-credit schemes is a deterrent to pursuing these projects.

One of the first NCS carbon credit projects took place in 2015 in the Burns Bog Ecological Conservancy Area (BBECA) in Delta, British Columbia — a multi-partner project called the BBECA Carbon Emission Reduction Plan (Welham 2020). Burns Bog is one of the world's largest protected natural areas in an urban landscape. While not a blue carbon ecosystem, it is an example of a wetland being restored alongside an emission reduction credit (ERC) program, created to contribute to government incentives for carbon neutrality by leveraging the wetland's natural carbon-sequestration services. The ERC program followed the government of British Columbia's "Green Communities Committee's (GCC) Becoming Carbon Neutral Guidebook" (Welham 2020). ERCs will be granted to the City of Delta and Metro Vancouver, who are the principal landowners of the BBECA and who fund restoration of the bog. In 2018, Metro Vancouver leveraged learnings from the BBECA and invested in the creation of the region's first carbon-storage database (Welham and Seely 2019). The dataset provides a spatial estimate of carbon stored in biomass and soil in the Metro Vancouver Region.

FINANCE AND RISK MANAGEMENT

Financial planning and risk management are cornerstones of local government planning and delivery of services. Local governments can take advantage of existing asset-management systems and risk-management strategies to build a business case for supporting blue carbon ecosystems.

Every local government manages its assets according to the Public Sector Accounting Board's (PSAB) accounting standards. These standards primarily consider "grey" or "hard" infrastructure, but not natural assets. Canada's leading authority on municipal natural-asset accounting and evaluation, the Municipal Natural Assets Initiative (MNAI), is seeking to have natural assets included in public sector accounting standards. MNAI believes that identifying, measuring and managing natural assets should be part of an overall asset-management strategy. This would let local governments save capital and operating costs, and reduce risk. Blue carbon ecosystems provide a range of services — such as stormwater management, flood mitigation and tourism — that benefit local governments. Typically, local governments do not value the services these natural assets provide because they are not required to. By including blue carbon natural assets in local government ledgers, we could help build a business case to invest in protecting, restoring and managing blue carbon ecosystems.

To highlight opportunities to invest in blue carbon ecosystems, we could create a decision-support tool for evaluating capital projects according to a climate-action lens. This tool could be as simple as a series of questions for project managers, such as the following:

- In which Indigenous Nation's (or Nations') territory does this project fall? What are the Nation's (or Nations') views on this project, and what opportunities are there to foster collaboration and mutual benefit?
- Does this project sequester carbon?
- Does the project have the potential to create or support a blue carbon ecosystem?
- Does this project damage or destroy blue carbon ecosystems?
- Does the project manage climate risks through stormwater management, flood mitigation or other?

The answers to these questions could be scored and used as part of a weighting scheme to identify project risks, costs and benefits. The output could be used to determine what projects or aspects of projects should receive funding. By including questions about climate action and blue carbon ecosystems, the decision-support tool would ensure that discussions and decisions factor in blue carbon NCS as part of financial planning.

Local governments can also support funding and business-case development for blue carbon NCS by creating an internal market for local blue carbon projects through policy and practices related to internal carbon pricing, internal carbon offset/sequestration protocols, and the evaluation of capital projects' carbon impacts (see previous paragraph). This complex space is mostly managed by local governments with support from provinces and within the context of national, provincial and local regulations and knowledge. Canada does not have any internal carbon pricing or offset markets exclusive to blue carbon ecosystems. Internal carbon offset programs do exist in a few jurisdictions, such as the City of Vancouver, Metro Vancouver, and the City of Toronto, but they do not address blue carbon ecosystems exclusively, if at all (CUSP 2019).

Climate change poses a variety of risks to local government. The Task Force on Climate-related Financial Disclosures (TCFD) presents a framework that local governments can use to evaluate and publicly disclose their risk. TCFD's goal is for local governments to investigate their financial and risk interests to better understand and respond to climate risks. Since blue carbon ecosystems mitigate some climate risks, such as those related to flooding and sea-level rise, TCFD could be a used as a tool to promote investment in blue carbon NCS. To date, Calgary, Edmonton, Toronto, Mississauga, Vancouver and Montreal are the only communities to participate in TCFD, and none has invested in blue carbon NCS (CUSP 2020).

PARTNERSHIPS AND ADVOCACY

It is important that local governments pursue local NCS in dialogue and collaboration with local Indigenous Nations and communities, whose territories encompass present-day cities, municipalities and districts. Some cities, like the City of Vancouver, have reconciliation frameworks and goals that outline a commitment to working with local Indigenous Nations and communities. These provide additional impetus for collaborating on NCS.

The ownership, regulation and history of coastal and shoreline areas are complex. Local governments can act as conveners to cultivate discussions about how to reduce complexity, align values, and forge partnerships to support blue carbon projects. For example, in 2017, the City of Yokohama secured a grant from the Carbon Neutral Cities Alliance to co-host a blue carbon workshop with the City of Vancouver. In 2018, the two cities hosted a two-day workshop on blue carbon ecosystems in Vancouver, bringing together NGOs, academics and local governments. The purpose of the workshop was to build relationships and learn about blue carbon ecosystems, regulations and carbon-credit frameworks to support blue carbon projects. This workshop sparked relationships that led to multi-year collaborations.

As one of the orders of government in Canada, local governments can advocate to other orders and government agencies for support, clarification, and establishment of governance for blue carbon projects and nearshore ecosystems. Local governments can leverage their leadership and authority (e.g., as many did in response to the Trans-Mountain Pipeline project) or answer provincial and federal calls for feedback and provide their recommendations (e.g., Canada's consultation on the national adaptation strategy).

Local governments are part of many climate-action and environmental networks. They can leverage their connections with existing multi-agency working groups — whose mandates include carbon offsets, marine science and climate adaptation — to advance blue carbon knowledge and progress.

Internal and external education and stewardship programs are often part of municipal climate-action and environmental plans. Internally, local governments could educate their staff on policies and projects relevant to blue carbon. Externally, they could raise community awareness of blue carbon and support for relevant projects.

RECOMMENDATIONS FOR MUNICIPAL POLICY AND LEGISLATION

Local governments may influence, and in some circumstances regulate, the protection, restoration and management of blue carbon systems. They may do this either directly, or indirectly through their powers and interests related to land-use planning, infrastructure, climate action, environmental planning, and other aspects of municipal service delivery (e.g., financial planning, partnerships and advocacy).

Local governments can support blue carbon ecosystems and sequestration by taking the following actions:

- ✓ In collaboration with Indigenous Nations and communities, set sequestration targets in addition to greenhouse gas-reduction targets. These targets will create a demand for blue carbon sequestration services.
- ✓ In collaboration with Indigenous Nations and communities, plan for and invest in blue carbon NCS as part of climate-change adaptation.
- ✓ Advocate for blue carbon by lobbying other levels of government to take action, and by bringing interested parties together.
- ✓ Leverage infrastructure investments to protect and restore blue carbon ecosystems. Commit to no-net-loss of blue carbon ecosystems, and to reducing stormwater volumes and improving water quality.
- ✓ Leverage regulatory and policy powers to protect, conserve and restore blue carbon ecosystems as part of land-use planning and decision-making.
- ✓ Provide funding and support for Indigenous-led conservation and NCS.

BLUE CARBON ECOSYSTEMS

Brianne Kelly

In Canada, blue carbon ecosystems include seagrasses and salt marshes — though macroalgae and Arctic ecosystems are also explored as blue carbon ecosystems in this report. In the marine environment, water is a main driver of carbon cycling (Ward *et al.* 2017), resulting in the constant transformation and transport of carbon among blue carbon habitats, other marine habitats (such as unvegetated sediments), and terrestrial and freshwater ecosystems. Understanding blue carbon dynamics requires a holistic systems approach and knowledge of the full marine carbon cycle.

Organic carbon produced in one blue carbon habitat can be transported laterally to other habitats where it is either remineralized or stored long-term (Ward *et al.* 2021). The coastal marine environment has two main pathways for carbon transport: the first is passive transport on tidal flows, or wind-driven currents or large-scale oceanic currents; and the second is biologically mediated transport through the movement, migration or foraging of marine animals (Hyndes *et al.* 2013; Brown *et al.* 2021). Through these mechanisms, organic carbon sequestered in seagrass ecosystems can, for example, be stored within the sediments of that ecosystem or transported, deposited and stored in salt marshes or in the deep sea (Kennedy *et al.* 2010; Ricart *et al.* 2015; Duarte *et al.* 2017; Ward *et al.* 2021). Likewise, organic carbon from kelp forests can be transported, deposited and stored onshore, in the deep sea, in salt marshes or in seagrass meadows (Boyer and Fong 2005; Wernberg *et al.* 2006; Krumhansl and Scheibling 2012a; Prentice *et al.* 2019). The distinctions between carbon sinks and sources — sinks absorb more carbon from the atmosphere than they release, while sources release more carbon than they absorb — are important for understanding carbon dynamics, as well as for integrating carbon considerations into management plans, protection strategies and carbon-accounting efforts such as Canada's Nationally Determined Contributions (NDCs).

In addition to those typically considered blue carbon habitats, a number of marine habitats can act as sources and/or sinks for organic carbon. These include mudflats, such as the microphytobenthos that grow on their surface (Redzuan *et al.* 2020), water column phytoplankton and macroalgae. Surface and groundwater flows among marine, terrestrial and freshwater ecosystems can likewise result in significant carbon cycling. For example, overland runoff and groundwater outflows (Chen *et al.* 2018) transport carbon from land to the ocean, while organic carbon produced in the marine environment is routinely washed ashore (Liu *et al.* 2019). Riverine systems transport carbon from inland ecosystems to estuaries and coastal environments, and tidal flows can influence carbon dynamics in rivers where they reach the sea. Failure to account for carbon dynamics across the full marine environment impedes our understanding of marine carbon stocks, fluxes, and accumulation rates. This can result in biases in climate projections, miscalculation of carbon budgets and misinterpretation of marine ecosystems' potential to mitigate climate change.

Several tools have been developed to track carbon transport across ecosystems. Carbon and nitrogen isotopes are often applied to trace the source of carbon (e.g., Douglas *et al.* 2022), but as a tool these isotopes are not highly specific (Geraldi *et al.* 2019). Compound-specific isotope analyses (for example of lipids within a sample) may provide more detailed information (Geraldi *et al.* 2019). Environmental DNA (eDNA) can provide information on the source of carbon at the species level (Ortega *et al.* 2020) but requires species-specific primers to be developed (Geraldi *et al.* 2019). Additional biomarkers may be applicable for tracing carbon but require more research and refinement (Geraldi *et al.* 2019).

Despite the connectivity among blue carbon habitats and between terrestrial and inland waters, most blue carbon studies focus on an individual habitat. These targeted studies provide important detail on the carbon dynamics within a habitat type and contribute greatly to our understanding of carbon dynamics within specific settings. However, given the importance and complexity of carbon cycling, we also need systems-based approaches and studies that focus on the transport of carbon among ecosystems. It is especially important to gain a full understanding of the marine carbon cycle: the human activities that drive habitat loss, changes to primary productivity, overfishing and climate change can also influence carbon stocks, fluxes and accumulation rates in the marine environment (Hyndes et al. 2013).

Canada currently has a limited number of blue carbon studies. Moving forward, as we collectively build the body of research on blue carbon and carbon cycling in the marine environment, a systems approach would provide valuable insights and understanding. Such an approach will require collaboration among researchers and practitioners across areas of expertise, ecosystems and disciplines.

RECOMMENDATIONS FOR BLUE CARBON ECOSYSTEMS

- ✓ Build collaborations across disciplines to improve our understanding of carbon transport, storage and accumulation in blue carbon ecosystems.
- ✓ Take a systems-based approach to understanding carbon dynamics to improve our ability to mitigate climate change.
- ✓ Enhance understanding of the efficacy of restoration approaches and how carbon dynamics of restored ecosystems compare to undisturbed ecosystems.
- ✓ Complete feasibility studies for all blue carbon NCS pathways — incorporating multiple ecological and socioeconomic considerations — to evaluate the full range of costs and benefits.
- ✓ Create a national repository for data on blue carbon ecosystems to support conservation efforts and long-term monitoring.
- ✓ Invest in, incentivize and support research to improve the understanding of variability in carbon sequestration and storage within and among sites, ecosystems and regions, including the drivers of that variation.
- ✓ Include carbon measurement and monitoring in current conservation efforts.
- ✓ Expand blue carbon distribution and carbon models, including the collection of validation data (e.g., extent, threats, carbon dynamics), and refining machine learning models using a wide variety of available technologies.
- ✓ Seek out the work of Indigenous scientists and knowledge holders, and fund Indigenous-led research projects. This will expand perspectives on how the marine carbon cycle works and how climate impacts are affecting coastal Indigenous communities.


© Elisabeth Kruger / WWF-US

SEAGRASS

Brianne Kelly, Lauren McNeilly, Marlow Pellatt, Tanya Prystay and Jordy Thomson

GLOBAL AND NATIONAL CONTEXT

Scientific and political communities are becoming increasingly aware of the role that natural ecosystems play in sequestering and storing carbon. There is NCS potential in protecting, sustainably managing and restoring seagrasses since they can store carbon in the sediments where they grow (Unsworth *et al.* 2022). More specifically, seagrasses sequester carbon dioxide through photosynthesis, and store organic carbon in their soils. With that said, much work is needed to understand where seagrasses are located and how their potential to mitigate climate change varies according to different coasts, latitudes and marine conditions. In Canada, knowledge of carbon dynamics — including stocks, accumulation rates, lateral transfer, export, deposition and fluxes — is in its infancy. Canadian seagrass ecosystems may differ considerably from seagrass ecosystems in milder climates and where other species are found. In Canada, we also need research on the national distribution and carbon dynamics of seagrass to contextualize its role in climate-change mitigation on a global scale.

Seagrass is spawning habitat for Pacific herring (*Clupea pallasii*), a cultural keystone species[24] for Indigenous Peoples on the Northwest Coast of North America (Moss 2016; Gauvreau *et al.* 2017; Jones *et al.* 2017). For this reason, decisions about restoring, monitoring and managing seagrass may carry additional import for coastal Indigenous Peoples who hold local ecological knowledge about these interrelated species. This points to opportunities to work with coastal Indigenous communities on NCS related to seagrass, including supporting Indigenous efforts to protect and restore coastal ecosystems.

Despite their ecological and cultural importance and the ecosystem services generated, seagrasses are declining globally, at an accelerating rate due to a variety of anthropogenic and natural pressures (Orth *et al.* 2006; Waycott *et al.* 2009). A recent review of available time-series data found that 19 per cent of global seagrass coverage has been lost since 1880, with an estimated average annual loss of 1–2 per cent (Dunic *et al.* 2021). All bioregions have shown declines in seagrass area relative to the earliest recorded baseline, although trajectories have not all been linear, and the rate and timing of loss differ considerably among regions (Dunic *et al.* 2021). Furthermore, variation in the length and timing of published time series may complicate interpretation through the use of different baselines. For example, published data for the Temperate Northwest Atlantic bioregion began after the period of wasting disease in the early 20th century, which is known to have caused catastrophic losses in the Temperate Northeast Atlantic (Milne and Milne 1951). It is also important to note that published data sets on seagrass area cover only an estimated one-tenth of total global seagrass area, so it is unknown whether the documented bioregional trends reflect trends for unstudied meadows (Dunic *et al.* 2021). There is a critical need to comprehensively map blue carbon in Canada and around the world.

Canada is home to six seagrass species: *Zostera marina, Zostera japonica, Ruppia maritima, Phyllospadix scouleri, Phyllospadix serrulatus* and *Phyllospadix torreyi*. Of these, *Z. marina* or eelgrass is by far the most widely distributed and abundant species found in soft-bottom habitats (Green and Short 2003; Murphy *et al.* 2021). Because of its importance as habitat for fish, invertebrates and waterfowl, as well as the role its physical structure plays, eelgrass has been identified by Fisheries and Oceans Canada (DFO) as an ecologically significant species (DFO 2009). Within Canada, eelgrass grows in a wide range of abiotic and biotic conditions from polar to temperate coastal ecosystems and is subject to a similarly wide range of human impacts. As a result, these ecosystems vary considerably on a number of fronts: the physical structure of the plants, the species communities they support, their responses to disturbance and the ecosystem services they provide (Murphy *et al.* 2021).

MAPPING AND MONITORING

Seagrass meadows have been mapped along all three Canadian coasts (Murphy *et al.* 2021). Mapping has been more extensive along the Pacific coast than along the Atlantic, and mapping in the Arctic has been the most scarce (Figure 1). Mapping efforts have been site-specific and conducted in isolation, therefore estimates of the total extent, area, and temporal trends in the spatial extent of seagrass meadows throughout Canada remain unknown (Murphy *et al.* 2021). Currently, many groups are working to estimate seagrass distribution and area in Canada.

Many Indigenous Guardian programs are currently monitoring and stewarding seagrass (for examples, see the management plans developed in collaboration with the Marine Plan Partnership for the North Pacific Coast; MaPP). Indigenous Guardians, such as the Coastal Guardians Watchmen[25] off the coast of B.C., play a critical role monitoring and protecting coastal B.C. Their work includes managing species such as herring, educating land users, and enforcing regulations (Kitasoo Xai’xais Stewardship Authority 2020; Gilpin 2023; Land Needs Guardians n.d.). There are many ways to support the capacity of, and build partnerships with, Indigenous Guardians with local knowledge — for example, providing funding for Guardian programs, or sharing data and resources to initiate or expand monitoring and mapping programs for seagrass. Indigenous knowledge, when Indigenous Peoples wish to share it, could expand methodologies and enhance understanding of seagrass and its NCS potential.

---

[24] Garibaldi and Turner (2004) coined “cultural keystone species” as an concept analogous to ecological keystone species. Cultural keystone species are “the culturally salient species that shape in a major way the cultural identity of a people, as reflected in the fundamental roles these species have in diet, materials, medicine, and/or spiritual practices” (p. 4). Indigenous Peoples may use other terms to describe these species, such as *culturally significant species*, *sacred* or *important*, or they may use Indigenous names and descriptors.

[25] Coastal Guardians Watchmen are made up of First Nations on the North and Central Coast of B.C. and Haida Gwaii (Coastal Fist Nations 2022b).

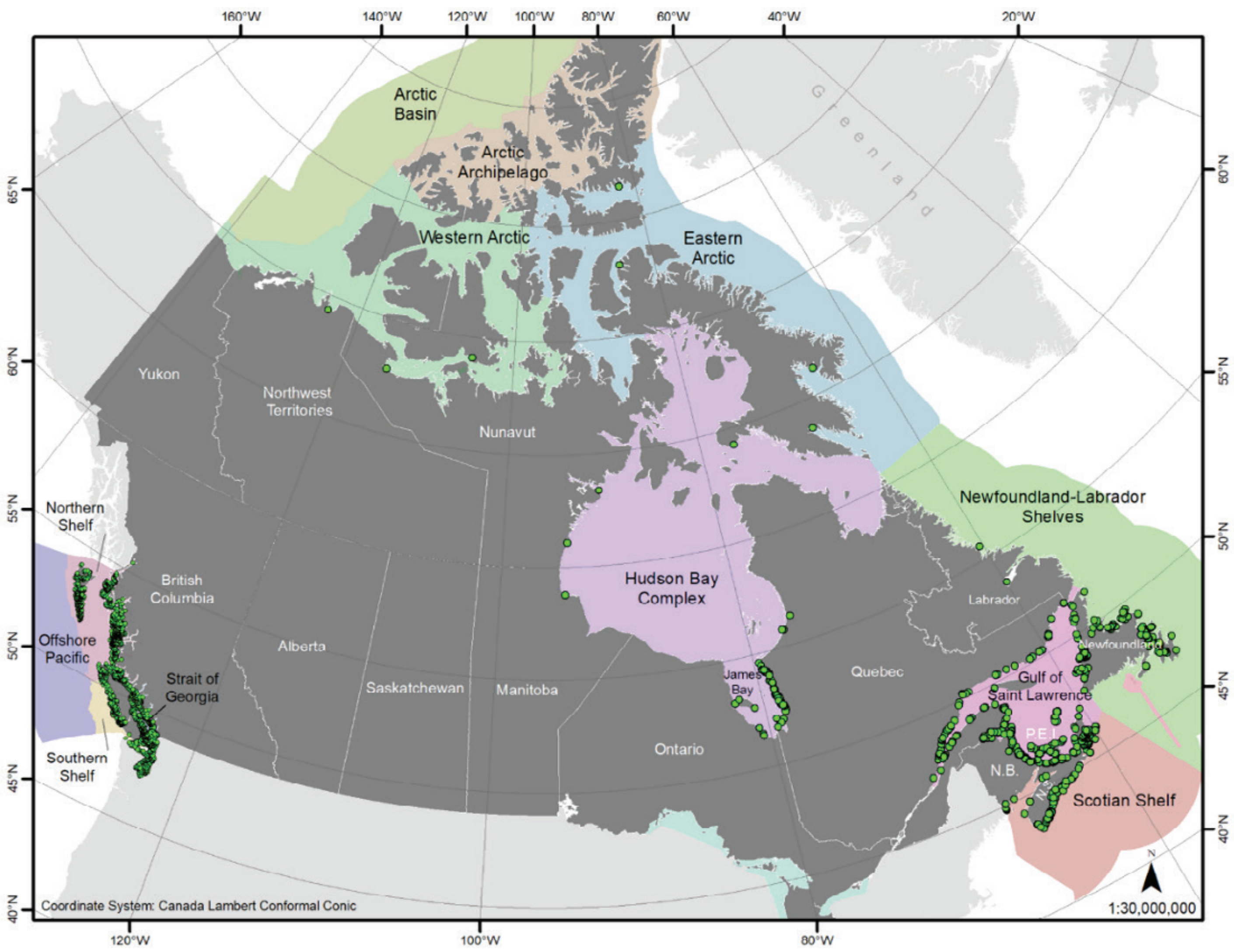


Figure 1. Distribution of eelgrass (*Zostera marina*) across Canada's marine bioregions (included with permission from Murphy *et al.* 2021).

Numerous tools have been used to map *Zostera marina* meadows at the full-meadow scale in Canada. These include underwater videography, aerial imagery, satellite, benthic sonar and remotely piloted aircraft systems (RPAS) (e.g., Vandermeulen 2014; Barrell *et al.* 2015; Wilson *et al.* 2022; Nahirnick *et al.* 2019a,b; Forsey *et al.* 2020). It is difficult to map submerged seagrass meadows using satellite and RPAS techniques when environmental conditions are unfavourable and varying. For example, cloud cover, water turbidity (e.g., suspended silt, phytoplankton, tannins), wind and waves — common conditions along all three Canadian coastlines — all inhibit the detection of benthic habitats (Joyce *et al.* 2018; Nahirnick *et al.* 2019a). Additionally, as water depth increases to >5 m, light scatters, making it harder to distinguish seagrass from other benthic habitats such as macroalgae (Tait *et al.* 2019; Nahirnick *et al.* 2019a,b). Acoustic methods, such as side-scan and single-beam sonars, are less affected by water turbidity and typically survey in deeper water; however, due to reduced beam spread in shallow water, acoustic surveys cover smaller scales than satellite imagery (Barrell and Grant 2013; Barrell *et al.* 2015). Finally, measures of seagrass extent and area estimated from maps can vary depending on the data resolution and classification process used. By supplementing classification models with site characteristics, such as sediment and depth profiles, we could improve the accuracy of such models (e.g., Wilson *et al.* 2019), enabling long-term habitat monitoring. Regardless of the approach used, collecting *in situ* data is important for validating seagrass maps, yet can be time consuming and resource intensive.

Mapping seagrass meadows in isolation limits our understanding of the natural variability in seagrass extent and area along Canadian coastlines. This makes it challenging to assess seagrass status (nationally and regionally) and can bias estimates of the provision of ecosystem services. To address gaps in existing maps, we could use habitat suitability and distribution modelling to (i) prioritize future in-field data collection, and (ii) project seagrass distribution under future climatic conditions. However, to estimate the long-term contribution of Canadian seagrass to climate change mitigation, we will need to establish feasibly reproducible methods of mapping and monitoring seagrass at scale.

CARBON STOCKS AND ACCUMULATION RATES

There is an urgent need to characterize the regional variability in carbon stocks and accumulation rates in seagrass meadows in Canada. Most seagrass carbon-sequestration data come from tropical and sub-tropical regions, and few studies have been conducted in Canada, with varying spatial and temporal scales (Table 6). As yet, no studies have estimated carbon sequestration by seagrass meadows in the Canadian Arctic, and there is currently no published seagrass carbon data for Newfoundland and Labrador. However, work is ongoing.

Studies that have quantified carbon sequestration in eelgrass meadows have measured different parts of the meadow, impeding regional comparisons. Carbon sequestration rates have only been estimated in intertidal and shallow subtidal eelgrass meadows in British Columbia (Postlethwaite *et al.* 2018; Prentice *et al.* 2019; Prentice *et al.* 2020) and results have indicated that carbon stocks per unit area and CARs are much lower than in tropical and subtropical eelgrass ecosystems. C:N ratios revealed that carbon predominantly originated from marine sources (Spooner 2015; Postlethwaite *et al.* 2018). By contrast, studies estimating blue carbon in seagrass meadows in Atlantic Canada have focused solely on aboveground or belowground biomass (no sediment estimates). Estimates of carbon ranged between approximately 25 and 38 per cent by weight, depending on the type of tissue measured (Schmidt *et al.* 2011; Hitchcock *et al.* 2017; Namba *et al.* 2018), and did not incorporate rates of sequestration.

Carbon stocks vary within and between seagrass meadows in Canada (and globally). This emphasizes the need for spatio-temporal estimates of carbon sequestration to validate extrapolated estimates to the national level (Postlethwaite *et al.* 2018; Ricart *et al.* 2020).

Factors that can affect carbon sequestration include distance from the estuary, water quality (e.g., salinity, pH, temperature), meadow configuration (e.g., canopy height, shoot density, patchiness, aboveground biomass and belowground biomass ratio), location in the meadow (i.e., inside vs. edge), nitrogen levels, sedimentation/sediment discharge/ sediment composition (fine sediments trap more carbon), and light availability (Schmidt *et al.* 2011; Postlethwaite *et al.* 2016; Hitchcock *et al.* 2017; Oreska *et al.* 2017; Ricart *et al.* 2020). The contribution of each of these variables may vary by region. If we could identify which variables best explain the variability in seagrass-sequestered carbon, we could better predict carbon stocks and sequestration rates in regions with no data.

Various methods have been used to measure carbon sequestration in Canadian seagrass meadows. These methods may use different-sized corers, sample to various depths, section cores at different depth intervals, measure different variables (e.g., ^{210}Pb, $\%C_{org}$, $\delta^{13}C$), and employ different laboratory approaches (e.g., loss on ignition vs. elemental analyzer). Studies have also focused on measuring different sections of the meadow. Some measure carbon in seagrass tissues only (e.g., Schmidt *et al.* 2011; Hitchcock *et al.* 2017; Namba *et al.* 2018), others in sediment only (e.g., Spooner 2015), and still others in both tissues and sediment (e.g., Postlethwaite *et al.*). Studies that measure only sediment carbon exclude carbon that is fixed via photosynthesis in the existing standing stock, downplaying the contribution of eelgrass meadows to the carbon budget. Furthermore, if we fail to account for variability in organic carbon sequestration between meadows and within meadows, we will produce inaccurate estimates of the regional/global contribution of seagrass to the carbon budget (Postlethwaite *et al.* 2016; Johannessen and MacDonald 2016). Adopting a standardized protocol for estimating carbon sequestration, like those described in Howard *et al.* (2014), will allow us to compare regions more accurately.


© Lewis Jefferies / WWF-Canada

Table 6. Summary of seagrass studies that measured seagrass carbon stock, carbon accumulation rates (CAR) and carbon sequestration in Canada.

Study	**Province**	**Portion of meadow measured**	**C_{org} (%)**	**CAR (g C m^{-2} y^{-1})**	**C stock (g C m^{-2})**
Prentice *et al.* 2020[1]	B.C.	top 25 cm			1846 154; range 600 – 5,125
		top 1 m			7,168
		Total	0.75	24.8; range 4.6 – 93.0	
Prentice *et al.* 2019	B.C.	top 0 – 5 cm			83 – 1089
		15 – 20 cm			59 – 1407
		Total	0.45 ± 0.02 (SE); range 0 – 2.98	22.4; range 4.6 – 33.1	
Postlethwaite *et al.* 2018	B.C.	AGB (intertidal)			16.78
		AGB (subtidal)			16.25
		BGB (intertidal)			6.17
		AGB (subtidal)			5.03
		Sediment	0.02 – 1.29		1343
		Total		10.8 ± 5.2	
Spooner 2015 (MSc thesis)	B.C.	Sediment	0.2 (estuary)	11.8	
			2.15 (deep basin)		
Namba *et al.* 2018	N.S.	AGB	~35*		
		BGB	~27*		
	N.B.	AGB	~32*		
		BGB	~25*		
	P.E.I.	AGB	~35*		
		BGB	~27*		
McGowan 2016	B.C.	Sediment	≤ 1.3 (sediment only)	0.1 – 0.3	
Hitchcock *et al.* 2017	N.B. (site 1)	ABG	36.67		
	N.B. (site 2)		37.64		
	P.E.I. (site 1)	ABG	36.34		
	P.E.I. (site 2)		35.97		
Schmidt *et al.* 2011	N.S.	ABG	36*		

AGB = aboveground tissue biomass; BGB = belowground tissue biomass

**approximated from a figure*

[1] *Not restricted to Canada*

GREENHOUSE GAS FLUXES

The GHG emission potential of seagrass ecosystems remains largely understudied, likely because these ecosystems are perceived as highly effective at accumulating and storing carbon. Several research studies on carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) fluxes from seagrass ecosystems have concluded that CH_4 and N_2O emissions are low (especially relative to salt marsh and mangrove ecosystems, e.g., Rosentreter *et al.* 2021) and that these systems remain carbon sinks when GHG emissions are accounted for (Asplund *et al.* 2022; Ollivier *et al.* 2022). One study on the GHG flux of a restored seagrass ecosystem found that even though the restoration activities resulted in an increase in CH_4 and N_2O emissions, the ecosystem remained a net sink of GHG emissions (Oreska *et al.* 2020). However, studies note that there is high temporal and spatial variability in GHG fluxes from seagrass ecosystems and outline the need to collect more data to understand the factors driving these fluxes (Rosentreter *et al.* 2021; Ollivier *et al.* 2022).

Given the limited number of studies and the high variability in GHG fluxes from seagrass ecosystems, more research is needed to understand these ecosystems' true potential to mitigate climate change. This is especially true as there may be understudied processes that result in a significant flux of GHGs to the atmosphere. For example, Liu *et al.* (2019b) found that seagrass beach wrack was a significant source of CO_2 emissions that is not taken into account when quantifying the GHG budget of seagrass ecosystems. Schorn *et al.* (2021) found that in a *Posidonia oceanica* meadow, the plants themselves were producing methylated compounds. These were a higher contributor of CH_4 flux than the fermentation of organic carbon buried in the sediments. Similar to carbon dynamics, GHG fluxes in seagrass meadows likely show large species and regional variability that needs to be quantified in order to assess the true climate change mitigation potential of an ecosystem and the feasibility and economics of using blue carbon within a carbon offsetting program (Ollivier *et al.* 2022). Many coastal Indigenous Peoples monitor seagrass systems through their Guardian programs; if the measurement of GHG fluxes from these systems aligns with the priorities of Guardian programs, partnering with and providing funding for Guardians to conduct this research could provide valuable information and support, filling the current data gaps while meeting Guardian program goals.

THREATS AND TRENDS

Seagrasses typically occur in shallow water at the land-sea interface, and are therefore susceptible to a wide range of impacts originating from human activities both on land and at sea (Orth *et al.* 2006; Waycott *et al.* 2009; Unsworth *et al.* 2019). Anthropogenic threats to seagrass meadows range from global to local, with multiple stressors often combining across spatial and temporal scales that cumulatively affect seagrass health (Orth *et al.* 2006). As a result, there is a high level of geographic variability, as well as uncertainty, underlying research identifying the specific driver(s) of change in seagrass ecosystems.

In Canada, seagrass meadows have been affected by many factors, including coastal development, overwater structures, nutrient loading, aquaculture, invasive species and commercial and recreational fishing/boating activities (Murphy *et al.* 2019; Murphy *et al.* 2021) (Table 7). These stressors can reduce water quality, limit light availability, and cause physical damage to eelgrass habitats. Climate change can also directly and indirectly harm eelgrass through changes to the physical environment. These include rising water temperatures, increasing turbidity due to sea-level rise and greater storm frequency/severity, and increasing carbonate concentration associated with acidification (Short and Neckles 1999; Wilson and Lotze 2019).

Severe declines in seagrass coverage are particularly prevalent in areas of intense human settlement (Quiros *et al.* 2017). For example, in the northeast U.S., an estimated 65 per cent of eelgrass has been lost in the populated and industrialized area south of Cape Cod (as of 2003) compared to 20 per cent north of Cape Cod where human population density is lower (DFO 2009).

A recent compilation of eelgrass surveys by the Canadian Environmental Sustainability Indicators Program (ECCC 2020), summarized by Murphy *et al.* (2021), identified 456 meadows across seven bioregions; of these, only 23 per cent had enough observations to assess trends over time. Accordingly, temporal trends in eelgrass biomass, extent and/or cover for the majority of meadows are not well known. Of the available surveys with trend estimates, 85 per cent were either increasing, in recovery, restored or stable, while 15 per cent experienced declines. However, there were clear differences in sample size and trends among coasts. For instance, 10 trend estimates were available for the Arctic-Subarctic — eight of which (80 per cent) were categorized as "in recovery" largely due to enhanced eelgrass cover following a decline in hydroelectric development in the James Bay region. By comparison, 57/61 (93 per cent) of Pacific meadows were assessed as stable, restored or increasing, while 11/36 (31 per cent) of Atlantic meadows were in decline. Temporal trends in eelgrass meadows also vary according to region. For example, within Atlantic Canada, eelgrass meadows have been assessed as stable or increasing along the Newfoundland and Labrador shelves, while declines have been reported in the southern Gulf of St. Lawrence and the Scotian Shelf (Hanson 2004; DFO 2009; Murphy *et al.* 2021). In fact, some locations in the Maritime provinces reported interannual declines of 30–95 per cent (DFO 2009) including several sites in Nova Scotia (Hanson 2004). Importantly, however, that variation in the timing and methodology of surveys, and the lack of standardized baseline data, means that these trends in eelgrass meadows must be interpreted very cautiously (Murphy *et al.* 2021).

Where known, the drivers of declines in eelgrass meadows also vary. In the southern Gulf Islands of B.C., loss of eelgrass meadow area and increase in meadow complexity correlated to increased shoreline activities, residential development and associated water-quality issues (Nahirnick *et al.* 2020). Along the Scotian shelf, major drivers of decline included urban and agricultural land use, poor water quality, commercial fishing, among many other anthropogenic activities. In contrast, regions with nearby protected land exhibited comparatively little human impact on eelgrass ecosystems — showcasing the importance of the land-sea interface and protected areas as a conservation tool. For example, on Nova Scotia's Atlantic coast, sites with a significant amount of protected adjacent land showed relatively little human impact compared with nearby locations that were affected by urban and agricultural use, poor water quality, commercial fishing and other activities. Impacted beds in the Gulf region were linked to differences in water quality, riparian land alteration and overwater structures, among other factors. And while an increase in eelgrass abundance has been reported in Newfoundland (DFO 2014), an expansion of invasive European green crab (*Carcinus maenas*) into coastal waters, first reported in 2007, has been linked with severe declines in eelgrass coverage at multiple sites in Placentia Bay (Matheson *et al.* 2016).

Much like elsewhere in Canada, baseline data for eelgrass distribution in the Canadian Arctic is lacking and thus temporal trends and patterns in drivers of decline have not been quantified. Some areas along the Arctic coast are expected to have an increase in eelgrass cover as a result of a climate-induced northward range shift (Krause-Jensen *et al.* 2020). Nevertheless, eelgrass populations in James Bay have historically experienced drastic declines since the 1970s (Consortium Genivar-Waska 2017), likely a result of decreased water salinity and clarity, and an overgrowth of seaweeds and epiphytes (Short 2019b).

Table 7. Summary of key threats to eelgrass meadows across Canada and globally with examples of key publications. This list is not comprehensive and additional threats are expected to impact eelgrass communities in Canada.

Stressor	**Atlantic**	**Pacific**	**Arctic**	**Global**
Eutrophication/water quality	Hitchcock *et al.* 2017; McIver *et al.* 2019	Nahirnick *et al.* 2020		Orth *et al.* 2006; Dunic *et al.* 2021
Aquaculture	Howarth *et al.* 2021	Tallis *et al.* 2009		
Climate change	Murphy *et al.* 2021; Krumhansl *et al.* 2020, 2021	Thom *et al.* 2014	Krause-Jensen *et al.* 2020	Orth *et al.* 2006
Green crab/invasive species	Malyshev and Quijón 2011; Garbary *et al.* 2014; Matheson *et al.* 2016	Howard *et al.* 2019		Orth *et al.* 2066
Boating and anchoring/ mooring	Murphy *et al.* 2019	Nahirnick *et al.* 2020		Unsworth *et al.* 2017
Coastal development	Murphy *et al.* 2019	Nahirnick *et al.* 2020		Dunic *et al.* 2021

A key challenge posed by loss of seagrass coverage is the potential for feedback loops that reinforce a degraded state and limit natural recovery or restoration (van der Heide *et al.* 2011). Seagrasses trap and stabilize suspended sediments, improving water clarity and light availability. When seagrass loss occurs, this effect is dampened or lost, and formerly stable sediments can be resuspended. If turbidity exceeds a threshold following seagrass loss, growing conditions may no longer be suitable for re-establishment. This is an important factor to consider when selecting sites for restoration of eelgrass meadows (see below) and highlights the importance of preserving and protecting natural meadows.

RESTORATION POTENTIAL

Restoration of seagrass meadows aims to mitigate population declines and recover ecological functions and ecosystem services, including carbon sequestration. However, success rates of seagrass-restoration projects around the world have been highly variable to date (van Katwijk *et al.* 2016). This suggests that we continue to face challenges regarding seagrass restoration, and need additional research to improve the chances of long-term success (Macreadie *et al.* 2021). Nevertheless, there are reasons for optimism: some prominent successes provide evidence that large-scale restoration of damaged or lost seagrass meadows is possible (e.g., Virginia coastal lagoons, Rezek *et al.* 2019; Orth *et al.* 2020). On the east coast of the United States, restoration of *Z. marina* has been shown to increase carbon sequestration of a site over time (Greiner *et al.* 2013); this added benefit could promote future restoration of eelgrass meadows specifically for climate-mitigation purposes. However, considerable challenges regarding seagrass restoration exist and require well-researched solutions to improve the chances of long-term success (Macreadie *et al.* 2021).

There are two main methods of restoring seagrass: transplanting adult shoots and seeding (Busch *et al.* 2010). Regardless of which method is selected, potential sites must be evaluated to ensure that they are suitable for restoration. Restoration sites may be deemed ineligible if they possess characteristics — such as heavy wave action or nutrient loading — that would inhibit eelgrass establishment, or if the primary cause for seagrass loss is not addressed. Where large-scale seagrass loss has occurred, meadows may struggle to recover naturally and/or through restoration due to feedback loops that degrade suitable habitat conditions following initial seagrass loss (e.g., Wilson and Garbary 2019). If shoots are being transplanted, donor sites should be selected carefully to increase the probability of restoration success, and to limit the degradation of donor sites. Harvesting donor shoots (Novak *et al.* 2017) or seeds (Reynolds *et al.* 2012) from multiple source meadows should be considered to increase the resilience of the restored meadow and limit stress on donor sites.

In Canada, most eelgrass-restoration projects have transplanted harvested adult shoots from nearby donor meadows. This method has varied levels of success depending on trial size and removal of threats (van Katwijk *et al.* 2016). Transplanting methods are more commonly used in smaller-scale restoration projects, whereas seeding has been found to be more effective for larger-scale projects (Busch *et al.* 2010). While records of eelgrass-restoration projects in Canada date back to the 1990s (ECCC 2020a), recent projects funded by Fisheries and Oceans via the Coastal Restoration Fund (CRF) have enhanced the scale and extent of seagrass recovery along Canada's coasts (DFO 2019a; Table 8).

Table 8. Summary of projects funded by Coastal Restoration Fund that highlight eelgrass restoration as a key component.

Region	Project Title	Fund Allocation	Source
British Columbia	Salish Sea Nearshore Habitat Recovery Project	$1,309,333	SeaChange Marine Conservation Society n.d.
British Columbia	Restoring marine habitat around log handling facilities in Haida Gwaii	$1,162,263	Fisheries and Oceans Canada 2021a
Newfoundland and Labrador	Coastal management and restoration of Elmastukmek (Bay of Islands), NL	$778,726	Fisheries and Oceans Canada 2021b
Newfoundland and Labrador	Restoring a healthy Placentia Bay coastal ecosystem	$4,779,255	Fisheries and Oceans Canada 2021b
Quebec	Joint action plan on coastal habitat restoration in Innu communities on the North Shore of the Estuary and the Gulf of St. Lawrence	$1,200,000	Fisheries and Oceans Canada 2021d
Quebec	Integrating local and scientific knowledge into the restoration of ecologically valuable coastal ecosystems in the estuary and Gulf of St. Lawrence	$555,000	Fisheries and Oceans Canada 2021d

Elsewhere in Atlantic Canada, Wilson and Garbary (2019) compared eelgrass transplant survival at two sites in Nova Scotia. They found very low shoot survival at a heavily impacted site where a formerly lush meadow had been extirpated, likely due to European green crab activity. In contrast, survival was high at an intact control site. Parks Canada has conducted green crab control and eelgrass restoration at the Kejimkujik Seaside Adjunct on Nova Scotia's south shore. Eelgrass coverage at this site rebounded to 34 per cent after hitting a low mark of 2 per cent of 1987 coverage (Parks Canada 2020).

POTENTIAL OF NATURAL CLIMATE SOLUTIONS

Seagrass meadows provide numerous ecosystem services in addition to GHG emission-mitigation, including providing habitat for fish species (Jackson *et al.* 2001), improving water quality (Moore 2004), removing nitrogen through denitrification (Reynolds *et al.* 2016) and attenuating wave energy (Bradley and Houser 2009; Reidenbach and Thomas 2018). Seagrass meadows also provide valuable social and cultural services, although these have received less attention in published literature (Ruiz-Frau *et al.* 2017). An estimated 3 per cent of seagrass meadows within Canadian waters are in decline (Drever *et al.* 2021); however, NCS that result in robust protection and management could prevent further degradation of these ecosystems, safeguarding the services they provide. Where seagrass meadows have already been lost, restoration can increase the speed of recovery relative to natural processes and successfully bring back ecosystem services (Reynolds *et al.* 2016).

A recent paper by Drever *et al.* (2021) quantified the NCS potential of seagrass in Canada for the first time. The authors estimated the CO_2e reduction potential for avoided conversion and restoration of seagrass meadows. Overall, the carbon-mitigation potential for seagrass as a NCS is low relative to other pathways quantified by Drever *et al.* (2021); the annual mitigation potential was estimated at 0.1 Tg CO_2e yr^{-1} and < 0.1 Tg CO_2e yr^{-1} in 2030 for the avoided conversion and restoration pathways, respectively. The cumulative potential to the year 2050 was estimated at 1.4 and 2.8 Tg CO_2e for the avoidance and restoration pathways, respectively. For comparison, the authors estimated the annual mitigation potential of avoided conversion of grasslands at 12.7 Tg CO_2e yr^{-1}, and the restoration of forest cover at 24.86 Tg CO_2e yr^{-1} in 2030. The relatively low mitigation potential of seagrass systems is likely driven by the limited area of current seagrass beds and potential restoration sites. While seagrass meadows have a high potential for GHG mitigation, their estimated total area in Canada is only 192,469 ha (although this is likely an underestimate given the gaps in seagrass mapping) (Drever *et al.* 2021).

Given the important services that seagrass meadows provide and their high area-based GHG mitigation potential, NCS that protect and restore seagrass ecosystems are valuable despite the relatively low estimates for GHG mitigation (Drever *et al.* 2021). As well, the numerous data gaps detailed in the above sub-chapters relating to the extent, carbon stocks and CAR of seagrass ecosystems across the country provide a caution for discounting seagrass protection and restoration as an NCS. While Drever *et al.* (2021) provide a first estimate of the GHG mitigation potential of seagrass meadows based on the best available data, continued research along Canada's coastlines will improve our understanding of the potential of seagrass meadows as an NCS.

RECOMMENDATIONS FOR SEAGRASS

- ✓ Address barriers to implementing and monitoring NCS in seagrass habitats.
- ✓ Share restoration best practices from coast to coast to coast to improve the success rate of seagrass-restoration projects.
- ✓ Increase research on the factors driving carbon storage, accumulation and sequestration in seagrass ecosystems to support the development of more accurate region-specific estimates.
- ✓ Connect seagrass mapping efforts, adopt standardized protocols and use new technology to improve understanding of seagrass distribution and carbon dynamics to further the protection and management of these important habitats.
- ✓ Support and build partnerships with Indigenous communities and local communities in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on seagrass. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).


© Lewis Jefferies / WWF-Canada

SALT MARSH

Allen Beck, Becky Dodge, Brianne Kelly, Sarah Kent and Abby McCarthy

GLOBAL AND NATIONAL CONTEXT

Salt marshes are coastal marshes that are regularly flooded with salt water by the tidal cycle. They range in salinity from 18 to 35 ppt. Salt marshes can accumulate carbon at rates similar to those of mangrove ecosystems, and higher than those of seagrass and terrestrial ecosystems (McLeod *et al.* 2011). Their ability to out-pace carbon accumulation rates (CAR) in terrestrial ecosystems stems in part from the fact that they accrete carbon vertically; vertical accretion can also enable salt marsh elevation to keep pace with sea-level rise if there is a sufficient supply of mineral sediment or organic matter (Andersen *et al.* 2011). Salt marshes also provide numerous ecosystem services such as shoreline protection (Shepard *et al.* 2011), contaminant remediation (Mahmoudi *et al.* 2013), nursery habitat for commercially important fish species and recreational value (Barbier *et al.* 2011).

Despite the importance of salt marshes, large data gaps remain in our understanding of their distribution and carbon dynamics (Macreadie *et al.* 2021). Salt marsh area in Canada was recently estimated at 3,602 km^2, although this is an underestimate as 1,304 km of coastline classified as salt marsh have not been mapped for area measurements (Rabinowitz and Andrews 2022). Based on mapping efforts in Canada, the United States, Europe and South Africa, a conservative estimate of global salt marsh area is 22,000 km^2 (Chmura *et al.* 2003); however, this estimate requires updating. Global salt marsh loss was recently estimated at 0.26 per cent per year (Campbell *et al.* 2022); no recent estimate for salt marsh loss in Canada was found. Estimates of global salt marsh CAR range from 18 to 1713 g C m^{-2} yr^{-1} with an average of 57.2 g C m^{-2} yr^{-1} (Chmura *et al.* 2003). The wide range of CAR estimates, the age of these estimates and the Canada-specific data gaps suggest that more research is needed. We also need research into the potential of salt marshes to act as NCS and their vulnerability or resilience to climate change and sea-level rise.

MAPPING AND MONITORING

Compiled by Rabinowitz and Andrews (2022), the most recent estimate of salt marsh extent in Canada (3,602 km^2) made use of the best available data; however, Canada's coastlines have not been fully mapped. The Rabinowitz and Andrews (2022) estimate was compiled using ArcMap 10.8.1 from international, federal and provincial remote-sensing and satellite datasets, some of which were ground-truthed. The Hudson Bay area has the largest mapped area of salt marsh (2,271 km^2), with substantial mapped areas also present in the Gulf of St. Lawrence (309 km^2), the Scotian Shelf (Nova Scotia and New Brunswick) (214 km^2) and the north coast of British Columbia (635 km^2) (Rabinowitz and Andrews 2022). Significant gaps in mapping remain for Newfoundland and Labrador and the northern coastline (Rabinowitz and Andrews 2022).

Salt marshes can be mapped on the ground through field sampling. Though the most accurate, this method is also time intensive and challenging if the goal is to map at scale. There are several techniques for mapping salt marsh remotely, but each has drawbacks and must be validated with field sampling. For example, aerial photography can be collected by plane or Remotely Piloted Aircraft System (RPAS) and analyzed to delineate salt marsh boundaries. Satellite imagery can also be used to delineate salt marsh boundaries and vegetation characteristics (Darvishzadeh *et al.* 2019; Blount *et al.* 2022). Freely available satellite data make this approach relatively accessible. Some satellite data go back decades, so satellite imagery can be used to track changes in salt marsh boundaries over time (Blount *et al.* 2022). However, the spatial resolution of satellite imagery has improved over time; the lower resolution of older imagery limits the ability to detect small changes over time and can result in over- or underestimating both erosion and accretion (Blount *et al.* 2022).

Marsh boundaries and vegetation can be delineated with light detection and ranging (LiDAR) derived digital elevation models (DEMs) (Pinton *et al.* 2021; van Ardenne and Chmura 2021). LiDAR is less time intensive than, say, manually tracing marsh boundaries based on aerial photographs (van Ardenne and Chmura 2021). However, LiDAR can have difficulties delineating microtopography such as tidal pools and channels as well as along the edge of rivers (van Ardenne and Chmura 2021). LiDAR-derived DEMs have been used to evaluate salt marsh sites suitable for restoration by comparing elevation between an undisturbed reference site and a degraded site that is a candidate for restoration (Millard *et al.* 2013). Multispectral imagery can be used to characterize vegetation communities in salt marshes by using different wavebands to discriminate among plant species, biomass, density and physiological state (Doughty and Cavanaugh 2019; Norris *et al.* 2022).

CARBON STOCKS AND ACCUMULATION RATES

Salt marshes are complex ecosystems. Their ability to sequester and store carbon is influenced by a number of factors, including sea-level rise (Connor *et al.* 2001), tectonic activity (Chastain *et al.* 2018), sediment supply (Chmura *et al.* 2003; Fagherazzi *et al.* 2013), proximity to tidal channels (Chmura and Hung 2004; Moffett *et al.* 2010), elevation (Moffett *et al.* 2010), vegetation type (Gailis *et al.* 2021) and tidal inundation (Chmura *et al.* 2003). Within a given salt marsh, carbon stocks and carbon accumulation rates (CAR) vary across abiotic and biotic gradients. To partially account for spatial differences in carbon stocks and CAR, salt marshes are routinely separated into "high" and "low" marsh for sampling. High marsh habitat is inundated with tidal water once or twice a month, while low marsh areas are inundated with tidal water daily. Each zone exhibits distinct plant communities (Bertness 1991).

Carbon stocks and accumulation rates have been measured for several salt marshes on the east and west coasts of Canada (Table 9). There is a wide range in both carbon stocks and CAR among marshes and within marshes between low and high areas, and the differences within marshes do not exhibit reliable trends. There can also be differences in how stocks and accumulation rates are measured and/or reported, which complicates direct comparisons. However, in general, several studies have noted that carbon accumulation rates in Canadian salt marshes tend to be lower than the global average, recently estimated at 244.7 g C m^2 yr^{-1} (Ouyang and Lee 2014; Chastain *et al.* 2018; Gailis *et al.* 2021; Douglas *et al.* 2022). Overall, the variability in carbon stocks and accumulation rates among and within sites emphasizes the need for continued research and data collection, as well as investigations into the mechanisms that drive salt marsh carbon dynamics.

Table 9. Per cent organic carbon, carbon accumulation rates (CAR) and carbon stock measurements in Canadian ecosystems.

Study	Province	Location in marsh sampled	C_{org} (per cent)	CAR (g C m^{-2} yr^{-1})	C stock (Mg C ha^{-1})
Chastain and Kohfeld 2016	B.C. (Clayoquot Sound)	Range		75 – 264	35 – 113* 56.4 – 173**
		Regional average		173	80.6 ± 43.8* 126 ± 71.2**
Chastain *et al.* 2018	B.C. (Clayoquot Sound)	Average across seven salt marshes		146 ± 102	80.6 ± 43.8
Chastain *et al.* 2022	B.C. (Clayoquot Sound)	Average ± SE (to the base peat layer)	20 ± 1	184 ± 50	67 ± 9
		High marsh only	21 ± 2	303 ± 45	80 ± 14
		Low marsh only	18.5 ± 2	63.5 ± 7	52 ± 8
Connor *et al.* 2001	N.B. Bay of Fundy (average accumulation rates over 30 year period)	High marsh, outer bay		188	
		High marsh, upper bay		194	
		Low marsh, outer bay		76	
		Low marsh, upper bay		39	
Douglas *et al.* 2022	B.C. Cowichan Estuary	Soil		68.21 ± 21	58.78 ± 19.3
Gailis *et al.* 2021	B.C. Boundary Bay	High marsh	11.3 ± 4.9	198.1 ± 228.9	83.3 ± 29.3
		Low marsh	4.3 ± 2.6	75.0 ± 68.4	39.3 ± 24.2
Chmura *et al.* 2003	N.B. Bocabec River			456	
	N.B. Bocabec River			113	
	N.B. Dipper Harbour			445	
	N.B. Dipper Harbour			94	
	N.B. Cape Enrage			582	
	N.B. Cape Enrage			186	
	N.B. Lorneville			277	
	N.B. Lorneville			330	
	N.B. St. Martins			265	
	N.B. St. Martins			928	
	N.B. Wood Point			264	
	N.B. Wood Point			253	
Chmura and Hung 2004 as reported in Chmura *et al.* 2003	N.B. Kouchigouguacis			102	
	N.B. Bay St. Louis			93	
	N.B. Tabousintac Bay			66	
	P.E.I. Malpeque Bay			71	
	P.E.I. Brackley Bay			89	
	N.S. Pubnico Harbour			113	
	N.S. Cheboque Harbour			75	
	N.S. Little River Harbour			304	
	N.S. Cole Harbour			161	
	N.S. Lawrencetown Lake			60	
	N.S. Chezzetcook Inlet			106	
	P.E.I. Rustico Bay			125	

**Method 1: soil carbon density for 1 cm samples summed to the depth of refusal*

***Method 2: average soil carbon density estimated for each core and multiplied by the depth of refusal*

GREENHOUSE GAS FLUXES

Several factors influence the magnitude of GHG fluxes from salt marshes at temperate latitudes, including temperature (Abdul-Aziz *et al.* 2018), tidal inundation/water table level (Abdul-Aziz *et al.* 2018; Capooci *et al.* 2019), salinity, plant biomass (Magenheimer *et al.* 1996), nutrient loading (Chmura *et al.* 2016; Martin *et al.* 2018; Moseman-Valtierra *et al.* 2022) and animal activity such as crab burrowing (Agusto *et al.* 2022; Grow *et al.* 2022) (Table 10). However, the extent to which these factors influence GHG fluxes varies across sites, and different factors may interact, complicating the dynamics of salt marsh GHG fluxes. For example, the effect of water level on CH_4 fluxes is variable and likely involves an interaction with salinity and nutrients. High water levels typically increase CH_4 emissions in freshwater wetlands (Knox *et al.* 2021), but the situation in tidal marshes is complicated by additional interactions with salinity (a proxy for sulfate) and nitrate, which by themselves tend to lower CH_4 emissions (Poffenbarger *et al.* 2011; Bridgham *et al.* 2013; Holm *et al.* 2016; Krauss *et al.* 2016). Indeed, the influence of inundation on CH_4 emissions in tidal marshes varies across studies, and even on a global scale, there is not yet enough information on the effects of regular and episodic flooding to make general predictions about the CH_4 response to inundation (Al-Haj and Fulweiler 2020). The influence of salinity is a bit more predictable, at least in higher-salinity marshes (Poffenbarger *et al.* 2011), but even polyhaline (> 18 ppt) marshes can emit some CH_4 (Conrad 2020). Lastly, it is still unclear whether nitrogen loading has a positive or negative effect on CH_4 emissions, with both experimental results represented in the literature (Al-Haj & Fulweiler 2020).

The net fluxes of CO_2, CH_4 and N_2O have been measured at several salt marsh sites on the east coast of Canada (Table 11). The limited number of sites for which data is available and the complexity of gas fluxes from salt marsh habitats point to the need for additional research within Canada to increase understanding of the magnitude of GHG fluxes across the full range of physical, chemical and biological conditions.

Table 10. Factors which can affect GHG flux in salt marsh.

Factor	Effect on GHG flux	Examples
Temperature	Net CO_2 uptake (i.e., NEP) or gross CO_2 uptake (i.e., Photosynthesis) increases with increased temperature. CH_4 is also a strong function of temperature.	Abdul-Aziz *et al.* 2018
Tidal inundation/water table depth	Drier conditions typically reduce CH_4 emissions and enhance ecosystem respiration (i.e., higher CO_2 emissions).	Magenheimer *et al.* 1996; Abdul-Aziz *et al.* 2018; Capooci *et al.* 2019
Salinity	Salinity can be a proxy for sulfate; as sulfate levels increase, methanogenic archaea are outcompeted, reducing CH_4 production and emissions.	Magenheimer *et al.* 1996
Plant biomass	Higher plant biomass can result in higher respiration rates (increased CO_2 emissions) and higher CH_4 emissions for sites that are CH_4 sources. Higher plant biomass can result in higher productivity (seasonally dependent) resulting in increased CO_2 uptake.	Magenheimer *et al.* 1996
Nutrient loading	Nitrogen loading leads to increased N_2O emissions Nutrient loading can increase productivity, leading to increased uptake of CO_2, and positive or negative effects on CH_4 emissions.	Chmura *et al.* 2016; Martin *et al.* 2018; Moseman-Valtierra *et al.* 2022
Animal activity	CO_2 and CH_4 emissions increase with crab burrowing activity.	Agusto *et al.* 2022; Grow *et al.* 2022

© Jarrett Corke / WWF-Canada

Table 11. CO_2, CH_4 and N_2O net flux data from studies conducted in Canadian salt marshes. Note that multiple studies report measurements for the same salt marsh.

Study	Location	Site characteristics	Sampling frequency	CO_2 (mmols m^{-2} hr^{-1})	CH_4 (µmol m^{-2} hr^{-1})	N_2O (µmol m^{-2} hr^{-1})
Chmura *et al.* 2016	N.B. Kouchibouguac, Gulf of St. Lawrence	Microtidal, unfertilized	Monthly 2011-2012	13	0.23	-0.05
				0.16	0.30	0.30
	Microtidal, N fertilization		19			
				-0.24	0.52	0.52
	Microtidal NPK fertilization		28			
	N.B. Dipper Harbour, Bay of Fundy	Macrotidal, unfertilized	Monthly 2011-2012	12	1.29	-0.07
				1.26	0.08	0.08
	Macrotidal, N fertilization		15			
				0.77	1.70	1.70
	Macrotidal NPK fertilization		19	1.21	0.35	0.35
	Macrotidal high N/low P		21			
Chmura *et al.* 2011	N.B. Dipper Harbour	microtidal	August 2006	11 ± 6	1.2 ± 3.6	0.30 ± 0.68
	N.B. Kouchoboiguac	macrotidal	August 2006	9 ± 5	0.80 ± 1.75	0.13 ± 1.63
Roughan *et al.* 2018*	P.E.I. Wilmot	Agricultural land use; high marsh	Monthly June-October 2013		0.04	0.03
	P.E.I. Indian River	Agricultural land use; high marsh	Monthly June-October 2013		0.05	0.18
	P.E.I. Tryon	Agricultural land use; high marsh	Monthly June-October 2013		0.03	0.09
		Low marsh		5.79	0.30	0.30
	P.E.I. DeSable	Agricultural land use; high marsh	Monthly June-October 2013		0.03	0.17
		Low marsh			2.21	6.83
	N.B. Kouchibouguac	Reference site; high marsh	Monthly April - November		0.35	0
Magenheimer *et al.* 1996	N.B. Dipper Harbour; results reported by dominant plant community within the marsh	Low marsh	Weekly July-September 1993	2.5 ± 0.5	1.5 ± 0.3	
			2.6 ± 0.4	1.6 ± 0.9		1.6 ± 0.9
	Middle marsh					
			2.2 ± 1.0	1.3 ± 0.4		1.3 ± 0.4
	High marsh					
			2.3 ± 0.6	9.6 ± 9.2		9.6 ± 9.2
	Upland edge		2.2 ± 0.7	4.1 ± 3.8		4.1 ± 3.8
			0.7 ± 0.3	2.9 ± 2.7		2.9 ± 2.7
	Panne					
	Pool					

Overall average calculated from monthly averages; monthly averages available in publication supplemental material

THREATS AND STATUS OF SALT MARSHES IN CANADA

Drivers of salt marsh loss in Canada include land conversion (e.g., agriculture) and coastal development (e.g., industrial, commercial, residential) (Fraser River Study Steering Committee 1978; Government of Canada 1991 Government of New Brunswick 2002; Government of Nova Scotia 2011). Historically, land conversion for agricultural purposes in Canada has accounted for 85 per cent of wetland loss or conversion. In comparison, urban and industrial expansion has accounted for 9 per cent (Government of Canada 1991). One older estimate suggests 0.5 ha of wetlands may be lost every minute due to agriculture and development (Bond *et al.* 1992). The extent of salt marsh loss in Canada is unknown or comes with great uncertainty. However, limited information is available for parts of Canada, such as the Maritime provinces and parts of British Columbia.

In the Maritimes (Nova Scotia, New Brunswick, Prince Edward Island), two-thirds of coastal salt marshes have been lost to extensive diking for drainage and agriculture (Government of Canada 1991; Austen and Hanson 2007). The Government of Nova Scotia estimated that 50 per cent of salt marshes had been lost province-wide since the early 1700s due to diking and land conversion (Government of Nova Scotia 2009). The loss of salt marsh ecosystems in New Brunswick is estimated to be even higher (65 per cent) due to agriculture and land conversion (Government of New Brunswick 2002). The Bay of Fundy, a shore zone connecting New Brunswick and Nova Scotia, contains the largest portion of salt marsh in the Maritime region (53 per cent) (Hanson and Calkins 1996; Neily *et al.* 2003). The Bay of Fundy has seen the most extensive loss, with estimates ranging between 65 and 69 per cent (Government of Canada 1991; Hanson and Calkins 1996). Prince Edward Island wetlands only cover 5.6 per cent of the land base, but salt marshes account for a large portion of this (21 per cent). The extent of salt marsh loss in P.E.I. is unknown, but has similarly been driven by agriculture, urbanization and shoreline development (Government of Prince Edward Island 2003).

In British Columbia, the main sources of historical salt marsh loss or degradation are coastal development and land conversion to agriculture (Government of Canada 1991). It is estimated that 70 per cent of salt marshes have been lost province-wide (Government of Canada 1991). The estimated loss of salt marshes in the Lower Mainland of British Columbia is even higher at 80 per cent (Government of Canada 1991). Climate change, invasive species, and the filling and draining of wetlands pose additional direct and indirect threats to salt marshes in B.C. (Wetland Stewardship Partnership 2010).

When salt marshes are lost in Canada, so is the carbon stored in these systems. To maintain blue carbon ecosystem services, mitigate climate impacts and contribute to international climate targets, we urgently need to protect and restore salt marshes, preventing any further loss and recovering the damage that has occurred (Sutton-Grier and Moore 2016; Moomaw *et al.* 2018).

POTENTIAL OF NATURAL CLIMATE SOLUTIONS

Due to their unique characteristics, healthy salt marshes may act as carbon sinks. Through NCS, there are opportunities for degraded and/or drained salt marshes to provide this ecosystem service as well. Conservation, management and restoration, including adaptations to sea-level rise, are major themes in salt marsh research in Canada (Beauregard and Holcomb 1984; Chmura and Hung 2004; Bowron *et al.* 2012; Coulombier *et al.* 2012; Millard *et al.* 2013; Tuihedur Rahman *et al.* 2019; Drever *et al.* 2021; Macreadie *et al.* 2021; Billah *et al.* 2022). In addition to climate-change mitigation, NCS of salt marshes provide a suite of environmental and social benefits and can be implemented at various scales (Townsend *et al.* 2020; Drever *et al.* 2021).

A study by Drever *et al.* (2021) identifies 24 distinct NCS pathways that could be applied to various terrestrial and aquatic ecosystems in Canada. These pathways include a combination of improved management techniques and best practices, protection of existing ecosystems, and restoration activities. The study identifies pathways for forests, agricultural land, and wetland ecosystems (peatlands, freshwater mineral wetlands, seagrass beds and salt marshes). It identifies one pathway as a potential NCS for temperate salt marshes in Canada: salt marsh restoration in the Atlantic coast. This pathway uses a restorative approach that focuses on restoring or reclaiming drained salt marsh ecosystems to decrease GHG emissions (or enhance GHG uptake), thereby leading to climate cooling. The study identified 441.13 km^2 of "dikeland" (a salt marsh that has been diked and drained to create agricultural land) in Quebec, New Brunswick and Nova Scotia as potential sites for salt marsh restoration. Only areas that could be reflooded without damaging infrastructure and buildings were considered. Drever *et al.* (2021) also consider a protection approach for three types of wetlands (freshwater inland, eelgrass beds and peatlands), but do not extend this NCS to salt marshes. Conservation and protection of existing salt marsh ecosystems that would otherwise have been drained (e.g., through existing or strengthened legislation) may be prioritized over restoration actions, as conservation and improved environmental management are typically less invasive and more cost effective (Drever *et al.* 2021). We need further study into NCS for salt marshes in Canada to fill gaps in the literature, and to fully understand the benefits and impacts (e.g., cultural, socioeconomic) of these activities.

Protection and Management of Salt Marshes in Canada

When adequately protected, salt marshes can mitigate climate change while simultaneously providing essential ecosystem services, including biodiversity conservation and coastal protection for climate-change adaptation (e.g., storm buffering) (Sutton-Grier and Moore 2016; Moomaw *et al.* 2018). Broad-scale protection and management of these coastal ecosystems and the land-sea interface safeguard valuable carbon sinks. Marine Protected Areas, National Parks, National Wildlife Conservation Areas, Migratory Bird Sanctuaries, and other federal areas established for conservation purposes can protect coastal marshes and, in turn, blue carbon (Government of Canada 1991; Howard *et al.* 2014; Moomaw *et al.* 2018; Carlson 2020). These established protection measures offer direct (e.g., MPAs) and indirect protection (e.g., terrestrial protected and conserved areas). Within Canada, provinces and territories have adopted different approaches to coastal protection.

The degree of salt marsh protection varies between provinces and municipalities in the Atlantic provinces. For example, Nova Scotia is establishing the Coastal Protection Act (2021) to protect sensitive coastal ecosystems from development and climate change-related threats. Nova Scotia, New Brunswick and Prince Edward Island have all adopted Wetland Conservation Policies to protect and manage wetlands (Government of New Brunswick 2002; Government of Prince Edward Island 2003; Government of Nova Scotia 2011).

Salt marshes in British Columbia are protected to some degree by various municipal, provincial and federal laws and regulations. Federal policies, laws and regulations for wetlands and associated ecosystems exist and can be essential tools for protecting and managing salt marsh ecosystems and blue carbon (WWF-Canada 2022). However, the level of protection varies depending on the location and the development type, and responsibility for wetland management is often shared among various authorities. Initiatives favourable to wetland conservation include the B.C. Conservation Framework, Riparian Areas Regulation, and the B.C. Climate Change Strategy (Wetland Stewardship Partnership 2010). It is important to note that no single statute directly addresses the loss of wetlands (and consequently salt marshes) in B.C. (Wetland Stewardship Partnership 2010). B.C. has acts and regulations to manage and allocate water in relation to wetlands (e.g., Water Sustainability Act 2014), but other policies may directly or indirectly impact these management practices. The B.C. Wetland Action Plan (2010) is one guide to protecting and conserving current wetlands, and restoring ones that have been damaged or destroyed.

Salt Marsh Restoration on the East Coast

Given its long history of draining salt marshes for agricultural purposes, the East Coast of Canada has seen considerable loss of salt marsh habitat. Recently, there has been increased interest in restoring these habitats (Waltham *et al.* 2021) as they have been shown to provide valuable habitat, protect coastal infrastructure, and contribute to climate-change mitigation and adaptation. Generally, there are three coastal regions, each of which contains a distinct combination of hydro- and geomorphological conditions (Hatcher *et al.* 1981; Roberts and Robertson 1986; Wells and Hirvonen 1988): the Bay of Fundy, the Atlantic Coast and the Gulf of St. Lawrence. The Bay of Fundy is a sediment-rich megatidal system where historical diking, and therefore salt marsh loss, has been extensive (Ganong 1903). The Atlantic Coastal zone is predominantly rocky shore, with salt marsh pockets at the mouths of estuaries and tidal creeks (Chagueé-Goff *et al.* 2001). Within the Gulf of St. Lawrence, the Northumberland Strait contains comparatively warm waters (~19^{o}C average August sea surface temperature; DFO 2021c) and a tidal regime that changes from diurnal to semidiurnal and mesotidal to microtidal, depending on the local conditions. Restoration of salt marshes must be adjusted to the variability between sites (e.g., elevation profiles, sediment supply in the tidal water, hydrological restrictions, historical landscape modifications, etc.; Waltham *et al.* 2021). Hydrology is the most important factor influencing salt marsh functioning and restoration (Warren *et al.* 2002; Montalto and Steenhuis 2004; Bowron *et al.* 2012). To restore salt marshes, we generally need to identify how the hydrology of a site has been altered, and then restore regular tidal flooding.

Salt marsh restoration is often complicated by the high amount of coastal private landownership. Approximately 86 per cent of Nova Scotia's coastline is privately owned (Figure 2; CBCL Limited 2009). Often, restoration projects require the involvement of and permission from multiple landowners. This can be difficult since the value of salt marsh habitat is not necessarily understood or appreciated by the public, and restoration often involves relinquishing owned land "back to nature." Restoration can be further complicated by the need to involve government bodies, who may have higher priorities than habitat restoration or experience difficulty working on the short timeframes that constrain grant-funded programs (which provide much of the current funding for coastal restoration work on the East Coast). The local government bodies required to complete salt marsh restoration often include those that oversee agriculture, transportation, public lands, forestry and parks.

A wide variety of salt marsh restoration projects have been undertaken, specifically over the last 40 years (e.g., Bowron *et al.* 2012; DFO 2019a). These projects have seen varying levels of success because of variability in approaches and site characteristics. Salt marsh projects on the east coast have covered a broad spectrum in terms of restoration techniques and scale (both spatial and budgetary). The project case studies below showcase these various scales, the techniques currently being applied on the east coast, and the long-term success and progression of restoration. Examples only, these cases do not cover the full extent of restoration projects and techniques used.

Small-Scale Restoration: The Brule Shore Salt Marsh Restoration Project

The Brule Shore Restoration Project, near Tatamagouche (Taqamiku'jk), Nova Scotia (i.e., Northumberland Strait), is an example of a small-scale restoration project (restoring approximately 0.01 km^2 of habitat) addressing historical landscape modifications. The project was one component of a multi-part, $2.4 million Northumberland Strait saltwater marsh restoration program funded by Fisheries and Oceans Canada under the Coastal Restoration Fund (CRF) (DFO 2021g).

More than 70 years ago, a dike was erected through the middle of the marsh parallel to the shoreline, dividing the high and low marsh zones, and a large ditch was dug through the middle of the marsh perpendicular to the shoreline (Figure 3). Ditch spoils were left on the banks, raising the edge of the ditch. The elevated ditch edge and the remnant dike impounded a shallow pool of water on the marsh surface. Sitting high in the tidal frame, this pool was only very rarely inundated by tidal water. In consequence, the pool was hyper-saline (nearly 60 ppt) and would frequently dry up entirely in the hot summer months (Figure 4). It was decided to restore this marsh because this impoundment did not provide valuable habitat for either fish or vegetation. This project was carried out by Clean Foundation in 2020 as part of their CRF project on restoring salt marsh habitat in the Northumberland Strait.

To address the impoundment, volunteers dug "runnels" through the built-up creek edge to restore hydrological connectivity to the tidal creek (Figure 5) in October 2020. Runnels are shallow ditches (~15 cm deep) dug through the marsh to assist in moving surface waters and restore hydrological connectivity through a site. One year after the installation of runnels, there was natural revegetation of *Spartina alterniflora* along the edges of the former impoundment (Figure 6). This is a hardy, halophytic grass that dominates the low marsh, where environmental stress is high. Two years after restoration, revegetation had begun in the inner areas of the site (Figure 7). Revegetation is expected to continue throughout the former impoundment, likely becoming fully dominated by *S. alterniflora* over the five years following restoration, given the timelines of similar projects. It is uncertain what the long-term vegetation community will look like as restored marshes can remain distinct in their community structure compared to unimpacted marshes (Byers and Chmura 2007; Mossman *et al.* 2012). Given the recency of this work, its impact on carbon sequestration and GHG fluxes of the marsh is yet to be determined. Small-scale restoration projects — accessible to small organizations with limited budgets — can meaningfully improve the functioning of a salt marsh and potentially carbon sequestration.

Here are two more examples of small-scale restoration projects on the East Coast:

- The Kensington Estuary Restoration Project was completed by the P.E.I. Watershed Coalition in 2021. The project aimed to improve fish habitat in the streams of Hunter's Creek and Baltic River and surrounding estuaries. To expand the existing salt marsh a thin layer of dredged creek sediment was deposited, and vegetation was planted along the shoreline. The project also restored the riparian zone adjacent to farmland in order to further improve shoreline health and water quality.
- The ongoing Sitmuk Restoration Project, carried out by Clean Foundation, began in 2020. The project is taking several steps to restore the salt marsh shoreline: waste rock material on the shoreline is being removed, local community volunteers are planting native grasses to create a living shoreline, and shoreline reef balls — artificial reef structures built by Mi'kmaw Conservation Group — are enhancing shoreline habitat and supporting the growth of marine plants to sequester carbon.

Large-Scale Restoration: The Cheverie Creek Salt Marsh Restoration Project

Altering the regular tidal influence on a salt marsh greatly affects the marsh's health and function (Warren *et al.* 2002; Montalto and Steenhuis 2004; Bowron *et al.* 2012). This alteration is often deliberate — as when salt marshes converted to agricultural lands through diking — but can also be unintentional. Nova Scotia has seen extensive unintentional alterations to tidal hydrology. This can happen when a culvert is improperly sized because only freshwater drainage needs are accounted for, and not tidal water needs. Undersized culverts can harm functioning of the upstream salt marsh, with impacts such as irregular tidal inundation, altered salinity levels, and restricted fish passage. In 2005, a project upgraded an undersized culvert in Cheverie Creek, Nova Scotia (i.e., Bay of Fundy). This project was led by the Nova Scotia government but relied on many partnerships, including Fisheries and Oceans Canada Small Craft Harbours, Ducks Unlimited Canada, the Ecology Action Centre, and later CB Wetland and Environmental Specialists. There is potential for large restoration projects in the Bay of Fundy. However, these are often highly complex projects requiring partnerships across private and public sectors at both the local and national level.

The installation of a new culvert in Cheverie Creek increased the cross area opening of the culvert from 4.7 m^2 (Figure 8) to 32.6 m^2 (Figure 9). This significant upgrading reinstated regular tidal hydrology, with exceptions for the largest high tides, and restored tidal influence from only 0.05 km^2 to 0.43 km^2 of the upstream marsh (Figure 10). The site had a rapid response in the growth of halophytic vegetation; however, as with many other restoration projects, the restored habitat's vegetative community remained distinct from reference conditions as of 2012. In addition, sediment accretion in the restoration site was higher than the reference site (but not significantly different). Because this was the first intentional salt marsh restoration project in Nova Scotia, it was essential to plan carefully and monitoring extensively in order to design a successful restoration plan and showcase success. The project's monitoring plan was a modified version of the Global Programme of Action Coalition for the Gulf of Maine Regional Monitoring Protocol. It covered many measurement aspects, including mapping, hydrology, soils and biotics (Bowron *et al.* 2013). This project reinforced the viability of salt marsh restoration in Atlantic Canada and encouraged the restoration of additional sites.

Here are two more examples of large-scale restoration projects on the East Coast:

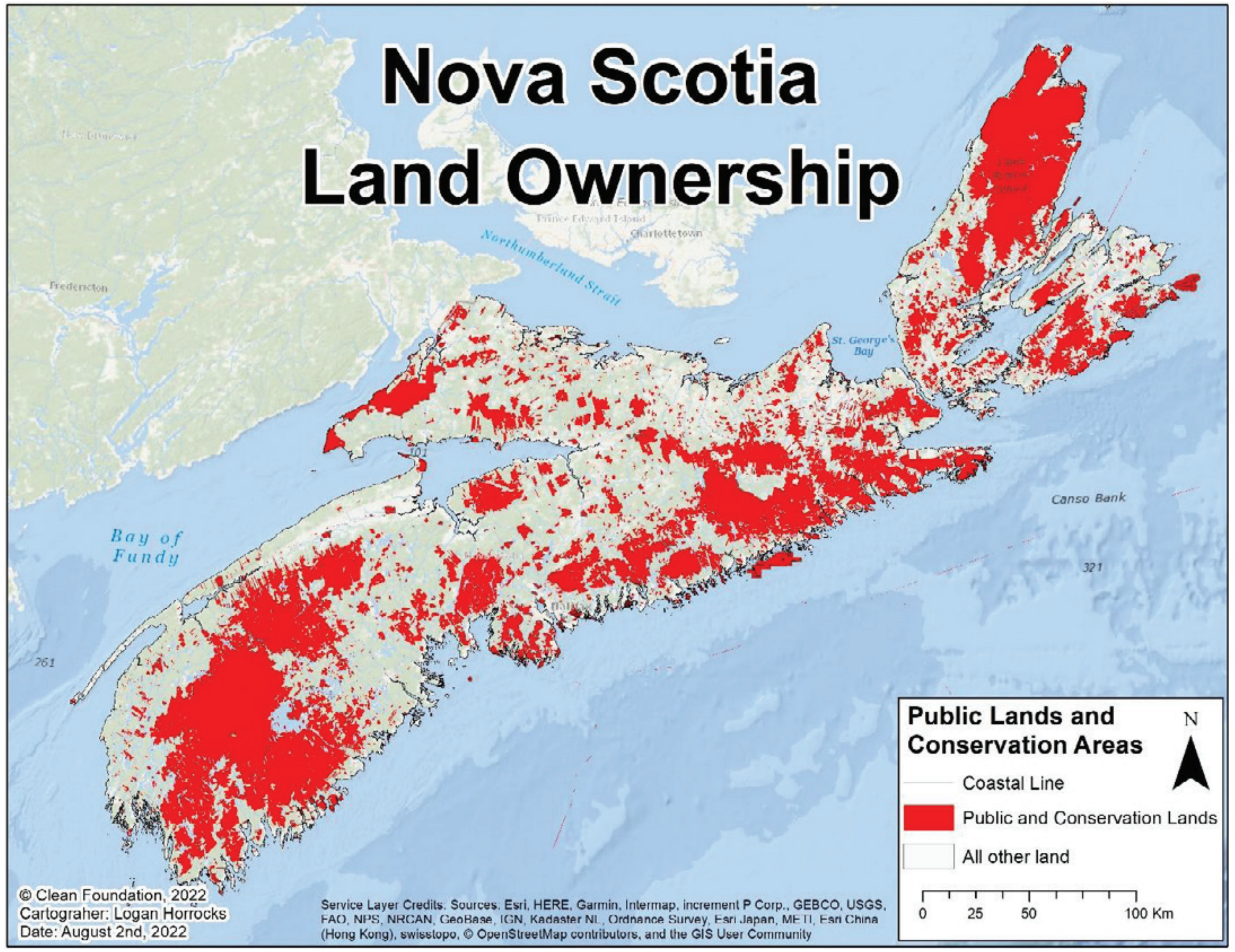
- The Musquash Estuary, which contains a large tidal wetland, was designated a Marine Protected Area in 2006 as it provides valuable habitat to coastal species of interest (e.g., harbour seals and black ducks). The estuary has seen several restoration projects, most recently a 2018 project by Ducks Unlimited Canada. This project aimed to restore an original salt marsh that had been converted to pastureland through diking in the 1960s and 1970s, and then converted to an impoundment of open water in the 1980s. To restore the salt marsh habitat, the project breached the dike in 2018. The project has restored 0.38 km^2 of salt marsh and its progress has been monitored annually by the Coastal Marine Ecology Lab at the University of New Brunswick.
- The Onslow-North River Managed Dike Realignment and Tidal Wetland Restoration Project was completed by TransCoastal Adaptations in 2021. Taking place in Truro, Nova Scotia, this project was designed to restore floodplain (i.e., salt marsh habitat) that had been diked off from the tides for use as agricultural lands. This project is notable as it was primarily designed to alleviate flooding pressures on the upstream town of Truro. New dikes were built inland from the old ones, and the old dikes were intentionally breached to restore tidal flooding and 0.93 km^2 of salt marsh habitat.

Long-term Restoration/Creation Process: Coastal Marsh Conservation in Aulac

In 2006, the New Brunswick Department of Agriculture replaced failing dikes that were eroding on the edge of two coastal agricultural sites in Aulac, New Brunswick (Figure 11 and Figure 12), where diurnal tides reach ~14 m. These sites had originally been salt marsh habitat before they were diked, drained, and converted to agricultural lands. This region of New Brunswick had been subjected to extensive diking since the 17th century. The failing dikes had been constructed in the early 1950s (Virgin *et al.* 2020) and were replaced in 2006. These new dikes were constructed approximately 100 m inland from the old dikes to avoid the heavy shoreline erosion that impacted the previous dikes and hopefully prolong the lifespan of the new dikes. Led by Ducks Unlimited Canada, the project brought together many partners to develop plans for intentionally breaching the old dikes in a manner that would restore salt marsh habitat in the ~100 m gap between the new and old dikes (areas of approximately 0.06 km^2 and 0.1 km^2 for the two restoration sites). The breaching occurred in October 2010, creating two isolated cells of passively restoring marsh. These marshes, as well as two nearby reference sites, have been extensively monitored annually since before they were breached (2009) for sediment deposition, erosion, blue carbon, vegetative communities, and more (Virgin *et al.* 2020). This has been an important project as it shows the short- and long-term progression of successful salt marsh restoration under the most dramatic environmental conditions, with tides over 14 m, heavy winter ice, high waves from a fetch of up to 20 km, and importantly, a complete absence of tidal influence in the cells for more than 50 years.

After 7 – 8 years, mean sediment deposition was 34 – 67 cm in restoration sites, compared to only 6 cm in a nearby reference site (Virgin *et al.* 2020). The new marshes (Figure 11 and Figure 12) sit atop the compacted soils of the former agricultural lands, which can still be felt when one plunges an auger deep into the marsh. The reintroduction of salt water in 2010 rapidly killed the salt-intolerant vegetation. This essentially converted the landscape into a mudflat in 2011 due to the very high rate of sediment deposition. Despite the lack of abundant vegetation, the deposit contained an average 1329 g C m^{-2} yr^{-1} by 2016 (Wollenberg *et al.* 2018). While some salt marsh restoration projects struggle with low sediment supply in the water, the Bay of Fundy waters are often heavily loaded with sediment (range: 0.12 – 12.67 g L^{-1}; Amos and Tee 1989), so sediment accretes rapidly under the right conditions. The dike breaches were designed to maximize flooding at high tide and slow drainage at low tide, allowing for maximum sediment deposition in the site (Boone *et al.* 2017). This was necessary to elevate the site to a level that would allow salt marsh vegetation to begin growing.

Between 2012 and 2015, the marsh maintained high levels of sediment deposition, accreting more than 1 m of sediment in some places (Boone *et al.* 2017), and the marsh surface became progressively more consolidated. Halophytes began growing on the site in 2012, notably *Spartina alterniflora*, a bioengineer species for salt marshes. This grass dominates the low marsh, where environmental stressors related to tidal inundation are high. It first began growing in small patches, then covered the marsh in seedlings in 2014, and dominated the marsh by 2016 (Figure 11). As the sites continue to accrete sediment, gain elevation, and develop into mature marshes, we expect that high marsh vegetation will begin to outcompete *S. alterniflora* and dominate the high marsh zones. A series of annual aerial photos documents the site's progression (see Figure 2 of Virgin *et al.* 2020). This project has shown that new salt marshes can be created under extreme environmental conditions, and has allowed scientists to develop timelines and detailed descriptions of how restoration can be expected to progress under such conditions.



© Clean Foundation, 2022
Cartograher: Logan Horrocks
Date: August 2nd, 2022

Service Layer Credits. Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 2. Map of Nova Scotia showing the high amount of private land ownership (white areas) of the coasts compared to public and conservation areas (red areas; Clean Foundation 2022).

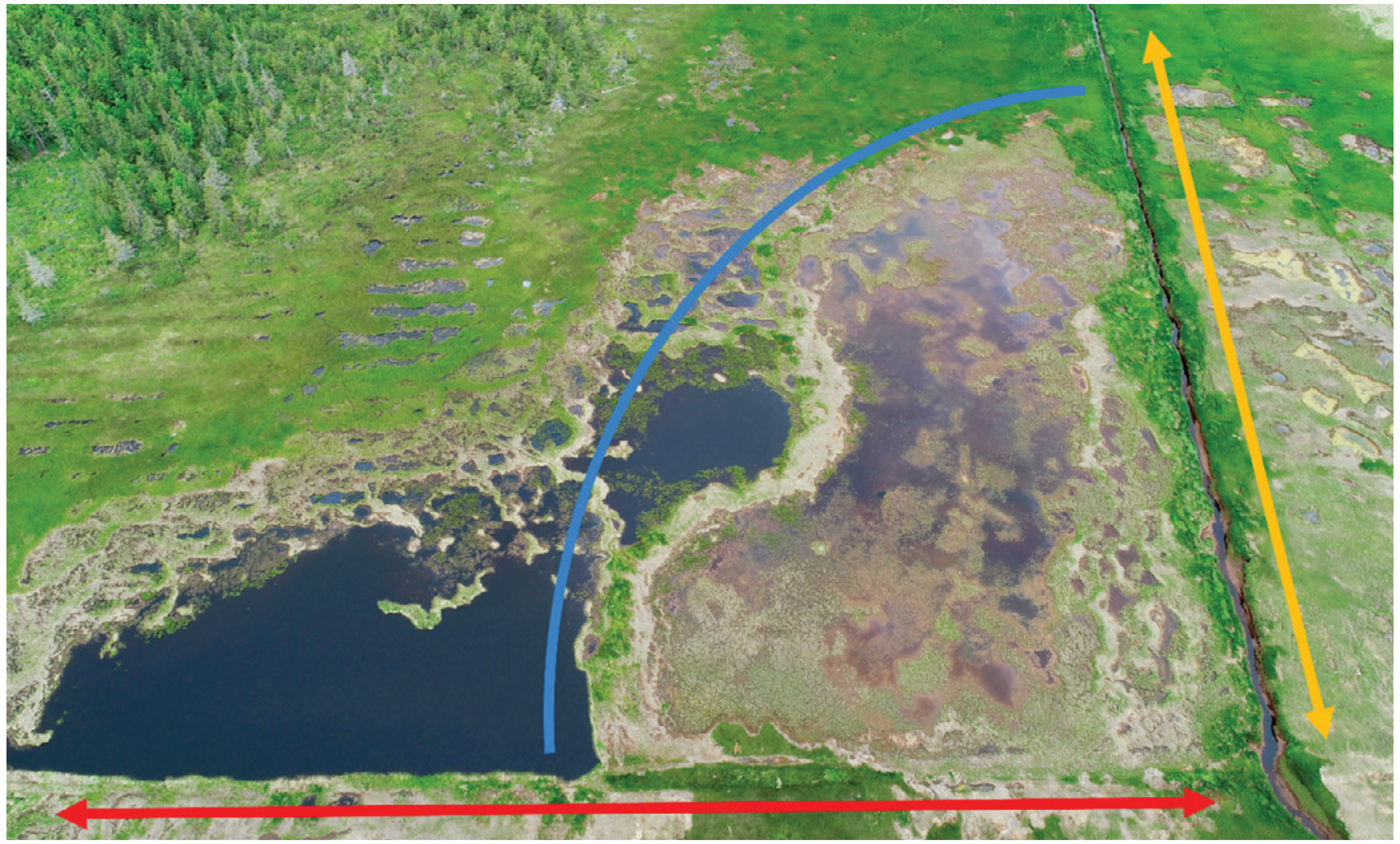


Figure 3. The restoration site (the space enclosed by the red, yellow and blue lines) of the Brule Shore salt marsh prior to restoration (taken 26 June 2019). This site held a shallow impoundment of water caused by the low-lying remnants of an agricultural dike (above the red line) and built-up creek edge (left of the yellow line).

Figure 4. On-the-ground view of the restoration site at the Brule Shore salt marsh prior to restoration work (taken 29 June 2019). High summer temperatures have evaporated most of the surface water, leaving hot, hyper-saline pools. The restoration site was covered in dead grasses, bare patches, and exposed, decaying roots.

Figure 5. Volunteers digging runnels (shallow ditches) with shovels to drain the surface water off the marsh and restore “proper” hydrology to the site, thus restoring the marsh (taken October 2020). A sill is installed at the mouth of the runnels to slow or halt water flow and reduce the loss of sediment.

Figure 6. The restoration site of the Brule Shore salt marsh two years post restoration (taken 20 July 2022). There is revegetation around the site’s perimeter, where surface-water drainage was most impacted by runnel installation.

Figure 7. On-the-ground view of the restoration site at the Brule Shore salt marsh two years after restoration work was completed (taken 20 July 2022).

Figure 8. The culvert facilitating tidal exchange for the Cheverie Creek salt marsh prior to restoration. Photo credit: Tony Bowron 2002

Figure 9. The culvert installed in December 2005 for the restoration of the Cheverie Creek salt marsh. Photo credit: Nancy Neat 2006

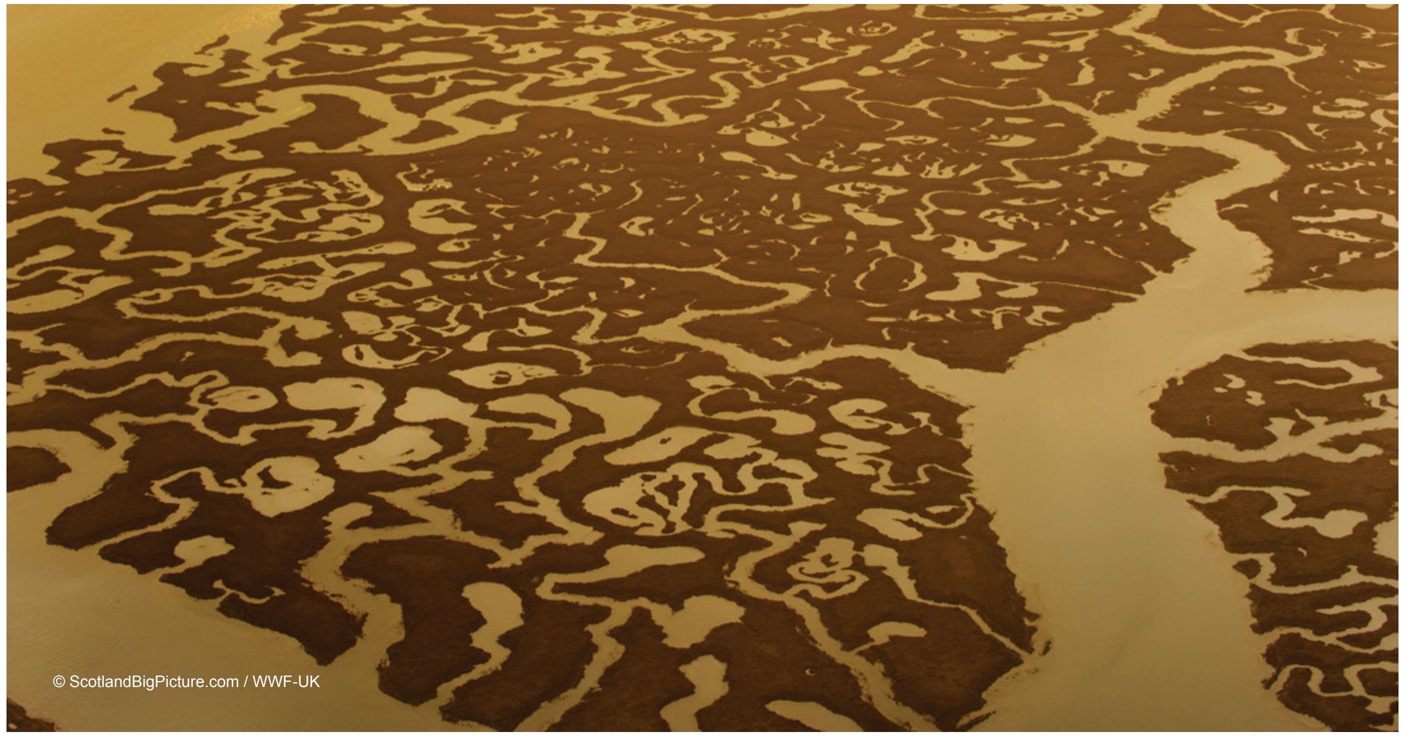
Figure 10. The Cheverie Creek salt marsh restored by the installation of a larger culvert under the road on the right side of the photo. Photo credit: CBWES 2013

Figure 11. The western Aulac restoration cell 11 years after the seaward dike (left side of photo) was intentionally breached (at what is now the mouth of the creek running through the site; photo taken in July 2022). The restored marsh cell (~11 ha) is bordered by the remnants of the dike on the seaward edge and the new, inland dike (right side of the photo) that runs parallel to it. As of the time of this photo, the marsh surface is blanketed by *Spartina alterniflora*.

Figure 12. The eastern Aulac restoration cell 11 years after the seaward dike (right side of photo) was intentionally breached (both near the middle of the site and on the far end; photo taken July 2022). The restored marsh cell (~5.5 ha) is bordered by the remnants of the dike on the seaward edge and the new, inland dike (left side of the photo) that runs parallel to it. As of the time of this photo, the marsh surface is blanketed by *Spartina alterniflora*.

RECOMMENDATIONS FOR SALT MARSH

- ✓ Address barriers to implementation and monitoring of NCS in salt marsh habitats.
- ✓ Increase research on the factors influencing carbon dynamics and their spatial variability to improve management of salt marsh habitats.
- ✓ Undertake and validate national-scale, high-resolution mapping of Canada's salt marsh habitats to support protection and management of these valuable ecosystems.
- ✓ Increase research into the resilience of salt marsh ecosystems to climate change and sea-level rise.
- ✓ Support and build partnerships with Indigenous communities and local communities in ways that advance their priorities and initiatives, including restoration and conservation projects. For example, provide funding, share data and information, and offer support in other ways identified by Guardians and Indigenous Nations and communities, and engage in co-development, co-management and co-governance.
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on salt marshes. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).


© ScotlandBigPicture.com / WWF-UK

KELP

Karen Filbee-Dexter, Margot Hessing-Lewis, Anna Metaxas and Julia Baum

KELP FORESTS AND BLUE CARBON

Kelp forests, which are made up of true kelps (order Laminariales), are among the most abundant vegetated coastal ecosystems in temperate and Arctic waters, where they provide habitat for ecologically and economically important fish and invertebrate species (UNEP 2023). Kelp forests are biodiverse, can improve coastal water quality, and support the livelihoods and cultural identities of many coastal people around the world. These underwater forests grow in shallow coastal zones, predominantly on rocky substrata, in areas where sufficient light reaches the seafloor to support photosynthesis. Canadian waters are thought to support a considerable portion of the world's kelp forests, with current estimates placed at ~12 per cent (Duarte *et al.* 2022). Canada's kelp forest ecosystems are created by over 30 different species (Table 12).

Indigenous communities in Canada have long had a relationship and connection with kelp forests (Kobluk *et al.* 2021). As noted in the seagrass chapter, Pacific herring (*Clupea pallisii*) is a cultural keystone species and important food source for many Pacific coastal Indigenous Peoples (Gauvreau *et al.* 2017). Pacific herring lay their eggs on kelp blades, which are sustainably harvested using traditional methods by many Pacific coastal Indigenous Peoples (Moss 2016; Mac Monagail *et al.* 2017). Inuit communities in Nunavut and Nunavik use kelp for food and medicine (Black *et al.* 2008; Clark 2012). Harvesting and gathering of kelp are often intrinsically linked to the cultural identity and well-being of coastal communities (Mac Monagail *et al.* 2017), and kelp management can be connected to traditional Indigenous knowledge systems and practices (Krumhansl *et al.* 2017; UNEP 2023). In consequence, NCS that affect kelp in coastal Indigenous territories may be of interest or concern to Indigenous Peoples, many of whom have insights into harvesting practices that encourage kelp reproduction (Kobluk *et al.* 2021).

Kelp forests are highly productive ecosystems that take up CO_2 from the surrounding seawater and convert it into organic, carbon-rich biomass (Pessarrodona *et al.* 2022). Despite this productivity, to date kelp forests have not been formally recognized as blue carbon ecosystems by blue carbon policy and funding mechanisms, and standards to account and verify atmospheric CO_2 removal from kelp forests are lacking (Vanderklift *et al.* 2022). This is in part because kelp forests are different from other blue carbon ecosystems. Mangroves, salt marshes and seagrasses are plants rooted in soft sediment, and they store captured carbon in this sediment. In contrast, kelp have holdfasts that anchor them to rocks. Therefore, the carbon produced by kelp forests is not captured and stored in the sediment within the habitat, but rather, exported — mainly as detritus —and transported to other ecosystems (Krumhansl and Scheibling 2012a; Pedersen *et al.* 2020). Kelp detritus can also contain refractory compounds, which are stable over long time periods and therefore not broken down by detritivores or microbes but can instead contribute to carbon sequestration (Trevathan-Tackett *et al.* 2015). A portion of this particulate and dissolved kelp organic carbon can become buried or entrained in long-term sinks on the continental shelf or deep ocean (Krause-Jensen and Duarte 2016; Ortega *et al.* 2019). Although the exact proportion of kelp production that reaches these sinks is uncertain, evidence suggests that kelp-derived carbon may be transported large distances, buried in shelf sediments (Queirós *et al.* 2019; Frigstad *et al.* 2021; Filbee-Dexter *et al.* 2022b), and/or held within deep water bodies for extended timescales (Ortega *et al.* 2019). However, the timescales and drivers of the processes underpinning carbon storage in deep ocean regions are less well understood than in situ burial and storage of carbon (Hurd *et al.* 2022). This is a key reason why kelp forests are considered an "emerging climate solution," while salt marshes, mangroves and seagrasses are more established blue carbon habitats. The IPCC does not currently recognized kelp as contributing to a country's emission-reduction goal. However, future initiatives to conserve kelp, mitigate declines, and/or restore kelp forests may act as NCS by increasing the standing stock of kelp-associated carbon and by altering ocean-based CO_2 dynamics, including atmospheric carbon dioxide removal and carbon sequestration (Krause-Jensen *et al.* 2018; Macreadie *et al.* 2019).

Table 12. Dominant kelp species in Canada.

Northeast Pacific Ocean	Arctic	North Atlantic
Macrocystis pyrifera, Nereocystis luetkeana, Eisenia arborea, Egregia menziesii, Saccharina spp., *Laminaria* spp., *Hedophylum nigripes, Cymathere triplicata, Alaria* spp, *Postelsia palmaeformis, Pleurophycus garderni, Pterygophora californica, Agarum* spp., and *Costaria costata*	*Saccharina latissima, Laminaria solidungula, Alaria esculenta, Hedophyllum nigripes, Agarum clathratum*	*Saccharina latissima, Laminaria digitata, Alaria esculenta, Agarum clathratum*

KELP FORESTS: EXTENT, BIOMASS AND PRODUCTIVITY

To estimate the potential of kelp forests as NCS, we need the following information: (i) spatial extent of kelp forest habitat along the coast, (ii) per-area biomass, and (iii) carbon content (Table 6). These data can be used to calculate the standing carbon stock of kelp (kg C m^{-2}). To calculate carbon assimilation rates and carbon fluxes associated with these ecosystems, we need secondary measurements of kelp net primary productivity (NPP). Often measured in kg C m^{-2} y^{-1}, NPP is mainly derived in two ways (Pessarrodona *et al.* 2021):

- examining biomass accumulation (and loss) over time through harvests or tagging
- using photorespirometry to measure direct carbon assimilation via changes in dissolved oxygen, photosynthesis-irradiance curves or carbon isotope uptake

Finally, to estimate carbon sequestration rates, we need to know the percentage of annual production (% NPP) that is exported to deep ocean regions, where it can be sequestered in sediments or slow-cycling carbon pools (Krause-Jensen and Duarte 2016) or the percentage of kelp detritus that is refractory over long timescales (Li *et al.* 2022). Our understanding of carbon dynamics could be enhanced through research into these carbon fluxes — incorporating estimates of potential CO_2 sources such as increased calcification (which can release CO_2) or enhanced community respiration (Bach *et al.* 2021).

We need these five types of information — extent, biomass, carbon content, productivity and export potential — to quantify carbon flows within and from kelp forests in Canada. Data availability and uncertainty associated with these values vary across Canada's Pacific, Atlantic and Arctic Oceans. We review key aspects of these kelp carbon measures, and outline important knowledge gaps associated with current values, based on published and emerging work from these regions (Table 13).

Table 13. Status of data on kelp forest blue carbon potential for Canada's three oceans.

Data	Atlantic	Arctic	Pacific
Extent	Extrapolated from global model[1]: 17,103 km^2 Total coastline length[13]: 42,000 km	Regional model[2]: 312,000 km^2 Total coastline length: 176,000 km	Extrapolated from global model[1]: 9,621 km^2 Observational data of surface canopy[3]: 190 km^2 Total coastline length[13]: 26,000 km
Confidence and resolution (extent)	Low certainty, based on cropped global model of kelp extent. Assumes depth limit is 30 m.	Moderate certainty, based on modelled distributions for this area using limited bathymetric data, global environmental data but limited information on substrata. Does not include the western Arctic.	Conservative estimate of minimum extent based on aggregated mapped distributions from 1976–2004 (BC Marine Conservation Atlas 2011) and remotely sensed maximum extents (2004–2019; Gulf Islands and Southern Vancouver Island, compiled by S. Schroeder) and estimate of upper limit based on cropped global model.
Standing stock per area (kg C m^{-2})	0.372 (± 0.08 SE) range: 0.025 – 1.27 [4]	0.233 (± 0.08 SD) range: 0.014 – 0.391 [5]	0.107 (± 0.05 SD) range: 0.027 – 0.252 [6]
Standing stock (Tg C)	Data deficient	72.7 Tg C [5]	Data deficient
Confidence and spatial resolution (standing stock)	Low certainty. Average biomass values based on data from three regions in Nova Scotia.	Moderate to low certainty. Average values from 31 sites haphazardly spaced across the Eastern Canadian Arctic.	Very low certainty. Average biomass values from one region.[14] Spatial data is very conservative and does not cover the full coastline of B.C.
NPP per area (kg C m^{-2} y^{-1})	0.259 (0.055 SE) range: 13.8-751 [8]	0.023 to 0.068 [5,8] and 0.020 (± 0.012 SD)[10]	1.3 – 1.4 [11]
NPP (Tg C y^{-1})	NA	10 to 68 [5]	NA
Export beyond continental shelf (%)	0.43 (± 0.25 SE) [12]	6.8 (± 2.8 SE) [12]	2.8 (± 2.7 SD) [12]
Confidence and spatial resolution (NPP and % export)	Moderate confidence of NPP based on 15 studies. Export from global model that has not been ground-truthed	Low certainty, based on NPP data from 6 sites. Export from global model that has not been ground-truthed	NPP extrapolation not possible due to data gaps/limitations
Trend in extent and abundance	In Nova Scotia, kelps are declining due to invasive species and indirect effects of temperature.[5] Kelps are stable in Gulf of St. Lawrence.	Kelps are predicted to increase in biomass and extent in some areas due to reduced sea ice.[2]	Variable regional trends: evidence for stability/persistence, declines and expansion
Confidence and spatial resolution (trend)	Moderate to high certainty. Data mainly from Nova Scotia, extensive monitoring of some areas since 1980s.	Moderate to low certainty, based on models and space for time substitutions. No long-term monitoring and little baseline data exist.	Low certainty, based on limited mapping. New mapping and modelling are underway as of 2022.

[1]Duarte *et al.* (2022); [2]Goldsmit *et al.* (2021); [3]Lang-Wong *et al.* (2022); [4]Filbee-Dexter *et al.* (2016; [5]Filbee-Dexter *et al.* (2022); [6]Nereocystis and Macrocystis values from Mora-Soto conversions in Lang-Wong *et al.* (2022); [8]Pessarrodona *et al.* (2021); [9]K. Filbee-Dexter, unpublished data from five sites around Southampton Island, Nunavut; [10]Chapman and Lindley (1980) [11]Wheeler and Druehl (1986) and Foreman (1984); [12] Filbee-Dexter, unpublished data; [13]Andersen (2021); [45]Sutherland *et al.* (2008).

Pacific Coast

The Northeast Pacific Ocean is considered to be the evolutionary origin of kelp (Starko *et al.* 2019b), and indeed Canada's most diverse forests are found on the Pacific Coast (Table 1). There, kelp forests with floating canopies are dominated by two species: giant kelp *Macrocystis pyrifera* and bull kelp *Nereocystis luetkeana* (Figure 13 and Figure 14, Table 10). These species are distributed from the southern extents of the Salish Sea (bordering Washington State) to the northern border with Alaska. Fringing forests of the annual *N. luetkeana* dominate the southern waters, whereas both species are prevalent north of Vancouver Island, sometimes growing together in mixed stands. Subsurface kelps are also present throughout the coast of British Columbia, but have not been mapped at the regional scale.

There is still considerable uncertainty about the extent and productivity of kelp forest ecosystems along British Columbia's extensive coastline. A recent value of 190 km^2 of kelp forest extent, derived from aerial survey data and high-resolution satellite imagery (Mora-Soto in Lang-Wong *et al.* 2022), was based on incomplete sampling of B.C.'s coastline, and is thus almost certainly an underestimate. In contrast, global kelp distribution models yield an estimate of 9621 km^2 for B.C. (Duarte *et al.* 2022). Fifty times higher than the previous estimate, this is likely an overestimate as it assumes a lower depth limit of 30 m and coarsely approximates rocky reef at 63 per cent. These examples illustrate the need for improved estimates.

Many studies that are currently in progress will help resolve critical knowledge gaps and improve estimates relevant to the potential blue carbon contribution of these ecosystems for this region. As of 2023, coastwide kelp mapping and modelling projects in B.C. include the following:

- Using digitized nautical charts from 1858–1956 (Costa *et al.* 2020) and modern-day (1980–present) archival high-resolution satellite imagery to map spatiotemporal canopy-forming kelp in large regions of the coast (Costa Lab; Kelp Resilience Alliance project).
- Automating the use of Landsat imagery through the Google Earth Engine and using MESMA (Multiple Endmember Spectral Mixture Analysis) to generate medium-resolution maps and time series of canopy-forming kelps (Hakai Institute).
- Building species-distribution models to generate province-wide current coastal kelp distributions and future projections under climate change, for a range of species (Baum Lab, Blue Carbon Canada).

These ongoing studies build on mapping work from the 1970s–2000s collated in BCMCA (British Columbia Marine Conservation Atlas). Numerous smaller-scale studies are collecting spatial information on kelp extent and distribution for both understory and canopy-forming kelps (e.g., Watson and Estes 2011; Schroeder *et al.* 2020; Starko *et al.* 2019a, 2022). Many long-term monitoring initiatives are mapping local extent using drones, boat-based methodologies (e.g. using remotely operated vehicles (ROVs) and drop cams), underwater SCUBA surveys and AI imagery processing (Kelp Rescue (Bamfield Marine Sciences Centre), Hakai, MaPP, BATI, Baum Lab (UVic), CMEC (SFU), Spectral Lab (UVic), J. Watson, North Island College).

Information on per-area biomass is limited to the Central Coast region (Sutherland 2008; Pontier *et al.* 2022a,b). For *M. pyrifera*, individual biomass can range from 0.04 to 1.0 kg dry weight in the summer growing season (June to August) (Pontier *et al.* 2022a). Blade production for *N. luetkeana* peaks at over 0.1 kg dw m^{-2} day^{-1} (Pontier *et al.* 2022b; Okamoto *et al. unpublished data*). While metrics of annual productivity for the Pacific Coast of Canada are limited, research from surrounding areas suggests it may be comparatively high. Annual productivity for *M. pyrifera* has been estimated at 1.3 kg C m^{-2} y^{-1} (Wheeler and Druehl 1986) and for *N. luetkeana* at 1.4 kg C m^{-2} y^{-1} (Foreman 1984), which is in the higher range of global macroalgae productivity rates (Pessarrodona *et al.* 2021; Duarte *et al.* 2022). Average carbon-based productivity rates have been reported for *M. pyrifera* from California (U.S.), Falkland Islands, and Tasmania (Australia) of 0.920 kg C m^{-2} y^{-1} ± 0.11 SE (n = 51 measures), and for *N. luetkeana* in Alaska and Washington (U.S.) of 0.780 kg C m^{-2} y^{-1} ± 0.41 SE (n = 5 measures) (Pessarrodona *et al.* 2022).

Figure 13. *Nereocystis* sp. Mama Islet, British Columbia. Photo credit: Markus Thompson

Figure 14. *Nereocystis leutkeana* in Owen Bay, Sonora Island, British Columbia. Photo credit: Markus Thompson

Arctic Coast

Kelp forests in the Eastern Canadian Arctic are estimated to currently cover 312,000 km^2 of the coastal zone (Goldsmit *et al.* 2021). This is 9 per cent of the estimated global distribution of kelp (1.5–2.5 million km^2) (Duarte *et al.* 2022) and represents the largest area of kelp forests in Canada. Extensive dive surveys in 2014 and 2019 found that standing biomass of Arctic kelp forests ranged from 0.2 to 6.2 kg m^{-2} wet weight and averaged 3.7 kg WW m^{-2} (± 0.6 SD) (Figure 15) (Filbee-Dexter *et al.* 2022a). There are large uncertainties around the total area of these ecosystems. However, two factors suggest that Arctic kelp forests could be an important, though underappreciated, standing stock of carbon: the relatively high average measures of per-area biomass and cover across the Canadian Arctic (Filbee-Dexter *et al.* 2022a; Figure 16), and the large, shallow coastline that can support these ecosystems (Goldsmit *et al.* 2022). To provide context, the total standing stock for the Eastern Canadian Arctic of 72.7 Tg C is 4.4 times more than the standing stock of Australia's kelp forests (16.6 Tg C; Filbee-Dexter and Wernberg 2020) and 10 times the standing stock of kelp forests in Norway (7.1 Tg C; Frigstad *et al.* 2021).

Several measures of annual productivity rates exist for kelps in the Canadian Arctic. Measures of NPP for *S. latissima* and *L. solidungula* (Figure 17) at sites near Southampton Island ranged from 23.1 to 67.8 g C m^{-2} y^{-1} (Filbee-Dexter *et al.* 2022a). In 1977, NPP for *L. solidungula* in Igloolik (Foxe Basin) was estimated at 20 (± 12.1 SD) g C m^{-2} y^{-1} (Chapman and Lindley 1980). These measures of NPP are an order of magnitude lower than the productivity of most kelp forests globally (global average 560 (± 30 SE) g C m^{-2} y^{-1}; Pessarrodona *et al.* 2022). However, the large distribution kelp in the Eastern Canadian Arctic suggests these habitats are cycling substantial quantities of carbon in the coastal zone, ranging from 2.2 to 6.4 Tg C y^{-1} and 10.4 to 30.6 Tg C y^{-1}, based on a lower depth limit of 10 and 40 m, respectively.

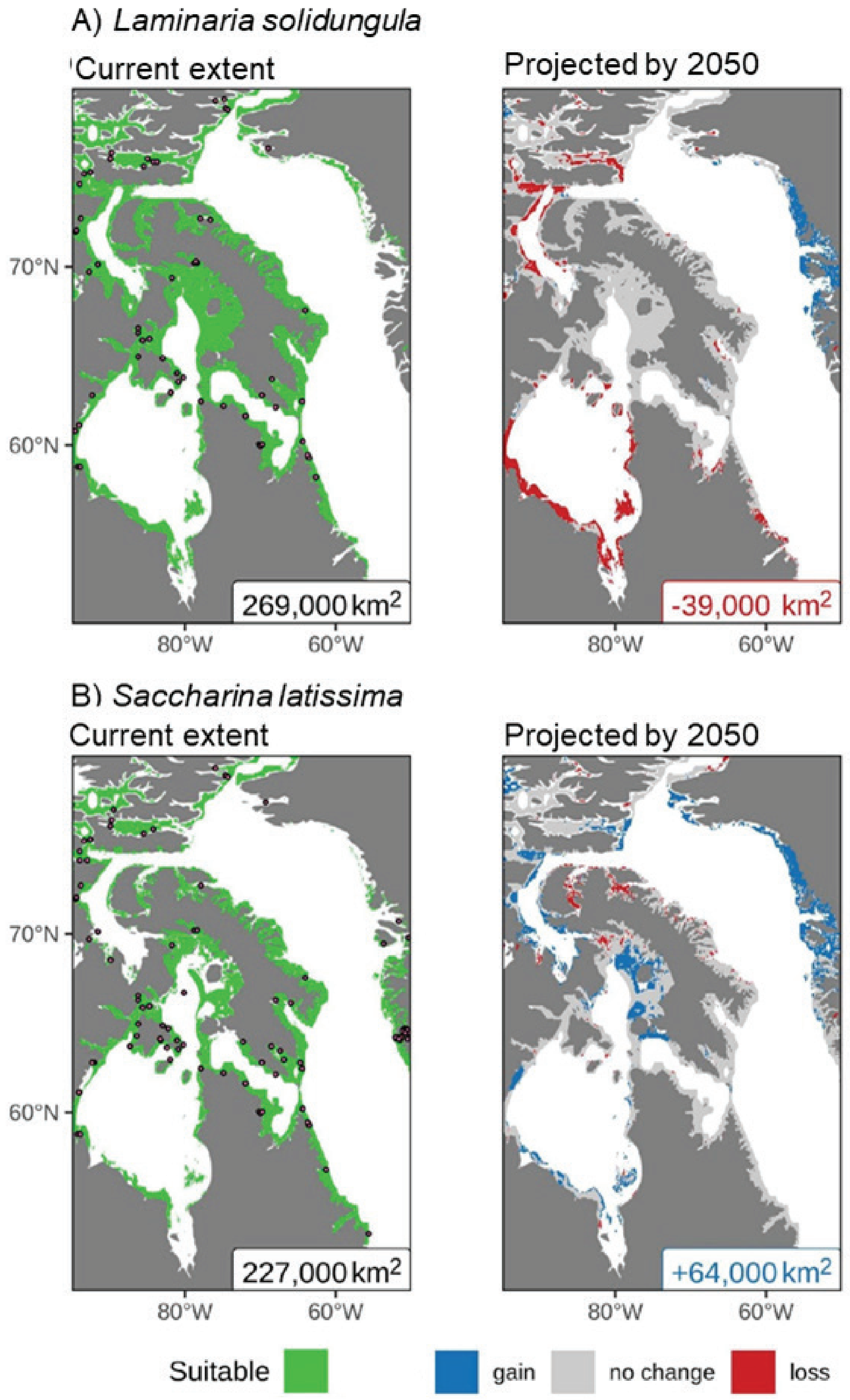


Figure 15. Habitat suitability models showing current and predicted future (2050 under regional climate projections 8.5) distribution of the endemic Arctic kelp (A) *Laminaria solidungula* and (B) the temperate kelp *Saccharina latissima* in the Eastern Canadian Arctic. Distributions for *Agarum clathratum* and *Alaria esculenta* are not shown. Adapted from Goldsmit *et al.* (2021).

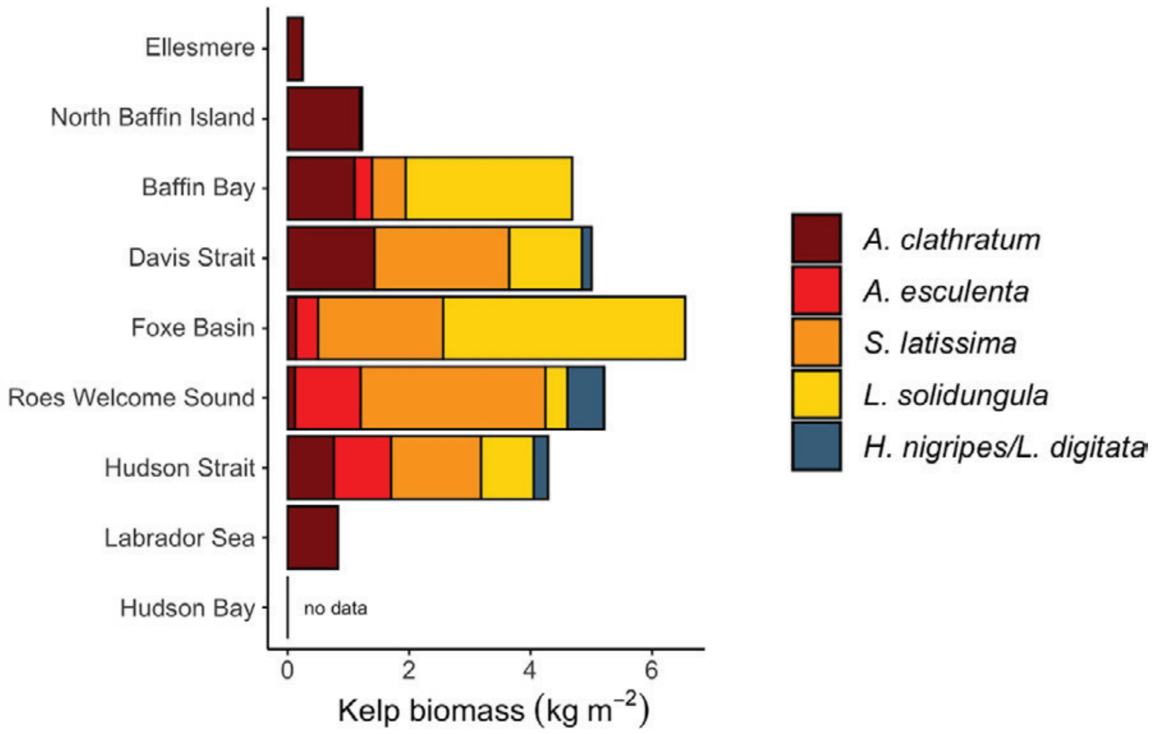


Figure 16. Average kelp biomass (wet weight) for dominant species (*Agarum clathratum, Alaria esculenta, Saccharina latissima, Laminaria solidungula,* and digitated kelps *Hedophylum nigripes* and *Laminaria digitata*) in the Eastern Canadian Arctic. Adapted from Filbee-Dexter *et al.* (2022).

Figure 17. *Alaria esculenta* on mixed sand and pebbles in Frozen Strait, Foxe Basin and a forest of *Saccharina latissima* and *Laminaria solidungula* in Roes Welcome Sound, Nunavut. Photo credit: Ignacio Garrido, ArcticKelp

Atlantic Coast

On the Atlantic coast, kelp forests are found throughout the Bay of Fundy, the Atlantic coast of Nova Scotia, Northumberland Strait, the Gulf of St. Lawrence and Newfoundland and Labrador (Figure 18). Models of kelp distribution globally estimate that kelp forests occur across 17,103 km^2 in Atlantic Canada (Duarte *et al.* 2022; Table 6). However, there is considerable uncertainty in these models, which do not properly estimate available rocky substrata for the area, assuming 63 per cent rock for the area. High-resolution models of the spatial extent and biomass of kelp forests in the Atlantic region are not available. Studies of long-term change in the region (1952–present) have documented widespread declines of kelp in some areas. Once-luxuriant kelp forests (*S. latissima*, *L. digitata*) in the southwestern shore of the Atlantic coast of Nova Scotia have been replaced by turf algae, particularly in wave-protected embayments, with biomass in some areas declining from ~20 kg m^{-2} to < 5 kg m^{-2} (Filbee-Dexter *et al.* 2016). However, healthy kelp forests remain in the Bay of Fundy (Cooper *et al.* 2019) and the eastern shore of Atlantic Nova Scotia (Attridge *et al.* 2022). In the northern Gulf of St. Lawrence (GSL), the dominant kelps are *A. esculenta* in shallow water and *A. cribosum* in deeper water, both of which occur in scattered patches (Bégin *et al.* 2004). *A. esculenta* occurs outside embayments, possibly because of low tolerance to low light in increased turbidity. *S. latissima* is present throughout the Sept-Îles region (Picard *et al.* 2022). The biomass of *A. esculenta* in the GSL and northern Newfoundland has been estimated as relatively low at < 5 kg WW m^{-2} or 0.315 g C m^{-2} (Merzouk and Johnson 2011). Kelp productivity in Atlantic Canada varies seasonally and spatially, ranging from 0.02 and 14 g DW d^{-1} for *S. latissima* and between 0.02 and 0.39 g DW d^{-1} for *L. digitata* (Krumhansl and Scheibling 2011). However, the ratio of blade erosion to blade productivity can vary by two orders of magnitude, from ~0.1 to 10 (Krumhansl and Scheibling 2011). Given the lack of current data on kelp biomass along the Atlantic coast, it is not possible to estimate kelp standing stock accurately on a regional scale.

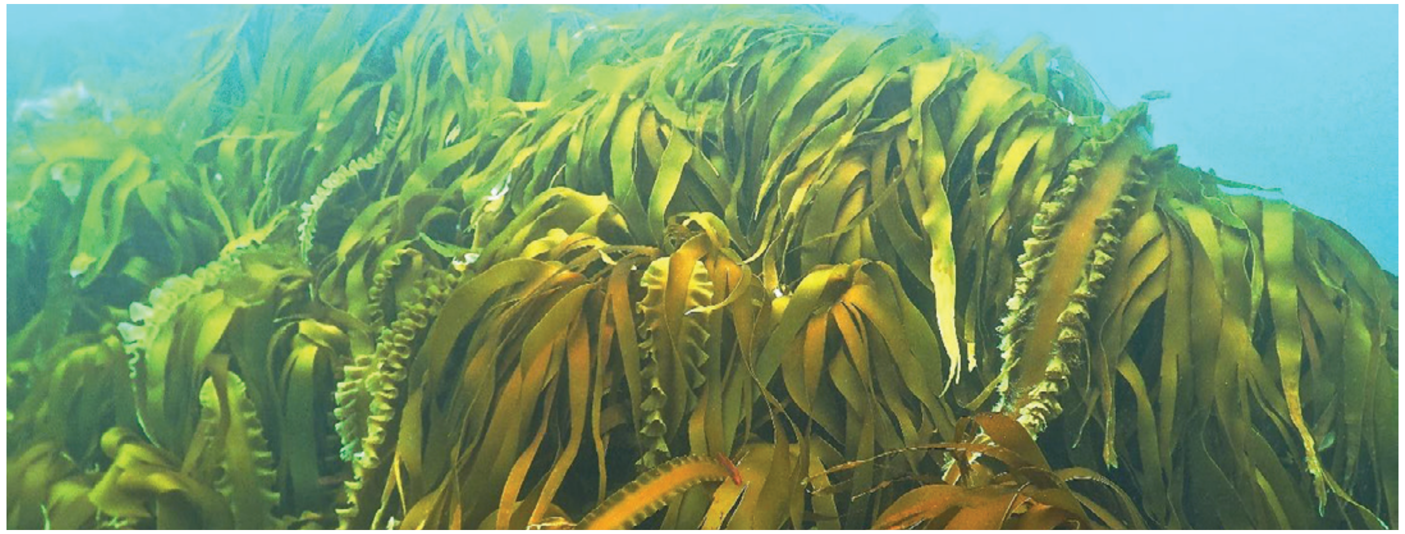


Figure 18. East coast kelp forest. Photo credit: Anna Metaxas

POTENTIAL EXPORT OF KELP CARBON TO OCEAN SINKS

Similar to land-based plants, the photosynthetic process for seaweeds underwater and at the water's surface is driven by sunlight and takes up CO_2. In the case of kelp, CO_2 is removed from the surrounding seawater and used to form new kelp biomass. Kelp forests are highly productive, taking up CO_2 at per-area rates similar to those of rainforests (Pessarrodona *et al.* 2022). Like terrestrial forests, kelp forests deliver other benefits: they provide habitat for marine species and support healthy coastal ecosystems. While the extent that kelp can draw in CO_2 from the water column is widely documented and estimates of the standing stock of these ecosystems exist, the fate of the large annual organic carbon production in kelp forests remains a critical yet contentious and unresolved component of the global carbon cycle (Macreadie *et al.* 2019; Hurd *et al.* 2022). Because most of the kelp biomass is exported from these nearshore habitats, sequestration only takes place for the portion of detritus that is refractory or where and when kelp detritus becomes buried or entrained in long-term sinks, either on the continental shelf or in deeper waters (Krause-Jensen and Duarte 2016; Ortega *et al.* 2019, Filbee-Dexter *et al.* 2022b). For Canada's kelp forests, there is limited information on the fate of kelp-derived carbon. Carbon in kelp biomass enters the broader coastal ecosystem as detritus that can be transported with ocean currents and consumed, decomposed or sequestered as it is moves away from kelp forest habitats (Krumhansl and Scheibling 2012a). Detritus that reaches the deep ocean may be considered "sequestered" as it is trapped deep within the water column and can be retained for a geologically significant period (hundreds to thousands of years) (Krause-Jensen and Duarte 2016; Baker *et al.* 2022).

For most of Canada's coastal zone, there is little regional information on the rate of transport of kelp to deep ocean sinks. Geomorphic features such as a narrow continental shelf or submarine canyons may facilitate transport to deeper waters. Such features are most prominent in British Columbia, yet kelp also has been recorded at 2500 m depth off Nova Scotia (A. Metaxas, *unpublished data*). Ultimately, the fate of drifting kelp and other seaweeds will depend on direction of transport by ocean currents, consumption when they reach the seabed, and rates of decomposition and burial. Because limited nutrients reach the deep seabed, most carbon that arrives is immediately consumed and only a small proportion is buried and sequestered into the sediment; however, rates of nutrient regeneration are relatively slow, with lag times of hundreds of years (Snelgrove *et al.* 2018). Carbon that reaches the deep sea can be considered sequestered as it is removed from rapid carbon-mineralization pathways in the photic zone and stored within the deep ocean (Baker *et al.* 2022). Seaweeds in Arctic waters decompose slowly and can therefore stay in the water column for long time periods; in some areas, this facilitates the movement of kelp carbon to the deep seabed prior to decomposition (Filbee-Dexter *et al.* 2022b). Emerging evidence from deep sea sediments and faunal samples shows that seaweeds, such as kelp, can provide a significant portion of organic material entering in deep sea areas.

Local and regional estimates of per cent export are limited. However, the estimated export potential of kelp carbon to the deep ocean (beyond the continental shelf break) can be coarsely calculated for each ecoregion in Canada from global models of coastal residence times (Liu *et al.* 2019; Filbee-Dexter *et al. unpublished data*). Filbee-Dexter *et al.* (*unpublished*) used modelled simulations of coastal residence times based on the NOAA Modular Ocean Model (MOM6) (Griffies *et al.* 2020) to track parcels of coastal water bodies in three dimensions from at 0.125° resolution, and then calculated an average time in days for a parcel of source water in the coastal domain to exit to the open ocean (beyond the 200 m isobath) for each starting point from 1998 to 2007. Using these coastal residence times for the coastal zone (<50 m depth), and average decomposition rates for kelp tissue (Pedersen *et al.* 2021; Filbee-Dexter *et al.* 2022b), we can estimate that the average export potential of kelp detrital production (68 per cent NPP, Krumhansl and Scheibling 2012) is 2.8 per cent (± 2.7 SD) for Pacific ecoregions, 6.8 per cent (± 2.8 SE) in Arctic ecoregions (excluding the High Arctic Archipelago), and 0.43 per cent (± 0.25 SE) for Atlantic ecoregions (Table 14). Transport dynamics of detritus can be complex, and this model is a coarse tool for understanding the export potential of kelp detritus. Previous estimates, based on in situ observations of macroalgae in sediments globally, found a mean value of ~10 per cent NPP export to the deep sea and below mixed-layer depths (Krause-Jensen and Duarte 2016). To determine sequestration rates for Canada's kelp forests at scales appropriate for management decisions, we need better regional information on detrital production, decomposition, and coastal currents, as well as material properties of kelp detritus for different species (e.g., buoyancy, floating longevity, material density, sinking speeds and refractory components).


© Erling Svensen / WWF

Table 14. Export potential of kelp detritus across the shelf break (200 m isobath) calculated using average decomposition rates and average coastal residence times (days) simulated for the 0–50 m depth zone in each ecoregion in Canada (CRT from Liu *et al.* 2019a; export calculations for kelp forests Filbee-Dexter *et al.* unpublished data).

Ecoregion	Average per cent C export (%)	Ocean
Baffin Bay – Davis Strait	16.5	Arctic
Beaufort-Amundsen-Viscount Melville-Queen Maud	2.8	Arctic
Hudson Complex	0.01	Arctic
Lancaster Sound	7.8	Arctic
Northern Labrador	7.1	Arctic
High Arctic Archipelago	24.3	Arctic
Gulf of Maine/Bay of Fundy	0.0	Atlantic
Gulf of St. Lawrence – Eastern Scotian Shelf	0.7	Atlantic
Scotian Shelf	0	Atlantic
Southern Grand Banks – South Newfoundland	1.0	Atlantic
North American Pacific Fjordland	5.5	Pacific
Puget Trough/Georgia Basin	0.03	Pacific

STATUS AND THREATS

Canada's kelp forests are vast and variable, and only some regions have long-term monitoring that allows us to accurately detect change. Kelp forests also face a range of threats, including losses due to direct and indirect effects of climate change, overgrazing by sea urchin, invasive species, and pollution and coastal development (Wernberg *et al.* 2019). Overall, there are reported trends of kelp decline along some areas of Canada's Pacific and Atlantic coasts, and predictions of possible expansion of kelp along Arctic coasts.

Climate Change

Climate change represents the largest threat to kelp forests, particularly at warm range edges. The IPCC ranks kelp forests as the temperate marine ecosystems most vulnerable to climate change (second overall, behind tropical coral reefs) (IPCC 2022). Kelps are particularly vulnerable to temperature anomalies, particularly marine heat waves. These are increasing in duration, frequency and intensity with accelerating climate change (Oliver *et al.* 2018; Wernberg *et al.* 2019) and have already caused kelp loss in parts of North America (Rogers-Bennett and Catton 2019; Filbee-Dexter *et al.* 2020; Starko *et al.* 2021). For instance, declines in bull kelp (*N. luetkeana*) have been recorded in Gulf Islands (Schroeder *et al.* 2020), and subtidal and intertidal kelp species have been lost on the west coast of Vancouver Island as a result of marine heat waves (Starko *et al.* 2022). In Barkley Sound, on the west coast of Vancouver Island, kelp forests were lost at roughly 40 per cent of sites during the 2014–2016 Northeast Pacific heat wave, with most losses occurring at inshore sites where temperatures were greatest (Starko *et al.* 2022). Recently, sea star wasting disease led to sea urchin outbreaks, contributing to kelp declines along British Columbia's coast (Burt *et al.* 2018). In northern areas of Haida Gwaii (Gendall *et al.* 2022) and along a sea otter recovery gradient on the West Coast of Vancouver Island (Watson and Estes 2011), kelp forest trends have been variable, with reported declines and/or areas of relative stability. More broadly, a new assessment of 11 regions across British Columbia found variable responses in the province's two canopy-forming kelp species, with net losses in six regions, net gains in two regions, and stability in the other three (Starko *et al.* 2023). Losses occurred primarily in southern regions and were related to recent high summer temperatures that at times exceeded the species' thermal tolerances (Starko *et al.* 2023). Along these temperate coasts, the potential for Canada's kelp forests to contribute as natural climate solutions will depend upon their persistence under intensifying climate-change impacts.

For the Canadian Arctic, species distribution models, combined with relationships between current kelp extent across environmental gradients, all predict an expansion of Arctic kelp forests with sea-ice loss and warming. These include predictions of larger standing stock and higher percent cover (Filbee-Dexter *et al.* 2022a), greater depth extent (Castro de la Guardia *et al.* 2023), and (in some areas) larger ranges (Goldsmit *et al.* 2021). This expansion could represent increased carbon standing stock and annual sequestration potential in this region; however, this will be offset by increased turbidity and reduced salinity in some areas with high meltwater (Filbee-Dexter *et al.* 2019a). Although baseline data on kelp forests dates back to the 1980s (Filbee-Dexter *et al.* 2019a), there are currently no long-term monitoring sites in this region. In fact, repeated sampling has been conducted in only one location, Eclipse Sound; this sampling simply examined shifts in community composition and diversity, not abundance or extent (Küpper *et al.* 2016; Krause-Jensen *et al.* 2021). As a result, predictions of change in Arctic kelp due to climate change are based entirely on species distribution models and changing environmental conditions (Goldsmit *et al.* 2021; Bringloe *et al.* 2022).

In Atlantic Canada, climate change has driven the loss of kelp forests along 110 km of coastline in Nova Scotia, due to a combination of direct and indirect effects of warming sea temperatures (Filbee-Dexter *et al.* 2016). Warmer temperatures are associated with reduced kelp growth, increased mortality and tissue breakage, and increased damage due to changes in temperature-mediated interactions with small grazers and encrusting species (Simonson *et al.* 2015; Krumhansl *et al.* 2011). These impacts were compounded by an invasive bryozoan, which caused extensive damage to kelps in the last two decades and grows faster in warmer temperatures (Saunders and Metaxas 2009).

Sea Urchins

Substantial portions of Canada's kelp forests have been overgrazed by sea urchins, creating a state dominated by coralline algae, with altered productivity and lower carbon stocks (Filbee-Dexter and Scheibling 2014). In British Columbia, the overexploitation of sea otters has led to an explosion of sea urchin densities, resulting in a transition from kelp-dominated ecosystems to barrens (Watson and Estes 2011). To facilitate the reestablishment of kelp forests along Vancouver Island and Alaska, Wilmers *et al.* (2012) estimated the effect of sea otter predation on reducing sea urchin densities. They found that the presence of sea otters resulted in higher NPP (25–70 g C m^{-2} yr^{-1} in barrens compared to 313–900 g C m^{-2} yr^{-1} in kelp forests) and carbon stock (of 8–14 g C m^{-2} in barrens to 101–180 g C m^{-2} in kelp forests). They estimated that the effect of sea otter predation on urchins resulted in a 4.4 to 8.7 Tg C increase in standing kelp carbon stock within the North American range of sea otters.

A similar overgrazing occurred along the coast of Nova Scotia in the 1980s (Hart and Scheibling 1988). However, recurrent disease — rather than predation by sea otters — has controlled sea urchin populations, effectively recovering kelp forests on the Scotian Shelf (Feehan and Scheibling 2014). Interestingly, barrens are found throughout Newfoundland and Labrador (with a northern limit near Makkovik) (Filbee-Dexter *et al.* 2022a) and the Gulf of St. Lawrence (Johnson *et al.* 2019). When sea urchins are removed from these regions, kelp or seaweed forests (e.g., *Desmarestia* sp.) quickly recolonize the area (Gagnon *et al.* 2004). However, there is little historical information that would allow us to determine whether these regions naturally supported kelp forests or whether barrens are the historic ecosystem state.

Invasive Species

Since the 1990s, the invasive epiphytic bryozoan *Membranipora membranacea* has led to near-complete defoliation of kelp forests in some sections of Atlantic Canada (Saunders and Metaxas 2009; Scheibling and Gagnon 2009). More recently, the same bryozoan has been observed in British Columbia, in association with changing climatic conditions (Denley *et al.* 2022). With an annual reproductive cycle, the bryozoan reaches maximum cover on kelp blades in the fall of each year, compromising their structural integrity and increasing their susceptibility to breakage during storms (Krumhansl *et al.* 2011). Increasing temperatures due to climate change are expected to increase the population growth and spread of the bryozoan northwards (Denley *et al.* 2019a, b; Pratt *et al.* 2021). Although the projected spread of current southern bryozoan populations does not pose a significant threat to Arctic kelp forests, a secondary invasion from populations in northern Europe may have a significant cumulative impact (Pratt *et al. in press*). Despite the extensive defoliation, healthy kelp forests remain in Atlantic and Pacific Canada, particularly in areas of exposure to waves, suggesting that phenotypic adaptations may make kelp more resilient to invasive species (Attridge *et al.* 2022).

RESTORATION, PROTECTION AND MANAGEMENT

Restoration

Most kelp restoration in Canada has occurred in British Columbia, and on a limited scale (Eger *et al.* 2021). One tool for recovering kelp forests is increased commercial fishing of red sea urchins (*Mesocentrotus franciscanus*) (DFO 2020). In Gwaii Haanas, British Columbia, the Council of the Haida Nation, Parks Canada and Fisheries and Oceans Canada conducted a large-scale kelp forest restoration project covering 0.2 km^2 of shallow subtidal rocky reef (Lee *et al.* 2021). Haida and commercial divers were employed to remove, crush and maintain low urchin densities at the sites, mimicking the role of extirpated sea otters in controlling their abundance (Lee *et al.* 2021). New methods for restoring kelp forests are also being explored in British Columbia, using techniques such as "Green Gravel"" (Fredriksen *et al.* 2020) that seed kelp plants on gravel or larger rocks for distribution to sites where assistance with recovery is needed (Kelp Rescue Initiative, Seaforestation, Green Gravel Action Group). However, restoration efforts will be inefficient and ineffective unless the main stressors, such as sustained ocean warming or the presence of invasive species, are addressed, as is the case in Atlantic Canada (Wood *et al.* 2019).

Protection and Management

Kelp forests are managed through several approaches, including area-based management (e.g., marine protected areas and marine spatial planning), sustainable harvest of kelp and associated species, and threat reduction (e.g., restricted shoreline development, limits on nutrient pollution) (UNEP 2023). In British Columbia, kelp representativeness in marine protected areas has been assessed as a component of the MPA Network process (Rubidge DFO, pers comm.), including MPA connectivity via the transport of kelp spores (Cristiani *et al.* 2023). In addition, MaPP (the Marine Plan Partnership for the North Pacific Coast, a partnership with 17 First Nations and the Province of B.C.) has used canopy-forming kelp as a valued ecosystem component to pilot under their Integrated Ecosystem-based Management (EBM) Program. As part of this, MaPP has developed a Regional Kelp Monitoring Program. This program uses monitoring to learn about kelp-habitat health, distribution and abundance, in order to inform marine plans and management decisions. It also aims to increase First Nations' participation in management and monitoring activities.

In Atlantic Canada, areas of significant concentrations of kelp fall under the coastal conservation priority of biogenic habitats of DFO-Maritimes. The current "Draft Conservation Network Design for the Scotian Shelf-Bay of Fundy Bioregion" includes three proposed sites: one in the Bay of Fundy, one on the Atlantic coast of Nova Scotia, and one in the Eastern Shore Islands Area of Interest. In the Arctic, the Southampton Island EBSA in Nunavut has been designated an area of interest for a Marine Protected Area, in part due to the dense kelp forests in the area that provide habitat for fish and marine mammals (Loewen *et al.* 2020; Filbee-Dexter *et al.* 2019b).

In British Columbia, kelp harvests and kelp aquaculture are managed by the provincial government. Wild harvests have historically dominated the seaweed industry, which is currently expanding within the province. However, kelp aquaculture — which has been established since the 1980s — is also on the rise. The sustainability of small-scale kelp harvests has been scientifically assessed (e.g., Krumhansl *et al.* 2017), and active monitoring of wild harvests and kelp aquaculture is in development. However, both industries need enhanced standardization (i.e., for reporting and verification of standing stocks, productivity and distribution). First Nations in British Columbia also use kelp to collect herring spawn in the Roe-on-Kelp (ROK) fishery. In the Maritimes, kelp harvest is "almost non-existent" (DFO 2013). However, any additional harvest would require an assessment of standing stock, and only low-impact approaches (e.g., hand harvest by SCUBA at least 10 cm above the meristem, during periods outside of peak growth) would be permitted (DFO 2013).

Critically, prominent drivers of kelp loss in Canada include direct and indirect effects of global warming and invasive species. These can be challenging to manage on regional and even national scales, and require strong international action.

KELP SUMMARY

Though not initially included in global blue carbon assessments, kelp forests are increasingly gaining recognition as blue carbon ecosystems. In Canada, kelp forests may provide substantial carbon sequestration because of their extensive distribution along all three coastlines, particularly in the Arctic. However, we need further information regarding their spatial extent, NPP and carbon cycling/export to enhance the accuracy of estimates. We also need local and regional information to validate modelling efforts, especially since global mapping initiatives lack data specific to Canadian coasts. This research is necessary for Canada to report on international initiatives in ocean accounting, include targets for kelp forests within its NDCs, and improve measurement and monitoring of kelp forest emissions and removals as part of Canada's international emissions reporting.

There is also strong evidence that Canada's kelp forests are changing throughout their distribution due to the combined impact of multiple stressors, including climate change and the trophic impacts of predation, herbivory and invasive disease within these systems. High-quality data exist for parts of British Columbia and Atlantic Canada, including historic data (1958–1956) for B.C. (Costa *et al.* 2020) and long-term study sites (1952–present) and surveys (1980–present) from Atlantic Canada (Scheibling 1986; Filbee-Dexter *et al.* 2016; Watanabe *et al.* 2010). However, many coastal regions are not adequately monitored, and for much of the Arctic little to no historic data exist, making it impossible to detect change.

Kelp blue carbon habitats have the potential to act as NCS if actions are taken to increase carbon accumulation and transfer in these ecosystems (e.g., restoration or enhanced management) and/or to prevent habitat declines (e.g., protected areas). As a first step, however, the extensive kelp forests along Canada's coasts need to be better monitored. To guide local conservation efforts, it would be useful to have an assessment of effective management actions that can support kelp protection, management and restoration. Conservation actions will need to be assessed through a social-ecological lens, taking into account cultural, environmental and economic considerations. There is clearly work to be done, and research gaps to fill, before sound protection and management of Canada's kelp forests become more pervasive in the NCS lexicon. However, to meet ambitious targets for greenhouse gas emissions, we need to explore all mitigation options, including those provided by Canada's largest coastal vegetated ecosystem.

RECOMMENDATIONS FOR KELP

- ✓ Research kelp spatial extent, NPP, and carbon cycling and burial at local and regional scales. This data will improve estimates of carbon sequestration, validate modelling efforts and inform ocean accounting to support kelp conservation as an NCS.
- ✓ Improve the monitoring of kelp along Canada's coastline to facilitate the detection of temporal trends and associated drivers, while establishing baseline information for Arctic kelp forests.
- ✓ Promote the recognition of kelp as blue carbon by documenting kelp-derived carbon sequestered throughout the ocean ecosystem, exploring the lateral carbon transfer between habitats, and demonstrating that management actions can increase sequestration.
- ✓ Develop and improve effective conservation pathways for kelp forests that integrate cultural, environmental and economic considerations to prevent ecosystem declines and recover degraded areas.
- ✓ Support and build partnerships with Inuit communities and local Arctic communities, and strengthen partnerships with Indigenous communities and stewardship initiatives on the Pacific and Atlantic costs in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on kelp. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

THE ARCTIC: A UNIQUE BLUE CARBON REGION

Stephanie Meakin, Maya Gold and Alex Kerr

For the purposes of this chapter, the Arctic region is defined as the lands and waters north of the 60th parallel. However, to the Inuit who have inhabited the region for millennia, the Arctic region is known as Inuit Nunangat (Figure 19) and includes the Inuvialuit Settlement Region, the territory of Nunavut, Nunavik in northern Quebec, and Nunatsiavut in Newfoundland and Labrador. This region includes nearly a third of Canada's landmass and more than half of its coastline. The Arctic marine, coastal and freshwater environments are an integral element of the Inuit daily life and territory; they provide food through the harvesting of many of the animals that live at sea, provide ease of travel over water and ice, and play a critical role in Inuit culture and well-being. With the exception of the inland community of Baker Lake, communities across Inuit Nunangat are small, coastal and remote, and only accessible by air or sea during the short open-water navigation season. It is vital that Inuit leadership, priorities, knowledge and ways of life be represented and respected at all levels of planning, decision-making, and policy-making and execution — and not only for climate policy, but for all policy affecting the Arctic. NCS in the Arctic can only be undertaken with the full free, prior and informed consent and leadership of Inuit. NCS that prioritize Indigenous leadership in conservation, such as Indigenous Protected and Conserved Areas (IPCAs), should be used to ensure sustainable and effective ecological stewardship in the Arctic and across Canada.

The Arctic Ocean is the smallest and shallowest of the Earth's five oceans. The U.S. National Snow and Ice Data Center tracks when the area of Arctic sea ice is smallest each year (Fetterer 2022). For the year 2022, sea ice was likely at its smallest (4.67 million km^2) on September 18. In the nearly 44-year satellite record, the 2022 minimum is tied for tenth lowest with 2018 and 2017. The last 16 years, from 2007 to 2022, have the 16 lowest extents of sea ice in the satellite record. Arctic sea-ice reduction has a multitude of impacts on the global and Arctic carbon cycle. Sea ice also provides essential ecosystem services, such as climate regulation, and enhances human well-being. In particular, sea ice is important to Inuit as it extends the coastal region and improves accessibility to the many leads and areas of open ocean via Arctic ice (land-fast ice, pack ice, sea ice). For much of the year, many Inuit travel and hunt on the ice, blurring the distinction between coastal areas and open ocean. The sea ice also extends habitat for blue carbon plants. For example, algae, although often found in shallow coastal waters anchored to the sea floor, is not limited to the coastal regions in the Arctic. Arctic sea ice allows algae to extend its area of growth, and subsequent carbon sequestration, into ice-covered pelagic ecosystems.

Figure 19. Inuit Nunangat Map (Inuit Tapiriit Kanatami 2019).

The Canadian Arctic is a vast region dominated by a wide range of coastal and marine ecosystems. At 162,000 km, the Canadian Arctic coastline is the country's longest (Morrison 2006). Dominated by large areas of seasonally formed sea ice over extensive shelves and a large central area of perennial (multi-year) pack ice, the Arctic Ocean is characterized by extreme seasonal fluctuations in solar irradiance, ice cover, temperature and associated atmospheric exchanges, and — on the coastal shelves — riverine inflow. The many islands and long coastlines provide areas where sea ice can freeze securely to the land (land-fast ice), more so than in any other polar region (Fisheries and Oceans Canada 2020). This chapter will discuss the importance and contributions of coastal ecosystems to carbon sequestration and storage along the Canadian coastline of the Arctic Ocean. It will also examine potential threats to these ecosystems, such as climate change, permafrost melt, glacial scouring of the seafloor, and bottom trawling.

Carbon sequestration and storage within Arctic blue carbon ecosystems are a growing area of study in Canada and around the world. However, understanding the state and blue carbon potential of the Canadian Arctic coastline is challenging — more so than for Canada's other coasts. Our knowledge of Arctic blue carbon has many gaps as there has been little long-term, sustained scientific monitoring of ocean conditions, biodiversity and carbon cycling in the Canadian Arctic. In addition, it is inherently difficult and expensive to conduct research in the region due to poor accessibility, remoteness, and a limited operating season for in-field marine research. The lack of western scientific data makes it challenging to advance the understanding of blue carbon in the Arctic, including the best ways to manage it now and in the future. The Arctic Ocean is also in a state of extraordinary transition, and the high rate of environmental change limits our ability to apply past knowledge to the present and future (ONCS, WWF-Canada and DUC 2018). All these factors make Arctic blue carbon an emerging and critical area of study in the climate crisis.

Other regions have seen partial mapping of salt marshes, seagrass and kelp forests, but these important ecosystems are not well mapped along Arctic coastlines. However, extensive research suggests that the Arctic Ocean plays an important role in the global carbon cycle (Chen *et al.* 2002; Stein and Macdonald 2004; Bates and Mathis 2009). This chapter will discuss the unique features relevant to the sequestration and storage of blue carbon across the coastal and marine waters of Inuit Nunangat, the gaps in our knowledge of those processes in the region, and potential management needs for the area in the context of NCS.

© Kim Dunn / WWF-Canada

THE ARCTIC OCEAN

Like other oceans, the Arctic Ocean stores carbon within its sediments, flora and fauna — including blue carbon ecosystems — and within the water column. Carbon mapping has proven especially difficult in the Arctic Ocean due to its remoteness, extreme weather conditions, barriers to the use of remote sensing products (e.g., multiyear ice), and the equipment needed for in-field measurement, which is both costly and difficult to transport in such harsh conditions. With the exception of kelp research done in the eastern Arctic (see Kelp), there has been little mapping of blue carbon ecosystems such as seagrass, salt marsh and kelp forests. The Commission for Environmental Cooperation (CEC) North American blue carbon mapping initiative has few data points for seagrass and saltmarsh ecosystems in the Canadian Arctic (CEC 2016; CEC 2021; Pasos 2022). To understand the full distribution and scale of Arctic blue carbon ecosystems, we will need further mapping efforts — and importantly, these need to be led and supported by coastal communities.

The Arctic Ocean plays a critical role in the global climate system and is generally considered to be a sink for atmospheric CO_2, largely due to its blue carbon ecosystems (DeGrandpre *et al.* 2020). The Arctic Ocean absorbs, stores and circulates CO_2 through numerous physical processes, including the solubility pump and ocean currents. Measurements of air-sea CO_2 flux suggest that the Arctic Ocean, with a surface area of only 3 per cent of the global ocean, is responsible for roughly 5 to 14 per cent of present-day global oceanic carbon uptake (Bates and Mathis 2009). Several factors unique to the Arctic Ocean heavily influence carbon sequestration and storage. The relatively large carbon uptake is driven by numerous interacting variables, including organisms and their ecosystems, only some of which are traditionally considered to be blue carbon ecosystems. Other factors include ice coverage, sea shelf processes, sediment dynamics, water temperatures, and ocean depth (MacGilchrist *et al.* 2014).

ARCTIC BIOTA

Of the carbon sequestered by biological sources, over half is captured by living marine organisms, highlighting the importance of blue carbon and the need for conservation (Nellemann and Corcoran 2009). The Arctic supports more than 21,000 species of mammals, birds, fish, invertebrates, plants and fungi, plus an estimated several thousand species of endoparasites and microorganisms, many of which have yet to be described. In the marine realm, biodiversity tends to be high near the Arctic gateways from the North Atlantic and North Pacific Oceans (Christiansen and Reist 2013). Different groups of organisms play different roles in maintaining the integrity, structure, services and health of Arctic ecosystems; however, the groups with the greatest functional significance are generally among the least understood. Though key elements of Arctic ecosystems, microorganisms have been little studied (Christiansen and Reist 2013). Within the Arctic Ocean, main contributors to marine primary production and carbon sequestration include phytoplankton, ice algae, macroalgae, salt marshes and seagrass (eelgrass). Although phytoplankton and some algae ecosystems are not currently considered blue carbon ecosystems, they are gaining recognition as large contributors to blue carbon. Lovelock and Duarte (2019) detail possible reasons why they have not been recognized as blue carbon ecosystems, including gaps in scientific understanding of carbon stocks or greenhouse gas fluxes, limited potential for management, and limited accounting for ecosystem extent and carbon sequestration.

Plankton

The term “plankton” is used to describe a group of organisms that live in water and are carried along by ocean currents that they lack the means to swim against. Plankton can be flora (phytoplankton, made up of unicellular algae) or fauna (zooplankton such as eggs, larvae, small animals and gelatinous creatures). In the Arctic Ocean, the algae component of plankton grows in the surface water, down to a depth of a few dozen metres, where the sunlight is still strong enough to drive photosynthesis. Like land-based plants, phytoplankton needs both mineral elements and sunlight to grow. There are thousands of different species of planktonic algae, all of them microscopic (Polar Pod 2016).

The spring-to-early-summer phytoplankton bloom is often considered the single most important event in the Arctic’s seasonal cycle of production, followed closely by the bloom of ice algae. These Arctic blooms can be large enough to see from space. It has been documented that phytoplankton blooms under the Arctic Ocean ice reach magnitudes similar to — or even greater than — blooms observed in the open ocean, with carbon fixation rates exceeding 30 g C m^{-2} d^{-1} (Arrigo *et al.* 2014; Oziel *et al.* 2019). Data show that Arctic phytoplankton has increased by almost half over the past decade, suggesting that the Arctic is becoming more productive and could export more carbon in the future (Lewis *et al.* 2020).

Phytoplankton blooms not only sequester large amounts of carbon, but also play an essential role in the Arctic food web: they feed krill that are then ingested by seabirds, seals, whales and many other Arctic Ocean animals. The transfer of primary production from the short-lived phytoplankton bloom to upper trophic levels depends on whether grazers are present when and where the bloom occurs, and also on what the bloom’s taxonomic composition is. In the warming Arctic, earlier sea-ice retreat and later freeze-up are changing the phenology of the phytoplankton bloom. Predictions for a second fall bloom due to longer open-water seasons (Vincent *et al.* 2011) are now documented throughout the Arctic and on Canadian shelves (Michel *et al.* 2015; Ardyna *et al.* 2020).

Marine phytoplankton significantly contributes to primary production in not only the Arctic Ocean, but also the global ocean, accounting for roughly 50 per cent of all photosynthesis on Earth. This contribution to global primary production results in the fixing of roughly 50 Gt carbon annually (Baumert and Petzoldt 2008). During photosynthesis, the phytoplankton lower the CO_2 partial pressure of the upper ocean. This increases the gradient of CO_2 from the atmosphere to the upper ocean, allowing more CO_2 to diffuse into the surface waters (Lecher and Mackey 2018). A byproduct of this photosynthesis is the formation of particulate organic carbon. This carbon is processed by other organisms such as zooplankton and then exported to the deep ocean (Turner 2015). Zooplankton are consumed by numerous Arctic marine species, including Arctic cod, capelin, and young herring. Small Arctic cod are found in great numbers in dense schools, and are a key food source for marine mammals, seabirds and other fish.

Sea-ice loss and ocean acidification are presenting new challenges and opportunities for phytoplankton. Reduced sea ice in the Arctic Ocean has led to longer growing seasons and created more accessible habitat for phytoplankton (Pabi *et al.* 2008; Kahru 2016). Net primary production within the open Arctic Ocean increased 30 per cent from 1998 to 2012 (Arrigo and Van Dijken 2015) after sea-ice extents reached then-record minimums. The largest increases in primary production were seen in the Arctic Ocean's interior shelves, including the Beaufort shelf off the coast of the Inuvialuit settlement region and Alaska, with an increase of 10–112 per cent within the same time period. Exterior shelves showed less primary production — for example, the Baffin and eastern Greenland shelves experienced changes of +8% and -15%, respectively (Arrigo and Van Dijken 2015). Although sea-ice reduction gives phytoplankton more growth opportunities, it also has potentially harmful consequences. Changing ocean dynamics, including ocean stratification causing nutrient limitations, have altered phytoplankton and algae cell structure and size, favouring smaller sizes. This potentially affects the uptake of carbon during production and the subsequent exportation of carbon, as well as food-web connections depended upon by other organisms within the Arctic ecosystem, such as high-Arctic top predators (Matsuoka *et al.* 2017; Ardyna *et al.* 2020). Earlier breakup of ice can cause the phytoplankton blooms to occur prematurely, altering the subsequent export of carbon down the water column which is relied upon by numerous pillars of the Arctic food web such as zooplankton (Leu *et al.* 2015; Dünweber *et al.* 2010). We need further research on such ecological changes, with an emphasis on long-term consequences, to properly monitor and manage these sea-ice habitats.

Algae

There are an estimated 4,000 algal species within the circumpolar Arctic, including both freshwater and marine habitats. Marine phytoplankton and macroalgae contribute to the Arctic marine food web, providing sustenance for numerous species both directly (e.g., as a food source for urchins) and indirectly (e.g., as detrital material) (Norderhaug and Christie 2009; Krumhansl and Scheibling 2012; Petersen *et al.* 2020).

It was previously estimated that algae's contribution to the total carbon sequestered was 57 per cent of the primary production occurring within the central Arctic Ocean (Gosselin *et al.* 1997). Up to 25 per cent of that takes place on Arctic shelves (Legendre *et al.* 1992). This disproportionate contribution results from their ability to filter particulate carbon from the water column and use it in primary production (Greiner *et al.* 2013). However, there are few estimates of their contribution in recent studies. Rates of carbon sequestration by algae can be affected by numerous factors, among them the algae's distance from the estuary, water quality (e.g., salinity, pH and temperature), meadow configuration (e.g., canopy height and shoot density), location in the meadow (inside vs. edge), nitrogen levels, sediment composition and light availability (Schmidt *et al.* 2011; Postlethwaite *et al.* 2016; Hitchcock *et al.* 2017; Oreska *et al.* 2017; Ricart *et al.* 2020). Despite algae's host of ecosystem services, there has been no comprehensive mapping of algae in the Arctic. Mapping is done with numerous tools, including underwater videography, aerial imagery, satellite, benthic sonar, LiDAR, and remotely piloted aircraft systems (RPAS) (Wilson *et al.* 2019; Nahirnick *et al.* 2019; Forsey 2020).

These vegetated ecosystems not only contribute to primary production, but also provide many essential ecosystem services. For example, they provide habitats for other organisms, protect coastal communities by combatting coastal erosion, and contribute to the food security of all those within the Arctic (Christie *et al.* 2009; Teagle *et al.* 2017).

Ice Algae

Living within and on the underside of sea ice, ice algae are primarily composed of diatoms. Like those of phytoplankton, ice algal blooms contribute to both Arctic Ocean carbon fixation and the food web. Sea-ice algal blooms start within and underneath sea ice in the early spring, while phytoplankton blooms in the water column once ice has reached an advanced state of melt and disintegration in the latter half of summer (Leu *et al.* 2011; Arrigo *et al.* 2011; Mundy *et al.* 2014). In seasonally ice-covered regions, ice algae can contribute up to 40 per cent of the total primary production (Dupont 2012; Mäkelä *et al.* 2018).

Once the bloom detaches from the sea ice, a large mass of organic carbon begins sinking through the water column. A portion of this mass is recycled by microbes, while the rest sinks to the sea floor. Most of the latter is then recycled by seafloor microbes, and the rest is stored in sediment. This microbial loop is responsible for much of the blue carbon held within the Arctic Ocean and its carbon cycle. The loop also supports Arctic Ocean copepod and euphausiid shrimps (krill); as both of these have extremely large species biomass, they contribute significantly to carbon storage and turnover. However, it is unclear how much of this carbon is ultimately buried (CRRC 2010).

Previous estimates of ice algal biomass and production in the coastal ice-covered Arctic Ocean often included only phytoplankton, neglecting the contributions of sea-ice algae (Gosselin *et al.* 1997; Sakshaug *et al.* 2004; Fernandez-Mendez *et al.* 2018). Other studies have used indirect measuring approaches, such as measuring nitrate drawdown in surface waters over the entire period of ice algal bloom. A study by Matrai and Apollonio suggests that primary production within ice algal blooms is much higher than had previously been assumed (Matrai and Apollonio 2013; Leu *et al.* 2015).

Ice algae's sizable contribution to primary production may be at risk, for as sea ice diminishes, so does the habitat of ice algae (Dupont 2012). Reduced sea ice drives ice algae from the coastal shores and towards the deep basins of the Central Arctic Ocean (Barber *et al.* 2015). The changing climate, causing an earlier seasonal melting of sea ice and later formation, results in a temporal shift in when ice algae blooms occur. This change further impacts the primary and secondary producers that depend upon the bloom as an essential food source, potentially altering the amount of carbon sequestered and transferred up the food chain (Søreide *et al.* 2010; Leu *et al.* 2011; Ji *et al.* 2013). We urgently need year-round in situ sampling, especially to better understanding the incorporation of sea ice algae into the sea ice during its formation, possible early brine drainage at the end of winter, and the impact of these physical processes on ice algal development. With the ongoing warming climate in the Arctic, the general trend toward thinner sea ice, longer open-water periods (Stroeve and Notz 2018) and less snowfall (Bintanja 2018) would drastically increase the availability of light and affect microalgal growth beneath the ice cover in areas such as in the Baffin Bay. It is expected that an earlier onset of ice melt would shorten the sea-ice algal growth season, yet increase the potential for under-ice phytoplankton blooms in these regions.

Another climate-related risk to ice algae is the rising ocean acidification that causes stratification of surface water and limits the nutrient supply to the algal bloom. This leads to premature termination of the algal blooms. The shorter production period diminishes the total primary production and export of ice algal biomass and their contribution to the Arctic food web (Søreide *et al.* 2010; Leu *et al.* 2011; Leu *et al.* 2015).

Macroalgae

There are roughly 200 to 215 species of macroalgae in the Arctic, but their distribution within the Arctic is poorly mapped. Macroalgae make up the most extensive and productive vegetated seafloor marine habitats; these are widely distributed across coastal latitudes, including kelp forests in cold, coastal waters (Krause-Jensen and Duarte 2016; Krause-Jensen *et al.* 2018). The most abundant Arctic macroalgae are kelp. Although fewer than 12 of the 210 macroalgal species documented by Archambault *et al.* (2010) grow within the Canadian Arctic, they often have the largest total biomass of any macroalgae due to their size (Archambault *et al.* 2010; Johnsen *et al.* 2020; Krause-Jensen *et al.* 2020).

Macroalgae's growth is limited by a number of factors, including the Arctic's extreme variability in climate and weather events (Johnsen *et al.* 2020). Many of the algae species found in the Arctic have adapted to facilitate photosynthesis and tolerate their environment. However, algae's ability to flourish can be impeded by a number of environmental factors, including long periods with limited sunlight to drive photosynthesis, physical scouring of the seafloor, and cold temperatures (Wiencke and Amsler 2014; Fredriksen *et al.* 2019). Despite these constraints, macroalgae biomass has been increasing in the Arctic (Krause-Jensen *et al.* 2020).

Kelp

Kelp species are some of the most abundant macroalgae species in the Arctic Ocean, thanks to their ability to thrive in the cold waters and their large biomass (Johnsen *et al.* 2020). The kelp species that inhabit the Arctic coasts include *Saccharina latissima*, *Laminaria solidungula*, *Alaria esculenta*, *Hedophyllum nigripes* and *Agarum clathratum* (Krause-Jensen and Duarte 2016). Hard substrates dominate the benthic zones of much of the Canadian Arctic coast, allowing the wide distribution of kelp along the Canadian coast from the coast of the Inuvialuit region in the Beaufort Sea across to the eastern Baffin Bay off the coast of Nunatsiavut (CRRC 2011). Kelp also inhabits subarctic waters including the western and eastern shores of Hudson Bay, as far south as the Belcher Islands and community of Sanikiluaq and adjacent waters that are included in Inuit Nunangat. Despite this large distribution, gaps in our knowledge exist across the entirety of the Canadian Arctic Ocean coast in kelp distributions, biomass, carbon uptake, and the potential drivers that may affect such kelp forests (Filbee-Dexter *et al.* 2019).

Kelp forests provide a host of ecosystem services. For example, they provide fish and other fauna with habitat and nursery grounds, provide sustenance for pelagic and benthic organisms, support Arctic food webs, protect coasts and coastal communities from erosion, and play large roles in the sequestration of blue carbon (Krause-Jensen and Duarte 2016; Eger *et al.* 2021; Goldsmit *et al.* 2021). Kelp forests in the Arctic export carbon via three principal methods: direct export of kelp matter to the deep-sea water column and eventually sediments, consumption of kelp biomass by another organism, and direct export to shallow shelf-sediments where kelp is surrounded by soft sediments (Krause-Jensen and Duarte 2016).

Recent studies in the Eastern Canadian Arctic and subarctic by Goldsmit *et al.* (2021) have addressed the large gaps in our knowledge of kelp along the Canadian Arctic coastline, and made projections about kelp's future. They found current estimates of kelp distribution and contribution to carbon uptake in the Arctic Ocean to be vastly underestimated. Most coastal regions of the Eastern Canadian Arctic were found to currently provide suitable habitat for kelp. Therefore, the potential extent of kelp along the Eastern Canadian Arctic coast is much greater than previously thought, with a potential suitable habitat of over 312,000 km^2 in the Eastern Canadian Arctic alone (Goldsmit *et al.* 2021). The data gathered in this area alone may increase estimates for subtidal macroalgae in the entire Arctic, as well as the estimated global distribution of kelp forests, as the values underestimate the extent of suitable habitat in the Arctic (Krause-Jensen and Duarte 2016; Filbee-Dexter 2020; Jayathilake and Costello 2020). We need to understand the extent of kelp in the Arctic to evaluate its contribution to blue carbon. The total standing stock of carbon within kelp forests of the Eastern Canadian Arctic is 72.7 Tg C, accounting for over four times more than the standing stock of carbon within the kelp in all of Australia (16.6 Tg C) (Filbee-Dexter and Wernberg 2020) and 10 times the standing stock of carbon within the kelp in Norway (7.1 Tg C) (Frigstad *et al.* 2021). The Arctic provides abundant suitable habitat due to its lengthy coastline — the result of its many islands, fjords and bays — and the wide shallow coastal shelves that fall within the depth limits of macroalgae (Goldsmit *et al.* 2021).

Because the importance of kelp in blue carbon within the Arctic Ocean is underestimated, we lack data on kelp's export of carbon. More research is needed on biomass, detrital production, decomposition rates, and material properties of kelp detritus to accurately estimate the sequestration rates and to determine appropriate management measures for Canada's kelp forests.

Kelp forests are threatened by both climate change and human impacts, which have caused recent documented decline in global kelp stocks in coastal areas (Duarte *et al.* 2018; Wernberg *et al.* 2019). The IPCC previously ranked kelp forests among the ecosystems most vulnerable to the threats of climate change (IPCC 2019b). Marine heat waves, which are increasing in both frequency and intensity due to climate change, are particularly harmful to kelp (Wernberg *et al.* 2019; Rogers-Bennett and Catton 2019). Kelp in North America have experienced documented declines after marine heat waves (Filbee-Dexter *et al.* 2020; Starko *et al.* 2021).

Climate change also presents threats to Arctic kelp stocks as coastal erosion from melting sea ice, seabed disturbance from ice scouring, permafrost melting, and high glacial inputs are altering ocean and carbon dynamics along the Canadian Arctic coasts (Fritz *et al.* 2017; Filbee-Dexter *et al.* 2019). Physical disturbance of coastal regions from erosion, permafrost and shelf collapse, and ice scouring disturb the carbon stored in coastal sediments, increase turbidity and so limit light availability, and harm the ecosystems present, including kelp. Ocean freshening and reduced salinity caused by sea ice and glacial melt have harmful impacts on kelp, including nutrient limitation (Spurkland and Iken 2011; Traiger and Konar 2018). An area where this influence on kelp becomes of particular importance in the Canadian Arctic is within the Hudson Bay bioregion. This is an area that is predicted, utilizing climate change scenarios, to experience large changes in salinity or freshening, where freshwater river discharge is known to influence ocean dynamics (Déry *et al.* 2018).

Climate change presents not only threats, but also opportunities to kelp forests in the Arctic. Climate change-induced warming of the Arctic, loss of sea ice, and reduced snow cover may increase the amount of suitable habitat. Loss of sea ice and decreased depth of snow cover over the sea ice increase light availability, supporting photosynthesis in previously unsuitable regions (Krause-Jensen *et al.* 2020). Goldsmit *et al.* (2021) predict that this increase in suitable habitat may cause a northward expansion for all kelp species along the Eastern Canadian Arctic coast, except for *L. solidungula* as it is less suited for warming waters (Goldsmit *et al.* 2021).

Kelp in the Arctic has been documented for decades in areas such as the Aleutian Islands and the Beaufort Sea's "Boulder Patch" in Alaska, with records of kelp abundance from the 1970s to the mid-2010s (Metzger *et al.* 2019). However, there are minimal long-term studies on the extent of kelp in the Canadian Arctic and on climate change's effects on kelp. The lack of baseline data makes it difficult to predict how kelp biomass will change in the future. However, in line with Goldsmit *et al.*'s findings (2021), research from other Arctic States such as Greenland, Russia and Norway suggests that increased temperatures and decreased sea ice may support increased kelp productivity and biomass in the Arctic by expanding both habitat and depth limits (Filbee-Dexter *et al.* 2019; Krause-Jensen *et al.* 2020). However, the positive effects from an increase in suitable habitat will vary by region, depending on detrimental influences such as glacial and sea ice melt, permafrost collapse, turbidity increase, and freshening in coastal areas (Bartsch *et al.* 2016; Bonsell and Dunton 2018; Traiger and Konar 2018).

Salt Marshes

An important blue carbon ecosystem, salt marshes can accumulate carbon at rates similar to those of mangrove ecosystems and higher than those of seagrass and terrestrial ecosystems (McLeod *et al.* 2011). Salt marshes also provide many other ecosystem services. For example, they protect other ecosystems and coastal communities from coastal erosion, provide habitat and nursery habitat for fish and other organisms, and play a crucial role in nutrient cycling.

Previously Arctic salt marshes were thought to be relatively uncommon; it was estimated that they grew along roughly 5 per cent of the Arctic Ocean coastline. Statistics Canada indicates there is currently 3,602 km^2 of mapped salt marsh in Canada, with 63 per cent of Canada's mapped salt marsh located on the Arctic coast, mainly on Hudson's Bay (Statistics Canada 2022a). Of the documented salt marsh, 38 per cent along the Arctic coast has been conserved, compared to 33 per cent on the Pacific coast, and 23 per cent on the Atlantic coast (Statistics Canada 2022a). These "conserved" salt marsh ecosystems, although protected from direct threats such as human disturbance, are vulnerable to indirect threats and are affected by both marine and terrestrial changes.

Along the Arctic Ocean coast, salt marshes often grow in flat areas, within the intertidal zone of estuaries. Salt marshes grow along the tidal river channels, tidal lagoons and estuaries, and across inundated tundra. Although in the Canadian Arctic salt marshes have been documented as far north as Ellesmere Island, they thrive in more temperate waters, such as those found in the Mackenzie Delta and along southern Hudson Bay (Flagstad 2016). Salt marsh's ability to act as a blue carbon ecosystem and sequester carbon is threatened by climate change, human activities and other interacting variables (Moomaw *et al.* 2018; Windham-Myers *et al.* 2018a). Along the Arctic coast, a number of factors hinder carbon uptake and exacerbate potential release of stored carbon by salt marshes: permafrost melt, mass ice and snow melt, coastal erosion, sediment disturbance due to ice scouring, extreme storms, human activity such as shipping or fishing, invasive species, land-use changes and coastal development, temperature increases, nutrient limitation resulting from ocean stratification and freshening, and accelerated sea-level rise and subsistence (Mcleod *et al.* 2011; Pendleton *et al.* 2012; Windham-Myers *et al.* 2018a,b; Gailis *et al.* 2021).

Despite their carbon-sequestration abilities, salt marshes can also release GHGs, such as CO_2, CH_4 and N_2O, as a result of the remineralization of organic matter. The degree of GHG release is influenced by numerous factors, including water temperature, tidal inundation, salinity, biomass, nutrient availability and sediment disturbance (Abdul-Aziz *et al.* 2018; Capooci *et* *al.* 2019; Moseman-Valtierra *et al.* 2022; Agusto *et al.* 2022). Along the Canadian Arctic coast, increasing water temperature, decreasing salinity, nutrient limitation, as well as sediment and ecosystem disturbance, may have detrimental effects on Arctic salt marshes, potentially resulting in increased GHG emissions. Data concerning the magnitude and effects resulting from this release of GHGs was found for the only East Coast of Canada, and indicated the degree of emission is small relative to their carbon uptake (NatureServe 2022). There are large data gaps concerning Canadian Arctic salt marshes and their GHG emission. Due to the importance of salt marshes along the Canadian Arctic coast and the potential impact changing factors may have on their carbon uptake and GHG emissions, it is vital to conduct more research into salt marshes along the Canadian Arctic coast.

According to global estimates, since the 20th century roughly 50 per cent of worldwide salt marshes have been lost or degraded due to increasing human activities (Barbier *et al.* 2011; Li *et al.* 2018). Though estimated to be high, the extent of salt marsh loss in Canada is unknown as we lack both long-term and current studies on salt marsh distribution and health along Canada's coasts.

Seagrass

Seagrass is an important blue carbon ecosystem that has been documented along all three Canadian coasts. Seagrass ecosystems not only sequester carbon, but also provide a multitude of ecosystem services, including protection against coastal erosion, habitat and nursery creation, sediment stabilization, and improved water quality (Mtwana Nordlund *et al.* 2016). Within the Canadian Arctic and subarctic, eelgrass meadows flourish in Hudson Bay and James Bay, and are thought to be the largest marine meadows along the North American coasts (Lalumière *et al.* 1994; Murphy *et al.* 2021). Although south of the 60th parallel and not a part of Inuit Nunangat, James Bay represents a crucial environment for eelgrass and demonstrates the vital importance and fragility of eelgrass ecosystems. Along the high Arctic coast, gaps in seagrass distribution exist; however, eelgrass has been observed near settlements in the Northwest Territories and Nunavut, with the most northern observation at Grise Fiord in Nunavut in the Eastern Arctic (Murphy *et al.* 2021).

Murphy *et al.* (2021) estimate that 80 per cent of the identified Arctic and subarctic eelgrass ecosystems are marked as "in recovery," with biomass increasing in James Bay after a 75 per cent decline in health and biomass between 1975 and 2013 that was first observed by the Cree Nation while hunting and fishing (Consortium Genivar-Waska 2017). Decreased water salinity and clarity from increased runoff, along with an overgrowth of seaweeds and epiphytes, were hypothesized to be the cause of the mass loss of biomass (Short 2019a).

Seagrass is threatened by numerous interacting variables, many of which also jeopardize other blue carbon ecosystems: coastal erosion, extreme storms, marine heat waves, human disturbance, sea level rise, decreased salinity due to increased runoff and ocean freshening, sediment disturbance, and nutrient limitation. The loss of seagrass raises the spectre of further loss as it creates a negative feedback loop, reinforcing degradation and limiting recovery. Seagrass meadows calm and stabilize sediments, supporting the water clarity and light availability seagrass depend upon (van der Heide *et al.* 2011).

Although climate change is harming seagrass meadows in temperate waters, it presents new opportunities for Arctic seagrass. Along Arctic coasts, eelgrass biomass and extent seem to be increasing. As reduced ice and snow cover increase ocean temperature and light availability, it is predicted that the northward habitat range will continue to expand (Krause-Jensen *et al.* 2020). Marbà *et al.* (2018) indicate that the Arctic Ocean's current warming conditions, and those projected by the IPCC, may enhance eelgrass growth (Marbà *et al.* 2018).

Seagrasses along the Canadian Arctic coast have an increasingly important role as their habitat and carbon-sequestration ability grow due to climate change. The lack of long-term studies regarding the distribution and health of seagrass in the Canadian Arctic, especially the high Arctic coast, present challenges in effectively managing and studying populations; there is minimal baseline data against which we can compare potential future changes in extent and biomass.

COASTAL SHELVES AND OCEAN SEDIMENTS

The coastal shelf along the Canadian coast of the Arctic Ocean is significantly larger than any other Canadian coastal shelf, covering approximately 1.2 million km^2, as described in Canada's Arctic Ocean continental shelf submission to the Commission on the Limits of the Continental Shelf (Global Affairs Canada 2019). Although not considered blue carbon ecosystems in their own right, continental shelves facilitate large amounts of carbon sequestration through their distinct geographical and biological features, such as water depth and the nutrient availability. These shelves also provide suitable habitat for blue carbon ecosystems, facilitating their blue carbon uptake. Uniquely broad and shallow (<200 m deep), Arctic Ocean shelves make up as much as 50 per cent of the Arctic Ocean floor. Their large carbon uptake results from a mechanism called the "continental shelf pump" (Tsunogai *et al.* 1999). The high biological production in shelf surface waters sinks carbon, while strong currents push the cold, dense, carbon-rich waters down the shelf to be either buried in shelf sediments or pushed off the shelf to the water column of the deep ocean (Thomas *et al.* 2004).

Most of the water entering the Canadian Arctic Ocean flows from the Pacific Ocean, passing through the Bering and Chukchi Seas. This water brings nutrient inputs to the shallow coastal shelf waters. The water's high nutrient concentration supports high rates of primary production, with new production of up to 160 g C m^{-2} yr^{-1} (Springer *et al.* 1996; Hill and Cota 2005). This high productivity can result in a large amount of carbon being deposited in the shelf sediments or into the central Arctic Ocean (McGuire *et al.* 2009; Fennel *et al.* 2018). Primary production rates vary spatially: the primary inflow shelves experience the highest rates of nutrient input and subsequent primary production, the interior shelves experience moderate to low primary production, and the central Arctic Ocean experiences the lowest primary production (Carmack and Wassmann 2006). Extremely broad and shallow, Arctic shelves support high levels of primary production, and are thus an ideal region for carbon export and eventual burial in shelf sediments.

In the winter, shelf waters become colder than the adjacent open water due to a lack of water mixing, increasing both the density of shelf waters and solubility of CO_2. This allows more CO_2 to diffuse from the atmosphere into the shelf waters. As these shelf waters then flow down the continental slope, either being buried or sinking to the deep ocean, they take in the absorbed CO_2 and detritus matter containing carbon with it (Legge *et al.* 2020). In the Arctic Ocean, the flow of the colder, dense water off the shelf into the central basin relies on the inflowing waters to the Arctic Ocean that pass over these large shelves. These shallow, broad, shelves unique to the Arctic are critical for the long-term storage of blue carbon in sediments. The shelves facilitate the circulation of carbon throughout not only the Arctic Ocean but also the global ocean, driving cold, carbon-rich waters to the ocean floor. Carbon is deposited in both shelf and deep-ocean sediments where, if undisturbed, it can be stored for millennia. However, these Arctic shelf ecosystems are highly vulnerable to changing ocean and climate dynamics associated with climate change, including the continual loss of sea ice, coastal erosion, ice gouging and scouring, changing river runoff, and warming surface waters (Michel *et al.* 2015). Given both the vulnerability and the role of shelf and deep-ocean sediment in carbon burial, as well as the dominant role Arctic continental shelves play in ocean circulation, we need to consider the blue carbon consequences of any activity that may disturb either Arctic coastal shelves or seafloor sediment.

THREATS

The delineation of the Arctic coastal region and ocean is unique and not as clear as other regions due to the land-fast ice and permanent ice cover in the region. Therefore, threats to both the coastal and ocean regions must be considered. Threats to Arctic coastal blue carbon ecosystems — and their subsequent carbon sequestration and held stocks — include climate change (including warming-induced permafrost melt and ocean acidification) and human disturbance.

Climate Change

The Canadian Arctic is warming at rates three times faster (or more; see Rantanen *et al.*, 2022) than global averages, and has experienced the greatest observed reductions of sea-ice cover, duration and concentration (Stammerjohn *et al.* 2012; Mudryk *et al.* 2018). This vastly impacts all aspects of this region, including the coastlines, the living organisms within it, and the region's ability to sequester carbon (Comiso and Hall 2014; Meier *et al.* 2014; Serreze and Stroeve 2015; Bush and Lemmen 2019). Unless action is taken to reduce climate change, it is predicted that the Arctic will be ice-free each summer before 2050 (Hwang *et al.* 2020).

According to recent IPCC assessments, Arctic air temperature has likely increased by more than double the global average within the last two decades, with decreased sea ice and snow cover creating a feedback loop that contributes to further warming. During the winters of 2016 and 2018, mean Arctic air temperatures were 6°C above the 1981–2010 average (IPCC 2019b). The increase in air temperature directly contributes to warming surface water temperatures (Carvalho and Wang 2020).

An increase in both mean air and water temperature in the Arctic can influence blue carbon through numerous mechanisms. These include changes in ocean chemistry, ice formation, the duration and physical constraints on primary production, food-web connections and processes, biomass growth rates, and releases of land-based sources of carbon into the ocean. As the Arctic Ocean continues to warm, its ability to sequester carbon lessens. Warmer surface waters absorb less carbon from the atmosphere and contribute to increased ocean thermal stratification, altering ocean circulation and decreasing vertical mixing of both carbon and nutrients to and from surface waters (IPCC 2019b). This presents a feedback loop that amplifies Arctic warming. As ocean temperatures and stratification increase, while circulation and salinity decreases, less carbon is able to diffuse into surface waters, further warming the atmosphere.

The warming of Arctic air and waters directly increases the threat of glacial and sea-ice ablation (melt). This increases runoff and freshwater inputs to coastal ecosystems, decreases water salinity, increases glacial scouring, increases coastal erosion from storm surges as land-fast ice decreases, and decreases mixing and nutrient supply to coastal ecosystems (Barnes and Tarling 2017; IPCC 2019b; Bush and Lemmen 2019; Flato *et al.* 2019; Carvalho and Wang 2020).

Sea-ice melt, glacial melt and calving directly result in sea-level rise and freshwater runoff. Sea-level rise is extremely harmful to Arctic coastal ecosystems: as sea levels rise and the seaward edge of the intertidal zone is increasingly submerged, wetland ecosystems must migrate upslope toward the land in order to survive (Barnes 2019). In a phenomenon called coastal squeeze, coastal development prevents this upslope migration of coastal ecosystems. This negatively impacts the coastal ecosystems, limiting their habitat and biomass, and thus impacting their blue carbon stocks (Schuerch *et al.* 2018; Lovelock and Reef 2019). Lovelock and Reef (2019) use IPCC-projected changes in coastal ecosystems to evaluate the change in global mean carbon stocks and rates of carbon sequestration resulting from the expected sea-level rise. They predict blue carbon ecosystems could see gains in habitat due to sea-level rise in the order of 1.5 Pg to 2100, but only if coastal squeeze is minimized. If coastal squeeze is not minimized, losses of blue carbon habitat are expected, resulting in CO_2 emissions in the range of 3.4 Pg to 2100. However, sea-level rise also affects ecosystems not found in the Arctic, and it was found that changes to mangrove ecosystems had the biggest impact on global blue carbon (Lovelock and Reef 2019). Data gaps and uncertainties remain regarding the effects sea-level rise may have on Arctic coastal ecosystems.

Ice scouring — a result of sea-ice and glacial breakup and melt — directly impacts blue carbon along the Canadian Arctic coast. Ice scouring causes coastal erosion, endangers blue carbon ecosystem habitat, disturbs coastal ecosystems' carbon stocks, and potentially releases stored carbon through sediment disturbance (Barnes and Tarling 2017; Barnes 2019).

Panarctic rates of freshwater runoff to Arctic Ocean coastal ecosystems have increased substantially between 1980 and 2010, from 3900 ± 390 km^3 to 4200 ± 420 km^3 (Haine *et al.* 2015). As previously discussed, decreased salinity harms blue carbon ecosystems such as eelgrass (Lovelock and Reef 2019). In addition, decreased salinity directly impacts the amount of carbon that can diffuse from the atmosphere into the surface waters. Decreased salinity reduces the solubility of carbon within the ocean waters and affects water density, inhibiting the diffusion of atmospheric carbon into surface waters and eventual sinking and storage of dissolved carbon (Garcia-Soto *et al.* 2021).

Arctic sea ice is decreasing by roughly 13.1 per cent per decade at the time of minimal extent in the summer (September 1979–2020), and by roughly 2.6 per cent per decade during the winter (March 1979–2018) (Fetterer *et al.* 2017; Perovich *et al.* 2020). Land-fast sea ice plays a crucial role in protecting the Arctic coast from erosion caused by extreme storms and increased temperatures. Sea ice creates a barrier from the Arctic coast to the open ocean. This lessens the effects of intense open-ocean storms and waves on coastal communities, ecosystems and sediment; in addition, this barrier protects the coastline against erosion by controlling the delivery of heat to the coast. Coastal erosion and disturbance of coastal ecosystems and sediment are detrimental to blue carbon. Coastal erosion from storms and permafrost melt harms blue carbon ecosystems through habitat loss and changes in nutrient supply, affecting their biomass and subsequent carbon stocks and sequestration (Schuur *et al.* 2015). When sediment is disturbed, stored carbon can be released into the coastal waters and potentially back into the atmosphere. As the amount of ice separating Canadian Arctic coasts from open water decreases, and with it protection from coastal erosion, Barnhart *et al.* (2014) predict a panarctic increase in the duration and intensity of storms, leading to increased rates of coastal erosion (Barnhart *et al.* 2014).

Finally, sea-ice and glacial melting increases ocean stratification caused by upper-layer freshening and increased runoff, and limits nutrient mixing. This limits the availability of nutrients needed for primary production. As previously mentioned, this causes a decrease in coastal Arctic vegetation, as well as in phytoplankton biomass and carbon uptake, because of a shift to favour smaller phytoplankton cells. This favouring of low-energy systems may alter entire food-web and carbon-cycling processes. The stratification of the Arctic Ocean's upper layer also prevents the downward mixing of carbon absorbed from the atmosphere into the surface waters. Without this mixing, carbon is unable to descend the water column to the ocean floor; it either becomes buried in sediment or is consumed by organisms along the way (Behrenfeld *et al.* 2006).

Permafrost Melt

As the Arctic warms, so does the perennially frozen ground known as permafrost, potentially resulting in landscape changes or ground collapse. This directly impacts the foundation on which much of the coastal Canadian Arctic relies (Farquharson *et al.* 2019). The IPCC estimate that roughly 20 per cent of Arctic land permafrost is vulnerable to abrupt permafrost thaw and ground subsidence (IPCC 2019b). The resulting ground collapse and reshaping of landscapes directly impact the infrastructure, cultural sites, land-based natural resources and way of life of Inuit communities. The melting of permafrost also poses a major threat to blue carbon and other carbon-sequestering coastal ecosystems — such as kelp, salt marshes, eelgrass and coastal shelves — and may lead to the release of stored carbon (Wild *et al.* 2019; Mann *et al.* 2022). Coastal permafrost thaw can liberate peat and permafrost-derived carbon from soils and discharge it into coastal marine ecosystems through runoff, disturbing food webs, ocean dynamics, and primary production. Permafrost melt can also modify the physical and physicochemical environment through coastal and habitat erosion and destruction, decreased water clarity and light penetration, and hindered carbon cycling and storage, among other threats. All of these factors impact the biomass, extent and health of coastal Arctic ecosystems (Schuur *et al.* 2015; González-Eguino and Neumann 2016; IPCC 2019b).

Global projections indicate that Arctic permafrost melt and subsequent discharge of terrestrial carbon via runoff to the coastal ocean will continue to worsen; further, the melt rate may accelerate over much of the Arctic during the coming decades (Haine *et al.* 2015; Brown *et al.* 2020).

Ocean Acidification

As the ocean continues to absorb CO_2 from the atmosphere, buffering much of the potential impacts of climate change felt by humans, the pH of ocean water decreases. In particular, dissolved CO_2 forms a weak acid in ocean water, causing the pH and CO_2^{-3} concentrations to decrease and leading to ocean acidification and an undersaturation of aragonite (Bates 2007; Bates and Peters 2007). These changes affect many aspects of the ocean, including the carbon saturation of surface water, sea-ice retreat, increases in air temperatures, health of marine calcifiers, primary production, ocean stratification, nutrient supply to coastal ecosystems, and ocean biogeochemical cycles (IPCC 2019b). While Arctic Ocean acidification harms species such as red king crab and Arctic cod (Pilcher *et al.* 2019), the increase in carbon may benefit photosynthesizing organisms such as seagrass and kelp.

Ocean acidification negatively affects the biophysical processes of Arctic marine invertebrates (Widdicombe and Spicer 2008; Pan *et al.* 2015). Many of the coastal Arctic marine organisms that rely on blue carbon ecosystems are calcifying organisms susceptible to dissolution at reduced availability of carbonate ions (Peijnenburg *et al.* 2020). The increased concentration of carbon and decreased pH of the ocean negatively impact the saturation levels of minerals such as aragonite and calcite. Produced by marine calcifiers, both of these minerals are essential to the production of calcium carbonate shells and skeletons. Ocean water pH and CO_2 saturation levels reduce the saturation states and availability of these calcium carbonate minerals, which planktonic and benthic calcifying biota need to form shells and skeletons (Fabry *et al.* 2008; Armstrong *et al.* 2019; Terhaar *et al.* 2020). Ocean acidification harms invertebrates, with consequences that reverberate across the Arctic marine food web (Queirós *et al.* 2015; Duarte *et al.* 2016; Kamya *et al.* 2017).

Acidification alters the calcium carbonate saturation of the water column and sediments. This greatly affects the diffusion of carbon into the Arctic Ocean, and the subsequent ability of coastal blue carbon ecosystems to sequester carbon. The percentage of the Arctic Ocean water column that is experiencing aragonite undersaturation has increased from 5 per cent in 1994 to 31 per cent in 2010, with an average rate of increase of 1.5 per cent per year (Qi *et al.* 2017). This dramatic acidification of the Arctic Ocean and its coastal ecosystems is expected to worsen. Qi *et al.* (2017) predict that surface waters of the Arctic Ocean will be entirely undersaturated with respect to aragonite within approximately the next two decades (Qi *et al.* 2017).

The large input of river and melt water — resulting from glacial, sea-ice, and snow melt — dilutes calcium carbonate concentrations, and impacts the Arctic Ocean's ability to absorb atmospheric carbon (Steinacher *et al.* 2009; Brown *et al.* 2020; Woosley and Millero 2020). This diminishing of the Arctic Ocean's inherent carbon-sequestration abilities is coupled with a reduction in primary production and physiological alterations to phytoplankton resulting from ocean warming and acidification (Armstrong *et al.* 2019; Terhaar *et al.* 2020). This reduction is expected to slow the sinking of organic carbon to the deep ocean and eventually to the sediments by 10 to 15 per cent by the year 2100, according to high emission forecasts (Flombaum *et al.* 2020). The rapid acidification of the Arctic Ocean is another unique factor that could affect carbon-sequestering coastal ecosystems and the potential of organisms in this region to contribute to blue carbon. It is worth considering NCS that may counteract the effects of acidification.

Human Disturbance

Human disturbance of the Arctic Ocean and its coastal environment is expected to intensify as newly ice-free waters make Arctic waters more accessible to human exploration and potential exploitation. Activities such as bottom trawling (dragging large nets along the open ocean and coastal shelves), resource exploration and extraction, and increased shipping traffic can disturb carbon stored within sediments and ecosystems; they can also harm the ecosystems themselves and their future ability to sequester carbon (Lovelock and Reef 2019; Armstrong *et al.* 2019). These human activities can impact sensitive Arctic coastal ecosystems and in turn blue carbon sequestration through sediment and habitat disturbance, coastal development, increased nutrient pollution, and food-web alterations (Lovelock and Reef 2019).

Coastal development presents increasingly alarming threats to blue carbon ecosystems along the coastlines. As development along the Canadian Arctic increases, so does the risk of "coastal squeeze" that would limit the upslope migration of coastal ecosystems. This negatively impacts the coastal ecosystems, limiting their habitat and biomass, and thus impacting their blue carbon stocks (Schuerch *et al.* 2018; Lovelock and Reef 2019). Human activities and development can also alter nutrient and sediment supply to coastal ecosystems, which can increase the risk of coastal ecosystem submergence; for example, the damming of rivers alters the capacity of coastal wetlands to accrete sediment (Meier *et al.* 2014; Armstrong *et al.* 2019).

Finally, human influences on biological processes such as the Arctic food web can harm blue carbon storage and stock within coastal ecosystems. Loss of predators from blue carbon ecosystems through human activities such as overfishing may reduce carbon sequestration. This is because many commercially fished species heavily regulate the activity of grazers and bioturbators, directly impacting the biomass and extent of blue carbon ecosystems and thus levels of primary production (Meier *et al.* 2014; Armstrong *et al.* 2019; Seeger *et al.* 2022).

More research and monitoring are needed to fully understand the impact human activities have on Canadian Arctic coastal ecosystems and their carbon stocks and sequestration abilities.

ARCTIC COASTAL MANAGEMENT

As the Arctic Ocean and its coastal environments continue to change in an exponential manner, comprehensive mapping and monitoring of blue carbon ecosystems become increasingly important. The management of blue carbon in the Arctic is especially challenging given the large data gaps in the location and spatial extent of blue carbon ecosystems, the rate of change of physical parameters in the Arctic, the difficulty in addressing threats to large-scale oceanic processes that have historically driven high carbon storage in Arctic waters, and the sea-ice reduction that has led to increased industrial activity. This critical knowledge gap is particularly worrisome because of rapid ongoing environmental changes along Arctic coasts. Anticipating these changes and understanding these new ecosystems and their functioning are a key priority for northern communities. Many uncertainties are related to this knowledge gap.

There is clearly work to be done, and research gaps to fill to effectively account for and manage Arctic blue carbon. It is particularly important to evaluate the current state of these ecosystems before substantial changes occur (and can no longer be measured or estimated). For kelp management to be considered as a NCS and properly accounted for from the perspective of greenhouse gas emissions, we need information on management pathways that prevent future declines (i.e., mitigate loss) or restore degraded habitats.

As humans continue to exploit the Arctic Ocean and its blue carbon ecosystems, threats emerge to these ecosystems' ability to both sequester and store carbon. This could potentially cause a reduction in the rate of sequestration and the release of stored carbon back into the ocean and eventually into the atmosphere. Increased interest in Arctic fisheries was identified as a threat to stored Arctic carbon, and bottom trawling has been shown to have significant impacts on the release of sequestered carbon in sediments (Sala *et al.* 2021). The recent Qikiqtani Inuit Association prospectus for potential protection of Sarvarjuaq and Qikitait (QIA 2022) indicated that 46 billion tonnes of blue carbon is stored in the Arctic seabed surrounding the Qikiqtani region, representing 26 per cent of Canada's total marine carbon stock, much of which is coastal. Inuit have recognized that mitigation and management strategies are required to protect coastal sequestered carbon in Arctic sediments; these strategies include limiting industrial activity and development, and prohibiting bottom trawl fishing. In addition, establishing and managing marine protected areas can help safeguard important carbon stores in the Arctic, as is the case with all blue carbon ecosystems along Canada's coastlines (Sala *et al.* 2021). As mentioned above, coastal environments play a vital role in the well-being of Inuit communities, contributing to food security, the ability to travel, and cultural practices. Therefore, Inuit leadership and representation of Inuit priorities in both research and management measures are absolutely vital to ensure the health of the Canadian Arctic coast.

To avoid potential harmful impacts to Inuit communities and foster success, blue carbon NCS should be developed in partnership with Inuit governments, organizations and communities. At minimum, proponents of NCS must respect Inuit rights and relevant agreements with the Crown that outline Inuit jurisdiction, governance, authority and specific rights. This includes ensuring, at minimum, the free, prior and informed consent of Inuit communities before proceeding with NCS. There may be opportunities to collaborate with Inuit governments, communities and organizations to co-develop blue carbon NCS that incorporate Inuit values, priorities and knowledge. To facilitate such partnerships, Inuit communities must be enabled to participate to the extent they desire, for example through financial support.

Generating conservation-based economies and enacting strong management measures can be complementary means of protecting blue carbon while benefitting Inuit communities. Thus, it is important to prioritize management actions that will deliver benefits for climate, biodiversity and Inuit Peoples. Creating conservation economies involves generating economic opportunities from coastal marine protection and conservation. For example, community fisheries, environmental research and ecotourism are all consistent with conservation economies. One complementary management measure is to close nearshore large-scale commercial fisheries to bottom trawling; this will both protect carbon storage in sediments and maintain community fisheries. The overall well-being of Inuit communities must be balanced with the need to seek NCS. Thus alternative forms of income must be considered, including payment for the thoughtful management and guardianship of healthy blue carbon ecosystems.

RECOMMENDATIONS FOR ARCTIC BLUE CARBON

- ✓ Connect mapping efforts, adopt standardized protocols, and use new technology for mapping and carbon measurements to facilitate site and regional comparisons, enhance understanding of habitat distribution and carbon storage, and improve protection and management.
- ✓ Ensure that all research, policy, and management measures that take place within or affect the Arctic are co-developed with Indigenous rightsholders, and honour Indigenous Peoples' priorities, governance structures, knowledge and values.
- ✓ Consider Arctic blue carbon in the context of new and existing management and protection measures to reduce impacts on stored carbon both on land (i.e., to reduce lateral transfer) and in marine habitats.
- ✓ Prioritize Inuit-led and co-managed areas and initiatives to improve understanding of Arctic blue carbon, and outline Indigenous-led opportunities for the long-term management of these important and remote ecosystems.
- ✓ Collaborate with Inuit governments, communities and organizations to improve the understanding of Arctic blue carbon and provide support for Inuit-led initiatives that advance the long-term management of these important and remote ecosystems.
- ✓ In collaboration with Inuit governments, communities and organizations, organize a workshop to explore the high-latitude carbon cycle from diverse perspectives.
- ✓ Support and build partnerships with Inuit communities and local Arctic communities in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on Arctic blue carbon. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

THE BLUE ECONOMY

Brianne Kelly

The “blue economy” has many definitions, ranging from broad ones that include all ocean-based economic activity to narrower ones that emphasize sustainability, equity and good governance. The broader definitions focus on growth and expansion, while the narrower ones emphasize a transformation towards social well-being (Cisneros-Montemayor *et al.* 2019). For the purposes of this report, we will adopt the Cisneros-Montemayor *et al.* (2019) definition of the blue economy as “ocean resource-based development that is socially equitable, environmentally sustainable, and economically viable.” Key components of this definition include procedural justice, which ensures inclusion; and distributional justice, which guarantees the equitable distribution of risks and benefits (Cisneros-Montemayor *et al.* 2019).

Developing the blue economy comes with multiple risks and benefits for coastal communities. A thorough discussion of key risks to people and the environment can be found in Bennett *et al.* (2021), who also provide recommendations for developing the blue economy in a just manner. In general, the robustness and sustainability of a blue economy in Canada will be improved by the following:

- the collection of robust data to refine our understanding of ecosystem services and guide the design of regulations to protect marine ecosystems (Rayner *et al.* 2019)
- strong governance to mandate policies and regulations that prioritize social equity (Cisneros-Montemayor *et al.* 2022)
- consent from, participation by, and inclusion in the economic benefits for Indigenous Peoples (Lyons *et al.* 2023)

The long-term success of coastal development and relevant industries in a blue economy will depend on our ability to meet the economic needs of coastal communities and develop the economy in line with the values and priorities of Indigenous Peoples who have inhabited and thoughtfully managed coastal environments for thousands of years. Rather than suggesting that coastal communities forgo economic opportunities, we must work together to develop economic opportunities that actively manage, protect and restore. This includes developing conservation economies. We need to look for economic opportunities that provide training and capacity building for local communities, and that diversify employment to promote resiliency to climate change and other potential disruptions.

DFO has shown interest in developing the blue economy in Canada, working to engage Canadians on priority areas of action. They sought feedback through their Blue Economy Strategy Engagement Paper (Fisheries and Oceans Canada 2021e) and publicly reported their findings (Fisheries and Oceans Canada 2022f). While the strategy emphasizes sustainability and inclusivity, it also includes continued support for unsustainable industries that drive climate change (e.g., offshore oil and gas exploration and drilling). However, a blue economy that includes growth of traditional energy sectors like offshore oil and gas is incompatible with Canada’s carbon reduction targets.

The chapters below discuss options for increasing revenue from coastal ecosystems, financing stewardship programs and developing sustainable blue economy-based projects.

CARBON MARKETS

Cornelia Rindt

VOLUNTARY MARKETS

The voluntary carbon market is growing dramatically. Since 2019, there has been an 80 per cent increase in the volume of traded voluntary carbon offsets, amounting to over $1 USD billion globally (Ecosystem Marketplace). Voluntary carbon markets provide participants with a way to contribute to climate action and invest in sustainability. Nature-based carbon projects are carbon-offset projects that focus on managing, protecting and restoring forests, wetlands and other ecosystems. Recently, interest has grown in developing blue carbon projects, which are offset projects focused on coastal and marine ecosystems (e.g., World Economic Forum; Seascape Carbon Initiative; Economist). Crucial to the regions they are found in, these ecosystems contribute to water quality, fisheries, and protection against extreme weather and natural disasters (Lecerf *et al.* 2021). Research and initiatives for blue carbon-offset projects are underway and are being supported by many policy and research groups (e.g., Oceans 2050; Silvestrum; Ostrom Climate Solutions; Blue Carbon Initiative; Namibia Seaweed).

CARBON FINANCING

Carbon markets open up potential financing opportunities. These environmental markets can be used to finance the development of blue carbon projects that would otherwise not take place. Currently, there is growing interest in supporting the research and development of blue carbon protocols and projects as the importance of blue carbon ecosystems is being recognized around the globe (Seascape Carbon Initiative - Verra).

HOW DO CARBON MARKETS ENABLE PROJECT DEVELOPMENT?

Carbon markets enable project development by offering carbon offsets for sale. A carbon offset represents one tonne of carbon dioxide equivalent (t CO_2e) emission that has been avoided or removed from the atmosphere through changes in land-management practices. The specific project activities that are supported by the carbon markets vary greatly, but there are fundamental requirements for all carbon-offset projects. Carbon standards, such as Verra's Verified Carbon Standard, have released a number of blue carbon-focused methodologies (VM007, VM0027, VM0033, VM0036) to support the development of blue carbon projects. Both VM0033 and VM0036 are eligible for project development in Canada.

A purchaser may enter into an agreement to purchase verified carbon offsets from a blue carbon project at the end of the project development (upon verification) or at the start of the project. Upfront financing can provide the funding a blue carbon project needs to get off the ground. Once a blue carbon project is developed and offsets are verified, the purchaser receives the carbon offsets for which they provided upfront funding.

Carbon offsets are required to be additional and therefore require a change from business as usual to support the management, restoration and protection of natural ecosystems. To be effective, projects must address issues of permanence, leakage and additionality. A carbon offset is "additional" if the project represents emission reductions that are above and beyond business as usual. For instance, if a project proponent can demonstrate that the blue carbon area they are protecting was at risk of development (i.e., generating emissions) prior to protection, then the conservation action would result in emissions reductions over and above business as usual.

The concept of "additionality", however, is a barrier to Indigenous-led NCS (Townsend *et al.* 2020). Ecosystems that Indigenous Peoples have been stewarding, typically over very long periods of time, do not represent an "additional" net reduction in carbon emissions, even if they choose to protect their territories at an economic loss (e.g., by not pursuing commercial harvesting of species or impactful development initiatives).

CHALLENGES TO USING CARBON FINANCE FOR BLUE CARBON PROJECTS

As of 2022, the main challenge is that the existing methodologies do not cover all the types of blue carbon projects that have potential to create offsets. Carbon projects and the carbon markets require robust protocols and methodologies to guide project development. These standards provide the certainty that carbon projects developed to their criteria meet all the requirements of the market, and that the offsets generated are real, measurable, and have created an actual reduction or removal of emissions from the atmosphere. Projects must meet the additionality criteria to demonstrate the offsets are real and contribute to mitigating climate change. These projects must also demonstrate that the benefits arising from the project activity result in "permanent" changes to the atmosphere. In other words, the GHG reduction and removal must be in place for a significant period of time, otherwise there are no long-term benefits to the atmosphere. Another key consideration is leakage: a project must demonstrate that it has led to real emission reductions and removals, and that the activity hasn't simply shifted elsewhere.

As the science around blue carbon continues to evolve and provide more information, we anticipate that more methodologies will be developed to support blue carbon projects. If we rush to develop carbon offsets without clear methodologies and protocols, we risk developing projects that do not contain proper GHG accounting or provide the long-term benefit needed to effectively address climate change.

As carbon markets recognize the need for robust science and blue carbon's value becomes more widely recognized, there will be renewed interest in funding research that addresses current gaps. Funding can support the creation of blue carbon methodologies that will lead to additional carbon financing being deployed in this space, reinforcing a positive feedback loop.

OTHER FINANCE TOOLS

Brianne Kelly

In addition to carbon markets, a variety of finance tools have been developed that can support the protection, sustainable management and restoration of ecosystems. Most tools have been focused on terrestrial environments, but could be adapted and applied to blue carbon ecosystems. Several of these tools are discussed below.

BONDS

Bonds are tools for raising capital to fund projects that would otherwise be unaffordable. Investors in the bond are paid a fixed interest rate on a fixed schedule and receive their principal back at a pre-determined end point (Roth *et al.* 2019). Green bonds, which raise capital for projects with an environmental goal, have been issued internationally since 2008. Blue bonds, which focus specifically on the marine environment, are now entering the international finance space. The World Bank defines blue bonds as "a debt instrument issued by governments, development banks or others to raise capital from impact investors to finance marine and ocean-based projects that have positive environmental, economic and climate benefits" (World Bank 2018). Green and blue bonds often aim to support specific United Nations Sustainable Development Goals (SDGs) and track indicators related to social well-being as well as environmental benefits.

In 2021, the Asian Development Bank (ADB) issued the first blue bond to increase investments supporting healthy oceans and the blue economy (ADB 2021a). The ADB blue bond funds projects through repayable loans to the project proponents. Projects can focus on sustainable aquaculture (including the cultivation of kelp and other seaweeds), marine-pollution control, or GHG capture and storage in the marine environment (ADB 2021b). Eligible projects directly relevant to blue carbon ecosystems include salt marsh and seagrass restoration, while other eligible projects reduce threats and stressors such as non-point source pollution (ADB 2021c). The ADB bond framework explicitly recognizes the terrestrial-marine connection by allowing projects located up to 200 km from the coast and along river basins near the ocean. The Bank of China and Nordic Investment Bank have also issued blue bonds.

In 2022, the Government of Canada issued its first green bond for $5 billion, reaching maturity at 7.5 years. The rationale for the green bond includes fighting climate change and conserving nature, and NCS are explicitly mentioned (Government of Canada 2022). Marine projects eligible under the bond that could benefit blue carbon ecosystems include sustainable aquaculture, the restoration of wetlands to capture and store carbon, protection and restoration of biodiversity in marine ecosystems, improving resiliency to climate risks such as floods, and improving water and wastewater management (Government of Canada 2022). Examples of programs that could be paid for with capital raised by the green bond include the Nature Smart Climate Solutions Fund and Canada Nature Fund. Although it is likely that a significant portion of the capital raised will be allocated to terrestrial-based projects, it is encouraging that the framework explicitly states that marine-based projects are eligible for funding. Canada's first green bond was oversubscribed by $6 billion upon the initial offering, signalling strong investor interest. If the blue carbon community can demonstrate a sizable pipeline of available projects, a case could be made for Canada issuing a blue bond next.

NATURE-BASED INSURANCE SOLUTIONS

Many "natural assets," including blue carbon ecosystems, provide protection for human infrastructure like roads and buildings. Nature-based insurance solutions (NBIS) aim to protect natural assets, which in turn protect human infrastructure, and to provide the funding to restore ecosystems when necessary. NBIS therefore lower the long-term costs of repairing or relocating human infrastructure while improving the resilience of ecosystems and safeguarding the services they provide (Deutz *et al.* 2020). Likely purchasers of NBIS policies are municipalities and businesses that directly benefit from the protection provided by natural assets.

NBIS insurance policies have several key components: a defined physical boundary where the policy applies (e.g., a section of coastline), a quantifiable risk to the ecosystem and/or human infrastructure (e.g., flooding), a defined trigger event that results in a payout (e.g., a certain water level), and beneficiaries who receive the protection against the risk and are willing to pay for it (e.g., governments or businesses) (Melcer 2021). NBIS insurance payouts are used to restore damage to natural assets such as salt marshes so that they can continue to provide ecosystem services. The payouts can be managed by an independent board to ensure that the funds are used effectively and equitably to increase the resilience of the system (Melcer 2021). Challenges to building NBIS include the following:

- quantifying the value of and the risk to natural assets (Sumaila *et al.* 2020) since these assets provide environmental, social, economic and cultural benefits
- defining the physical boundaries where the policy is active (Melcer 2021), especially in the fluid marine environment
- convincing beneficiaries to pay for the ecosystem services they are accustomed to receiving for free

While no complete implementation of NBIS was found to date in Canada, the Insurance Bureau of Canada (2021) has outlined a theoretical framework for Truro, Nova Scotia. This case study suggests that an insurance policy could protect the resilience of local salt marshes, which in turn would protect the town from flooding. The insurance policy purchased by the town of Truro could be designed to provide the following:

- coverage for creating and restoring salt marshes to protect coastal infrastructure
- protection of salt marshes
- coverage for related risks from climate change, such as business interruption (Insurance Bureau of Canada 2021)

NBIS can also be purchased by a group of communities or municipalities affected by the same risk. This lowers costs for individual buyers and potentially reduces risk at the ecosystem level (Insurance Bureau of Canada 2021; Melcer 2021). By harnessing the purchasing power of large institutions such as municipalities, we could use NBIS to protect blue carbon ecosystems over the long term, while reducing costs from climate change-driven damage.

TRUST FUNDS

Trust funds are private legal entities that manage financial resources and are designed for a specific purpose, such as protecting or stewarding an ecosystem (Bladon *et al.* 2014). They generally include a board of directors and full-time staff (Bladon *et al.* 2014) to manage the funds. Funding for trusts can come from a variety of sources, including philanthropic, government or private funding, as well as revenue from carbon credits, other payments for ecosystem services, or impact investments.

Trust funds have been used successfully to fund conservation work in Canada and throughout the world. They are most effective when used to supply funding over the long term — for example, for maintaining and monitoring MPAs (Bladon *et al.* 2014) or for supporting Guardian programs (CRP 2021). They provide a bridge between those willing to pay for conservation work and those who undertake the on-the-ground projects (Bladon *et al.* 2014).

An example of a trust fund is Coast Funds, a $120 million endowment trust fund founded through the 2006 Great Bear Rainforest agreements in British Columbia. The trust works in partnership with 27 West Coast First Nations, funding Indigenous conservation initiatives, stewardship organizations and Guardian programs. Designed to operate in perpetuity, the fund is managed by two organizations: the Coast Economic Development Society and the Coast Conservation Endowment Fund Foundation. Initial funding was provided by six private foundations, the federal government and the British Columbia government. Merv Child, the founding director and board chair from 2010 to 2018, describes the fund as follows:

> "Coast Funds serves as a model for how conservation finance can and should be led by Indigenous Peoples whose territories are at the centre of land, marine, and resource management decisions. Most importantly, the Coast Funds model demonstrates how to link a healthy environment with the prosperity and well-being of Indigenous Peoples (Coast Funds 2019)."

Community well-being is at the centre of every project. It is monitored according to the Fund's Outcomes Measurement Methodology, with a focus on four key areas: environmental conservation, economic prosperity, social empowerment and cultural vitality (Coast Funds 2019). Results from individual projects are aggregated and reported on the Coast Funds website. For example, as of December 31, 2021, Coast Funds investments had secured the following results: 344 research-and-restoration initiatives had been conducted; 112 businesses had been created, acquired or expanded by First Nations; 1,198 permanent new jobs had been created by First Nations, and 89 projects had facilitated the transfer of knowledge from Elders to youth. In addition to supporting numerous coastal stewardship and Guardian programs, the trust can serve as a model for establishing new trust funds that aim to support stewardship in blue carbon ecosystems while enhancing community well-being.

IMPACT INVESTING

Impact investing is purpose-driven investing with the dual goals of obtaining a financial return and supporting companies that create measurable environmental or social impact. The blue economy focus on sustainable activities could provide a suite of opportunities for impact investing. And given the emphasis on social and environmental impact, investors may accept below-market return rates (Clarmondial AG 2017; Sumaila *et al.* 2020), increasing the scope of eligible projects. Impact investing can take a variety of forms:

- reporting measurable social and/or environmental impacts in addition to financial returns
- providing seed money to support the growth of small companies that create social and/or environmental benefits
- providing a combination of repayable and non-repayable loans
- providing "first loss" capital or accepting below-market returns to entice additional investors (Kosciolek *et al.* 2020)

Some aspects of the blue economy, such as kelp farming, are ideal candidates for impact investing as they deliver a financial return while supporting environmental and social goals. For example, WWF-US is currently using impact investing to support the seaweed-farming industry. Their program invests in young companies that lack access to large capital markets, enabling them to develop and innovate faster. The investments include companies that farm kelp as well as companies that process seaweed for food and other uses, such as cosmetics. To date, their impact investments have been in companies based outside of Canada. However, as the seaweed-farming sector in Canada grows, there may be more opportunities to attract impact investors.

RECOMMENDATIONS FOR THE BLUE ECONOMY

- ✓ Ensure that the benefits of blue economy-based development are distributed equitably, and that the risks are not borne by Indigenous Peoples or marginalized communities.
- ✓ Recognize the cost of lost economic development, and support conservation economies that support blue carbon protection, management and restoration.
- ✓ Remove barriers to Indigenous engagement in carbon markets, such as the principle of additionality as it is currently conceptualized.
- ✓ Adapt financing mechanisms to support natural climate solutions that involve blue carbon.
- ✓ Develop the blue economy in collaboration with Indigenous Peoples so that their rights, interests and priorities are reflected in blue carbon initiatives.
- ✓ Develop blue economy opportunities that actively protect, manage and restore coastal ecosystems, including blue carbon ecosystems.
- ✓ Add to the protocols and methodologies for potential blue carbon-based offsets in Canada to include seaweed farming and kelp restoration.

© Yoon S. Byun / WWF-US

KELP AQUACULTURE AND ITS POTENTIAL TO SUPPORT BLUE CARBON

Heidi Alleway, Jenn Burt, Cameron Bullen, John Driscoll and Edward Gregr

INTRODUCTION TO KELP AQUACULTURE

Seaweed aquaculture is the growing and harvesting of algae for commercial or subsistence purposes. Around 97 per cent of commercially used seaweeds worldwide are sourced via aquaculture; in 2020, the production of aquatic plants accounted for 35.1 million tonnes, almost 30 per cent of all aquaculture production by weight (FAO 2022). Seaweeds can be grown in nearshore and offshore ocean waters, drawing on marine nutrients and sunlight to fuel their growth and production. Currently, over 80 per cent of seaweed farmed globally is used for human consumption (Cai *et al.* 2021), serving as a good source of fibre, minerals, iodine, antioxidants, vitamins and amino acids. Seaweeds are also used as food additives as they can emulsify, stabilize and thicken a wide variety of goods. In addition, seaweeds support the production of various non-food products, such as fertilizers, biofuels, biomaterials, pharmaceuticals and nutraceuticals (cosmetics).

This chapter focuses on the cultivation of brown seaweeds, or kelps (Order Laminaria), through aquaculture in Canada's marine environment, and on its potential to support carbon-reduction targets via sequestration or offset carbon emissions. In cold-water oceans, kelp aquaculture begins when seed and seedlings (sporophytes) are produced in a hatchery and "seeded" onto long lines of rope. These ropes are then "out planted" to a marine farm; this entails suspending the lines in the surface waters of a designated site. The kelp grows in the ocean environment without the need for supplementary nutrients or additives. As a result, kelp, and seaweed aquaculture more broadly, can often be a low-input farming system; when located close to shore, the system produces large amounts of biomass with lower requirements for maintenance, fuel and energy (Gephart *et al.* 2021).

The broader aquaculture industry in Canada is significant and growing. However, the commercial-scale production of kelp has yet to feature in nationally reported statistics as most operations in Canada are currently small or in a "pilot" phase of development. For instance, in British Columbia, only two companies were reportedly engaged in seaweed production in the marine environment in 2021, despite approximately 30 licences being held across 23 companies (B.C. Ministry of Agriculture 2022 pers. comm.). On the Atlantic coast, three companies in Quebec and one in New Brunswick are engaged in seaweed farming as an aquaculture activity (i.e., to produce seaweed for sale of a product); Nova Scotia has three such companies (Howarth *et al.* 2022). Indigenous communities in Canada have expressed interest in seaweed aquaculture as an economic-development strategy compatible with their culture, customs and environmental values. Canadian companies and researchers are also exploring "co-culture" opportunities, where kelp or other seaweeds would be grown at aquaculture sites primarily used for shellfish and/or finfish. Co-culture can add economic opportunities by producing a wider range of species, and by making more efficient use of space and farming equipment. It can also be practised as "Integrated Multi-Trophic Aquaculture" (IMTA), a form of farming that intentionally uses the byproducts or waste from the production of one species (e.g., finfish) as inputs for another within the same culture system. In Canada, IMTA has been a driver for seaweed aquaculture development in the past. It may present an important opportunity to increase production in the future if linked to the well-established and high-output salmon and shellfish aquaculture industries (Chopin 2015).

The current emerging scale of seaweed aquaculture in Canada contrasts with the abundant natural distribution of kelp species across much of Canada's coastline (see Kelp), a range of which are well-suited for cultivation: *Saccharina latissima* (sugar kelp), *Alaria marginata* (ribbon/winged kelp), *Macrocystis pyrifera* (giant kelp), *Nereocystis luetkeana* (bull kelp) and *Neoagarum fimbriatum* (sieve kelp). At a global scale, estimates suggest that 10,000 ha to 11,900 million ha of marine environments may be suitable for seaweed aquaculture, with widespread feasibility expressed in these models throughout Canada (Froehlich *et al.* 2019; Spillias *et al.* 2023). Canada has also been identified as one of nine countries best placed to implement and scale up kelp production to reduce greenhouse gas emissions (Alleway *et al.* 2022).

There is mounting and widely publicized interest in kelp aquaculture as a tool to mitigate climate change; the International Panel on Climate Change and the United Nations High-Level Panel for a Sustainable Ocean Economy have both recommended kelp production as an important area for research and development to mitigate atmospheric carbon (Hoegh-Guldberg *et al.* 2019; IPCC 2019b). However, we need to better understand how to use the low emissions profile and high carbon uptake of kelp in aquaculture systems to sustainably and consistently improve blue carbon outcomes. We also need supporting policy, markets mechanisms and infrastructure. For these reasons, kelp aquaculture is currently best described as an "emerging" opportunity, rather than an actionable pathway for credited carbon sequestration in national targets to reduce GHG emissions (Howard *et al.* 2017). There are also important ecological differences in how carbon is cycled and sequestered by marine plants. This means that kelp aquaculture systems must be assessed independently from natural blue carbon habitats when we develop carbon-sequestration methodologies for kelp. Mangroves, saltmarshes and seagrass store the bulk of the carbon they capture in sediments, thereby removing it from the atmosphere for a long period of time. By contrast, kelp store carbon in their biomass, meaning that the sequestered carbon may be remineralized and make its way back into the atmosphere if the kelp is harvested or decays. While this biomass (harvested and detrital material) could make an important contribution to carbon sequestration (Duarte *et al.* 2017), we need to address some outstanding questions to validate kelp aquaculture as viable blue carbon pathway. In particular, we need to answer the following question: can we design kelp aquaculture systems to ensure the carbon removed or avoided exceeds the carbon emitted from the aquaculture activities?

CARBON PATHWAYS IN KELP AQUACULTURE

Like natural kelp habitats, farmed kelp has the potential to be highly productive, with high net primary productivity (NPP) whereby CO_2 is taken up from the surrounding water and converted into carbon-rich biomass (Duarte *et al.* 2017). In consequence, seaweed aquaculture is being explored for its potential contribution to carbon dioxide removal. Opportunities for carbon sequestration from kelp aquaculture can be categorized in two pathways. Farmed kelp may:

- contribute to carbon sequestration in the marine environment
- reduce carbon-intensive activities or contribute to sequestration through kelp-based products

In each instance, overall calculations of climate benefits from kelp aquaculture must consider pathways for both sequestration (carbon sinks) and emissions associated with the production life cycle (Figure 20). Kelp aquaculture systems must also consider a range of uncertainties and risks (see further discussion below), such as the variability of NPP between species and the design of aquaculture systems, both of which are influenced by inherent differences (e.g., species traits) and local environmental factors (e.g., temperature and light availability). We also need to ensure that the species farmed are native to the local area; more research and development may be needed to effectively establish native-species production.


© Yoon S. Byun / WWF-US

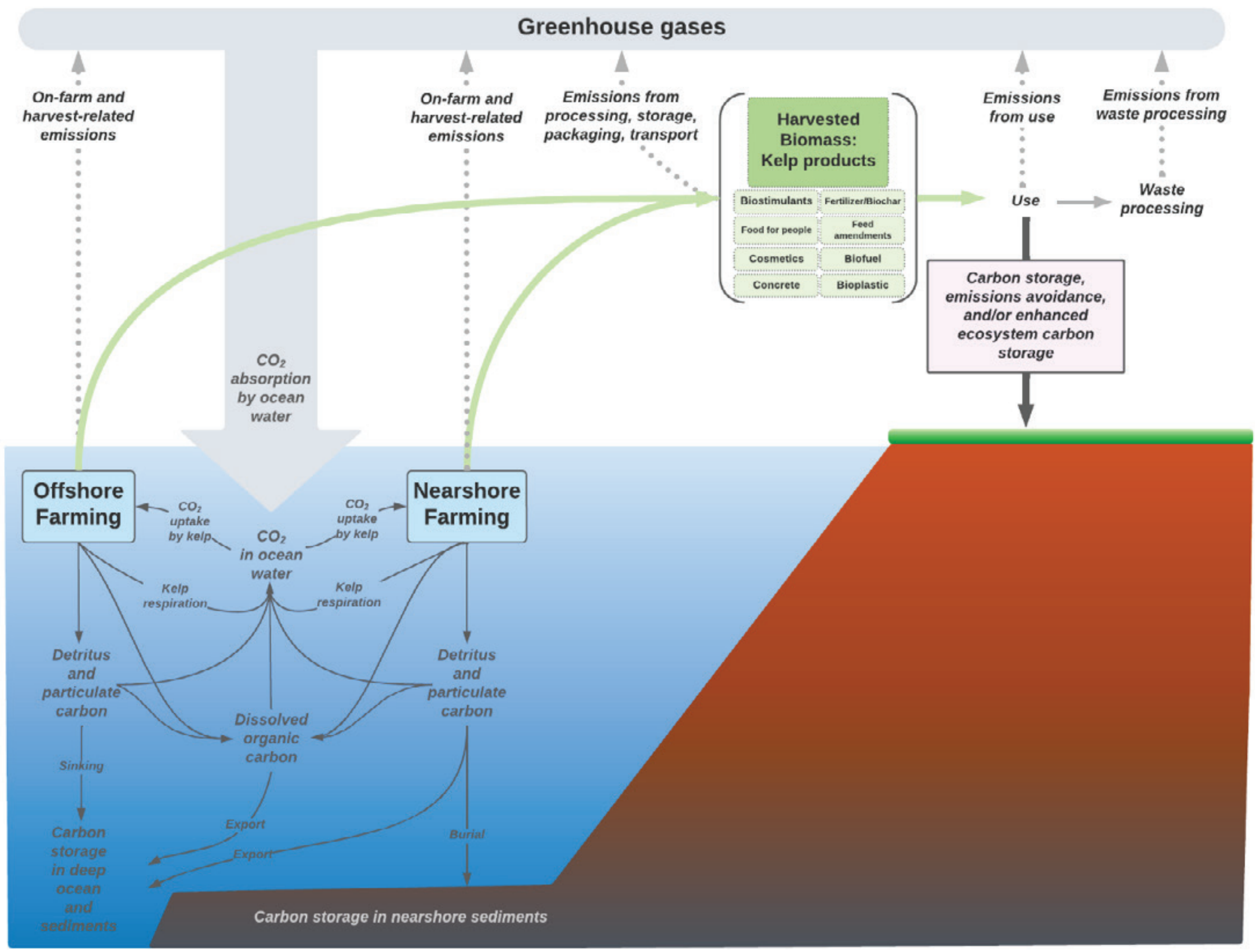


Figure 20. Pathways of carbon mitigation and sequestration from kelp aquaculture.

Carbon Cycling and Sequestration in the Marine Environment

At every kelp aquaculture site, a portion of the kelp biomass grown is lost as dissolved or particulate organic carbon, via erosion or the breakage of fronds during seaweed cultivation (e.g., Fieler *et al.* 2021; and see Figure 20). While most of this detritus is recycled (remineralized) and nourishes the coastal ecosystem, some is eventually buried in sediments, underneath or adjacent to nearshore farms, or in distant or offshore habitats (Broch *et al.* 2022). Research suggests that a large proportion of macroalgae productivity in natural kelp ecosystems becomes detritus. For instance, Krumhansl and Scheibling (2012b) estimate that detritus accounts for 82 per cent of annual global seaweed productivity, and Krause-Jensen and Duarte (2016) estimate that 45 per cent of annual global seaweed productivity is exported from seaweed beds. However, the proportion of this carbon that is then exported to effective carbon sinks and sequestered over meaningful time periods (e.g., > 100 years) is substantially less, potentially 11 per cent of annual production (Krause-Jensen and Duarte 2016) and 4–5% of the flux of particulate organic carbon (Queirós *et al.* 2019).

The dynamics of carbon uptake and eventual storage (in terms of magnitude, spatial distribution and permanence) driven by kelp aquaculture systems subsequently introduce some uncertainties in the potential for carbon sequestration (Hurd *et al.* 2022). Currently, our understanding of carbon sequestration by seaweed aquaculture is based mainly on our understanding of rates of carbon cycling in natural kelp beds (i.e., Krause-Jensen and Duarte 2016; Quierós *et al.* 2019; Hurd *et al.* 2022; and see Kelp), but increasingly, research in Canada and elsewhere is exploring the carbon dynamics of kelp aquaculture specifically, including the export of carbon to nearshore and deep-sea habitats (Broch *et al.* 2022; Duarte *et al.* 2023). Research suggests that rates of passive carbon cycling and sequestration are spatially variable and may be dependent on farm location and local environmental conditions (Gundersen *et al.* 2021; Filbee-Dexter *et al.* 2022a). High-latitude regions such as Canada have been highlighted as promising locations for carbon sequestration in natural kelp systems, in part because cold water slows decomposition and facilitates sequestration (Filbee-Dexter *et al.* 2022b). We need more research to address the gaps in our understanding of the flux through carbon export pathways, in natural as well as aquaculture systems. This will help us design aquaculture systems that provide a consistent, ecologically sustainable effect on carbon sequestration. For example, Gallagher *et al.* (2022) suggest that increased dissolved and particulate organic carbon in a system may lead to greater cycling and increased respiration in the kelp community. The nature of such fluxes across a range of Canada's marine ecosystems is a critical part of understanding the local and regional-scale role of kelp aquaculture in these environments (National Academies of Sciences, Engineering, and Medicine 2021).

Carbon exported to the surrounding marine environment and other, more distant locations or habitats by kelp detritus is one potential process for carbon sequestration associated with a kelp aquaculture site. The other main process is intentionally sinking a larger quantity of kelp biomass to the ocean floor to facilitate carbon sequestration in deep-sea environments. Multiple companies are currently exploring this second process (Coleman *et al.* 2022). However, there are some significant knowledge and data gaps associated with the process, both with respect to its carbon-storage potential and ecological consequences. Increasing kelp biomass and the cycling of carbon (and other nutrients) in local ecosystems at a significant scale will create novel uncertainties and risks that are poorly understood. One study found that < 70% of kelp sunk to 50–150 m depth was remineralized (Pedersen *et al.* 2021); another found only a limited increase (0.5 per cent for less than six months) in organic sediment content after sinking 100 kg parcels of kelp to a much greater depth of 1,670 m (Bernardino *et al.* 2010). The National Academy of Sciences (2021) estimated that for seaweed cultivation to be an effective strategy for removing carbon dioxide, the flow of organic matter below the 2,000 m depth horizon would have to increase by about 25 per cent. Yet, increases of this magnitude could alter mesopelagic and deep-sea food webs and water chemistry, likely threatening existing deep-sea communities (Boyd *et al.* 2022). Also, some have questioned the ethics of disposing of such large quantities of a nutritionally valuable product, in light of global hunger and the disproportionate burden of climate change that is being carried by developing economies (Ricart *et al.* 2022). We therefore need further research, experimentation and social engagement before intentional export of kelp to the deep ocean becomes a viable option for carbon sequestration.

Carbon in Kelp Biomass and Products

Another major pathway for carbon cycling and uptake in kelp aquaculture involves carbon storage in seaweed products. While these products do not constitute direct, in-water carbon sequestration, they do have the potential to offset carbon emissions within and across production systems (e.g., by transitioning food systems to a lower climate impact or producing biofuels as opposed to fossil fuels) or enable carbon sequestration in other production systems (Gephart *et al.* 2021; Jones *et al.* 2022). For example, kelp can be sequestered in building materials such as concrete, or converted to biochar (charcoal-like substance created by burning biomass in the absence of oxygen) supporting sequestration in agricultural soils for extended periods (Roberts *et al.* 2015). Such agricultural uses of seaweed are an especially important opportunity for "downstream" increases in carbon sequestration, and including greater use of kelps in products such as fertilizers, biostimulants (compounds that increase plant productivity and/or stress tolerance), and feed amendments. Seaweed-based agricultural products offer several benefits: increased soil health, accelerated plant growth and carbon storage, and long-term storage of recalcitrant carbon in soil (Roberts *et al.* 2015; Boukhari *et al.* 2020). As kelp can be produced with fewer greenhouse gas emissions, including net negative emissions, it could potentially provide lower-carbon alternatives for these products, in addition to food, biofuels, plastics and pharmaceuticals (Laurens *et al.* 2020; Jones *et al.* 2022; Troell *et al.* 2022). Kelp-based alternatives could therefore indirectly support regional carbon loadings and reduction targets. In Canada, and in fact globally, an immediate limitation to this pathway is that most of seaweed harvested from aquaculture sites is currently used for human consumption (Cai *et al.* 2021; Troell *et al.* 2022). However, since food production is responsible for one-quarter of all greenhouse gas emissions, targeted efforts to replace food items and systems with opportunities such as those afforded by kelp aquaculture appear to be a priority transition (FOLU 2019).

It is important to note that kelp farming does emit greenhouse gases. These are generated by processes on the farm as well as upstream (e.g., from the preparation of materials and infrastructure) and downstream of farming activities (e.g., from processing and product development). Standardized or consistent estimates of these emissions are limited and therefore variable. For example, Jones *et al.* (2022) estimate that the total emissions from upstream, on-farm, and downstream (excluding post-harvest transport) activities range from 3.108 to 7.68 kg of carbon per metric ton of seaweed produced. Some studies actively account for carbon emissions and sequestration within the same kelp aquaculture operation and consider local environmental conditions. However, as these studies are still emerging, it is making it unclear whether these systems are likely to be net sinks or sources of carbon. We need more information to determine the circumstances under which kelp aquaculture systems can be designed and operated as a blue carbon pathway across a wider range of operating scenarios, and the extent of their potential positive effect.

ADDITIONAL SOCIAL AND ECOLOGICAL BENEFITS OF KELP AQUACULTURE

In addition to taking up carbon from the ocean, kelp absorbs nitrogen and phosphorus; it therefore supports the overall health of nearshore ecosystems by reducing anthropogenic loading of nutrients (Barrett *et al.* 2022). There is also evidence that seaweed aquaculture can increase the pH of seawater and provide local refugia from ocean acidification (Duarte *et al.* 2017; Xiao *et al.* 2021). Suspended kelp in farm sites can furthermore provide additional habitat and nutrition for fish and invertebrates, much as natural kelp beds do (Corrigan *et al.* 2022; Gregr *et al.* 2020). In shallow waters, suspended kelp can effectively attenuate wave energy (Zhu *et al.* 2021), protecting shorelines and reducing the effects of erosion on other blue carbon habitats, such as eelgrass or marshland (Duarte *et al.* 2017). These ecological benefits of kelp aquaculture could therefore simultaneously support net positive environmental outcomes, leading to a "regenerative" farming system (Theuerkauf *et al.* 2019, The Nature Conservancy 2021). Still, the extent and consistency of these benefits remain notional within a local setting; like the potential benefits to carbon cycling, these will vary depending on location, time of growth and harvest, and the design of the kelp aquaculture system. Furthermore, many of these ecological benefits are tempered by ecological risks, such as the impetus to use species not native to an area, shading from infrastructure and the potential for disruption to biogeochemical processes, which can reduce the natural availability of the nutrients, prompt algal blooms, or increase microbial activity. For example, consider a situation in which aquaculture systems contribute more organic matter than can be assimilated into the surrounding environment, naturally or via engineered system such as IMTA. This situation could stimulate excessive microbial activity in underlying sediments, increasing the occurrence of anaerobic conditions and negating the benefits of increased carbon uptake (Bhuyan 2023). We need further research to quantify these potential co-benefits across marine ecoregions in Canada at a local or farm scale, and at increasingly broader scales to test how these benefits could "scale up" to provide the anticipated environmental benefits.

Other countries have shown that kelp aquaculture has social and economic value, providing sustainable economic livelihoods and contributing to community well-being (Duarte *et al.* 2021; Rimmer *et al.* 2021). It has the potential to provide similar benefits in Canada. However, as with the ecological co-benefits, there is little information demonstrating realized community outcomes from kelp aquaculture in Canada. For many coastal Indigenous communities in Canada, seaweed is an important source of food, livelihood and cultural connection. In British Columbia, First Nations are actively engaged in monitoring natural kelp habitats, conducting seaweed aquaculture pilots, and leading discussions about seaweed health, harvest, cultivation and management in their respective territories. Indigenous communities are also taking leadership in the movement toward lower-carbon communities and economies, and are engaged in dialogue about climate mitigation and adaptation at regional and national scales (Turner and Clifton 2009; Townsend *et al.* 2020). In many coastal regions, the participation of Indigenous communities will be essential to growing the kelp aquaculture industry in an equitable, just and rights-driven manner (Bennett *et al.* 2018). Equitable and effective development of kelp aquaculture will require supporting interested Indigenous communities to create farm designs that work with local conditions and expectations, providing technical support and skills training and development, and enabling the acquisition of capital equipment.

KELP AQUACULTURE AS A BLUE CARBON PATHWAY: CHALLENGES, RISKS AND UNKNOWNS

There are many gaps in our knowledge of kelp aquaculture's potential to mitigate climate. For example, one estimate suggests that 7.3 million hectares — an area equivalent to a 100 m wide strip along 63 per cent of the world's coastlines (National Academies of Sciences, Engineering, and Medicine 2021) — would be needed to sequester 0.1 Gt CO_2/year; this is more than half the area theoretically available based on suitable area for all seaweed species potentially viable for farming (Froehlich *et al.* 2019; Spillias *et al.* 2023). Aside from the logistical constraints of farming at this scale, concerns have been raised about the potential for negative, ecosystem-wide consequences, such as nutrient depletion and a reduction in phytoplankton productivity (Berger *et al.* 2022). Furthermore, if farm sites for native species are not well chosen, or biomass production exceeds what is appropriate for local ecosystems, cultivated kelp can compete with plankton growth for nutrients and the decomposition of local detritus from kelp may lead to anoxic zones (National Academies of Sciences, Engineering, and Medicin 2021). Feedbacks could then create compensatory impacts in marine productivity, leading to a reduction in the net carbon sequestration provided through kelp aquaculture itself (National Academies of Sciences, Engineering, and Medicine 2021).

Nevertheless, across smaller extents, kelp aquaculture could generate useful regional gains. For example, it is estimated that if 14 per cent of global seaweed production (based on 2019 production figures) were directed toward effective carbon-mitigation strategies and markets, seaweed aquaculture could support carbon neutrality throughout the entire aquaculture industry (Froehlich *et al.* 2019). As part of a broader carbon-sequestration portfolio, kelp aquaculture may therefore make a notable contribution towards Canada's goal for emission reductions.

Currently in Canada, the limited scale of kelp-aquaculture production and small number of operators present several immediate challenges and uncertainties. From the perspective of feasibility, the growth of this industry is hindered by undeveloped markets, uncertain but generally high production costs, and the need to better understand how productive native kelp species can be in aquaculture systems (Chopin 2012; Chopin 2015). Each species selected for aquaculture will need to be carefully considered with respect to its role in the ecosystem as well as in carbon and nutrient cycling. There are parallel research needs in natural kelp ecosystems on detrital production, export, decomposition, and the material properties of kelp detritus for different species (e.g., buoyancy, floating longevity, material density, sinking speeds; see Kelp). In short, we badly need data on many aspects of productivity and products to determine the sequestration potential of kelp in Canada.

We also need to know what to grow — and when, where and how to grow it — to optimize kelp productivity, and thus a farm's success. It may be that the productivity of farmed kelp is one of the biggest factors that will influence carbon sequestration potential from kelp aquaculture, and therefore the viability of farms to engage in blue carbon pathways (Coleman *et al.* 2022). For example, it has been reported that natural stands of macrocystis in California produce 10 kg/m^2 of seaweed (Rassweiler *et al.* 2018); however, species that would be most likely viable for aquaculture in Canada's local environmental conditions may have an NPP that is significantly less, or be significantly different from one system or location to the next (e.g., 0.1 kg/m^2; Held 2021). Strain selection (for locally adapted plants) and market development for fast-growing species would improve local productivity.

While ecologically productive, Canada's coastlines are also largely remote, and social acceptance of new aquaculture development or expansion varies (Flaherty *et al.* 2019). New aquaculture activities in remote communities could yield important social and economic benefits, but may also be too expensive to realize. Transportation costs will initially be high, likely increasing GHG emissions from transport associated with the operation, thus offsetting the carbon-mitigation potential. Transportation would likely be reduced as the production chain becomes more localized (e.g., processing capacity is added near to the farming area). Sustainable expansion of kelp aquaculture would therefore seem to require broad, supportive community-development plans — plans that are embraced by coastal communities and enabled by appropriate policy and investment.

Most of the uncertainties and risks described above are rooted in knowledge gaps around the dynamics and interactions of cultivated species in local environments, and how these may change as coastal primary production increases with farming production, and as the climate changes. There may be increased risks from endemic and emerging pathogens and diseases, and the potential for genetic interactions with wild seaweed populations (Augyte *et al.* 2021). Farm infrastructure and kelp will also interact with local invertebrate and finfish species (Theuerkauf *et al.* 2022). For example, seaweed aquaculture can provide habitat for macroinvertebrates and fish, but can also lead to negative interactions, such as the spawning of herring on seaweed farms, observed in the Pacific northwest and leading to significant detritus (loss of eggs and kelp; Tiffany Stephens, pers. comm.). We need more studies on Canada's coasts to better understand the role of increased kelp biomass in marine ecoregions and the interaction of local faunal species with kelp aquaculture systems.

LINKING KELP AQUACULTURE TO CARBON CREDITING

As the kelp aquaculture industry grows and begins to measure its carbon value, we will also need to consider how regulatory or market mechanisms can support climate benefits. Carbon-credit methodologies, such as those developed by Verra for blue carbon marine habitats (mangroves, seagrasses and salt marshes), offer an established template for this industry (Verra 2022). At present, no such methods have been developed for kelp aquaculture. However, Verra has received the initial elements of a methodology based on near-farm carbon storage in marine sediment from Oceans 2050, an organization leading global research quantifying carbon-sequestration rates at several kelp aquaculture sites worldwide (Duarte *et al.* 2023). Methods development faces several challenges: we need a robust scientific basis to calculate long-term carbon storage and climate mitigation for a given kelp aquaculture scenario, and approaches that will let us consistently monitor net carbon flux and permanence (Rose and Hemery 2023). Compounding these challenges are the complexities and dynamics of carbon transport and burial, including carbon fate and permanence, accounting for exchange the between atmospheric and oceanic CO_2 (Hurd *et al.* 2022; Rose and Hemery 2023), and how additionality in carbon sequestration can be achieved, and guaranteed, in such a dynamic system.

Additional challenges relate to determining which entity may claim the carbon credit. Typically, carbon credits are assigned to the party that takes the action that results in the climate benefit; therefore, kelp-based products would typically yield carbon credits for the end-user, and not the kelp farmer, though there may be additional production, economic activity and co-benefits that could create value for an operator (Jones *et al.* 2022). This lack of capacity to directly credit a carbon benefit may be especially problematic for Indigenous communities, where production may occur at smaller extents, in a dispersed or disaggregated manner, or at locations that vary in the quantity of kelp farmed from one year to the next. This difficulty in attributing credits to the producer may steer aquaculture proponents or investors away from product-based plans and toward carbon strategies that directly connect the producer with the action yielding the carbon credit (e.g., through direct carbon storage in the marine ecosystem). If incentives discourage industry entrants from investing into actions that will yield greater climate benefits in lieu of easier or cheaper carbon credits, the industry's overall climate-mitigation potential will suffer.

It remains uncertain whether farming kelp to support carbon sequestration can be a profitable activity. This may depend on optimizing the emissions efficiency of the production system, to enable parallel cost reductions through process improvement and decarbonized supply chains (Coleman *et al.* 2022). The kelp aquaculture industry can potentially contribute to the fight against climate change. But to maximize this contribution in Canada, we need to align carbon-credit methodologies with kelp aquaculture activities that ensure net sequestration while also providing a broad suite of social and ecological co-benefits. These co-benefits are needed to ensure ecologically sustainable development.

CONCLUSIONS AND RECOMMENDATIONS

Kelp aquaculture offers a range of direct and indirect ways to sequester carbon, and so is worth continuing to explore as a blue carbon pathway. If developed sustainably and in step with local ecological and social needs, kelp aquaculture could also bring many co-benefits that align with other critical needs, such as fostering resilient and productive marine environments and sustainable coastal livelihoods in the future. The nascency of the industry in Canada, its many conceptual and tentative connections to climate-mitigation outcomes, and its potential to provide a low-impact economic activity in remote locations — all of these factors make kelp aquaculture highly relevant to the country's many coastal and Indigenous communities. However, we have limited knowledge of how to realize these benefits consistently and sustainably, and there is a lack of supporting policy, markets, and infrastructure mechanisms. For these reasons, kelp aquaculture is currently an "emerging" opportunity, rather than an immediately actionable pathway for crediting of carbon sequestration in national GHG emission reduction targets (Howard *et al.* 2017). While kelp has the potential to naturally sequester large quantities of carbon in long-term sinks (i.e., export of carbon to the deep-sea or sediments), the amount exported from aquaculture systems varies greatly depending on local environmental factors. We therefore need to develop more accurate, data-grounded estimates of carbon sequestration, kelp productivity and carbon cycling in local aquaculture applications. These estimates would help us develop effective crediting methodologies and programs.

The ecological knowledge gaps mirror those in natural kelp ecosystems, further highlighting the need for research into kelp systems and carbon cycling and sequestration in Canada. In aquaculture systems, we also need a quantitative understanding of the processing and downstream product development to assess the sequestration potential of kelp-based products. Further, we need to understand existing and future markets for these products to effectively contribute to mitigating greenhouse gas emissions. Finally, where a carbon sequestration opportunity exists, effective monitoring, validation, and accounting processes will be needed; these not yet available for many blue carbon systems. Yet, because these knowledge gaps are known, with specific attention and appropriate investment, we can answer the environmental, technical, risk-related, and accounting questions, and so help kelp aquaculture make a contribution to Canada's greenhouse gas emissions reduction goals.

RECOMMENDATIONS FOR KELP AQUACULTURE

- ✓ Ensure that interested Indigenous and local communities are actively engaged in and compensated for planning and developing kelp aquaculture throughout the supply chain (planning and approval, upstream processes, on-farm activities, and downstream processes). Enable their inclusion in aquaculture operations through appropriate technical and financial support.
- ✓ Emphasize kelp aquaculture as a specific potential blue carbon pathway, similar to but distinct from natural kelp habitats. This will encourage the development of policies, markets and supporting infrastructure that maximizes the economic viability, carbon reduction, and ecological and social co-benefits of these connected systems.
- ✓ Support research into kelp aquaculture's potential interactions with marine ecosystems and native species in Canada. This research will allow us to develop regionally specific best practices and proactively establish policies and regulations that support ecologically sustainable development.
- ✓ Increase research effort and investment in the collection of field data, experimentation, and ecological and economic modelling, to address knowledge gaps in kelp aquaculture carbon dynamics, particularly the potential to act as a net carbon sink.


© Yoon S. Byun / WWF-US

MOVING FORWARD

How do we support the protection, restoration and management of blue carbon ecosystems? This chapter summarizes current and future needs in relation to science, policy, economics and Indigenous rights. It highlights the need for collaboration and integration in all spheres to develop a more holistic approach to fighting climate change, reducing biodiversity loss and improving the well-being of communities across Canada. As we move forward with work on blue carbon, it is important to connect knowledge holders, practitioners and decision-makers to ensure that this important work is carried out in an ethical and rights-driven way across Canada. Indigenous Peoples have deep connections with their lands and waters, and it is vital to recognize the knowledge of Indigenous Peoples who have successfully stewarded healthy ecosystems for millennia. It will be essential to share information across disciplines, organizations and governments, and to collaborate in a respectful manner that upholds the right to free, prior and informed consent (FPIC). Equally, we need to ensure that the risks and benefits associated with blue carbon-focused NCS are equitably distributed.

SCIENCE AND MANAGEMENT

The chapters on segrass, salt marsh, kelp, and Arctic blue carbon ecosystems highlight what we currently know about these systems, and where the gaps in our knowledge lie. As we attempt to address these gaps and enhance our understanding of blue carbon ecosystems, we need to embrace different ways of knowing and apply the principle of two-eyed seeing. Although we need much more research to understand these dynamic ecosystems, we should not use knowledge gaps as an excuse to delay action to protect, manage and restore them. Blue carbon ecosystems provide a variety of benefits beyond climate regulation, including wildlife habitat, water-quality improvement, protection from flooding and erosion, the support of cultural practices, and the generation of revenue for coastal communities. By collaborating with Indigenous Peoples and local communities, we can safeguard these valuable services while research on coastal carbon dynamics continues.

A fundamental knowledge gap is the distribution and extent of blue carbon ecosystems in Canada. Remote sensing imagery can provide valuable information for sizable areas of the coastline, but this information needs to be ground-truthed. Though limited, data for carbon stock and carbon accumulation rate (CAR) are understood to vary widely within and among sites. Many organizations work to protect and restore blue carbon ecosystems, but rarely collect carbon data related to their projects. This is a missed opportunity to broaden our understanding of the spatial variability of blue carbon. To remedy this, we can connect researchers and practitioners, share expertise, and build collaborative projects to overcome operational hurdles that limit data collection, data sharing, and application. In instances where blue carbon data is collected, there is no national repository where it can be shared and made accessible. A national repository for blue carbon data would advance our understanding of these ecosystems, and help us develop robust projects to safeguard and restore blue carbon. While the need for data is clear, efforts to collect and share data must respect the First Nations principles of ownership, control, access and possession.

In addition to baseline information about blue carbon distribution, extent, stocks, CARs, and dynamics, we need research to optimize restoration and management efforts. For example, more information is needed on the factors that influence the long-term success of restoration projects, the lag time between restoration efforts and increased carbon stocks, and comparisons between restored areas and natural ecosystems in terms of carbon stocks, CARs and other ecosystem services. This additional information would also support the explicit inclusion of blue carbon into the design, planning, and implementation of NCS.

While blue carbon ecosystems can protect coastlines and coastal infrastructure from climate change, they are also vulnerable to its impacts. To ensure that conservation efforts are resilient, we need more research on the climate vulnerability and long-term security of blue carbon habitats. This research will build greater understanding of the contribution that blue carbon-based NCS can have as well as the associated limitations. In order to develop and implement effective NCS, we need complete feasibility assessments of NCS pathways, including the full costs of management actions and socioeconomic valuation of ecosystem services. Taken together, this research will help to maximize the benefits of blue carbon conservation actions.

POLICY

Currently, the regulatory and policy landscape — federal, provincial and territorial — is at odds with the desire to advance blue carbon work. Canada and some provinces have signalled their support for NCS, including both climate-change mitigation and adaptation, but have yet to make the updates to policy and regulations needed to facilitate the protection, management, and restoration of blue carbon systems. Further research to fill current knowledge gaps would make it easier to incorporate blue carbon into the national GHG inventory, a step that would provide additional support for blue carbon protection. Likewise, the federal government has created few concrete incentives to protect and restore blue carbon habitats. Urgent action by federal and provincial governments is needed to transform the rhetoric of support for NCS into actions that maximize climate-change mitigation, adaptation, and ecosystem health. As discussed throughout this report, we can leverage various mechanisms — such as federal policy, revitalized Indigenous law, provincial regulation, municipal zoning and funding for on-the-ground work — to improve the resiliency of blue carbon ecosystems. With the longest coastline in the world, and a dedicated, collaborative approach, Canada can lead the way in including blue carbon ecosystems in international climate and policy agendas and targets — and can showcase the value of a truly sustainable blue carbon economy.

Federal, provincial, and municipal policy and regulatory advances and/or updates should not be limited to marine systems. Residing at the land-sea interface, blue carbon ecosystems feel the cumulative impact of terrestrial, freshwater and marine threats. A cumulative threats assessment and subsequent management plan could therefore act as an entry point for exploring blue carbon-related opportunities and risks. The health and functioning of blue carbon ecosystems should be considered within all jurisdictions and by all orders of government.

Blue carbon ecosystems and their management have a complex jurisdiction, with different levels of government responsible for various components of blue carbon ecosystems. We need a more holistic approach that spans governments to effectively manage the stressors to blue carbon ecosystems, both in situ and upstream (on land). While robust science is needed to design effective policy and regulations, the gaps in blue carbon data should not limit viable investment and on-the-ground action, including habitat protection and management to reduce anthropogenic stressors.

HIGH-LEVEL RECOMMENDATIONS

- ✓ Secure funding, support, and capacity to fill blue carbon research gaps, including (i) the adoption of standardized protocols to complete high-resolution, comprehensive mapping of all blue carbon ecosystems along Canada's coast, (ii) an evaluation of these ecosystems' long-term carbon dynamics (e.g., stocks, sequestration rates, fluxes, lateral transfers and associated climate impacts), and (iii) regional evidence for NCS implementation.
- ✓ Respectfully seek out Indigenous knowledge and perspectives on blue carbon ecosystems to develop a more holistic understanding of these ecosystems. Identify and acknowledge what has been lost and what needs to be restored by engaging in reciprocal knowledge exchange with Indigenous governments, communities and organizations.
- ✓ Ensure equitable approaches to blue carbon management that elevate and guarantee Indigenous governance, rights and responsibilities, including co-development, co-management and co-governance where desired.
- ✓ Foster respectful collaboration among Crown and Indigenous governments and across jurisdictions. Such collaboration will advance holistic approaches to blue carbon protection, management, and restoration in ways that uphold Indigenous rights and responsibilities.
- ✓ Build on existing government-to-government tables to more fully integrate blue carbon NCS and elevate its importance and value to ensure more dedicated research and funding.
- ✓ Develop blue economy opportunities in line with the priorities, needs and values of Indigenous Nations and communities to actively protect, manage and restore coastal ecosystems.

- ✓ Explicitly integrate “blue carbon” and/or climate-change mitigation and adaptation into relevant legislation and policies at all levels of government to improve the conservation of coastal ecosystems.
- ✓ Continue to grow a blue carbon community of practice that brings together policy-makers, rightsholders and practitioners from coast to coast to coast to learn and mobilize.

BLUE CARBON COMMUNITY OF PRACTICE

With the longest coastline in the world, Canada is home to many coastal communities. These communities rely on coastal and nearshore ecosystems for food security, prosperous livelihoods and cultural practices, and the many resources provided by these ecosystems extend inland throughout Canada. However, environmental degradation and over-exploitation of coastal resources threaten coastal economies and the benefits these ecosystems provide. There are opportunities to develop a sustainable blue economy while simultaneously increasing the well-being of coastal communities and conserving blue carbon ecosystems.

Developing and implementing blue carbon NCS will require robust science, legislative tools and collaboration across jurisdictions, departments and disciplines. Long-term funding is needed to facilitate many of the recommendations made throughout this report, particularly for on-the-ground implementation of NCS in blue carbon ecosystems (e.g., protection, management and restoration). In addition, a well-connected community of practice is needed to bring together differing expertise, knowledge and lessons learned from coast to coast to coast.

Indigenous Peoples’ territories encompass Canada’s vast coastlines. As we move forward as a community of practice, we need to acknowledge the leadership of Indigenous Peoples and actively support Indigenous Nations and communities in creating sustainable blue economies that provide benefits for all. Opportunities abound for supporting Indigenous-led conservation in ways that elevate Indigenous rights, responsibilities and leadership (ICE 2018). Indigenous Nations and communities from coast to coast to coast are leading conservation efforts — including research, monitoring, and conservation-based economies — through Guardian programs, IPCAs and other Indigenous-led initiatives.

To effectively protect blue carbon ecosystems, we need to continue to grow an inclusive community of practice — one that welcomes governments, individuals and organizations working on blue carbon from coast to coast to coast. Likewise, to optimize blue carbon management, we need to share knowledge and different ways of knowing, spark collaborations and explore synergies across sectors, departments and jurisdictions.

RECOMMENDATIONS FOR THE COMMUNITY OF PRACTICE

- ✓ Encourage Crown governments to fund blue carbon protection, management, and restoration at federal, provincial, territorial and municipal levels. Explore how to leverage finance tools to support blue carbon projects.
- ✓ Recognize that in many cases, the success of blue carbon NCS depends on co-management and Indigenous stewardship.
- ✓ Continue to grow a blue carbon community of practice where policy-makers, Indigenous leaders and knowledge holders, and practitioners from coast to coast to coast can come together to learn, collaborate and mobilize.
- ✓ Advocate for blue carbon work that aligns with UNDRIP and the TRC’s Calls to Action.


© Hui Sim


© Eiko Jones Photography

RECOMMENDATIONS: FULL LIST

Blue Carbon Natural Climate Solutions

- ✓ Work collaboratively with Indigenous Peoples and local communities to design solutions to protect, manage and restore blue carbon ecosystems that prioritize multiple benefits and values, including carbon stocks. Current knowledge gaps must not delay critical on-the-ground action.
- ✓ When designing NCS, adopt an equitable approach that respects Indigenous rights, responsibilities and self-determination (e.g., fulfil and surpass the principles and minimum standards outlined in the United Nations Declaration on the Rights of Indigenous Peoples). Work collaboratively with Indigenous Peoples from the outset to ensure their values and needs are accounted for.
- ✓ Respond proactively and affirmatively to the needs, requests and concerns of Indigenous partners and the Indigenous Peoples whose territories encompass blue carbon resources and ecosystems.
- ✓ Invite meaningful collaboration with Indigenous Nations and communities early in the development of NCS projects and provide support to enable this capacity where desired.
- ✓ Build NCS holistically to include cultural values, increase resilience, and support climate-change adaptation across the land¬-sea interface.
- ✓ Support Indigenous-led NCS and marine conservation projects in ways identified by the lead Indigenous Nations and communities (e.g., through funding, information sharing, advocacy and collaboration).
- ✓ Prioritize the protection of blue carbon ecosystems to address habitat loss, the release of greenhouse gas emissions, and the need for future restoration.
- ✓ Ensure that current knowledge gaps do not delay action on the ground. no regret actions, such as protected and conserved areas, can meaningfully benefit biodiversity and climate, regardless of the magnitude of the benefit.
- ✓ Secure long-term investments and incentivize NCS to protect, sustainably manage and restore blue carbon ecosystems across Canada.
- ✓ Uphold Indigenous knowledge, legal and governance systems to at least the same degree as western climate and conservation science and policy when working collaboratively or partnering with Indigenous Nations and communities.
- ✓ Support research to address knowledge gaps in carbon dynamics, cumulative threats, and climate feedback loops in coastal ecosystems to inform decision-making on conservation prioritization, to improve the design of NCS, and to facilitate GHG reporting and targets.

Federal Policy

- ✓ In consultation and collaboration with Indigenous governments, federal agencies to review and potentially update relevant policies, regulations and legislation to include blue carbon.
- ✓ Implement principles of UNDRIP and the Truth and Reconciliation Commission's Calls to Action to support collaborative governance with Indigenous Nations and communities.
- ✓ Moving forward, ensure that all updated and novel relevant federal policies integrate considerations for blue carbon protection, climate-change mitigation and adaptation, and Indigenous-led conservation. All components are important.
- ✓ In the spirit of reciprocity, federal agencies to ensure that Indigenous Nations and communities can participate in government-to-government and nation-to-nation processes around blue carbon.
- ✓ Facilitate national-level and nation-to-nation discussions to determine federal policy needs and priorities for managing, protecting and restoring blue carbon.
- ✓ Add blue carbon to Canada's national GHG inventory once knowledge gaps are filled.
- ✓ Federal government to follow the Indigenous Circle of Experts' 2018 recommendations pertaining to Indigenous-led conservation and Indigenous Protected and Conserved Areas.
- ✓ Work effectively across jurisdictional divides with provincial, territorial and Indigenous governments to advance climate- and conservation-related initiatives (including blue carbon NCS) that span marine and terrestrial ecosystems.

Spatial Protection Tools

- ✓ Ensure that climate-change mitigation and adaptation are included in legislation and prioritization for spatial protection.
- ✓ Support Indigenous-led marine and coastal conservation initiatives, including Indigenous-led marine IPCAs or MPAs.
- ✓ Integrate the restoration and protection of blue carbon ecosystems in the prioritization, design and management of current and future MPAs.
- ✓ Support (e.g., provide funding and capacity where appropriate) Indigenous-led blue carbon mapping efforts.
- ✓ Support and build partnerships with coastal Indigenous Guardians programs in ways that advance their priorities and initiatives (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities).

Provincial Policy and Legislation

British Columbia

The following points summarize Carlson's key recommendations (2020):

- ✓ Increase provincial support for blue carbon research.
- ✓ Create a provincial framework for decision-making for coastal regions and ecosystems.
- ✓ Develop partnerships among governments to facilitate government-to-government agreements for sustainable blue carbon management.
- ✓ Integrate blue carbon management and monitoring into provincial strategies for mitigating and adapting to climate change.
- ✓ Incentivize NCS for coastal and land-use management while also respecting United Nations Declaration on the Rights of Indigenous Peoples.

Atlantic Provinces

The Atlantic provinces neither recognize the importance of blue carbon ecosystem function nor prioritize their explicit protection within relevant legislation and policies. Atlantic Canadian laws and policies should identify the unique ability of blue carbon ecosystems to sequester carbon and prioritize the stewardship of these ecosystems specifically.

- ✓ In collaboration with Indigenous Nations and communities, revise provincial impact-assessment legislation or policy to consider the implications for climate-change mitigation and adaptation if blue carbon ecosystems are disrupted, altered or destroyed.
- ✓ In collaboration with Indigenous Nations and communities, design blue carbon conservation policies or update existing policies relevant to blue carbon to include considerations and priorities for blue carbon for each province.
- ✓ Explicitly protect blue carbon ecosystems in applicable law or policy to recognize and elevate the importance of these ecosystems.

Arctic Policy and Legislation

- ✓ Explore treaty and Indigenous rights frameworks as a mechanism to protect blue carbon ecosystems, and vice versa.
- ✓ Integrate blue carbon into existing legislation and policy to better safeguard blue carbon ecosystems.
- ✓ Create forums for collaboration and integration among jurisdictions and Indigenous Nations and communities to facilitate holistic approaches to safeguarding blue carbon ecosystems.

Municipal Policy and Legislation

Local governments may influence, and in some circumstances regulate, the protection, restoration and management of blue carbon systems. They may do this either directly, or indirectly through their powers and interests related to land-use planning, infrastructure, climate action, environmental planning, and other aspects of municipal service delivery (e.g., financial planning, partnerships and advocacy).

Local governments can support blue carbon ecosystems and sequestration by taking the following actions:

- ✓ In collaboration with Indigenous Nations and communities, set sequestration targets in addition to greenhouse gas-reduction targets. These targets will create a demand for blue carbon sequestration services.
- ✓ In collaboration with Indigenous Nations and communities, plan for and invest in blue carbon NCS as part of climate-change adaptation.
- ✓ Advocate for blue carbon by lobbying other levels of government to take action, and by bringing interested parties together.
- ✓ Leverage infrastructure investments to protect and restore blue carbon ecosystems. Commit to no-net-loss of blue carbon ecosystems, and to reducing stormwater volumes and improving water quality.
- ✓ Leverage regulatory and policy powers to protect, conserve and restore blue carbon ecosystems as part of land-use planning and decision-making.
- ✓ Provide funding and support for Indigenous-led conservation and NCS.

Blue Carbon Ecosystems

- ✓ Build collaborations across disciplines to improve our understanding of carbon transport, storage and accumulation in blue carbon ecosystems.
- ✓ Take a systems-based approach to understanding carbon dynamics to improve our ability to mitigate climate change.
- ✓ Enhance understanding of the efficacy of restoration approaches and how carbon dynamics of restored ecosystems compare to undisturbed ecosystems.
- ✓ Complete feasibility studies for all blue carbon NCS pathways — incorporating multiple ecological and socioeconomic considerations — to evaluate the full range of costs and benefits.
- ✓ Create a national repository for data on blue carbon ecosystems to support conservation efforts and long-term monitoring.
- ✓ Invest in, incentivize and support research to improve the understanding of variability in carbon sequestration and storage within and among sites, ecosystems and regions, including the drivers of that variation.
- ✓ Include carbon measurement and monitoring in current conservation efforts.
- ✓ Expand blue carbon distribution and carbon models, including the collection of validation data (e.g., extent, threats, carbon dynamics), and refining machine learning models using a wide variety of available technologies.
- ✓ Seek out the work of Indigenous scientists and knowledge holders, and fund Indigenous-led research projects. This will expand perspectives on how the marine carbon cycle works and how climate impacts are affecting coastal Indigenous communities.

Seagrass

- ✓ Address barriers to implementing and monitoring NCS in seagrass habitats.
- ✓ Share restoration best practices from coast to coast to coast to improve the success rate of seagrass-restoration projects.
- ✓ Increase research on the factors driving carbon storage, accumulation and sequestration in seagrass ecosystems to support the development of more accurate region-specific estimates.
- ✓ Connect seagrass mapping efforts, adopt standardized protocols and use new technology to improve understanding of seagrass distribution and carbon dynamics to further the protection and management of these important habitats.

- ✓ Support and build partnerships with Indigenous communities and local communities in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on seagrass. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

Salt Marsh

- ✓ Address barriers to implementation and monitoring of NCS in salt marsh habitats.
- ✓ Increase research on the factors influencing carbon dynamics and their spatial variability to improve management of salt marsh habitats.
- ✓ Undertake and validate national-scale, high-resolution mapping of Canada's salt marsh habitats to support protection and management of these valuable ecosystems.
- ✓ Increase research into the resilience of salt marsh ecosystems to climate change and sea-level rise.
- ✓ Support and build partnerships with Indigenous communities and local communities in ways that advance their priorities and initiatives, including restoration and conservation projects. For example, provide funding, share data and information, and offer support in other ways identified by Guardians and Indigenous Nations and communities, and engage in co-development, co-management and co-governance.
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on salt marshes. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

Kelp

- ✓ Research kelp spatial extent, NPP, and carbon cycling and burial at local and regional scales. This data will improve estimates of carbon sequestration, validate modelling efforts and inform ocean accounting to support kelp conservation as an NCS.
- ✓ Improve the monitoring of kelp along Canada's coastline to facilitate the detection of temporal trends and associated drivers, while establishing baseline information for Arctic kelp forests.
- ✓ Promote the recognition of kelp as blue carbon by documenting kelp-derived carbon sequestered throughout the ocean ecosystem, exploring the lateral carbon transfer between habitats, and demonstrating that management actions can increase sequestration.
- ✓ Develop and improve effective conservation pathways for kelp forests that integrate cultural, environmental and economic considerations to prevent ecosystem declines and recover degraded areas.
- ✓ Support and build partnerships with Inuit communities and local Arctic communities, and strengthen partnerships with Indigenous communities and stewardship initiatives on the Pacific and Atlantic costs in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on kelp. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

Arctic Blue Carbon

- ✓ Connect mapping efforts, adopt standardized protocols, and use new technology for mapping and carbon measurements to facilitate site and regional comparisons, enhance understanding of habitat distribution and carbon storage, and improve protection and management.
- ✓ Ensure that all research, policy, and management measures that take place within or affect the Arctic are co-developed with Indigenous rightsholders, and honour Indigenous Peoples' priorities, governance structures, knowledge and values.

- ✓ Consider Arctic blue carbon in the context of new and existing management and protection measures to reduce impacts on stored carbon both on land (i.e., to reduce lateral transfer) and in marine habitats.
- ✓ Prioritize Inuit-led and co-managed areas and initiatives to improve understanding of Arctic blue carbon, and outline Indigenous-led opportunities for the long-term management of these important and remote ecosystems.
- ✓ Collaborate with Inuit governments, communities and organizations to improve the understanding of Arctic blue carbon and provide support for Inuit-led initiatives that advance the long-term management of these important and remote ecosystems.
- ✓ In collaboration with Inuit governments, communities and organizations, organize a workshop to explore the high-latitude carbon cycle from diverse perspectives.
- ✓ Support and build partnerships with Inuit communities and local Arctic communities in ways that advance their priorities and initiatives, including restoration and conservation projects (e.g., provide funding, share data and information, and offer support in other ways identified by Guardians and coastal Indigenous Nations and communities, engage in co-development, co-management and co-governance).
- ✓ Respectfully seek out Indigenous knowledge, perspectives and consent when developing NCS or conducting research on Arctic blue carbon. For example, inform yourself before engaging, seek out publicly available information first, recognize the sensitive nature of some Indigenous knowledge, follow best practices for engaging with Indigenous knowledge systems including First Nations' principles of ownership, control, access and possession, and engage in reciprocal knowledge exchange (The First Nations Information Governance Centre 2021).

Blue Economy

- ✓ Ensure that the benefits of blue economy-based development are distributed equitably, and that the risks are not borne by Indigenous Peoples or marginalized communities.
- ✓ Recognize the cost of lost economic development, and support conservation economies that support blue carbon protection, management and restoration.
- ✓ Remove barriers to Indigenous engagement in carbon markets, such as the principle of additionality as it is currently conceptualized.
- ✓ Adapt financing mechanisms to support natural climate solutions that involve blue carbon.
- ✓ Develop the blue economy in collaboration with Indigenous Peoples so that their rights, interests and priorities are reflected in blue carbon initiatives.
- ✓ Develop blue economy opportunities that actively protect, manage and restore coastal ecosystems, including blue carbon ecosystems.
- ✓ Add to the protocols and methodologies for potential blue carbon-based offsets in Canada to include seaweed farming and kelp restoration.

Kelp Aquaculture

- ✓ Ensure that interested Indigenous and local communities are actively engaged in and compensated for planning and developing kelp aquaculture throughout the supply chain (planning and approval, upstream processes, on-farm activities, and downstream processes). Enable their inclusion in aquaculture operations through appropriate technical and financial support.
- ✓ Emphasize kelp aquaculture as a specific potential blue carbon pathway, similar to but distinct from natural kelp habitats. This will encourage the development of policies, markets and supporting infrastructure that maximizes the economic viability, carbon reduction, and ecological and social co-benefits of these connected systems.
- ✓ Support research into kelp aquaculture's potential interactions with marine ecosystems and native species in Canada. This research will allow us to develop regionally specific best practices and proactively establish policies and regulations that support ecologically sustainable development.
- ✓ Increase research effort and investment in the collection of field data, experimentation, and ecological and economic modelling, to address knowledge gaps in kelp aquaculture carbon dynamics, particularly the potential to act as a net carbon sink.

Community of Practice

- ✓ Encourage Crown governments to fund blue carbon protection, management, and restoration at federal, provincial, territorial and municipal levels. Explore how to leverage finance tools to support blue carbon projects.
- ✓ Recognize that in many cases, the success of blue carbon NCS depends on co-management and Indigenous stewardship.
- ✓ Continue to grow a blue carbon community of practice where policy-makers, Indigenous leaders and knowledge holders, and practitioners from coast to coast to coast can come together to learn, collaborate and mobilize.
- ✓ Advocate for blue carbon work that aligns with UNDRIP and the TRC's Calls to Action.

High-Level

- ✓ Secure funding, support, and capacity to fill blue carbon research gaps, including (i) the adoption of standardized protocols to complete high-resolution, comprehensive mapping of all blue carbon ecosystems along Canada's coast, (ii) an evaluation of these ecosystems' long-term carbon dynamics (e.g., stocks, sequestration rates, fluxes, lateral transfers and associated climate impacts), and (iii) regional evidence for NCS implementation.
- ✓ Respectfully seek out Indigenous knowledge and perspectives on blue carbon ecosystems to develop a more holistic understanding of these ecosystems. Identify and acknowledge what has been lost and what needs to be restored by engaging in reciprocal knowledge exchange with Indigenous governments, communities and organizations.
- ✓ Ensure equitable approaches to blue carbon management that elevate and guarantee Indigenous governance, rights and responsibilities, including co-development, co-management and co-governance where desired.
- ✓ Foster respectful collaboration among Crown and Indigenous governments and across jurisdictions. Such collaboration will advance holistic approaches to blue carbon protection, management, and restoration in ways that uphold Indigenous rights and responsibilities.
- ✓ Build on existing government-to-government tables to more fully integrate blue carbon NCS and elevate its importance and value to ensure more dedicated research and funding.
- ✓ Develop blue economy opportunities in line with the priorities, needs and values of Indigenous Nations and communities to actively protect, manage and restore coastal ecosystems.
- ✓ Explicitly integrate "blue carbon" and/or climate-change mitigation and adaptation into relevant legislation and policies at all levels of government to improve the conservation of coastal ecosystems.
- ✓ Continue to grow a blue carbon community of practice that brings together policy-makers, rightsholders and practitioners from coast to coast to coast to learn and mobilize.

© Andrew S. Wright / WWF-Canada

REFERENCES

Abdul-Aziz OI. Ishtiaq KS. Tang J. Moseman-Valtierra S. Kroeger KD. Gonneea ME. *et al.* (2018). Environmental controls, emergent scaling, and predictions of greenhouse gas (GHG) fluxes in coastal salt marshes. *Journal of Geophysical Research: Biogeosciences*, 123(7), 2234-2256. DOI: 10.1029/2018JG004556.

Agusto LE. Qin G. Thibodeau B. Tang J. Zhang J. Zhou J. *et al.* (2022). Fiddling with the blue carbon: Fiddler crab burrows enhance CO_2 and CH_4 efflux in saltmarsh. *Ecological Indicators*, 144, 109538. DOI: 10.1016/j.ecolind.2022.109538.

Al-Haj AN. and Fulweiler RW. (2020). A synthesis of methane emissions from shallow vegetated coastal ecosystems. *Global Change Biology*, 26(5), 2988-3005. DOI: 10.1111/gcb.15046.

Alleway HK. Jones AR. Theuerkauf SJ. and Jones RC. (2022). A global and regional view of the opportunity for climate-smart mariculture. *Philosophical Transactions of the Royal Society B,* 377, 20210128. DOI: 10.1098/rstb.2021.0128.

Amos CL. and Tee KT. (1989). Suspended sediment transport processes in Cumberland Basin, Bay of Fundy. *Journal of Geophysical Research,* 94, 407-417. DOI: 10.1029/JC094iC10p14407.

Anaya SJ. (2004). Indigenous Peoples in International Law (2nd ed.). *Oxford University Press.* New York, USA.

Andersen TJ. Svinth S. and Pejrup M. (2011). Temporal variation of accumulation rates on a natural salt marsh in the 20th century—The impact of sea level rise and increased inundation frequency. *Marine Geology*, 279(1-4), 178-187. DOI: 10.1016/j.margeo.2010.10.025.

Andersen CW. (2021). Atlantic ocean and Canada. *The Canadian Encyclopedia.* Retrieved online from: https://www.thecanadianencyclopedia.ca/en/article/atlantic-ocean-and-canada.

Archambault P. Snelgrove PV. Fisher JA. Gagnon JM. Garbary DJ. Harvey M. *et al.* (2010). From sea to sea: Canada's three oceans of biodiversity. *PLoS One,* 5(8), e12182. DOI: 10.1371/journal.pone.0012182.

Ardyna M. Mundy CJ. Mayot N. Matthes LC. Oziel L. Horvat C. *et al.* (2020). Under-ice phytoplankton blooms: Shedding light on the "invisible" part of Arctic primary production. *Frontiers in Marine Science,* 7, 608032. DOI: 10.3389/fmars.2020.608032.

Arif S. Dayaneni G. and Tan AL. (2021). Real solutions for climate justice. In *Hoodwinked in the Hothouse: Resist False Solutions to Climate Change*. Retrieved online from: https://climatefalsesolutions.org/wp-content/uploads/HOODWINKED_ThirdEdition_On-Screen_version.pdf.

Arrigo KR. Matrai PA. and Van Dijken GL. (2011). Primary productivity in the Arctic Ocean: Impacts of complex optical properties and subsurface chlorophyll maxima on large-scale estimates. *Journal of Geophysical Research: Oceans,* 116(C11). DOI: 10.1029/2011JC007273.

Arrigo KR. Perovich DK. Pickart RS. Brown ZW. van Dijken GL. Lowry KE. *et al.* (2014). Phytoplankton blooms beneath the sea ice in the Chukchi Sea. *Deep Sea Research Part II: Topical Studies in Oceanography,* 105, 1-16. DOI: 10.1016/j.dsr2.2014.03.018.

Arrigo KR. and van Dijken GL. (2015). Continued increases in Arctic Ocean primary production. *Progress in Oceanography,* 136, 60-70. DOI: 10.1016/j.pocean.2015.05.002.

Armstrong CW. Foley NS. Slagstad D. Chierici M. Ellingsen I. and Reigstad M. (2019). Valuing blue carbon changes in the Arctic. *Frontiers in Marine Science,* 6, 331. DOI: 10.3389/fmars.2019.00331.

Artelle KA. Stephenson J. Bragg C, Housty JA. Housty WG. Kawharu M. *et al.* (2018). Values-led management: The guidance of place-based values in environmental relationships of the past, present, and future. *Ecology and Society,* 23(3). DOI: 10.5751/ES-10357-230335.

Asian Development Bank (ADB). (2021a). Sovereign Blue Bonds Quick Start Guide. Retrieved online from: https://www.adb.org/sites/default/files/publication/731026/adb-sovereign-blue-bonds-start-guide.pdf.

Asian Development Bank (ABD). (2021b). ADB Blue Bonds. Retrieved online from: https://www.adb.org/sites/default/files/publication/731026/adb-blue-bonds.pdf.

Asian Development Bank (ADB). (2021c). Green and Blue Bond Framework. Retrieved online from: https://www.adb.org/sites/default/files/publication/731026/adb-green-blue-bond-framework.pdf.

Asplund ME. Bonaglia S. Boström C. Dahl M. Deyanova D. Gagnon K. *et al.* (2022). Methane emissions from Nordic seagrass meadow sediments. *Frontiers in Marine Science*, 8:811533. DOI: 10.3389/fmars.2021.811533.

Attridge CM. Metaxas A. and Denley D. (2022). Wave exposure affects the persistence of kelp beds amidst outbreaks of the invasive bryozoan *Membranipora membranacea*. *Marine Ecology Progress Series,* 702, 39-56. DOI: 10.3354/meps14191.

Augyte S. Kim JK. and Yarish C. (2021). Seaweed aquaculture—From historic trends to current innovation. *Journal of the World Aquaculture Society,* 52, 1004-1008. DOI: 10.1111/jwas.12854.

Austen E. and Hanson A. (2007). An analysis of wetland policy in Atlantic Canada. *Canadian Water Resources Journal,* 32(3), 163-178. DOI: 10.4296/cwrj3203163.

Bach LT. Tamsitt V. Gower J. Hurd CL. Raven JA. and Boyd PW. (2021). Testing the climate intervention potential of ocean afforestation using the Great Atlantic *Sargassum* Belt. *Nature Communications, 12*, 2556. DOI: 10.1038/s41467-021-22837-2.

Baker CA. Martin AP. Yool A. and Popova E. (2022). Biological carbon pump sequestration efficiency in the North Atlantic: A leaky or a long-term sink? *Global Biogeochemical Cycles,* 36, e2021GB007286. DOI: 10.1029/2021GB007286.

Barber DG. Hop H. Mundy CJ. Else B. Dmitrenko IA. Tremblay JE. *et al.* (2015). Selected physical, biological and biogeochemical implications of a rapidly changing Arctic Marginal Ice Zone. *Progress in Oceanography,* 139, 122-150. DOI: 10.1016/j.pocean.2015.09.003.

Barbier EB. (2017). Marine ecosystem services. *Current Biology*, 27(11), R507-R510. DOI: 10.1016/j.cub.2017.03.020.

Barbier EB. Hacker SD. Kennedy C. Koch EW. Stier AC. and Silliman BR. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169-193. DOI: 10.1890/10-1510.1.

Barnes DKA. (2019). Blue carbon sinks on polar seabeds and their feedbacks on climate change. *Conference of the Arabian Journal of Geosciences, New Prospects in Environmental Geosciences and Hydrosciences,* 71-73. DOI: 10.1007/978-3-030-72543-3_16.

Barnes DK. and Tarling GA. (2017). Polar oceans in a changing climate. *Current Biology,* 27(11), R454-R460. DOI: 10.1016/j.cub.2017.01.045.

Barnhart KR. Overeem I. Anderson RS. (2014). The effect of changing sea ice on the physical vulnerability of Arctic coasts. *The Cryosphere,* 8(5), 1777-1799. DOI: 10.5194/tc-8-1777-2014.

Barrell J. and Grant J. (2013). Detecting hot and cold spots in a seagrass landscape using local indicators of spatial association. *Landscape Ecology*, 28(10), 2005-2018. DOI: 10.1007/s10980-013-9937-2.

Barrell J. Grant J. Hanson A. and Mahoney M. (2015). Evaluating the complementarity of acoustic and satellite remote sensing for seagrass landscape mapping. *International Journal of Remote Sensing*, 36(16), 4069-4094. DOI: 10.1080/01431161.2015.1076208.

Barrett LT. Theuerkauf SJ. Rose JM. Alleway HK. Bricker SB. Parker M. *et al.* (2022). Sustainable growth of non-fed aquaculture can generate valuable ecosystem benefits. *Ecosystem Services* 53, 101396. DOI: 10.1016/j.ecoser.2021.101396.

Bartlett C. Marshall M. and Marshall A. (2012). Two-eyed seeing and other lessons learned within a co-learning journey of bringing together Indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies and Sciences,* 2, 331-340. DOI: 10.1007/s13412-012-0086-8.

Bartsch I. Paar M. Fredriksen S. Schwanitz M. Daniel C. Hop H. *et al.* (2016). Changes in kelp forest biomass and depth distribution in Kongsfjorden, Svalbard, between 1996–1998 and 2012–2014 reflect Arctic warming. *Polar Biology,* 39(11), 2021-2036. DOI: 10.1007/s00300-015-1870-1.

Bates NR. (2007). Interannual variability of the oceanic CO_2 sink in the subtropical gyre of the North Atlantic Ocean over the last 2 decades. *Journal of Geophysical Research: Oceans*, 112(C9). DOI: 10.1029/2006JC003759.

Bates NR. and Peters AJ. (2007). The contribution of atmospheric acid deposition to ocean acidification in the subtropical North Atlantic Ocean. *Marine Chemistry*, 107(4), 547-558. DOI: 10.1016/j.marchem.2007.08.002.

Bates NR. and Mathis JT. (2009). The Arctic Ocean marine carbon cycle: evaluation of air–sea CO_2 exchanges, ocean acidification impacts and potential feedbacks. *Biogeosciences*, 6(11), 2433-2459. DOI: 10.5194/bgd-6-6695-2009.

Baumert HZ. and Petzoldt T. (2008). The role of temperature, cellular quota and nutrient concentrations for photosynthesis, growth and light–dark acclimation in phytoplankton. *Limnologica,* 38(3-4), 313-326. DOI: 10.1016/j.limno.2008.06.002.

BC Marine Conservation Analysis. (2011). Marine Atlas of Pacific Canada: A Product of the British Columbia Marine Conservation Analysis. Retrieved online from: https://cmnmaps.ca/BCMCA/introdisclaimer.html.

Beauregard RA. and Holcomb HB. (1984). City profile: New Brunswick. *Cities,* 1(3), 215-220. DOI: 10.1016/0264-2751(84)90094-5.

Bégin C. Johnson LE. and Himmelman JH. (2004). Macroalgal canopies: Distribution and diversity of associated invertebrates and effects on the recruitment and growth of mussels. *Marine Ecology Progress Series*, 271, 121-132. DOI: 10.3354/meps271121.

Behrenfeld MJ. Worthington K. Sherrell RM. Chavez FP. Strutton P. McPhaden M. *et al.* (2006). Controls on tropical Pacific Ocean productivity revealed through nutrient stress diagnostics. *Nature*, 442(7106), 1025-1028. DOI: 10.1038/nature05083.

Bennett NJ. Blythe J. White CS. and Campero C. (2021). Blue growth and blue justice: Ten risks and solutions for the ocean economy. *Marine Policy,* 125, 104387. DOI: 10.1016/j.marpol.2020.104387.

Berkes F. (1999). Sacred Ecology: Traditional Ecological Knowledge and Resource Management. *Taylor & Francis.* Oxfordshire, UK.

Bernardino AF. Smith CR. Baco A. Altamira I. and Sumida PYG. (2010). Macrofaunal succession in sediments around kelp and wood falls in the deep NE Pacific and community overlap with other reducing habitats. *Deep Sea Research Part I: Oceanographic Research Papers,* 57, 708-723. DOI: 10.1016/j.dsr.2010.03.004.

Bertness MD. (1991). Zonation of *Spartina patens* and *Spartina alterniflora* in New England salt marsh. *Ecology*, 72(1), 138-148. DOI: 10.2307/1938909.

Bhuyan MS. (2023) Ecological risks associated with seaweed cultivation and identifying risk minimization approaches. *Algal Research,* 69, 102967. DOI: 10.1016/j.algal.2022.102967.

Billah MM. Bhuiyan MKA. Islam MA. Das J. and Hoque AR. (2022). Salt marsh restoration: an overview of techniques and success indicators. *Environmental Science and Pollution Research,* 29, 15347-15363. DOI: 10.1007/s11356-021-18305-5.

Binnema T. and Niemi M. (2006). “Let the line be drawn now”: Wilderness, conservation, and the exclusion of Aboriginal people from Banff National Park in Canada. *Environmental History,* 11(4), 724-750. DOI: 10.1093/envhis/11.4.724.

Bintanja R. (2018). The impact of Arctic warming on increased rainfall. *Scientific Reports,* 8, 16001. DOI: 10.1038/s41598-018-34450-3.

Black PL. Arnason JT. and Cuerrier A. (2008). Medicinal plants used by the Inuit of Qikiqtaaluk (Baffin Island, Nunavut). *Botany,* 86(2), 157-163. DOI: 10.1139/B07-052.

Bladon A. Mohammed EY. and Milner-Gulland EJ. (2014). A Review of Conservation Trust Funds for Sustainable Marine Resources Management: Conditions for Success. *IIED Working Paper*. Retrieved online from: https://www.iied.org/16574iied.

Blount TR. Carrasco AR. Cristina S. and Silvestri S. (2022). Exploring open-source multispectral satellite remote sensing as a tool to map long-term evolution of salt marsh shorelines. *Estuarine, Coastal and Shelf Science*, 266, 107664. DOI: 10.1016/j.ecss.2021.107664.

Bond WK. Cox KW. Heberlein T. Manning EW. Witty DR. and Young DA. (1992). Wetland Evaluation Guide: Final Report of the Wetlands Are Not Wastelands Project. Sustaining Wetlands Issues Paper 1992-1. *North American Wetlands Conservation Council.* Ottawa, ON. Retrieved online from: https://publications.gc.ca/site/eng/9.610361/publication.html.

Bonsell C. and Dunton KH. (2018). Long-term patterns of benthic irradiance and kelp production in the central Beaufort Sea reveal implications of warming for Arctic inner shelves. *Progress in Oceanography,* 162, 160-170. DOI: 10.1016/j.pocean.2018.02.016.

Boone LK. Ollerhead J. Barbeau MA. Beck AD. Sanderson BG. and Mclellan NR. (2017). Returning the tide to dikelands in a macrotidal and ice-influenced environment: Challenges and lessons learned. In *Coastal Wetlands: Alteration and Remediation*. Coastal Research Library, 21. DOI: 10.1007/978-3-319-56179-0_21.

Boukhari MEME. Barakate M. Bouhia Y. and Lyamlouli K. (2020). Trends in seaweed extract based biostimulants: Manufacturing process and beneficial effect on soil-plant systems. *Plants,* 9(3), 359. DOI: 10.3390/plants9030359.

Bowron TM. Neatt N. Proosdij DV. and Lundholm J. (2012). Salt marsh tidal restoration in Canada’s Maritime Provinces. In *Tidal Marsh Restoration,* 191-209. DOI: 10.5822/978-1-61091-229-7_13.

Bowron TM. Neat NC. Graham JM. Proosdij DV. Lundholm J. and Lemieux B. (2013). Post Restoration Monitoring (Year 7) of the Cheverie Creek Salt Marsh Restoration Project. Technical Report prepared for *Nova Scotia Department of Transportation and Infrastructure Renewal.* Retrieved online from: https://novascotia.ca/tran/works/enviroservices/saltmarshes/Cheverie%20Monitoring_Year%207_2013.pdf.

Boyd PW. Bach LT. Hurd CL. Paine E. Raven JA. and Tamsitt V. (2022). Potential negative effects of ocean afforestation on offshore ecosystems. *Nature Ecology* and *Evolution,* 6, 675-683. DOI: 10.1038/s41559-022-01722-1.

Boyer KE. and Fong P. (2005). Macroalgal-mediated transfers of water column nitrogen to intertidal sediments and salt marsh plants. *Journal of Experimental Marine Biology and Ecology*, 321(1), 59-69. DOI: 10.1016/j.jembe.2005.01.005.

Bradley K. and Houser C. (2009). Relative velocity of seagrass blades: Implications for wave attenuation in low-energy environments. *Journal of Geophysical Research: Earth Surface*, 114(F1). DOI: 10.1029/2007JF000951.

Bridgham SD. Cadillo-Quiroz H. Keller JK. and Zhuang Q. (2013). Methane emissions from wetlands: biogeochemical, microbial, and modeling perspectives from local to global scales. *Global Change Biology*, 19(5), 1325-1346. DOI: 10.1111/gcb.12131.

Bringloe TT. Wilkinson DP. Savoie AM. Filbee-Dexter K. Macgregor KA. Howland KL. *et al.* (2022). Arctic marine forest distribution models showcase potentially severe habitat losses for cryophilic species under climate change. *Global Change Biology*, 28, 3711-3727. DOI: 10.1111/gcb.16142.

British Columbia Ministry of Environment. (2008). Living WaterSmart: British Columbia’s Water Plan. *British Columbia, Canada.* Retrieved online from: https://waterbucket.ca/wcp/wp-content/uploads/sites/6/2017/11/livingwatersmart_book.pdf.

British Columbia Ministry of Environment. (2023). Ecosystems: Restrictive Covenants. British Columbia, Canada. Retrieved online from: https://www.env.gov.bc.ca/lower-mainland/ecosystems/restrictive_covenants/.

Broch OJ. Hancke K. and Ellingsen IH. (2022). Dispersal and deposition of detritus from kelp cultivation. *Frontiers in Marine Science, 9*, 840531. DOI: 10.3389/fmars.2022.840531.

Brown KA. Holding JM. and Carmack EC. (2020). Understanding regional and seasonal variability is key to gaining a Pan-Arctic perspective on Arctic Ocean freshening. *Frontiers in Marine Science*, 7, 606. DOI: 10.3389/fmars.2020.00606.

Brown PJ. McDonagh EL. Sanders R. Watson AJ. Wanninkhof R. King BA. *et al.* (2021). Circulation-driven variability of Atlantic anthropogenic carbon transports and uptake. *Nature Geoscience*, 14, 571-577. DOI: 10.1038/s41561-021-00774-5.

Busch KE. Golden RR. Parham TA. Karrh LP. Lewandowsk MJ. and Naylor MD. (2010). Large-scale *Zostera marina* (eelgrass) restoration in Chesapeake Bay, Maryland, USA. Part I: A comparison of techniques and associated costs. *Restoration Ecology,* 18, 490-500. DOI: 10.1111/j.1526-100X.2010.00690.x.

Bush E. and Lemmen DS. (2019). Canada's Changing Climate Report. *Government of Canada.* Ontario, Canada. Retrieved online from: https://changingclimate.ca/site/assets/uploads/sites/2/2020/06/CCCR_FULLREPORT-EN-FINAL.pdf.

Butterly L. and Richardson BJ. (2016). Indigenous Peoples and saltwater/freshwater governance. *Indigenous Law Bulletin,* 8(26), 3-8. DOI: 10.3316/ielapa.462506056796637.

Byers SE. and Chmura GL. (2007). Salt marsh vegetation recovery on the Bay of Fundy. *Estuaries and Coasts,* 30, 869-877. DOI: 10.1007/BF02841340.

Cai J. Lovatelli A. Aguilar-Manjarrez J. Cornish L. Dabbadie L. Desrochers A. *et al.* (2021). Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. Fisheries and Aquaculture Circular No. 1229. *Food and Agriculture Organization of the United Nations.* Rome, Italy. Retrieved online from: https://www.fao.org/3/cb5670en/cb5670en.pdf.

Campbell A. (2011). City buys last bog piece. *Richmond News.* Richmond, Canada. Retrieved online from: https://www.richmond-news.com/in-the-community/city-buys-last-bog-piece-2945624.

Campbell AD. Fatoyinbo L. Goldberg L. and Lagomasino D. (2022). Global hotspots of salt marsh change and carbon emissions. *Nature*, 612, 701-706. DOI: 10.1038/s41586-022-05355-z.

Canadian Urban Sustainability Practitioners (CUSP). (2019). Case Study 1. *Canadian Urban Sustainability Practitioners.* Retrieved online from: https://cuspnetwork.ca/advancing-innovations-in-climate-finance/internal-carbon-pricing/.

Canadian Urban Sustainability Practitioners (CUSP). (2020). Climate-Related Financial Risk Disclosures for Cities. *Canadian Urban Sustainability Practitioners.* Retrieved online from: https://cuspnetwork.ca/initiative-2/.

Capooci M. Barba J. Seyfferth AL. and Vargas R. (2019). Experimental influence of storm-surge salinity on soil greenhouse gas emissions from a tidal salt marsh. *Science of the Total Environment*, 686, 1164-1172. DOI: 10.1016/j.scitotenv.2019.06.032.

Carlson D. (2020). Policy and Planning for Coastal Ecosystems in British Columbia through a Blue Carbon Lens. *West Coast Environmental Law*. British Columbia, Canada. Retrieved online from: https://www.wcel.org/publication/policy-and-planning-coastal-ecosystems-british-columbia-through-blue-carbon-lens.

Carmack E. and Wassmann P. (2006). Food webs and physical–biological coupling on pan-Arctic shelves: Unifying concepts and comprehensive perspectives. *Progress in Oceanography*, 71(2-4), 446-477. DOI: 10.1016/j.pocean.2006.10.004.

Carvalho KS. and Wang S. (2020). Sea surface temperature variability in the Arctic Ocean and its marginal seas in a changing climate: Patterns and mechanisms. *Global and Planetary Change,* 193, 103265. DOI: 10.1016/j.gloplacha.2020.103265.

CBCL Limited (2009). The 2009 State of Nova Scotia's Coast Technical Report. Technical report prepared for and distributed by Nova Scotia Environment. *Nova Scotia Environment.*

Chagueé-Goff C. Hamilton TS. and Scott DB. (2001). Geochemical evidence for the recent changes in a salt marsh, Chezzetcook Inlet, Nova Scotia, Canada. *Proceedings of the Nova Scotia Institute of Science,* 41, 149-59. https://dalspace.library.dal.ca/handle/10222/35385.

Chapman ARO. and Lindley JE. (1980). Seasonal growth of *Laminaria solidungula* in the Canadian High Arctic in relation to irradiance and dissolved nutrient concentrations. *Marine Biology,* 57, 1-5. DOI: 10.1007/BF00420961.

Chastain S. and Kohfeld KE. (2016). Blue Carbon in Tidal Wetlands of the Pacific Coast of Canada. *Commission for Environmental Cooperation.* Montreal, Canada. Retrieved online from: http://www.cec.org/files/documents/publications/11723-blue-carbon-in-tidal-wetlands-pacific-coast-canada-examples-from-pacific-rim-en.pdf.

Chastain SG. Kohfeld K. and Pellatt MG. (2018). Carbon stocks and accumulation rates in salt marshes of the Pacific coast of Canada. *Biogeosciences Discussions*, 1-45. DOI: 10.5194/bg-2018-166.

Chastain SG. Kohfeld KE. Pellatt MG. Olid C. and Gailis M. (2022). Quantification of blue carbon in salt marshes of the Pacific coast of Canada. *Biogeosciences Discussions*, 19(24), 5751-5777. DOI: 10.5194/bg-19-5751-2022.

Chen X. Zhang F. Lao Y. Wang X. Du J. and Santos IR. (2018). Submarine groundwater discharge‐derived carbon fluxes in mangroves: An important component of blue carbon budgets? *Journal of Geophysical Research: Oceans*, 123(9), 6962-6979. DOI: 10.1029/2018JC014448.

Chen M. Huang Y. Guo L. Cai P. Yang W. Liu G. and Qiu Y. (2002). Biological productivity and carbon cycling in the Arctic Ocean. *Chinese Science Bulletin,* 47(12), 1037-1040. DOI: 10.1007/BF02907578.

Chmura GL. Anisfeld SC. Cahoon DR. and Lynch JC. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles*, 17(4), 1111. DOI: 10.1029/2002GB001917.

Chmura GL. and Hung GA. (2004). Controls on salt marsh accretion: A test in salt marshes of Eastern Canada. *Estuaries* 27, 70-81. DOI: 10.1007/BF02803561.

Chmura GL. (2016). Greenhouse gas fluxes from salt marshes exposed to chronic nutrient enrichment. *PLOS ONE,* 11(2), e0149937. DOI: 10.1371/journal.pone.0149937.

Chopin T. (2015). Marine aquaculture in Canada: Well-established monocultures of finfish and shellfish and an emerging Integrated Multi-Trophic Aquaculture (IMTA) approach including seaweeds, other invertebrates, and microbial communities. *Fisheries*, 40(1), 28-31. DOI: 10.1080/03632415.2014.986571.

Chopin T. Cooper JA. Reid G. Cross S. and Moore C. (2012). Open-water integrated multi-trophic aquaculture: Environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture*, 4(4), 209-220. DOI: 10.1111/j.1753-5131.2012.01074.x.

Christiansen J. and Reist J. (2013). Chapter 6: Fishes. Arctic Biodiversity Assessment. In *Conservation of Arctic Flora and Fauna.* Retrieved online from: https://www.caff.is/assessment-series/211-Arctic-biodiversity-assessment-2013-chapter-6-fishes.

Christie H. Noderhaug KM. and Fredriksen S. (2009). Macrophytes as habitat for fauna. *Marine Ecology Progress Series,* 396, 221-233. DOI: 10.3354/meps08351.

CIRNAC. (2019). Recognition and Reconciliation of Rights Policy for Treaty Negotiations in British Columbia. *Crown–Indigenous Relations and Northern Affairs, Government of Canada.* Ottawa, Canada. Retrieved online from: https://www.rcaanc-cirnac.gc.ca/eng/1567636002269/1567636037453#sec1.

CIRNAC. (2021a). First Nations - Indigenous Peoples and Communities. *Crown–Indigenous Relations and Northern Affairs, Government of Canada.* Ottawa, Canada. Retrieved online from: https://www.rcaanc-cirnac.gc.ca/eng/1100100013791/1535470872302.

CIRNAC. (2021b). Inuit - Indigenous Peoples and Communities. *Crown–Indigenous Relations and Northern Affairs. Government of Canada.* Ottawa. Retrieved online from: https://www.rcaanc-cirnac.gc.ca/eng/1100100014187/1534785248701.

Cisneros-Montemayor AM. Moreno-Báez M. Voyer M. Allison EH. Cheung WW. Hessing-Lewis M. *et al.* (2019). Social equity and benefits as the nexus of a transformative Blue Economy: A sectoral review of implications. *Marine Policy*, 109, 103702. DOI: 10.1016/j.marpol.2019.103702.

Cisneros-Montemayor AM. Ducros AK. Bennett NJ. Fusco LM. Hessing-Lewis M. Singh GG. *et al.* (2022). Agreements and benefits in emerging ocean sectors: Are we moving towards an equitable Blue Economy? *Ocean & Coastal Management,* 220, 106097. DOI: 10.1016/j.ocecoaman.2022.106097.

City of Richmond. (2012). City of Richmond and Ducks Unlimited Canada preserve largest remaining privately-owned Sturgeon Banks land. *City of Richmond.* British Columbia, Canada. Retrieved online from: https://www.newswire.ca/news-releases/city-of-richmond-and-ducks-unlimited-canada-preserve-largest-remaining-privately-owned-sturgeon-banks-land-509892691.html.

City of Surrey. (2021). Biodiversity design guidelines. *City of Surrey.* British Columbia, Canada. Retrieved online from: https://www.surrey.ca/renovating-building-development/land-planning-development/environmental-protection/biodiversity-0.

City of Vancouver. (2021). Climate Emergency Action Plan: Big move 6 – Natural climate Solutions. *City of Vancouver.* British Columbia, Canada. https://council.vancouver.ca/20211208/documents/cfsc2.pdf.

City of Vancouver. (2023). Sea2City Design Challenge. *City of Vancouver.* British Columbia, Canada. Retrieved online from: https://vancouver.ca/green-vancouver/sea2city-design-challenge.aspx?utm_campaign=sea2city&utm_medium=Vanity&utm_source=sea2city_Vanity.

Clark C. (2012). Inuit Ethnobotany and Ethnoecology in Nunavik and Nunatsiavut, northeastern Canada. *Master's Thesis, Université de Montréal.* Retrieved online from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1c4bb73d278b1a3084604228248b90e71db23ffb.

Clarmondial AG. (2017). Capitalizing Conservation: How Conservation Organizations Can Engage with Investors to Mobilize Capital. *Clarmondial AG.* Switzerland. Retrieved online from: https://www.clarmondial.com/capitalising-conservation/.

Coast Funds. (2019) Reflecting on 10 Years of Conservation Finance in the Great Bear Rainforest and Haida Gwaii. *Coast Funds.* British Columbia, Canada. Retrieved online from: https://coastfunds.ca/wp-content/uploads/2019/06/Talking-Stick-10-Years-of-Conservation-Finance-Spring-2019.pdf.

Coastal First Nations. (2022a). Carbon Credits. *Coastal First Nations Great Bear Initiative.* British Columbia, Canada. Retrieved online from: https://coastalfirstnations.ca/our-land/carbon-credits/.

Coastal First Nations. (2022b). Coastal Guardian Watchmen. *Coastal First Nations Great Bear Initiative.* British Columbia, Canada. Retrieved online from: https://coastalfirstnations.ca/our-stewardship/coastal-guardian-watchmen/.

Coastal Response Research Center (CRRC). (2010). Coastal and aquatic habitats and species present in the Beaufort and Chukchi Seas. In *NRDA in Arctic Waters: The Dialogue Begins.* Retrieved online from https://crrc.unh.edu/sites/default/files/migrated_unmanaged_files/nrda_arctic/arctic_species_and_habitats%20resource.pdf.

Cohen A. Melpatkwa M. Neville KJ. and Wrightson K. (2021). Colonialism in community-based monitoring: Knowledge systems, finance, and power in Canada. *Annals of the American Association of Geographers,* 111(7), 1988-2004. DOI: 10.1080/24694452.2021.1874865.

Cohen-Shacham E. Andrade A. Dalton J. Dudley N. Jones M. Kumar C. *et al.* (2019). Core principles for successfully implementing and upscaling nature-based solutions. *Environmental Science & Policy,* 98, 20-29. DOI: 10.1016/j.envsci.2019.04.014.

Coleman S. Dewhurst T. Fredriksson DW. St. Gelais AT. Cole KL. MacNicoll M. *et al.* (2022). Quantifying baseline costs and cataloging potential optimization strategies for kelp aquaculture carbon dioxide removal. *Frontiers in Marine Science*, 9. DOI: 10.3389/fmars.2022.966304.

Comiso JC. and Hall DK. (2014). Climate trends in the Arctic as observed from space. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 389-409. DOI: 10.1002/wcc.277.

Commission for Environmental Cooperation (CEC). (2016). North America's Blue Carbon: Assessing Seagrass, Salt Marsh and Mangrove Distribution and Carbon Sinks. *Commission for Environmental Cooperation.* Montreal, Canada. Retrieved online from: http://www.cec.org/files/documents/publications/11664-north-america-s-blue-carbon-assessing-seagrass-salt-marsh-and-mangrove-en.pdf.

Commission for Environmental Cooperation (CEC). (2021). North American Updates on Blue Carbon Science, Conservation and Collaboration. *Commission for Environmental Cooperation.* Montreal, Canada. Retrieved online from: http://www.cec.org/publications/north-american-updates-on-blue-carbon-science-conservation-and-collaboration/.

Connor RF. Chmura GL. and Beecher CB. (2001). Carbon accumulation in Bay of Fundy salt marshes: Implications for restoration of reclaimed marshes. *Global Biogeochemical Cycles*, 1-12. DOI: 10.1029/2000GB001346.

Conrad R. (2020). Importance of hydrogenotrophic, aceticlastic and methylotrophic methanogenesis for methane production in terrestrial, aquatic and other anoxic environments: A mini review. *Pedosphere*, 30(1), 25-39. DOI: 10.1016/S1002-0160(18)60052-9.

Conservation Through Reconciliation Partnership (CRP). (2021). Celebrating 20 years of Coastal First Nations: History, Governance and Lessons Learned. *Conservation Through Reconciliation Partnership.* Retrieved online from [Webinar]: https://conservation-reconciliation.ca/virtual-campfire-series-recordings/celebratingnbsp20-years-of-coastal-first-nations-history-governance-and-lessons-learned.

Consortium Genivar-Waska (2017). Eastmain-1-A and Sarcelle Powerhouses and Rupert Diversion: Follow-up of Eelgrass on Northeast Coast of Baie James (James Bay). Report prepared by Consortium Genivar-Waska for HydroQuebec Production. *Consortium Genivar-Waska.* Quebec, Canada.

Cook-Patton S. Drever CR. Griscom BW. Hamrick K. Hardman H. Kroeger, T. *et al.* (2021). Protect, manage and then restore lands for climate mitigation. *Nature Climate Change,* 11, 1027-1034. DOI: 10.1038/s41558-021-01198-0.

Cooper JA. Goodwin C. Lawton P. Brydges T. Hiltz C. Armsworthy S. *et al.* (2019). Characterisation of the sublittoral habitats of the Brier Island/Digby Neck Ecologically and Biologically Significant Area, Nova Scotia, Canada. *Canadian Technical Report of Fisheries and Aquatic Sciences* 3327. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40818111.pdf.

Corrigan S. Brown AR. Ashton IGC. Smale DA. Tyler CR. (2022). Quantifying habitat provisioning at macroalgal cultivation sites. *Reviews in Aquaculture*, 14(3), 1671-1694. DOI: 10.1111/raq.12669.

Costa M. Le Baron N. Tenhunen K. Nephin J. Willis P. Mortimor JP. *et al.* (2020). Historical distribution of kelp forests on the coast of British Columbia: 1858–1956. *Applied Geography*, 120, 102230. DOI: 10.1016/j.apgeog.2020.102230.

Coulombier T. Neumeier U. and Bernatchez P. (2012). Sediment transport in a cold climate salt marsh (St. Lawrence Estuary, Canada), the importance of vegetation and waves. *Estuarine, Coastal and Shelf Science* 101, 64-75. DOI: 10.1016/j.ecss.2012.02.014.

Craft A. McGregor D. Semour-Hourie R. and Chiblow S. (2021). Decolonizing Anishinaabe nibi inaakonigewin and gikendaasowin research. In *Decolonizing law: Indigenous, third world and settler perspectives* (1st ed.). *Routledge.* New York, USA.

Cristiani J. Rubidge EM. Thompson PL. Robb C. Hessing-Lewis M. and O'Connor MI. (2023). Quantifying marine larval dispersal to assess MPA network connectivity and inform future national and transboundary planning efforts. *In preparation.*

Currie J. and Marconi V. (2020). An analysis of threat and factors that predict trends in Canadian vertebrates designated as at-risk. *FACETS*, 5(1), 49-66. DOI: 10.1139/facets-2019-0017.

Daniel R. (2019). Understanding our Environment Requires an Indigenous Worldview. *Eos Earth and Space News.* Retrieved online from: https://eos.org/opinions/understanding-our-environment-requires-an-indigenous-worldview.

Darling K. Kerr A. and Meakin S. (2023). A framework for blue carbon in Canada's Arctic coastal ecosystems. *Living Tree Law.* Retrieved online from: https://wwf.ca/wp-content/uploads/2023/05/BlueCarbon_Contributed_KateDarling.pdf

Darvishzadeh R. Wang T. Skidmore A. Vrieling A. O'Connor B. Gara TW. *et al.* (2019). Analysis of Sentinel-2 and RapidEye for retrieval of leaf area index in a saltmarsh using a radiative transfer model. *Remote Sensing*, 11(6), 671. DOI: 10.3390/rs11060671.

Dayaneni G. Goldtooth T. Laboucan-Massimo M. and Tan AL. (2021). Introduction. In *Hoodwinked in the Hothouse* (3rd ed.). Retrieved online from: https://climatefalsesolutions.org/wp-content/uploads/HOODWINKED_ThirdEdition_On-Screen_version.pdf.

DeGrandpre M. Evans W. Timmermans ML. Krishfield R. Williams B. and Steele M. (2020). Changes in the Arctic Ocean carbon cycle with diminishing ice cover. *Geophysical Research Letters*, 47(12), e2020GL088051. DOI: 10.1029/2020GL088051.

Deloria B. Foehner K. and Scinta S. (1999). Spirit and Reason: The Vine Deloria. *Fulcrum Publishing.* Ottawa, Canada.

Denley D. Metaxas A. and Fennel K. (2019a). Community composition influences the population growth and ecological impact of invasive species in response to climate change. *Oecologia,* 189(2), 537-548. DOI: 10.1007/s00442-018-04334-4.

Denley D. Metaxas A. and Simard N. (2019b). Ocean temperature does not limit the establishment and rate of secondary spread of an ecologically significant invasive bryozoan in the northwest Atlantic. *Aquatic Invasions,* 14(4), 594-614. DOI: 10.3391/ai.2019.14.4.03.

Denley D. Frid A. and Salomon A. (2022). Chapter 1: Warm sea water and high kelp density magnify bryozoan abundance. In *Hidden Impacts of Climate Change on Canada's Undersea Forests*. Retrieved online from: https://www.ccira.ca/wp-content/uploads/2022/05/Bryozoan-Kelp-Surveys-Summary-Report-for-CCIRA_May2022.pdf.

Déry SJ. Stadnyk TA. MacDonald MK. Koenig KA. and Guay C. (2018). Flow alteration impacts on Hudson Bay river discharge. *Hydrological Processes,* 32(24), 3576-3587. DOI: 10.1002/hyp.13285.

Deutz A. Heal GM. Niu R. Swanson E. Townshend T. Zhu L. *et al.* (2020). Financing Nature: Closing the Global Biodiversity Financing Gap. *The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability.* Retrieved online from: https://www.paulsoninstitute.org/wp-content/uploads/2020/10/FINANCING-NATURE_Full-Report_Final-with-endorsements_101420.pdf.

Dietz S. Beazley KF. Lemieux CJ. St. Clair C. Coristine L. Higgs E. *et al.* (2021). Emerging issues for protected and conserved areas in Canada. *FACETS*, 6(1), 1892-1921. DOI: 10.1139/facets-2021-0072.

Diggon S. Bones J. Short CJ. Smith JL. Dickinson M. Wozniak K. *et al.* (2022). The Marine Plan Partnership for the North Pacific Coast – MaPP: A collaborative and co-led marine planning process in British Columbia. *Marine Policy,* 142, 104065. DOI: 10.1016/j.marpol.2020.104065.

District of North Vancouver. (2023). Development Permit Areas (DPA). *District of North Vancouver.* Retrieved online from: https://www.dnv.org/property-and-development/development-permit-areas.

Doughty CL. and Cavanaugh KC. (2019). Mapping coastal wetland biomass from high resolution unmanned aerial vehicle (UAV) imagery. *Remote Sensing*, 11(5), 540. DOI: 10.3390/rs11050540.

Douglas TJ. Schuerholz G. and Juniper SK. (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. DOI: 10.3389/fmars.2022.857586.

Drever CR. Cook-Patton SC. Akhter F. Badiou PH. Chmura GL. Davidson SJ. *et al.* (2021). Natural climate solutions for Canada. *Science Advances, 7*(23). DOI: 10.1126/sciadv.abd6034.

Duarte CM. and Krause-Jensen D. (2017). Export from seagrass meadows contributes to marine carbon sequestration. *Frontiers in Marine Science*, 4(13). DOI: 10.3389/fmars.2017.00013.

Duarte C. López J. Benítez S. Manríquez PH. Navarro JM. Bonta CC. *et al.* (2016). Ocean acidification induces changes in algal palatability and herbivore feeding behavior and performance. *Oecologia*, 180(2), 453-462. DOI: 10.1007/s00442-015-3459-3.

Duarte CM. Wu J. Xiao X. Bruhn A. and Krause-Jensen D. (2017). Can seaweed farming play a role in climate change mitigation and adaptation? *Frontiers in Marine Science*, 4. DOI: 10.3389/fmars.2017.00100.

Duarte CM. Bruhn A. and Krause-Jensen D. (2021). A seaweed aquaculture imperative to meet global sustainability targets. *Nature Sustainability*, 5, 185-193. DOI: 10.1038/s41893-021-00773-9.

Duarte CM. Gattuso J. Hancke K. Gundersen H. Filbee-Dexter K. Pedersen MF. *et al.* (2022). Global estimates of the extent and production of macroalgal forests. *Global Ecology and Biogeography,* 31(7), 1422-1439. DOI: 10.1111/geb.13515.

Duarte CM. Delgado-Huertas A. Marti E. Gasser B. San Martin I. Cousteau A. *et al.* (2023). Carbon burial in sediments below seaweed farms. *Preprint.* DOI: 10.1101/2023.01.02.522332.

Dunic JC. Brown CJ. Connolly RM. Turschwell MP. and Côté IM. (2021). Long-term declines and recovery of meadow area across the world's seagrass bioregions. *Global Change Biology,* 27, 4096-4109. DOI: 10.1111/gcb.15684.

Dünweber M. Swalethorp R. Kjellerup S. Nielsen TG. Arendt KE. Hjorth M. *et al.* (2010). Succession and fate of the spring diatom bloom in Disko Bay, western Greenland. *Marine Ecology Progress Series*, 419, 11-29. DOI: 10.3354/meps08813.

Dupont F. (2012). Impact of sea-ice biology on overall primary production in a biophysical model of the pan-Arctic Ocean. *Journal of Geophysical Research: Oceans,* 117(C8). DOI: 10.1029/2011JC006983.

Eberhardt AL. Burdick DM. Dionne M. and Vincent RE. (2015). Rethinking the freshwater eel: Salt marsh trophic support of the American eel, *Anguilla rostrata*. *Estuaries and Coasts,* 38(4), 1251-1261. DOI: 10.1007/s12237-015-9960-4.

Eger A. Marzinelli E. Baes R. Blain C. Blamey L. Carnell P. *et al.* (2021). The economic value of fisheries, blue carbon, and nutrient cycling in global marine forests. *Preprint.* DOI: 10.32942/osf.io/n7kjs.

Environment and Climate Change Canada (ECCC). (2020a). Canadian Environmental Sustainability Indicators: Eelgrass in Canada. *Environment and Climate Change Canada.* Retrieved online from: http://www.canada.ca/en/environment-climate-change/services/environmental-indicators/eelgrass-canada.html.

Environment and Climate Change Canada (ECCC). (2020b). Canada Joins the High Ambition Coalition for Nature and People. *Environment and Climate Change Canada.* Retrieved online from: https://www.canada.ca/en/environment-climate-change/news/2020/09/canada-joins-the-high-ambition-coalition-for-nature-and-people.html

Environment and Climate Change Canada (ECCC). (2022). Canada's Nature Legacy: Protecting our Nature. *Environment and Climate Change Canada.* Retrieved online from: https://www.canada.ca/en/services/environment/conservation/nature-legacy.html.

Ermine W. (2007). The Ethical Space of engagement. *Indigenous Law Journal,* 6(1), 193-203. Retrieved online from: https://jps.library.utoronto.ca/index.php/ilj/article/view/27669/20400.

Eyquem JL. (2021). Rising Tides and Shifting Sands: Combining Natural and Grey Infrastructure to Protect Canada's Coastal Communities. *Intact Centre on Climate Adaptation, University of Waterloo.* Waterloo, Canada. Retrieved online from: https://www.intactcentreclimateadaptation.ca/rising-seas-and-shifting-sands-combining-natural-and-grey-infrastructure-to-protect-canadas-eastern-and-western-coastal-communities/.

Fabry VJ. Seibel BA. Feely RA. and Orr JC. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science*, 65(3), 414-432. DOI: 10.1093/icesjms/fsn048.

Fagherazzi S. Wiberg PL. Temmerman S. Struyf E. Zhao Y. and Raymond PA. (2013). Fluxes of water, sediments, and biogeochemical compounds in salt marshes. *Ecological Processes*, 2(1), 1-16. DOI: 10.1186/2192-1709-2-3.

FAO (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. *Food and Agriculture Organization of the United Nations*. Rome, Italy. Retrieved online from: https://www.fao.org/documents/card/en/c/cc0461en.

Farguharson LM. Romanovsky VE. Cable WL. Walker DA. Kokelj SV. And Nicolsky D. (2019). Climate change drives widespread and rapid thermokarst development in very cold permafrost in the Canadian high Arctic. *Geophysical Research Letters,* 46(12), 6681-6689. DOI: 10.1029/2019GL082187.

Feehan CJ. and Scheibling RE. (2014). Disease as a control of sea urchin populations in Nova Scotian kelp beds. *Marine Ecology Progress Series*, 500, 149-158. DOI: 10.3354/meps10700.

Fennel K. Alin SR. Barbero L. Evans W. Bourgeois T. Cooley SR. *et al.* (2018). Chapter 16: Coastal ocean and continental shelves. In *Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report.* U.S. Global Change Research Program, Washington, DC, USA. DOI: 10.7930/ SOCCR2.2018.Ch16.

Fernandez-Mendez M. Olsen LM. Kauko HM. Meyer A. Rösel A. Merkouriadi I. *et al.* (2018). Algal hot spots in a changing Arctic Ocean: Sea-ice ridges and the snow-ice interface. *Frontiers in Marine Science,* 5(75). DOI: 10.3389/fmars.2018.00075.

Fetterer F. Knowles K. Meier WN. Savoie M. and Windnagel AK. (2022). Sea Ice Index, Version 3. *National Snow and Ice Data Center (NSIDC).* Boulder, CO, USA. DOI: 10.7265/N5K072F8.

Fieler R. Greenacre M. Matsson S. Neves L. Forbord S. and Hancke K. (2021). Erosion dynamics of cultivated kelp, *Saccharina latissima,* and implications for environmental management and carbon sequestration. *Frontiers in Marine Science,* 8. DOI: 10.3389/fmars.2021.632725.

Filbee-Dexter K. and Scheibling RE. (2014). Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. *Marine Ecology Progress Series*, 495, 1-25. DOI: 10.3354/meps10573.

Filbee-Dexter K. and Wernberg T. (2020). Substantial blue carbon in overlooked Australian kelp forests. *Scientific Reports,* 10(1), 1-6. DOI: 10.1038/s41598-020-69258-7.

Filbee-Dexter K. Feehan CJ. and Scheibling RE. (2016). Large-scale degradation of a kelp ecosystem in an ocean warming hotspot. *Marine Ecology Progress Series*, 543, 141-152. DOI: 10.3354/meps11554.

Filbee-Dexter K. Wernberg T. Fredriksen S. Norderhaug KM. and Pedersen MF. (2019). Arctic kelp forests: Diversity, resilience and future. *Global and Planetary Change*, 172, 1-14. DOI: 10.1016/j.gloplacha.2018.09.005.

Filbee-Dexter K. Wernberg T. Grace SP. Thormar J. Fredriksen S. Narvaez CN. *et al.* (2020). Marine heatwaves and the collapse of marginal North Atlantic kelp forests. *Scientific Reports*, 10(1), 1-11. DOI: 10.1038/s41598-020-70273-x.

Filbee-Dexter K. MacGregor KA. Lavoie C. Garrido I. Goldsmit J. Castro De La Guardia L. *et al.* (2022a). Sea ice and substratum shape extensive kelp forests in the Canadian Arctic. *Frontiers in Marine Science,* 9, 754074. DOI: 10.3389/fmars.2022.754074.

Filbee-Dexter K. Feehan CJ. Smale DA. Krumhansl KA. Augustine S. De Bettignies F. *et al.* (2022b). Kelp carbon sink potential decreases with warming due to accelerating decomposition. *PLOS Biology*, 20(8), e3001702. DOI: 10.1371/journal.pbio.3001702.

Finegan C. (2018). Reflection, acknowledgement, and justice: A framework for Indigenous-protected area reconciliation. *International Indigenous Policy Journal,* 9(3). DOI: 10.18584/iipj.2018.9.3.3.

Fisheries and Oceans Canada (DFO). (2008). Musquash Estuary. A Management Plan for the Marine Protected Area and Administered Intertidal Area. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://publications.gc.ca/site/eng/9.834474/publication.html.

Fisheries and Oceans Canada (DFO). (2009). Does Eelgrass (*Zostera marina*) Meet the Criteria as an Ecologically Significant Species? Canadian Science Advisory Secretariat Science Advisory Report 2009/018. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/337549.pdf.

Fisheries and Oceans Canada (DFO). (2013). Assessment of Information on Irish Moss, Rockweed, and Kelp Harvests in Nova Scotia. Canadian Science Advisory Secretariat Science Advisory Report 2013/004. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/348493.pdf.

Fisheries and Oceans Canada (DFO). (2014). Eelgrass (*Zostera marina*) Locations in Newfoundland and Labrador. Canadian Technical Report of Fisheries and Aquatic Sciences 3113. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://publications.gc.ca/collections/collection_2015/mpo-dfo/Fs97-6-3113-eng.pdf.

Fisheries and Oceans Canada (DFO). (2019a). Coastal Restoration Fund. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/crf-frc/description-eng.html.

Fisheries and Oceans Canada (DFO). (2019b). Musquash Estuary Marine Protected Area. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/mpa-zpm/musquash/index-eng.html.

Fisheries and Oceans Canada (DFO). (2020). Canada's Oceans Now: Arctic Ecosystems, 2019. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/soto-rceo/arctic-arctique/publications/public-report/index-eng.html.

Fisheries and Oceans Canada (DFO). (2021a). Coastal Restoration Fund: Projects in British Columbia. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/crf-frc/bc-cb-eng.html.

Fisheries and Oceans Canada (DFO). (2021b). Coastal Restoration Fund: Projects in Newfoundland and Labrador. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/crf-frc/nfl-tnl-eng.html.

Fisheries and Oceans Canada (DFO). (2021c). Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2020. Canadian Science Advisory Secretariat Research Document 2021/045. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40980856.pdf.

Fisheries and Oceans Canada (DFO). (2021d). Coastal Restoration Fund: Quebec Projects. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/crf-frc/qc-eng.html.

Fisheries and Oceans Canada (DFO). (2021e). Blue Economy Strategy Engagement Paper. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://waves-vagues.dfo-mpo.gc.ca/Library/40946721.pdf.

Fisheries and Oceans Canada (DFO). (2021f). Engaging on Canada's Blue Economy Strategy: What we Heard. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/engagement-paper-document-mobilisation/heard-entendu-eng.html.

Fisheries and Oceans Canada (DFO). (2021g). Coastal Restoration Fund: Projects in Nova Scotia. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/crf-frc/ns-ne-eng.html.

Fisheries and Oceans Canada (DFO). (2022). Ecologically Significant Areas Framework. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://talkfishhabitat.ca/consultation?consultation_id=14.

Fisheries and Oceans Canada (DFO). (2023). Canada's Marine Protected and Conserved Areas. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://www.dfo-mpo.gc.ca/oceans/conservation/areas-zones/index-eng.html.

Flagstad L. (2016). Arctic and Subarctic Coastal Salt Marsh. *NatureServe Explorer.* Arlington, USA. Retrieved online from: https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.858291/Carex_subspathacea_-_Dupontia_fisheri_Salt_Marsh_Group.

Flaherty M. Reid G. Chopin T. and Latham E. (2019). Public attitudes towards marine aquaculture in Canada: insights from the Pacific and Atlantic coasts. *Aquaculture International*, 27(1), 9-32. DOI: 10.1007/s10499-018-0312-9.

Flombaum P. Wang WL. Primeau FW. and Martiny AC. (2020). Global picophytoplankton niche partitioning predicts overall positive response to ocean warming. *Nature Geoscience*, 13(2), 116-120. DOI: 10.1038/s41561-019-0524-2.

FOLU (2019) Growing Better: Ten Critical Transitions to Transform Food and Land Use. The Global Consultation Report of the Food and Land Use Coalition. *Food and Land Use Coalition*. United Kingdom. Retrieved online from: https://www.foodandlandusecoalition.org/global-report/.

Ford JD. (2012). Indigenous health and climate change. *American Journal of Public Health,* 102(7), 1260-1266. DOI: 10.2105/AJPH.2012.300752.

Foreman, R. (1984) Studies on *Nereocystis* growth in British Columbia, Canada. *Hydrobiologia,* 116, 325-332. DOI: 10.1007/BF00027696.

Forsey DJ. (2020). Use of high-resolution optical satellite imagery to map eelgrass beds in shallow coastal waters in Atlantic Canada. *Master's Thesis, University of New Brunswick. https://unbscholar.lib.unb.ca/islandora/object/unbscholar%3A10374*.

Forsey D. Leblon B. LaRocque A. Skinner M. and Douglas A. (2020). Eelgrass mapping in Atlantic Canada using WORLDVIEW-2 imagery. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 43, 685-692. DOI: 10.5194/isprs-archives-XLIII-B3-2020-685-2020.

Fraser River Estuary Study Steering Committee. (1978). Fraser River Estuary Study Summary: Proposals for the Development of an Estuary Management Plan. *Government of British Columbia* and *Government of Canada.* Victoria, Canada. Retrieved online from: https://www.for.gov.bc.ca/hfd/library/documents/bib68894.pdf.

Fredriksen S. Karsten U. Bartsch I. Woelfel J. Koblowsky M. Schumann R. *et al.* (2019). Biodiversity of benthic macro-and microalgae from Svalbard with special focus on Kongsfjorden. *The Ecosystem of Kongsfjorden, Svalbard*, 2, 331-371. DOI: 10.1007/978-3-319-46425-1_9.

Fredriksen S. Filbee-Dexter K. Norderhaug KM. Steen H. Bodvin T. Coleman MA. *et al.* (2020). Green gravel: a novel restoration tool to combat kelp forest decline. *Scientific reports*, 10(1), 1-7. DOI: 10.1038/s41598-020-60553-x.

Frigstad H. Gundersen H. Andersen GS. Borgersen G. Kvile KO. Krause-Jensen D. *et al.* (2021). Blue Carbon – Climate Adaptation, CO_2 Uptake and Sequestration of Carbon in Nordic Blue Forests. *Nordic Council of Ministers.* Retrieved online from: https://pub.norden.org/temanord2020-541/.

Fritz M. Vonk JE. and Lantuit H. (2017). Collapsing Arctic coastlines. *Nature Climate Change,* 7(1), 6-7. DOI: 10.1038/nclimate3188.

Froehlich HE. Afflerbach JC. Frazier M. Halpern BS. (2019). Blue growth potential to mitigate climate change through seaweed offsetting. *Current Biology* 29, 3087-3093.e3. DOI: 10.1016/j.cub.2019.07.041.

Funes Y. (2022). The problem with nature-based solutions. *Atmos: The Frontline*. Retrieved online from: https://atmos.earth/nature-based-solutions-climate-indigenous/.

Gagnon P. Himmelman JH. and Johnson LE. (2004) Temporal variation in community interfaces: Kelp-bed boundary dynamics adjacent to persistent urchin barrens. *Marine Biology,* 144, 1191-1203. DOI: 10.1007/s00227-003-1270-x.

Gailis M. Kohfeld KE. Pellatt MG. and 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. DOI: 10.1080/21664250.2021.1894815.

Gallagher JB. Shelamoff V. and Layton C. (2022). Seaweed ecosystems may not mitigate CO_2 emissions. *ICES Journal of Marine Science,* 79, 585-592. DOI: 10.1093/icesjms/fsac011.

Ganong WF. (1903). The vegetation of the Bay of Fundy salt and diked marshes: An ecological study. *Botanical Gazette,* 36(5), 161-186. DOI: 10.1086/328394.

Garbary DJ. Miller AG. Williams J. and Seymour NR. (2014). Drastic decline of an extensive eelgrass bed in Nova Scotia due to the activity of the invasive green crab (*Carcinus maenas*). *Marine Biology* 161, 3-15. DOI: 10.1007/s00227-013-2323-4.

Garcia-Soto C. Cheng L. Caesar L. Schmidtko S. Jewett EB. Cheripka A. *et al.* (2021). An overview of ocean climate change indicators: Sea surface temperature, ocean heat content, ocean pH, dissolved oxygen concentration, Arctic sea ice extent, thickness and volume, sea level and strength of the AMOC (Atlantic Meridional Overturning Circulation). *Frontiers in Marine Science*, 8, 642372. DOI: 10.3389/fmars.2021.642372.

Garibaldi A. and Turner N. (2004). Cultural keystone species: Implications for ecological conservation and restoration. *Ecology and Society,* 9(3), 1. DOI: 10.5751/ES-00669-090301.

Gauvreau AM. Lepofsky D. Rutherford M. and Reid M. (2017). Everything revolves around the herring: The Heiltsuk–herring relationship through time. *Ecology and Society,* 22(2), 10. DOI: 10.5751/ES-09201-220210.

Gendall L. (2022). Drivers of Change in Haida Gwaii Kelp Forests: Combining Satellite Imagery with Historical Data to Understand Spatial and Temporal Variability. *Master's Thesis*, *University of Victoria*. Retrieved online from: https://dspace.library.uvic.ca/bitstream/handle/1828/14352/Gendall_Lianna_MASc_2022.pdf?sequence=1.

Gephart JA. Henriksson PJG. Parker RWR. Shepon A. Gorospe KD. Bergman K. *et al.* (2021). Environmental performance of blue foods. *Nature,* 597, 360-365. DOI: 10.1038/s41586-021-03889-2.

Geraldi NR. Ortega A. Serrano O. Macreadie PI. Lovelock CE. Krause-Jensen D. *et al.* (2019). Fingerprinting blue carbon: rationale and tools to determine the source of organic carbon in marine depositional environments. *Frontiers in Marine Science*, 6, 263. DOI: 10.3389/fmars.2019.00263.

Ghosh A. (2021). The Nutmeg's Curse: Parables for a Planet in Crisis. *The University of Chicago Press.* Chicago, USA. 336 p.

Gilpin E. (2022). The Coast is our Lifeblood: First Nation Launches 'World Class' Marine Protected Area. *Coastal First Nations Great Bear Initiative.* Retrieved online from: https://coastalfirstnations.ca/the-coast-is-our-lifeblood-first-nation-launches-world-class-marine-protected-area/.

Global Affairs Canada. (2019). Canada's Arctic Ocean Continental Shelf Submission. *Global Affairs Canada.* Ottawa, Canada. Retrieved online from: https://www.canada.ca/en/global-affairs/news/2019/05/canadas-arctic-ocean-continental-shelf-submission.html.

Goldsmit J. Schlegel RW. Filbee-Dexter K. MacGregor KA. Johnson LE. Mundy CJ. *et al.* (2021). Kelp in the Eastern Canadian Arctic: Current and future predictions of habitat suitability and cover. *Frontiers in Marine Science*, 8, 1453. DOI: 10.3389/fmars.2021.742209.

Gómez Martín E. Giordano R. Pagano A. van der Keur P. and Máñez Costa M. (2020). Using a system thinking approach to assess the contribution of nature-based solutions to sustainable development goals. *Science of the Total Environment,* 738, 139693. DOI: 10.1016/j.scitotenv.2020.139693.

González-Eguino M. and Neumann MB. (2016). Significant implications of permafrost thawing for climate change control. *Climatic Change*, 136(2), 381-388. DOI: 10.1007/s10584-016-1666-5.

Gordon (Iñupiaq) HSJ. Ross JA. Bauer-Armstrong C. Moreno M. Byington (Choctaw) R. and Bowman (Lunaape/Mohican) N. (2023). Integrating Indigenous traditional ecological knowledge of land into land management through Indigenous–academic partnerships. *Land Use Policy,* 125, 106469. DOI: 10.1016/j.landusepol.2022.106469.

Gosselin M. Levasseur M. Wheeler PA. Horner RA. and Booth BC. (1997). New measurements of phytoplankton and ice algal production in the Arctic Ocean. *Deep Sea Research Part II: Topical Studies in Oceanography*, 44(8), 1623-1644. DOI: 10.1016/S0967-0645(97)00054-4.

Gover K. (2015). Settler-state political theory, 'CANZUS' and the UN declaration on the rights of Indigenous Peoples. *The European Journal of International Law,* 26(2), 345-373. DOI: 10.1093/ejil/chv019.

Government of British Columbia. (2023). Atmospheric Benefit Sharing Agreements. *Government of British Columbia.* Victoria, Canada. Retrieved online from: https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations/first-nations-negotiations/atmospheric-benefit-sharing-agreements.

Government of Canada. (1991). The federal policy on wetland conservation. *Government of Canada.* Ottawa, Canada. Retrieved online from: http://publications.gc.ca/collections/Collection/CW66-116-1991E.pdf.

Government of Canada. (2022). Government of Canada Green Bond Framework. *Government of Canada.* Ottawa, Canada. Retrieved online from: https://www.canada.ca/content/dam/fin/publications/green-bond/21265%20Green%20Bond%20Framework_EN.pdf.

Government of Prince Edward Island. (2003). A Wetland Conservation Policy for Prince Edward Island. Fisheries, Aquaculture and Environment, Government of Prince Edward Islands. Retrieved online from: http://www.gov.pe.ca/photos/original/fae_wetland_con.pdf.

Government of New Brunswick. (2002). New Brunswick Wetland Conservation Policy. *Natural Resources and Energy and Environment and Local Government; Government of New Brunswick.* Retrieved online from: https://www2.gnb.ca/content/dam/gnb/Departments/nr-rn/pdf/Wetlands-TerresHumides.pdf.

Government of Nova Scotia. (2009). Historic Wetland Loss in Nova Scotia. *Government of Nova Scotia*. Halifax, Canada. Retrieved online from: https://novascotia.ca/nse/wetland/historic-wetland-loss-ns.asp.

Government of Nova Scotia. (2011). Nova Scotia Wetland Conservation Policy. *Government of Nova Scotia*. Halifax, Canada. Retrieved online from: https://novascotia.ca/nse/wetland/docs/Nova.Scotia.Wetland.Conservation.Policy.pdf.

Government of Nova Scotia. (2013). Our Parks and Protected Areas: A Plan for Nova Scotia. *Government of Nova Scotia*. Halifax, Canada. Retrieved online from: https://novascotia.ca/parksandprotectedareas/plan/.

Green EP. and Short FT. (2003). World Atlas of Seagrasses. *UN Environment Programme-World Conservation Monitoring Center.* Cambridge, UK. Retrieved online from: http://environmentalunit.com/Documentation/04%20Resources%20at%20Risk/World%20Seagrass%20atlas.pdf.

Gregr EJ. Christensen V. Nichol L. Martone RG. Markel RW. Watson JC. *et al.* (2020). Cascading social-ecological costs and benefits triggered by a recovering keystone predator. *Science*, 368, 1243-1247. DOI: 10.1126/science.aay5342.

Greiner JT. McGlathery KJ. Gunnell J. and McKee BA. (2013). Seagrass restoration enhances "blue carbon" sequestration in coastal waters. *PLoS ONE,* 8, e72469. DOI: 10.1371/journal.pone.0072469.

Griffies SM. Adcroft A. and Hallberg R. (2020). A primer on the vertical Lagrangian-remap method in ocean models based on finite volume generalized vertical coordinates. *Journal of Advances in Modeling Earth Systems,* 12(10), e2019MS001954. DOI: 10.1029/2019MS001954.

Griscom BW. Adams J. Ellis PW. Houghton RA. Lomax G. Miteva DA. *et al.* (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences,* 114(44), 11645-11650. DOI: 10.1073/pnas.1710465114.

Grow AK. Schutte CA. and Roberts BJ. (2022). Fiddler crab burrowing increases salt marsh greenhouse gas emissions. *Biogeochemistry*, 158(1), 73-90. DOI: 10.1007/s10533-021-00886-5.

Gundersen H. Rinde E. Bekkby T. Hancke K. Gitmark JK. and Christie H. (2021). Variation in population structure and standing stocks of kelp along multiple environmental gradients and implications for ecosystem services. *Frontiers in Marine Science,* 8, 578629. DOI: 10.3389/fmars.2021.578629.

Haine TWN. Curry B. Gerdes R. Hansen E. Karcher M. Lee C. (2015). Arctic freshwater export: Status, mechanisms, and prospects. *Global and Planetary Change,* 125, 13-35. DOI: 10.1016/j.gloplacha.2014.11.013.

Hanson AR. (2004). Status and Conservation of Eelgrass (*Zostera marina*) in Eastern Canada. Technical Report Series No. 412. *Canadian Wildlife Service.* Retrieved online from: https://publications.gc.ca/site/eng/9.858443/publication.html.

Hanson A. and Calkins L. (1996). Wetlands of the Maritime Provinces: Revised Documentation for the Wetlands Inventory. Technical Report Series No. 267. *Canadian Wildlife Service*. Retrieved online from: https://publications.gc.ca/site/eng/9.857785/publication.html.

Harris LM. (2022). Learning from Aotearoa: Water governance challenges and debates. *New Zealand Geographer,* 78(1), 104-108. DOI: 10.1111/nzg.12334.

Hart MW. and Scheibling RE. (1988). Heat waves, baby booms, and the destruction of kelp beds by sea urchins. *Marine Biology,* 99, 167-176. DOI: 10.1007/BF00391978.

Hatcher A. Patriquin DG. Fern YF. Hanson AJ. and Reade J. (1981). Salt Marshes in Nova Scotia: A Status Report of the Salt Marsh Working Group. *Institute for Resource and Environmental Studies, Dalhousie University*. Halifax, Canada. Retrieved online from: https://dalspace.library.dal.ca/bitstream/handle/10222/13114/SaltmarshesNS.pdf?sequence=1&isAllowed=y.

Havemann P. (2009). Ignoring the mercury in the climate change barometer: Denying indigenous peoples' rights. *Australian Indigenous Law Review,* 13(1), 2-26. DOI: 10.3316/ielapa.250377902600588.

Held L. (2021). Kelp at the crossroads: Should seaweed farming be better regulated? *CivilEats.* Retrieved online from: https://civileats.com/2021/07/20/kelp-at-the-crossroads-should-seaweed-farming-be-better-regulated/.

Hewson S. Nowlan L. Lloyd-Smith G. Carlson D. Bissonnette M. (2020). Guide to Coastal and Ocean Protection Law in British Columbia. *West Coast Environmental Law.* Vancouver, Canada. Retrieved online from: https://www.legal-atlas.com/uploads/2/6/8/4/26849604/west_coast_guide_to_coastal_ocean_protection_law_in_bc_2020.pdf.

Hill V. and Cota G. (2005). Spatial patterns of primary production on the shelf, slope and basin of the Western Arctic in 2002. *Deep Sea Research Part II: Topical Studies in Oceanography*, 52(24-26), 3344-3354. DOI: 10.1016/j.dsr2.2005.10.001.

Hitchcock JK. Courtenay SC. Coffin MR. Pater CC. and van den Heuvel MR. (2017). Eelgrass bed structure, leaf nutrient, and leaf isotope responses to natural and anthropogenic gradients in estuaries of the southern Gulf of St. Lawrence, Canada. *Estuaries and Coasts*, 40(6), 1653-1665. DOI: 10.1007/s12237-017-0243-0.

Hoegh-Guldberg O. Caldeira K. Chopin T. Gaines S. Haugan P. Hemer M. *et al.* (2019). The Ocean as a Solution to Climate Change: Five Opportunities for Action. *World Resources Institute.* Washington, DC, USA. Retrieved online from: https://www.wri.org/events/2019/10/ocean-solution-climate-change-5-opportunities-action.

Hoffman S. (2022). Challenges and opportunities of area-based biodiversity and sustainability goals. *Biodiversity and Conservation,* 31, 325-352. DOI: 10.1007/s10531-021-02340-2.

Holm GO. Perez BC. McWhorter DE. Krauss KW. Johnson DJ. Raynie RC. *et al.* (2016). Ecosystem level methane fluxes from tidal freshwater and brackish marshes of the Mississippi River Delta: Implications for coastal wetland carbon projects. *Wetlands*, 36, 401-413. DOI: 10.1007/s13157-016-0746-7.

Howard J. Hoyt S. Isensee K. Telszewski M. and Pidgeon E. (eds.) (2014). Coastal Blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors in Mangroves, Tidal Salt Marshes, and Seagrasses. *Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature.* Arlington, VA, USA. Retrieved online from: https://www.cifor.org/knowledge/publication/5095/.

Howard J. Sutton-Grier A. Herr D. Kleypas J. Landis E. Mcleod E. *et al.* (2017). Clarifying the role of coastal and marine systems in climate mitigation. *Frontiers in Ecology and the Environment*, 15(1), 42-50. DOI: 10.1002/fee.1451.

Howard BR. Francis FT. Côté IM. and Therriault TW. (2019). Habitat alteration by invasive European green crab (*Carcinus maenas*) causes eelgrass loss in British Columbia, Canada. *Biological Invasions,* 21, 3607-3618. DOI: 10.1007/s10530-019-02072-z.

Howarth LM. Lewis-McCrea L. LaBelle J. and Reid GK. (2021). Managing Aquaculture and Eelgrass Interactions in Nova Scotia. *Centre for Marine Applied Research (CMAR).* Dartmouth, Nova Scotia, Canada. Retrieved online from: https://cmar.ca/wp-content/uploads/sites/15/2021/03/Howarth-et-al-Managing-Aquaculture-and-Eelgrass-Final-1.pdf.

Hung GA. and Chmura GL. (2006). Mercury accumulation in surface sediments of salt marshes of the Bay of Fundy. *Environmental Pollution*, 142, 418-431. DOI: 10.1016/j.envpol.2005.10.044.

Hurd CL. Law CS. Bach LT. Britton D. Hovenden M. Paine ER. *et al.* (2022). Forensic carbon accounting: Assessing the role of seaweeds for carbon sequestration. *Journal of Phycology*, 58(3), 347-363 DOI: 10.1111/jpy.13249.

Hwang B. Aksenov Y. Blockley E. Tsamados M. Brown T. Landy J. *et al.* (2020). Impacts of climate change on Arctic sea ice. *Marine Climate Change Impacts Partnership Science Review*, 2020, 208-227. DOI: 10.14465/2020.arc10.ice.

Hyndes GA. Nagelkerken I. McLeod RJ. Connolly RM. Lavery PS. and Vanderklift MA. (2014). Mechanisms and ecological role of carbon transfer within coastal seascapes. *Biological Reviews*, 89(1), 232-254. DOI: 10.1111/brv.12055.

Indigenous Circle of Experts (ICE). (2018). We Rise Together: Achieving Pathway to Canada Target 1 through the Creation of Indigenous Protected and Conserved Areas in the Spirit and Practice of Reconciliation. *Indigenous Circle of Experts.* Canada. Retrieved online from: https://www.conservation2020canada.ca/resources.

Innes L. Attridge I. and Lawson S. (2021). Respect and Responsibility: Integrating Indigenous Rights and Private Conservation in Canada. *Olthuis Kleer Townshend – LLP* and *Conservation Through Reconciliation Partnership*. Retrieved online from: https://www.oktlaw.com/respect-and-responsibility-integrating-indigenous-rights-and-private-land-conservation-in-canada/.

Insurance Bureau of Canada. (2021). Insuring and Restoring the Natural Assets that Protect Coastal Communities. *Insurance Bureau of Canada.* Toronto, Canada. Retrieved online from: http://assets.ibc.ca/Documents/Disaster/IBC-Coastal-Flooding-Paper.pdf.

Inuit Tapiriit Kanatami. (2019). Inuit Nunangat. *Inuit Tapiriit Kanatami.* Retrieved online from: https://www.itk.ca/wp-content/uploads/2019/04/ITK-Map-20190118-digital-rgb.pdf.

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services. Diaz S. Settele J. Brondizio E. Ngo HT. Guèze M. Agard J. *et al.* (eds.). *Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services Secretariat.* Bonn, Germany. Retrieved online from: https://ipbes.net/global-assessment.

IPCC. (2018). Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Masson-Delmotte V. Zhai P. Pörtner H-O. Roberts D. Skea J. Shukla PR. *et al.* (eds.). *Intergovernmental Panel on Climate Change.* Geneva, Switzerland. Retrieved online from: https://www.ipcc.ch/sr15/.

IPCC. (2019a). Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Arneth A. Barbosa H. Benton T. Calvin K. Calvo E. Connors S. *et al.* (eds.). *Intergovernmental Panel on Climate Change.* Geneva, Switzerland. Retrieved online from: https://www.ipcc.ch/srccl/.

IPCC. (2019b). The Ocean and Cryosphere in a Changing Climate: A Special Report of the IPCC. Pörtner H-O. Roberts DC. Masson-Delmotte V. Zhai P. Tignor M. Poloczanska E. *et al.* (eds.). *Intergovernmental Panel on Climate Change.* Geneva, Switzerland. Retrieved online from: https://www.ipcc.ch/srocc/.

IPCC. (2021). Climate Change 2021: The Physical Science Basis; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte V. Zhai P. Pirani A. Connors SL. Péan C. Berger S. *et al.* (eds.). *Intergovernmental Panel on Climate Change.* Geneva, Switzerland. Retrieved online from: https://www.ipcc.ch/report/ar6/wg1/.

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Pörtner H-O. Roberts DC. Tignor M. Poloczanska ES. Mintenbeck K. Alegría A. *et al.* (eds.). *Intergovernmental Panel on Climate Change*. Geneva, Switzerland. Retrieved online from: https://www.ipcc.ch/report/ar6/wg2/.

Islands Trust. (2022). Gambier Island Official Community Plan and Land Use Bylaw Targeted Review. *Islands Trust.* Salt Spring Island, Canada. Retrieved online from: https://islandstrust.bc.ca/gambier-island-official-community-plan-and-land-use-bylaw-targeted-review/.

Jackson EL. Rowden AA. Attrill MJ. Bossey SJ. and Jones MB. (2001). The importance of seagrass beds as a habitat for fishery species. *Oceanography and Marine Biology*, 39, 269-304. ISBN: 9780429219061.

Jayathilake DR. and Costello MJ. (2020). The Kelp Biome. *Encyclopaedia of the World's Biomes.* ISBN: 9780128160978.

Ji R. Jin M. and Varpe Ø. (2013). Sea ice phenology and timing of primary production pulses in the Arctic Ocean. *Global Change Biology,* 19(3), 734-741. DOI: 10.1111/gcb.12074.

Jobin S. and Riddle E. (2019). The Rise of the First Nations Land Management Regime in Canada: A Critical Analysis. *Yellowhead Institute*. Toronto, Canada. Retrieved online from: https://yellowheadinstitute.org/wp-content/uploads/2019/09/fnlma-report.pdf.

Johannessen SC. and Macdonald RW. (2016). Geoengineering with seagrasses: is credit due where credit is given? *Environmental Research Letters,* 11, 113001. DOI: 10.1088/1748-9326/11/11/113001.

Johnsen G. Leu E. and Gradinger R. (2020). Marine micro- and macroalgae in the polar night. *Polar Night Marine Ecology,* 4, 67-112. DOI: 10.1007/978-3-030-33208-2_4.

Johnson LE. MacGregor KA. Narvaez CA. and Suskiewicz TS. (2019). Subtidal rocky shores of the north-west Atlantic Ocean. In *Interactions in the Marine Benthos,* 90-127. DOI: 10.1017/9781108235792.006.

Jones R. Rigg C. and Pinkerton E. (2017). Strategies for assertion of conservation and local management rights: A Haida Gwaii herring story. *Marine Policy,* 80, 154-167. DOI: 10.1016/j.marpol.2016.09.031.

Jones AR. Alleway HK. McAfee D. Reis-Santos P. Theuerkauf SJ. and Jones RC. (2022). Climate-friendly seafood: The potential for emissions reduction and carbon capture in marine aquaculture. *BioScience* 72(2), 123-143. DOI: 10.1093/biosci/biab126.

Joyce KE. Duce S. Leahy SM. Leon J. and Maier SW. (2018). Principles and practice of acquiring drone-based image data in marine environments. *Marine and Freshwater Research,* 70(7), 952-963. DOI: 10.1071/MF17380.

Kahru M. Lee Z. Mitchell BG. and Nevison CD. (2016). Effects of sea ice cover on satellite-detected primary production in the Arctic Ocean. *Biology Letters,* 12(11), 20160223. DOI: 10.1098/rsbl.2016.0223.

Kamya PZ. Byrne M. Mos B. Hall L. and Dworjanyn SA. (2017). Indirect effects of ocean acidification drive feeding and growth of juvenile crown-of-thorns starfish, *Acanthaster planci*. *Proceedings of the Royal Society B: Biological Sciences*, 284(1856), 20170778. DOI: 10.1098/rspb.2017.0778.

Kennedy H. Beggins J. Duarte CM. Fourqurean JW. Holmer M. Marbà N. and Middelburg JJ. (2010). Seagrass sediments as a global carbon sink: Isotopic constraints. *Global Biogeochemical Cycles*, 24(4). DOI: 10.1029/2010GB003848.

Kitasoo Xai'xais Stewardship Authority. (2020). Kitasoo/Xai'xais Management Plan for Pacific Herring. *Kitasoo Xai'xais Stewardship Authority.* Klemtu, Canada. Retrieved online from: https://klemtu.com/wp-content/uploads/2020/02/KX-Herring-Mgmt-Plan-Jan-2020-Final.pdf

Kitasoo Xai'xais Stewardship Authority. (2022). Gitdisdzu Lugyeks (Kitasu Bay) Marine Protected Area Management Plan (Draft). *Kitasoo Xai'xais Stewardship Authority.* Klemtu, Canada. Retrieved online from: https://klemtu.com/wp-content/uploads/2022/06/Kitasu-Bay-MPA-draft-Management-Plan-21.6.22_PC.pdf.

Knox SH. Bansal S. McNicol G. Schafer K. Sturtevant C. Ueyama M. *et al.* (2021). Identifying dominant environmental predictors of freshwater wetland methane fluxes across diurnal to seasonal time scales. *Global Change Biology*, 27(15), 3582-3604. DOI: 10.1111/gcb.15661.

Kobluk HM. Gladstone K. Reid M. Brown K. Krumhansl KA. Salomon AK. (2021). Indigenous knowledge of key ecological processes confers resilience to a small-scale kelp fishery. *People and Nature,* 3(3), 723-739. DOI: 10.1002/pan3.10211.

Kosciolek K. Kwan N. Longaphy C. Wilson R. (2020). Financing Conservation. How Conservation Financing Could be Used to Protect Canada's Ecosystems. *Nature Conservancy of Canada and Rally Assets.* Retrieved online from: https://rallyassets.com/wp-content/uploads/2020/11/Financing-Conservation.pdf.

Krause-Jensen D. and Duarte CM. (2016). Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience*, 9(10), 737-742. DOI: 10.1038/ngeo2790.

Krause-Jensen D. Lavery P. Serrano O. Marbà N. Masque P. and Duarte CM. (2018). Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology letters,* 14, 20180236. DOI: 10.1098/rsbl.2018.0236.

Krause-Jensen D. Archambault P. Assis J. Bartsch I. Bischof K. Filbee-Dexter K. *et al.* (2020). Imprint of climate change on pan-Arctic marine vegetation. *Frontiers in Marine Science, 7,* 617324. DOI: 10.3389/fmars.2020.617324.

Krauss KW. Holm Jr GO. Perez BC. McWhorter DE. Cormier N. Moss RF. *et al.* (2016). Component greenhouse gas fluxes and radiative balance from two deltaic marshes in Louisiana: Pairing chamber techniques and eddy covariance. *Journal of Geophysical Research: Biogeosciences*, 121(6), 1503-1521. DOI: 10.1002/2015JG003224.

Krumhansl KA. and Scheibling RE. (2011). Detrital production in Nova Scotian kelp beds: Patterns and processes. *Marine Ecology Progress Series,* 421, 67-82. DOI: 10.3354/meps08905.

Krumhansl KA. Lee JM. Scheibling RE. (2011). Grazing damage and encrustation by an invasive bryozoan reduce the ability of kelps to withstand breakage by waves. *Journal of Experimental Marine Biology and Ecology,* 407(1), 12-18. DOI: 10.1016/j.jembe.2011.06.033.

Krumhansl KA. and Scheibling RE. (2012a). Production and fate of kelp detritus. *Marine Ecology Progress Series,* 467, 281-302. DOI: 10.3354/meps09940.

Krumhansl KA. and Scheibling RE. (2012b). Detrital subsidy from subtidal kelp beds is altered by the invasive green alga *Codium fragile* ssp. *fragile*. *Marine Ecology Progress Series*, 456, 73-85. DOI: 10.3354/meps09671.

Krumhansl KA. Bergman JN. Salomon AK. (2017). Assessing the ecosystem-level consequences of a small-scale artisanal kelp fishery within the context of climate-change. *Ecological Applications,* 27(3), 799-813. DOI: 10.1002/eap.1484.

Krumhansl KA. Dowd M. and Wong MC. (2020). A Characterization of the physical environment at eelgrass (*Zostera marina*) sites along the Atlantic coast of Nova Scotia. Canadian Technical Report of Fisheries and Aquatic Sciences 3361. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://publications.gc.ca/site/eng/9.884622/publication.html.

Krumhansl KA. Dowd M. Wong MC. (2021) Multiple metrics of temperature, light, and water motion drive gradients in eelgrass productivity and resilience. *Frontiers in Marine Science*, 8, 1-20. DOI: 10.3389/fmars.2021.597707.

Küpper FC. Peters AF. Shewring DM. Sayer MD. Mystikou A. Brown H. *et al.* (2016). Arctic marine phytobenthos of northern Baffin Island. *Journal of Phycology*, 52(4), 532-549. DOI: 10.1111/jpy.12417.

Lalumière R. Messier D. Fournier JJ. and McRoy CP. (1994). Eelgrass meadows in a low Arctic environment, the northeast coast of James Bay, Québec. *Aquatic Botany,* 47(3-4), 303-315. DOI: 10.1016/0304-3770(94)90060-4.

Land Needs Guardians. (n.d.). Haíɫzaqv Guardians and Herring Roe. *Land Needs Guardians.* Ottawa, Canada. Retrieved online from: https://landneedsguardians.ca/videos/hazaqv-guardians-and-herring-roe

Lang-Wong A. Drews C. Schulz N. McDonald R. Plant T. Heavyside P. *et al.* (2022). Seaforestation: Benefits to the Climate, the Ecosystems, and the People of British Columbia. *Ocean Wise.* Vancouver, Canada. Retrieved online from: www.ocean.org/blog/seaforestation-benefits-to-the-climate-the-ecosystems-and-the-people-of-british-columbia/.

Lau WWY. (2013). Beyond carbon: Conceptualizing payments for ecosystem services in blue forests on carbon and other marine and coastal ecosystem services. *Ocean* and *Coastal Management*, 83, 5-14. DOI: 10.1016/j.ocecoaman.2012.03.011.

Laurens LML. Lane M. and Nelson RS. (2020). Sustainable seaweed biotechnology solutions for carbon capture, composition, and deconstruction. *Trends in Biotechnology,* 38, 1232-1244. DOI: 10.1016/j.tibtech.2020.03.015.

Lecerf M. Herr D. Thomas T. Elverum C. Delrieu E. and Picourt L. (2021). Coastal and Marine Ecosystems as Nature-Based Solutions in New or Updated Nationally Determined Contributions. *Ocean & Climate Platform, Conservation International, IUCN, GIZ, Rare, The Nature Conservancy* and *World Wildlife Fund.* Retrieved online from: https://ocean-climate.org/wp-content/uploads/2021/06/coastal-and-marine-ecosystem-2806.pdf.

Lecher AL. and Mackey KR. (2018). Synthesizing the effects of submarine groundwater discharge on marine biota. *Hydrology,* 5(4), 60. DOI: 10.3390/hydrology5040060.

Lee LC. McNeil GD. Ridings P. Featherstone M. Okamoto DK. Spindel N. *et al.* (2021). Chiixuu Tll iinasdll: Indigenous ethics and values lead to ecological restoration for people and place in Gwaii Haanas. *Ecological Restoration*, 39, 45-51. DOI: 10.3368/er.39.1-2.45.

Legendre L. Ackley SF. Dieckmann GS. Gulliksen B. Horner R. Hoshiai T. *et al.* (1992). Ecology of sea ice biota. *Polar biology*, 12(3), 429-444. DOI: 10.1007/BF00243113.

Legge O. Johnson M. Hicks N. Jickells T. Diesing M. Aldridge J. *et al.* (2020). Carbon on the northwest European shelf: Contemporary budget and future influences. *Frontiers in Marine Science*, 7, 143. DOI: 10.3389/fmars.2020.00143.

Lemieux CJ. Gray PA. Devillers R. Wright PA. Dearden P. Halpenny EA. *et al.* (2019). How the race to achieve Aichi Target 11 could jeopardize the effective conservation of biodiversity in Canada and beyond. *Marine Policy,* 99, 312-323. DOI: 10.1016/j.marpol.2018.10.029.

Leu E. Søreide JE. Hessen DO. Falk-Petersen S. and Berge J. (2011). Consequences of changing sea-ice cover for primary and secondary producers in the European Arctic shelf seas: timing, quantity, and quality. *Progress in Oceanography,* 90(1-4), 18-32. DOI: 10.1016/j.pocean.2011.02.004.

Leu E. Mundy CJ. Assmy P. Campbell K. Gabrielsen TM. Gosselin M. *et al.* (2015). Arctic spring awakening–Steering principles behind the phenology of vernal ice algal blooms. *Progress in Oceanography,* 139, 151-170. DOI: 10.1016/j.pocean.2015.07.012.

Lewis KM. Van Dijken GL. and Arrigo KR. (2020). Changes in phytoplankton concentration now drive increased Arctic Ocean primary production. *Science,* 369(6500), 198-202. DOI: 10.1126/science.aay8380.

Li X. Bellerby R. Craft C. and Widney SE. (2018). Coastal wetland loss, consequences, and challenges for restoration. *Anthropocene Coasts*, 1(1), 1-15. DOI: 10.1139/anc-2017-0001.

Li H. Zhang Z. Xiong T. Tang K. He C. Shi Q. *et al.* (2022). Carbon sequestration in the form of recalcitrant dissolved organic carbon in a seaweed (kelp) farming environment. *Environmental Science and Technology.* 56(12), 9112-9122. DOI: 10.1021/acs.est.2c01535.

Littlechild D. and Sutherland C. (2021). Enacting and Operationalizing Ethical Space and Two-Eyed Seeing in Indigenous Protected and Conserved Areas and Crown Protected and Conserved Areas. Retrieved online from: https://conservation-reconciliation.ca/s/Enacting-and-Operationalizing-Ethical-Space-in-IPCAs-and-Crown-Protected-and-Conserved-Areas-June-4.pdf.

Liu X. Dunne JP. Stock CA. Harrison MJ. Adcroft A. and Resplandy L. (2019a). Simulating water residence time in the coastal ocean: A global perspective. *Geophysical Research Letters,* 46, 13910-13919. DOI: 10.1029/2019GL085097.

Liu S. Trevathan-Tackett SM. Lewis CJE. Ollivier QR. Jiang Z. Huang X. *et al.* (2019b). Beach-cast seagrass wrack contributes substantially to global greenhouse gas emissions. *Journal of Environmental Management*, 231, 329-335. DOI: 10.1016/j.jenvman.2018.10.047.

Loewen TN. Hornby CA. Johnson M. Chambers C. Dawson K. MacDonell D. *et al.* (2020). Ecological and Biophysical Overview of the Southampton Island Ecologically and Biologically Significant Area in Support of the Identification of an Area of Interest. Canadian Science Advisory Secretariat Research Document Report 2020/032. *Fisheries and Oceans Canada.* Ottawa, Canada. Retrieved online from: https://publications.gc.ca/collections/collection_2020/mpo-dfo/fs70-5/Fs70-5-2020-032-eng.pdf.

Lovelock CE. and Duarte C. (2019). Dimensions of blue carbon and emerging perspectives. *Biological Letters,* 15, 20180781. DOI: 10.1098/rsbl.2018.0781.

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

Lynn K. Daigle J. Hoffman J. Lake F. Michelle N. Ranco D. *et al.* (2013). The impacts of climate change on tribal traditional foods. *Climatic Change,* 120(3), 545-556. DOI: 10.1007/978-3-319-05266-3_4.

Lyons P. Mynott S. and Melbourne-Thomas J. (2023). Enabling Indigenous innovations to re-centre social license to operate in the Blue Economy. *Marine Policy,* 147, 105384. DOI: 10.1016/j.marpol.2022.105384.

MacGilchrist GA. Garabato AN. Tsubouchi T. Bacon S. Torres-Valdés S. and Azetsu-Scott K. (2014). The Arctic Ocean carbon sink. *Deep Sea Research Part I: Oceanographic Research Papers*, 86, 39-55. DOI: 10.1016/j.dsr.2014.01.002.

Mac Monagail M. Cornish L. Morrison L. Araújo R. and Critchley AT. (2017). Sustainable harvesting of wild seaweed resources. *European Journal of Phycology,* 52(4), 371-390. DOI: 10.1080/09670262.2017.1365273.

Macreadie PI. Anton A. Raven JA. Beaumont N. Connolly RM. Friess DA. *et al.* (2019). The future of blue carbon science. *Nature communications*, 10(1), 1-13. DOI: 10.1038/s41467-019-11693-w.

Macreadie PI. Costa MD. Atwood TB. Friess DA. Kelleway JJ. Kennedy H. *et al.* (2021). Blue carbon as a natural climate solution. *Nature Reviews Earth* and *Environment*, 2(12), 826-839. DOI: 10.1038/s43017-021-00224-1.

Magenheimer JF. Moore TR. Chmura GL. and Daoust RJ. (1996). Methane and carbon dioxide flux from a macrotidal salt marsh, Bay of Fundy, New Brunswick. *Estuaries,* 19(1), 139-145. DOI: 10.2307/1352658.

Mahmoudi N. Porter TM. Zimmerman AR. Fulthorpe RR. Kasozi GN. Silliman BR. *et al.* (2013). Rapid degradation of Deepwater Horizon spilled oil by indigenous microbial communities in Louisiana saltmarsh sediments. *Environmental Science & Technology*, 47(23), 13303-13312. DOI: 10.1021/es4036072.

Mäkelä A. Witte U. and Archambault P. (2018). Short-term processing of ice algal- and phytoplankton-derived carbon by Arctic benthic communities revealed through isotope labelling experiments. *Marine Ecology Progress Series,* 600, 21-39. DOI: 10.3354/meps12663.

Malyshev A. and Quijón PA. (2011). Disruption of essential habitat by a coastal invader: new evidence of the effects of green crabs on eelgrass beds. *ICES Journal of Marine Science,* 68, 1852-1856. DOI: 10.1093/icesjms/fsr126.

Mann PJ. Strauss J. Palmtag J. Dowdy K. Ogneva O. Fuchs M. *et al.* (2022). Degrading permafrost river catchments and their impact on Arctic Ocean nearshore processes. *Ambio,* 51(2), 439-455. DOI: 10.1007/s13280-021-01666-z.

MaPP. (2016). Regional Action Framework. *Marine Plan Partnership for the North Pacific Coast.* Retrieved online from: https://coastalfirstnations.ca/wp-content/uploads/2017/06/raf_mapp_v2.22_web.pdf.

Marbà N. Krause-Jensen D. Masqué P. and Duarte CM. (2018). Expanding Greenland seagrass meadows contribute new sediment carbon sinks. *Scientific Reports,* 8(1), 1-8. DOI: 10.1038/s41598-018-32249-w.

Martin RM. Wigand C. Elmstrom E. Lloret J. and Valiela I. (2018). Long-term nutrient addition increases respiration and nitrous oxide emissions in a New England salt marsh. *Ecology and Evolution*, 8(10), 4958-4966. DOI: 10.1002/ece3.3955.

Matheson K. McKenzie CH. Gregory RS. Robichaud DA. Bradbury IR. Snelgrove PVR. *et al.* (2016). Linking eelgrass decline and impacts on associated fish communities to European green crab *Carcinus maenas* invasion. *Marine Ecology Progress Series,* 548, 31-45. DOI: 10.3354/meps11674.

Matrai P. and Apollonio S. (2013). New estimates of microalgae production based upon nitrate reductions under sea ice in Canadian shelf seas and the Canada Basin of the Arctic Ocean. *Marine Biology,* 160(6), 1297-1309. DOI: 10.1007/s00227-013-2181-0.

Matsuoka A. Boss E. Babin M. Karp-Boss L. Hafez M. Chekalyuk A. *et al.* (2017). Pan-Arctic optical characteristics of colored dissolved organic matter: Tracing dissolved organic carbon in changing Arctic waters using satellite ocean color data. *Remote Sensing of Environment,* 200, 89-101. DOI: 10.1016/j.rse.2017.08.009.

McGowan A. (2016). The extent, density, and biomass carbon of eelgrass (*Zostera marina*) meadows in Pacific Rim National Park Reserve and Clayoquot Sound, British Columbia. *Master's Thesis, Simon Fraser University.* Retrieved online from: https://summit.sfu.ca/_flysystem/fedora/sfu_migrate/18581/etd19809.pdf.

McGuire AD. Anderson LG. Christensen TR. Dallimore S. Guo L. Hayes DJ. *et al.* (2009). Sensitivity of the carbon cycle in the Arctic to climate change. *Ecological Monographs*, 79(4), 523-555. DOI: 10.1890/08-2025.1.

McIver R. Schmidt AL. Cullain N. and Lotze HK. (2019). Linking estimates of nitrogen loading and watershed characteristics to eelgrass bed structure and eutrophication symptoms across 7 bays in Atlantic Canada. *Marine Environmental Research,* 144, 141-153. DOI: 10.1016/j.marenvres.2018.11.013.

McKenzie LJ. Nordlund LM. Jones BL. Cullen-Unsworth LC. Roelfsema C. and Unsworth RKF. (2020). The global distribution of seagrass meadows. *Environmental Research Letters.* 15, 074041. DOI: 10.1088/1748-9326/ab7d06.

Mcleod E. Chmura GL. Bouillon S. Salm R. Björk M. Duarte CM. *et al.* (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment*, 9(10), 552-560. DOI: 10.1890/110004.

MacMillan LJ. and Prosper K. (2016). Remobilizing Netukulimk: Indigenous cultural and spiritual connections with resource stewardship and fisheries management in Atlantic Canada. *Reviews in Fish Biology and Fisheries* 26(4), 629-647. DOI: 10.1007/s11160-016-9433-2.

Meier WN. Hovelsrud GK. Van Oort BE. Key JR. Kovacs KM. Michel C. *et al.* (2014). Arctic sea ice in transformation: A review of recent observed changes and impacts on biology and human activity. *Reviews of Geophysics,* 52(3), 185-217. DOI: 10.1002/2013RG000431.

Melcer S. (2021). Nature-based Insurance for Watershed Protection. *Yale School of the Environment* and *Insurance Bureau of Canada.* Retrieved online from: http://assets.ibc.ca/Documents/Disaster/Nature-Based-Insurance-for-Watershed-Protection.pdf.

Merzouk A. and Johnson LE. (2011). Kelp distribution in the northwest Atlantic Ocean under a changing climate. *Journal of Experimental Marine Biology and Ecology,* 400, 90-98. DOI: 10.1016/j.jembe.2011.02.020.

Metzger JR. Konar B. and Edwards MS. (2019). Assessing a macroalgal foundation species: Community variation with shifting algal assemblages. *Marine Biology,* 166(12), 1-17. DOI: 10.1007/s00227-019-3606-1.

Michel C. Hamilton J. Hansen E. Barber D. Reigstad M. Iacozza J. *et al.* (2015). Arctic Ocean outflow shelves in the changing Arctic: A review and perspectives. *Progress in Oceanography,* 139, 66-88. DOI: 10.1016/j.pocean.2015.08.007.

Millard K. Redden AM. Webster T. and Stewart H. (2013). Use of GIS and high resolution LiDAR in salt marsh restoration site suitability assessments in the upper Bay of Fundy, Canada. *Wetlands Ecology and Management* 21, 243-262. DOI: 10.1007/s11273-013-9303-9.

Milne LJ. and Milne MJ. (1951). The eelgrass catastrophe. *Scientific American*, 184, 52-55.

Moffett KB. Robinson DA. and Gorelick SM. (2010). Relationship of salt marsh vegetation zonation to spatial patterns in soil moisture, salinity, and topography. *Ecosystems*, 13(8), 1287-1302. DOI: 10.1007/s10021-010-9385-7.

Montalto F. and Steenhuis T. (2002). The link between hydrology and restoration of tidal marshes in the New York/New Jersey estuary. *Wetlands,* 24(2), 414-425. DOI: 10.1672/0277-5212(2004)024[0414:TLBHAR]2.0.CO;2.

Moomaw WR. Chmura GL. Davies GT. Finlayson CM. Middleton BA. Natali SM. *et al.* (2018). Wetlands in a changing climate: Science, policy and management. *Wetlands*, 38(2), 183-205. DOI: 10.1007/s13157-018-1023-8.

Moore KA. (2004). Influence of seagrasses on water quality in shallow regions of the lower Chesapeake Bay. *Journal of Coastal Research*, (10045), 162-178. DOI: 10.2112/SI45-162.1.

Morrison W. (2006). Canadian Arctic Sovereignty. *The Canadian Encyclopedia.* Retrieved online from: https://www.thecanadianencyclopedia.ca/en/article/Arctic-sovereignty.

Moseman-Valtierra SM. Szura K. Eagle M. Thornber CS. and Wang F. (2022). CO_2 uptake offsets other greenhouse gas emissions from salt marshes with chronic nitrogen loading. *Wetlands*, 42(7), 1-15. DOI: 10.1007/s13157-022-01601-2.

Moss ML. (2016). The nutritional value of Pacific herring: An ancient cultural keystone species on the Northwest Coast of North America. *Journal of Archaeological Science: Reports,* 5, 649-655. DOI: 10.1016/j.jasrep.2015.08.041.

Mossman HL. Davy AJ. and Grant A. (2012). Does managed coastal realignment create saltmarshes with 'equivalent biological characteristics' to natural reference sites? *Journal of Applied Ecology,* 49, 1446-1456. DOI: 10.1111/j.1365-2664.2012.02198.x.

Mtwana Nordlund L. Koch EW. Barbier EB. and Creed JC. (2016). Seagrass ecosystem services and their variability across genera and geographical regions. *PLOS ONE,* 11(10), e0163091. DOI: 10.1371/journal.pone.0163091.

Mudryk LR. Derksen C. Howell S. Lalibert F. Thackeray C. Sospedra-Alfonso R. *et al.* (2018). Canadian snow and sea ice: historical trends and projections. *The Cryosphere,* 12, 1157-1176. DOI: 10.5194/tc-12-1157-2018.

Mundy CJ. Gosselin M. Gratton Y. Brown K. Galindo V. Campbell K. *et al.* (2014). Role of environmental factors on phytoplankton bloom initiation under landfast sea ice in Resolute Passage, Canada. *Marine Ecology Progress Series,* 497, 39-49. DOI: 10.3354/meps10587.

Murphy GEP. Wong MC. and Lotze HK. (2019). A human impact metric for coastal ecosystems with application to seagrass beds in Atlantic Canada. *FACETS,* 4, 210-237. DOI: 10.1139/facets-2018-0044.

Murphy GE. Dunic JC. Adamczyk EM. Bittick SJ. Côté IM. Cristiani J. *et al.* (2021). From coast to coast to coast: ecology and management of seagrass ecosystems across Canada. *FACETS*, 6(1), 139-179. DOI: 10.1139/facets-2020-0020.

Nahirnick NK. Hunter P. Costa M. Schroeder S. and Sharma T. (2019a). Benefits and challenges of UAS imagery for eelgrass (*Zostera marina*) mapping in small estuaries of the Canadian West Coast. *Journal of Coastal Research*, 35(3), 673-683. DOI: 10.2112/JCOASTRES-D-18-00079.1.

Nahirnick NK. Reshitnyk L. Campbell M. Hessing-Lewis M. Costa M. Yakimishyn J. *et al.* (2019b). Mapping with confidence; delineating seagrass habitats using unoccupied aerial systems (UAS). *Remote Sensing in Ecology and Conservation*, 5(2), 121-135. DOI: 10.1002/rse2.98.

Nahirnick NK. Costa M. Schroeder S. and Sharma T. (2020). Long-term eelgrass habitat change and associated human impacts on the west coast of Canada. *Journal of Coastal Research,* 36, 30-40. DOI: 10.2112/JCOASTRES-D-18-00112.1.

Namba M. Lotze HK. and Schmidt AL. (2018). Large-scale differences in community structure and ecosystem services of eelgrass (*Zostera marina*) beds across three regions in Eastern Canada. *Estuaries and Coasts*, 41(1), 177-192. DOI: 10.1007/s12237-017-0271-9.

National Academies of Sciences, Engineering, and Medicine. (2021). A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration. *The National Academies Press.* Washington, DC, USA. Retrieved online from: https://nap.nationalacademies.org/catalog/26278/a-research-strategy-for-ocean-based-carbon-dioxide-removal-and-sequestration.

NatureServe. (2022). NatureServe Network Biodiversity Location Data Accessed through NatureServe Explorer. *NatureServe.* Arlington, USA. Retrieved online from: https://explorer.natureserve.org/.

Neily P. Quigley E. Benjamin L. Stewart B. and Duke T. (2003). Ecological Land Classification for Nova Scotia: Volume 1 - Mapping Nova Scotia's Terrestrial Ecosystems. *Nova Scotia Department of Natural Resources.* Truro, Canada. Retrieved online from: https://novascotia.ca/natr/forestry/reports/ELCrevised.pdf.

Nellemann C. and Corcoran E. (2009). Blue Carbon: The Role of Healthy Oceans in Binding Carbon: A Rapid Response Assessment. *United Nations Environment Programme.* Nairobi, Kenya. Retrieved online from: https://wedocs.unep.org/20.500.11822/7772.

Norderhaug KM. and Christie HC. (2009). Sea urchin grazing and kelp re-vegetation in the NE Atlantic. *Marine Biology Research,* 5(6), 515-528. DOI: 10.1080/17451000902932985.

Norris GS. Leblon B. LaRocque A. Barbeau MA. And Hanson AR. (2022). Effect of textural features for landcover classification of UAV multispectral imagery of a salt marsh restoration site. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIII-B3-2022, 951-958. DOI: 10.5194/isprs-archives-XLIII-B3-2022-951-2022.

Novak AB. Plaisted HK. Hays CG. And Hughes RA. (2017). Limited effects of source population identity and number on seagrass transplant performance. *PeerJ,* 5, e2972. DOI: 10.7717/peerj.2972.

Oliver EC. Donat MG. Burrows MT. Moore PJ. Smale DA. Alexander LV. *et al.* (2018). Longer and more frequent marine heatwaves over the past century. *Nature Communications*, 9(1), 1-12. DOI: 10.1038/s41467-018-03732-9.

Ollivier QR. Maher DT. Pitfield C. and Macreadie PI. (2022). Net drawdown of greenhouse gases (CO_2, CH_4 and N_2O) by a temperate Australian seagrass meadow. *Estuaries and Coasts*, 45, 2026-2039. DOI: 10.1007/s12237-022-01068-8.

ONCS, WWF-Canada, and DUC. (2018). Canada's Arctic Marine Atlas. *Oceans North Conservation Society, World Wildlife Fund Canada, and Ducks Unlimited Canada*. Ottawa, Ontario. Retrieved online from: https://www.oceansnorth.org/en/canada-arctic-marine-atlas/.

Oreska MP. McGlathery KJ. And Porter JH. (2017). Seagrass blue carbon spatial patterns at the meadow-scale. *PloS one*, 12(4), e0176630. DOI: 10.1371/journal.pone.0176630.

Oreska MP. McGlathery KJ. Aoki LR. Berger AC. Berg P. and Mullins L. (2020). The greenhouse gas offset potential from seagrass restoration. *Scientific Reports*, 10, 7325. DOI: 10.1038/s41598-020-64094-1.

Ortega A. Geraldi NR. Alam I. Kamau AA. Acinas SG. Logares R. *et al.* (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience*, 12(9), 748-754. DOI: 10.1038/s41561-019-0421-8.

Ortega A. Geraldi NR. And Duarte CM. (2020). Environmental DNA identifies marine macrophyte contributions to Blue Carbon sediments. *Limnology and Oceanography*, 65(12), 3139-3149. DOI: 10.1002/lno.11579.

Orth RJ. Carruthers TJB. Dennison WC. Duarte CM. Fourqurean JW. Heck Jr. KL. *Et al.* (2006). A global crisis for seagrass ecosystems. *BioScience* 56, 987-996. DOI: 10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2.

Orth RJ. Lefcheck JS. McGlathery KS. Aoki L. Luckenbach MW. Moore KA. *Et al.* (2020). Restoration of seagrass habitat leads to rapid recovery of coastal ecosystem services. *Science Advances*, 6, eabc6434. DOI: 10.1126/sciadv.abc6434.

Osborne T. (2015). Tradeoffs in carbon commodification: A political ecology of common property forest governance. *Geoforum,* 67, 64-77. DOI: 10.1016/j.geoforum.2015.10.007.

Ouyang X. and Lee SY. (2014). Updated estimates of carbon accumulation rates in coastal marsh sediments. *Biogeosciences*, 11(18), 5057-5071. DOI: 10.5194/bg-11-5057-2014.

Oziel L. Massicotte P. Randelhoff A. Ferland J. Vladoiu A. Lacour L. *et al.* (2019). Environmental factors influencing the seasonal dynamics of spring algal blooms in and beneath sea ice in western Baffin Bay. *Elementa: Science of the Anthropocene*, 7(34). DOI: 10.1525/elementa.372.

Pabi S. van Dijken GL. And Arrigo KR. (2008). Primary production in the Arctic Ocean, 1998–2006. *Journal of Geophysical Research: Oceans*, 113(C8). DOI: 10.1029/2007JC004551.

Pan TCF. Applebaum SL. And Manahan DT. (2015). Experimental ocean acidification alters the allocation of metabolic energy. *Proceedings of the National Academy of Sciences*, 112(15), 4696-4701. DOI: 10.1073/pnas.1416967112.

Parks Canada. (2020). Coastal Estuary Restoration. *Parks Canada.* Ottawa, Canada. Retrieved online from: https://www.pc.gc.ca/en/pn-np/ns/kejimkujik/nature/conservation/ecosystem-cotier-coastal.

Pasos M. (2022). North American Blue Carbon, 2021. *Commission for Environmental Cooperation.* Montreal, Canada. Retrieved online from http://www.cec.org/north-american-environmental-atlas/north-american-blue-carbon-2021/.

Pedersen MF. Filbee-Dexter K. Norderhaug KM. Fredriksen S. Frisk NL. And Wernberg T. (2020). Detrital carbon production and export in high latitude kelp forests. *Oecologia*, 192(1), 227-239. DOI: 10.1007/s00442-019-04573-z.

Pedersen MF. Filbee-Dexter K. Frisk NL. Sárossy Z. and Wernberg T. (2021). Carbon sequestration potential increased by incomplete anaerobic decomposition of kelp detritus. *Marine Ecology Progress Series*, 660, 53-67. DOI: 10.3354/meps13613.

Peijnenburg KT. Janssen AW. Wall-Palmer D. Goetze E. Maas AE. Todd JA. *et al.* (2020). The origin and diversification of pteropods precede past perturbations in the Earth's carbon cycle. *Proceedings of the National Academy of Sciences*, 117(41), 25609-25617. DOI: 10.1073/pnas.1920918117.

Pendleton L. Donato DC. Murray BC. Crooks S. Jenkins WA. Sifleet S. *et al.* (2012). Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PloS ONE*, 7(9), e43542. DOI: 10.1371/journal.pone.0043542.

Perovich D. Meier W. Tschudi M. Hendricks S. Petty AA. Divine D. *et al.* (2020). Arctic Report Card 2020: Sea Ice. *National Oceanic and Atmospheric Administration.* Washington, DC, USA. DOI: 10.25923/n170-9h57.

Pessarrodona A. Filbee-Dexter K. Krumhansl KA. Pedersen MF. Moore PJ. And Wernberg T. (2022). A global dataset of seaweed net primary productivity. *Scientific Data*, 9, 484. DOI: 10.1038/s41597-022-01554-5.

Petersen LE. Kellermann MY. And Schupp PJ. (2020). Secondary metabolites of marine microbes: From natural products chemistry to chemical ecology. In *YOUMARES 9 – The Oceans: Our Research, Our Future,* 9, 159-180. DOI: 10.1007/978-3-030-20389-4_8.

Picard MM. Johnson LE. Ferrario F. Garrido I. Archambault P. Carrière J. *et al.* (2022). Drivers of kelp distribution in the Gulf of St. Lawrence: Insights from a transplant experiment. *Marine Biology*, 169, 50. DOI: 10.1007/s00227-022-04031-0.

Pilcher DJ. Naiman DM. Cross JN. Hermann AJ. Siedlecki SA. Gibson GA. *et al.* (2019). Modeled effect of coastal biogeochemical processes, climate variability, and ocean acidification on aragonite saturation state in the Bering Sea. *Frontiers in Marine Science*, 5, 508. DOI: 10.3389/fmars.2018.00508.

Pinton D. Canestrelli A. Wilkinson B. Ifju P. and Ortega A. (2021). Estimating ground elevation and vegetation characteristics in coastal salt marshes using UAV-based LiDAR and digital aerial photogrammetry. *Remote Sensing*, 13(22), 4506. DOI: 10.3390/rs13224506.

Poffenbarger HJ. Needelman BA. And Megonigal JP. (2011). Salinity influence on methane emissions from tidal marshes. *Wetlands*, 31(5), 831-842. DOI: 10.1007/s13157-011-0197-0.

Polar Pod. (2016). Arctic Plankton. *PolarPod*. Retrieved online from: https://www.polarpod.fr/en/encyclopaedia/arctic/4-ocean-and-marine-life/3-arctic-plankton.

Pontier O. Krumhansl K. Hessing-Lewis M. (2022a). *Macrocystis* kelp canopy productivity data from BC Central Coast, v1.3.0 [Data set]. *Hakai Institute.* DOI: 10.21966/k88j-1k50.

Pontier O. Burt J. Okamoto D. Hessing-Lewis M. (2022b). *Nereocystis* kelp canopy productivity data from BC Central Coast, v1.2.0 [Data set]. *Hakai Institute.* DOI: 10.21966/d1s2-s530.

Postlethwaite VR. McGowan AE. Kohfeld KE. Robinson CL. and Pellatt MG. (2018). Low blue carbon storage in eelgrass (*Zostera marina*) meadows on the Pacific Coast of Canada. *PloS One*, 13(6), e0198348. DOI: 10.1371/journal.pone.0198348.

Poucette TL. (2018). Spinning wheels: Surmounting the Indian Act's impact on traditional Indigenous governance. *Canadian Public Administration,* 61(4), 499-522. DOI: 10.1111/capa.12307.

Pratt C. (2021). Drivers of regional-scale variability in the abundance of an invasive bryozoan in the kelp beds of the northwest Atlantic Ocean. *Master's Thesis, Dalhousie University.*

Prentice C. Hessing-Lewis M. Sanders-Smith R. and Salomon AK. (2019). Reduced water motion enhances organic carbon stocks in temperate eelgrass meadows. *Limnology and Oceanography*, 64(6), 2389-2404. DOI: 10.1002/lno.11191.

Prentice C. Poppe KL. Lutz M. Murray E. Stephens TA. Spooner A. *et al.* (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. DOI: 10.1029/2019GB006345.

Qi D. Chen L. Chen B. Gao Z. Zhong W. Feely RA. *et al.* (2017). Increase in acidifying water in the western Arctic Ocean. *Nature Climate Change,* 7(3), 195-199. DOI: 10.1038/nclimate3228.

Qikiqtani Inuit Association (QIA). (2022). A Regional Conservation Approach. *Qikiqtani Inuit Association.* Iqaluit, Canada. Retrieved online from: https://www.qia.ca/wp-content/uploads/2022/11/qia-prospectus-2022-1.pdf.

Queirós AM. Stephens N. Widdicombe S. Tait K. McCoy SJ. Ingels J. *et al.* (2019). Connected macroalgal-sediment systems: Blue carbon and food webs in the deep coastal ocean. *Ecological Monographs*, 89(3), e01366. DOI: 10.1002/ecm.1366.

Quiros TEAL. Croll D. Tershy B. Fortes MD. and Raimondi P. (2017). Land use is a better predictor of tropical seagrass condition than marine protection. *Biological Conservation,* 209, 454-463. DOI: 10.1016/j.biocon.2017.03.011.

Rabinowitz T. and Andrews J. (2022). Valuing the Salt Marsh Ecosystem: Developing Ecosystem Accounts. *Statistics Canada.* Ottawa, Canada. Retrieved online from: https://www150.statcan.gc.ca/n1/pub/16-001-m/16-001-m2022001-eng.htm.

Rahman HT. Sherren K. and van Proosdij D. (2019). Institutional innovation for nature-based coastal adaptation: Lessons from salt marsh restoration in Nova Scotia, Canada. *Sustainability*, 11(23), 6735. DOI: 10.3390/su11236735.

Rantanen M. Karpechko AY. Lipponen A. Nordling K. Hyvärinen O. Ruosteenoja R. Vihma T. *et al.* (2022). The Arctic has warmed nearly four times faster than the globe since 1979. *Communications Earth & Environment*, 3, 168. DOI: 10.1038/s43247-022-00498-3.

Rassweiler A. Reed DC. Harrer SL. and Nelson JC. (2018). Improved estimates of net primary production, growth, and standing crop of *Macrocystis pyrifera* in Southern California. *Ecology,* 99, 2132-2132. DOI: 10.1002/ecy.2440.

Rayner R. Jolly C. and Gouldman C. (2019). Ocean observing and the blue economy. *Frontiers in Marine Science*, 6, 330. DOI: 10.3389/fmars.2019.00330.

Redzuan NS. and Underwood GJ. (2020). Movement of microphytobenthos and sediment between mudflats and salt marsh during spring tides. *Frontiers in Marine Science*, 7, 496. DOI: 10.3389/fmars.2020.00496.

Reed G. Brunet ND. McGregor D. Scurr C. Sadik T. Lavigne J. *et al.* (2022). Toward Indigenous visions of nature-based solutions: An exploration into Canadian federal climate policy. *Climate Policy*, 22(4), 514-533. DOI: 10.1080/14693062.2022.2047585.

Reidenbach MA. and Thomas EL. (2018). Influence of the seagrass, *Zostera marina,* on wave attenuation and bed shear stress within a shallow coastal bay. *Frontiers in Marine Science*, 5, 397. DOI: 10.3389/fmars.2018.00397.

Reynolds LK. Waycott M. McGlathery KJ. Orth RJ. and Zieman JC. (2012). Eelgrass restoration by seed maintains genetic diversity: Case study from a coastal bay system. *Marine Ecology Progress Series,* 448, 223-233. DOI: 10.3354/meps09386.

Rezek RJ. Furman BT. Jung RP. Hall MO. and Bell SS. (2019). Long-term performance of seagrass restoration projects in Florida, USA. *Scientific Reports,* 9, 15514. DOI: 10.1038/s41598-019-51856-9.

Ricart AM. Dalmau A. Pérez M. and Romero J. (2015). Effects of landscape configuration on the exchange of materials in seagrass ecosystems. *Marine Ecology Progress Series*, 532, 89-100. DOI: 10.3354/meps11384.

Ricart AM. York PH. Bryant CV. Rasheed MA. Ierodiaconou D. and Macreadie PI. (2020).

High variability of Blue Carbon storage in seagrass meadows at the estuary scale. *Scientific Reports*, 10, 5865. DOI: 10.1038/s41598-020-62639-y.

Ricart AM. Krause-Jensen D. Hancke K. Price NN. Masqué P. and Duarte CM. (2022). Sinking seaweed in the deep ocean for carbon neutrality is ahead of science and beyond the ethics. *Environmental Research Letters*, 17, 081003. DOI: 10.1088/1748-9326/ac82ff.

Rights and Resources Initiative. (2019). A Statement on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land from Indigenous Peoples and Local Communities from 42 Countries Spanning 76% of the World's Tropical Forests. *Indigenous + Community Response to IPCC Report.* Retrieved online from: https://ipccresponse.org/home-en.

Rimmer MA. Larson S. Lapong I. Purnomo AH. Pong-Masak PR. Swanepoel L. *et al.* (2021). Seaweed aquaculture in Indonesia contributes to social and economic aspects of livelihoods and community wellbeing. *Sustainability,* 13(19), 10946. DOI: 10.3390/su131910946.

Roberts BA. and Robertson A. (1986). Salt marshes of Atlantic Canada: Their ecology and distribution. *Canadian Journal of Botany,* 64, 455-67. DOI: 10.1139/b86-060.

Roberts DA. Paul NA. Dworjanyn SA. Bird MI. and de Nys R. (2015). Biochar from commercially cultivated seaweed for soil amelioration. *Scientific Reports,* 5, 9665. DOI: 10.1038/srep09665.

Rogers-Bennett L. and Catton CA. (2019). Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Scientific Reports*, 9, 15050. DOI: 10.1038/s41598-019-51114-y.

Rose DJ. and Hemery LG. (2023) Methods for measuring carbon dioxide uptake and permanence: Review and implications for macroalgae aquaculture. *Journal of Marine Science and Engineering*, 11(1), 175. DOI: 10.3390/jmse11010175.

Rosentreter JA. Al-Haj AN. Fulweiler RW. and Williamson P. (2021). Methane and nitrous oxide emissions complicate coastal blue carbon assessments. *Global Biogeochemical Cycles*, 35(2), e2020GB006858. DOI: 10.1029/2020GB006858.

Roth N. Thiele T. and von Unger M. (2019). Blue bonds: Financing resilience of coastal ecosystems. *Blue National Capital Financing Facility.* Retrieved online from: https://www.4climate.com/dev/wp-content/uploads/2019/04/Blue-Bonds_final.pdf.

Ruiz-Frau A. Gelcich S. Hendriks IE. Duarte CM. and Marbà N. (2017). Current state of seagrass ecosystem services: Research and policy integration. *Ocean and Coastal Management,* 149, 107-115. DOI: 10.1016/j.ocecoaman.2017.10.004.

Sakshaug E. (2004). Primary and secondary production in the Arctic Seas. In *The Organic Carbon Cycle in the Arctic Ocean*. Springer Berlin, Heidelberg.

Sala E. Mayorga J. Bradley D. Cabral RB. Atwood TB. Auber A. *et al.* (2021). Protecting the global ocean for biodiversity, food and climate. *Nature,* 592, 397-402. DOI: 10.1038/s41586-021-03371-z.

Salmon Parks. (n.d.). Muwačatḥ (Mowachaht/Muchalaht) and Nuchatlaht First Nations. *Salmon Parks.* Retrieved online from: https://www.salmonparks.ca/.

Sandlos J. (2008). Not wanted in the boundary: The expulsion of the Keeseekoowenin Ojibway Band from Riding Mountain National Park. *Canadian Historical Review,* 89(2), 189-221. DOI: 10.3138/chr.89.2.189.

Saunders MI. and Mextaxas A. (2009). Population dynamics of a nonindigenous epiphytic bryozoan *Membranipora membranacea* in the western North Atlantic: effects of kelp substrate. *Aquatic Biology,* 8, 83-94. DOI: 10.3354/ab00208.

Scheibling RE. (1986). Increased macroalgal abundance following mass mortalities of sea urchins (*Strongylocentrotus droebachiensis*) along the Atlantic coast of Nova Scotia. *Oecologia,* 68, 186-198. DOI: 10.1007/BF00384786.

Scheibling RE. and Gagnon P. (2009). Temperature-mediated outbreak dynamics of the invasive bryozoan *Membranipora membranacea* in Nova Scotian kelp beds. *Marine Ecology Progress Series*, 390, 1-13. DOI: 10.3354/meps08207.

Schmidt AL. Coll M. Romanuk TN. and Lotze HK. (2011). Ecosystem structure and services in eelgrass *Zostera marina* and rockweed *Ascophyllum nodosum* habitats. *Marine Ecology Progress Series*, 437, 51-68. DOI: 10.3354/meps09276.

Schorn S. Ahmerkamp S. Bullock E. Weber M. Lott C. Liebeke M. *et al.* (2022). Diverse methylotrophic methanogenic archaea cause high methane emissions from seagrass meadows. *Proceedings of the National Academy of Sciences*, 119(9), e2106628119. DOI: 10.1073/pnas.2106628119.

Schroeder SB. Boyer L. Juanes F. and Costa M. (2020). Spatial and temporal persistence of nearshore kelp beds on the west coast of British Columbia, Canada using satellite remote sensing. *Remote Sensing in Ecology and Conservation*, 6(3), 327-343. DOI: 10.1002/rse2.142.

Schuerch M. Spencer T. Temmerman S. Kirwan ML. Wolff C. Lincke D. *et al.* (2018). Future response of global coastal wetlands to sea-level rise. *Nature,* 561, 231-236. DOI: 10.1038/s41586-018-0476-5.

Schuur EA. McGuire AD. Schädel C. Grosse G. Harden JW. Hayes DJ. *et al.* (2015). Climate change and the permafrost carbon feedback. *Nature,* 520(7546), 171-179. DOI: 10.1038/nature14338.

SeaChange Marine Conservation Society. (n.d.a) Restoration. *SeaChange Marine Conservation Society.* Brentwood Bay, Canada. Retrieved online from: https://seachangesociety.com/restorationpg/.

Seddon N. Smith A. Smith P. Key I. Chausson A. Girardin C. *et al.* (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology, 27*(8), 1-29. DOI: 10.1111/gcb.15513.

Seeger I. McDonald H. Wienrich N. and Riedel A. (2022). The Arctic Blue Economy: Current State, Developments, and Implications for Marine Conservation. *Ecologic Institute*. Berlin, Germany. Retrieved online from: https://www.ecologic.eu/sites/default/files/publication/2022/50002-Arctic-Blue-Economy-web.pdf.

Serreze MC. and Stroeve J. (2015). Arctic sea ice trends, variability and implications for seasonal ice forecasting. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 373(2045), 20140159. DOI: 10.1098/rsta.2014.0159.

Shepard CC. Crain CM. and Beck MW. (2011). The protective role of coastal marshes: A systematic review and meta-analysis. *PloS One*, *6*(11), e27374. DOI: 10.1371/journal.pone.0027374.

Short FT. (2019a). Ecosystems, fish and wildlife monitoring and management. In *From Science to Policy in the Greater Hudson Bay Marine Region*. ArcticNet. Quebec City, Canada. Retrieved online from: https://arcticnet.ulaval.ca/wp-content/uploads/2022/06/IRIS_3_synthesis_to_print_rev1_compressed.pdf.

Short FT. (2019b). Eelgrass in Hudson Bay. In *From Science to Policy in the Greater Hudson Bay Marine Region*. ArcticNet. Quebec City, Canada. Retrieved online from: https://arcticnet.ulaval.ca/wp-content/uploads/2022/06/IRIS_3_synthesis_to_print_rev1_compressed.pdf.

Short FT. and Neckles HA. (1999). The effects of global climate change on seagrasses. *Aquatic Botany,* 63, 169-196. DOI: 10.1016/S0304-3770(98)00117-X.

Simonson EJ. Scheibling RE. Metaxas A. (2015). Kelp in hot water: Warming seawater temperature induces weakening and loss of kelp tissue. *Marine Ecology Progress Series,* 537, 89-104. DOI: 10.3354/meps11438.

Snelgrove PVR. Soetaert K. Solan M. Thrush S. Wei C-L. Danovaro R. *et al.* (2018). Global carbon cycling on a heterogeneous seafloor. *Trends in Ecology & Evolution,* 33, 96-105. DOI: 10.1016/j.tree.2017.11.004.

Søreide JE. Leu EV. Berge J. Graeve M. and Falk-Petersen STIG. (2010). Timing of blooms, algal food quality and *Calanus glacialis* reproduction and growth in a changing Arctic. *Global Change Biology*, 16(11), 3154-3163. DOI: 10.1111/j.1365-2486.2010.02175.x.

Spillias S. Valin H. Batka M. Sperling F. Havlík P. Leclère D. *et al.* (2023). Reducing global land-use pressures with seaweed farming. *Nature Sustainability*, 1-11. DOI: 10.1038/s41893-022-01043-y.

Spooner AM. (2015). Blue carbon sequestration potential in *Zostera marina* eelgrass beds of the K'ómoks Estuary, British Columbia. *Master's Thesis, Royal Roads University*. Retrieved online from: http://hdl.handle.net/10170/916.

Springer AM. McRoy CP. and Flint MV. (1996). The Bering Sea Green Belt: shelf-edge processes and ecosystem production. *Fisheries Oceanography*, 5(3-4), 205-223. DOI: 10.1111/j.1365-2419.1996.tb00118.x.

Spurkland T. and Iken K. (2011). Kelp bed dynamics in estuarine environments in subarctic Alaska. *Journal of Coastal Research*, 27(6A), 133-143. DOI: 10.2112/JCOASTRES-D-10-00194.1.

Stammerjohn S. Massom R. Rind D. and Martinson D. (2012). Regions of rapid sea ice change: An inter-hemispheric seasonal comparison. *Geophysical Research Leters,* 39(6), L06501. DOI: 10.1029/2012GL050874.

Starko S. Bailey LA. Creviston E. James KA. Warren A. Brophy MK. *et al.* (2019a). Environmental heterogeneity mediates scale-dependent declines in kelp diversity on intertidal rocky shores. *PLoS One*, 14(3), e0213191. DOI: 10.1371/journal.pone.0213191.

Starko S. Gomez MS. Darby H. Demes KW. Kawai H. Yotsukura N. *et al.* (2019b). A comprehensive kelp phylogeny sheds light on the evolution of an ecosystem. *Molecular Phylogenetics and Evolution*, 136, 138-150. DOI: 10.1016/j.ympev.2019.04.012.

Starko S. Wilkinson DP. and Bringloe TT. (2021). Recent global model underestimates the true extent of Arctic kelp habitat. *Biological Conservation*, 257, 109082. DOI: 10.1016/j.biocon.2021.109082.

Starko S. Neufeld CJ. Gendall L. Timmer B. Campbell L. Yakimishyn J. *et al.* (2022). Microclimate predicts kelp forest extinction in the face of direct and indirect marine heatwave effects. *Ecological Applications*, 32(7), e2673. DOI: 10.1002/eap.2673.

Starko S. Timmer B. Reshitnyk L. Csordas M. McHenry J. Schroeder S. *et al.* (2023). Temperature and food chain length, but not latitude, explain region-specific kelp forest responses to an unprecedented heatwave. *Preprint.* DOI: 10.1101/2023.01.07.523109.

Statistics Canada. (2022a). Census of Environment: A framework for Salt Marsh Ecosystem Accounting. *Statistics Canada*. Ottawa, Canada. Retrieved online from: https://www150.statcan.gc.ca/n1/daily-quotidien/221108/dq221108d-eng.htm.

Statistics Canada. (2022b). Indigenous Population Continues to Grow and is Much Younger Than the Non-Indigenous Population, Although the Pace of Growth has Slowed. *Statistics Canada*. Ottawa, Canada. Retrieved online from: https://www150.statcan.gc.ca/n1/daily-quotidien/220921/dq220921a-eng.htm.

Stein R. and MacDonald RW. (2004). The Organic Carbon Cycle in the Arctic Ocean. *Springer Publishing Company*. Berlin, Germany.

Steinacher M. Joos F. Frölicher TL. Plattner GK. and Doney SC. (2009). Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. *Biogeosciences*, 6(4), 515-533. DOI: 10.5194/bg-6-515-2009.

Stevens S. (2014). Indigenous Peoples, National Parks, and Protected Areas. *University of Arizona Press.* Tucson, USA.

Stroeve J. and Notz D. (2018). Changing state of Arctic sea ice across all seasons. *Environmental Research Letters,* 13, 103001. DOI: 10.1088/1748-9326/aade56.

Sumaila UR. Walsh M. Hoareau K. Cox A. Teh L. Abdallah P. *et al.* (2020). Financing a sustainable ocean economy. *Nature communications,* 12(1), 3259. DOI: 10.1038/s41467-021-23168-y.

Sutherland IR. Karpouzi V. Mamoser M. and Carswell B. (2008). Kelp Inventory, 2007: Areas of the British Columbia Central Coast from Hakai Passage to the Bardswell Group. *Ministry of Environment, Oceans and Marine Fisheries Branch. Victoria, Canada. Retrieved online from:* https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/338662.pdf.

Sutton-Grier AE. and Moore A. (2016). Leveraging carbon services of coastal ecosystems for habitat protection and restoration. *Coastal Management*, 44(3), 259-277. DOI: 10.1080/08920753.2016.1160206.

Tait L. Bind J. Charan-Dixon H. Hawes I. Pirker J. and Schiel D. (2019). Unmanned aerial vehicles (UAVs) for monitoring macroalgal biodiversity: Comparison of RGB and multispectral imaging sensors for biodiversity assessments. *Remote Sensing*, 11(19), 2332. DOI: 10.3390/rs11192332.

Tallis HM. Ruesink JL. Dumbauld B. Hacker S. and Wisehart LM. (2009). Oysters and aquaculture practices affect eelgrass density and productivity in a Pacific Northwest estuary. *Journal of Shellfish Research,* 28(2), 251-261. DOI: 10.2983/035.028.0207.

Teagle H. Hawkins SJ. Moore PJ. and Smale DA. (2017). The role of kelp species as biogenic habitat formers in coastal marine ecosystems. *Journal of Experimental Marine Biology and Ecology,* 492, 81-98. DOI: 10.1016/j.jembe.2017.01.017.

Terhaar J. Kwiatkowski L. and Bopp L. (2020). Emergent constraint on Arctic Ocean acidification in the twenty-first century. *Nature*, 582(7812), 379-383. DOI: 10.1038/s41586-020-2360-3.

The Nature Conservancy. (2021). Global Principles of Restorative Aquaculture. *The Nature Conservancy*. Arlington, USA. Retrieved online from: https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_PrinciplesofRestorativeAquaculture.pdf.

The First Nations Information Governance Centre. (2021). The First Nations Principles of OCAP®. *The First Nations Information Governance Centre*. Akwesasne, Canada. Retrieved online from: https://fnigc.ca/ocap-training/

Theuerkauf SJ. Morris Jr JA. Waters TJ. Wickliffe LC. Alleway HK. and Jones RC. (2019). A global spatial analysis reveals where marine aquaculture can benefit nature and people. *PLoS One*, 14(10), e0222282. DOI: 10.1371/journal.pone.0222282.

Thom R. Southard S. and Borde A. (2014). Climate-linked mechanisms driving spatial and temporal variation in eelgrass (*Zostera marina* L.) growth and assemblage structure in Pacific Northwest estuaries, U.S.A. *Journal of Coastal Research,* 68 (sp1), 1-11. DOI: 10.2112/SI68-001.1.

Thomas H. Bozec Y. Elkalay K. and de Baar HJW. (2004). Enhanced open ocean storage of CO_2 from shelf sea pumping. *Science,* 304(5673), 1005-1008. DOI: 10.1126/science.1095491.

Tormos-Aponte F. (2021). The influence of Indigenous Peoples in global climate governance. *Current Opinion in Environmental Sustainability*, 52, 125-131. DOI: 10.1016/j.cosust.2021.10.001.

Townsend J. (2022). Indigenous and Decolonial Futurities: Indigenous Protected and Conserved Areas as Potential Pathways of Reconciliation. *Doctoral Thesis, University of Guelph*. Retrieved online from: https://hdl.handle.net/10214/27210.

Townsend J. Moola F. and Craig M-K. (2020). Indigenous Peoples are critical to the success of nature-based solutions to climate change. *FACETS*, 5(1), 551-556. DOI: 10.1139/facets-2019-0058.

Traiger SB. and Konar B. (2018). Mature and developing kelp bed community composition in a glacial estuary. *Journal of Experimental Marine Biology and Ecology*, 501, 26-35. DOI: 10.1016/j.jembe.2017.12.016.

Tran TC. Ban NC. and Bhattacharyya J. (2020). A review of successes, challenges, and lessons from Indigenous protected and conserved areas. *Biological Conservation*, 241, 108271. DOI: 10.1016/j.biocon.2019.108271.

Trevathan-Tackett SM. Kelleway J. Macreadie PI. Beardall J. Ralph P. and Bellgrove A. (2015). Comparison of marine macrophytes for their contributions to blue carbon sequestration. *Ecology,* 96(11), 3043-3057. DOI: 10.1890/15-0149.1.

Troell M. Henriksson PJG. Buschmann AH. Chopin T. and Quahe S. (2022). Farming the ocean – Seaweeds as a quick fix for the climate? *Reviews in Fisheries Science & Aquaculture,* 1-11. DOI: 10.1080/23308249.2022.2048792.

Truth and Reconciliation Commission of Canada (TRC). (2015). Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada. *Truth and Reconciliation Commission of Canada*. Ottawa, Canada. Retrieved online from: https://publications.gc.ca/collections/collection_2015/trc/IR4-7-2015-eng.pdf.

Tsunogai S. Watanabe S. and Sato T. (1999). Is there a “continental shelf pump” for the absorption of atmospheric CO_2? *Tellus B: Chemical and Physical Meteorology*, 51(3), 701-712. DOI: 10.3402/tellusb.v51i3.16468.

Tuihedur Rahman HM. Sherren K. and van Proosdij D. (2019). Institutional innovation for nature-based coastal adaptation: Lessons from salt marsh restoration in Nova Scotia, Canada. *Sustainability,* 11(23), 6735. DOI: 10.3390/su11236735.

Turner N. (2014). Ancient pathways, ancestral knowledge: Ethnobotany and ecological wisdom of Indigenous peoples of northwestern North America. *McGill-Queen’s University Press.* Montreal, Canada.

Turner JT. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean’s biological pump. *Progress in Oceanography*, 130, 205-248. DOI: 10.1016/j.pocean.2014.08.005.

Turner NJ. and Clifton H. (2009) “It’s so different today”: Climate change and Indigenous lifeways in British Columbia, Canada. *Global Environmental Change*, 19(2), 180-190. DOI: 10.1016/j.gloenvcha.2009.01.005.

Turney C. Ausseil A-G. and Broadhurst L. (2020). Urgent need for an integrated policy framework for biodiversity loss and climate change. *Nature Ecology and Evolution,* 4(8), 996. DOI: 10.1038/s41559-020-1242-2.

UNEP. (2023). Into the Blue: Securing a Sustainable Future for Kelp Forests. *United Nations Environmental Programme.* Nairobi, Kenya. *In Press.*

Unsworth RKF. Williams B. Jones BL. and Cullen-Unsworth LC. (2017). Rocking the boat: Damage to eelgrass by swinging boat moorings. *Frontiers in Plant Science,* 8. DOI: 10.3389/fpls.2017.01309.

Unsworth RKF. McKenzie LJ. Collier CJ. Cullen-Unsworth LC. Duarte CM. Eklöf JS. *et al.* (2019). Global challenges for seagrass conservation. *Ambio*, 48, 801-815. DOI: 10.1007/s13280-018-1115-y.

Unsworth RKF. Cullen-Unsworth LC. Jones BLH. and Lilley RJ. (2022). The planetary role of seagrass conservation. *Science*, 377(6606), 609-613. DOI: 10.1126/science.abq6923.

van Ardenne LB. and Chmura GL. (2021). Applying airborne LiDAR to map salt marsh inland boundaries. *Remote Sensing*, 13(21), 4245. DOI: 10.3390/rs13214245.

van der Heide T. van Nes EH. van Katwijk MM. Olff H. and Smolders AJP. (2011). Positive feedbacks in seagrass ecosystems - evidence from large-scale empirical data. *PLoS ONE,* 6(1), e16504. DOI: 10.1371%2Fjournal.pone.0016504.

Vanderklift MA. Herr D. Lovelock C. Murdiyarso D. Raw JL. and Steven ADL. (2022). A guide to international climate mitigation policy and finance frameworks relevant to the protection and restoration of blue carbon ecosystems. *Policy and Practice Reviews.* 9. DOI: 10.3389/fmars.2022.872064.

Vandermeulen H. (2014). Bay-scale assessment of eelgrass beds using sidescan and video. *Helgoland Marine Research*, 68(4), 559-569. DOI: 10.1007/s10152-014-0412-5.

van Katwijk MM. Thorhaug A. Marbà N. Orth RJ. Duarte CM. Kendrick GA. *et al.* (2016). Global analysis of seagrass restoration: the importance of large-scale planting. *Journal of Applied Ecology,* 53(2), 567-578. DOI: 10.1111/1365-2664.12562.

Verra. (2022). The Verified Carbon Standard (VCS) program. *Verra*. Washington, DC, USA. Retrieved online from: https://verra.org/programs/verified-carbon-standard/.

Vincent WF. Callaghan TV. Dahl-Jensen D. Johansson M. Kovacs KM. Michel C. *et al.* (2011). Ecological implications of changes in the Arctic cryosphere. *Ambio*, 40(1), 87-99. DOI: 10.1007%2Fs13280-011-0218-5.

Virgin SDS. Beck AD. Boone LK. Dykstra AK. Ollerhead J. Barbeau MA. *et al.* (2020). A managed realignment in the upper Bay of Fundy: Community dynamics during salt marsh restoration over 8 years in a megatidal, ice-influenced environment. *Ecological Engineering,* 149, 105713. DOI: 10.1016/j.ecoleng.2020.105713.

Vogel B. Yumagulova L. McBean G. Charles Norris KA. (2022). Indigenous-led nature-based solutions for the climate crisis: Insights from Canada. *Sustainability,* 14 (11), 6725. DOI: 10.3390/su14116725.

Waltham NJ. Alcott C. Barbeau MA. Cebrian J. Connolly RM. Deegan LA. *et al.* (2021). Tidal marsh restoration optimism in a changing climate and urbanizing seascape. *Estuaries and Coasts,* 44, 1681-1690. DOI: 10.1007/s12237-020-00875-1.

Ward ND. Bianchi TS. Medeiros PM. Seidel M. Richey JE. Keil RG. *et al.* (2017). Where carbon goes when water flows: Carbon cycling across the aquatic continuum. *Frontiers in Marine Science*, 4. DOI: 10.3389/fmars.2017.00007.

Warrior M. Fanning L. and Metaxas, A. (2022). Indigenous peoples and marine protected area governance: A Mi'kmaq and Atlantic Canada case study. *FACETS,* 71, 1298-1327. DOI: 10.1139/facets-2021-0128.

Warren RS. Fell PE. Rozsa R. Brawley AH. Orsted AC. Olson ET. *et al.* (2002). Salt marsh restoration in Connecticut: 20 years of science and management. *Restoration Ecology,* 10(3), 497-513. DOI: 10.1046/j.1526-100X.2002.01031.x.

Watanabe S. Scheibling RE. and Metaxas A. (2010). Contrasting patterns of spread in interacting invasive species: *Membranipora membranacea* and *Codium fragile* off Nova Scotia. *Biological Invasions,* 12, 2329-2342. DOI: 10.1007/s10530-009-9647-5.

Watson J. and Estes JA. (2011). Stability, resilience, and phase shifts in rocky subtidal communities along the west coast of Vancouver Island, Canada. *Ecological Monographs*, 81(2), 215-239. DOI: 10.1890/10-0262.1.

Waycott M. Duarte CM. Carruthers TJB. Orth RJ. Dennison WC. Olyarnik S. *et al.* (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences,* 106(30), 12377-12381. DOI: 10.1073/pnas.0905620106.

Welham C. (2020). A Carbon Emission Reduction Credit Project Plan for Ecosystem Restoration Activities in the Burns Bog Ecological Conservancy Area (summary and guidelines). *3GreenTree Ecosystem Services Ltd.* Delta, Canada. Retrieved online from: https://lcrupload.s3.amazonaws.com/uploads/dutveslh.3ug/BurnsBogEcologicalConservancyAreaRestoration-Summary.pdf.

Welham C. and Seely B. (2019). Improving the Metro Vancouver Regional Carbon Storage Dataset: Final Report. *3GreenTree Ecosystem Services Ltd.* Delta, Canada. Retrieved online from: http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ImprovingMetroVancouverRegionalCarbonStorageDataset-2019Jan3.pdf.

Wells ED. and Hirvonen HE. (1988). Wetlands of Atlantic Canada. In *Wetlands of Canada*. National Wetlands Working Group Canada Committee on Ecological Land Classification. Ottawa, Canada. Retrieved online from: https://publications.gc.ca/collections/collection_2019/eccc/En73-3-24-eng.pdf.

Wernberg T. Vanderklift MA. How J. and Lavery PS. (2006). Export of detached macroalgae from reefs to adjacent seagrass beds. *Oecologia*, 147, 692-701. DOI: 10.1007/s00442-005-0318-7.

Wernberg T. Krumhansl K. Filbee-Dexter K. and Pedersen MF. (2019). Chapter 3: Status and Trends for the World's Kelp Forests. In *World Seas: An Environmental Evaluation, Vol III: Ecological Issues and Environmental Impacts*. Academic Press. Cambridge, USA.

Wetland Stewardship Partnership. (2010). A Wetland Action Plan for British Columbia. *Wetland Stewardship Partnership*. British Columbia, Canada. Retrieved online from: https://bcwetlandsca.files.wordpress.com/2016/11/bcwetlandactionplan_wsp_2010.pdf.

Wheeler WN. and Druehl LD. (1986). Seasonal growth and productivity of *Macrocystis integrifolia* in British Columbia, Canada. *Marine Biology, 90*, 181-186. DOI: 10.1007/BF00569125.

White Face C. (2013). Indigenous Nations' Rights in the Balance: An Analysis of the Declaration on the Rights of Indigenous Peoples. *Living Justice Press*. Minnesota, USA.

Whyte K. (2017). Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. *English Language Notes*, 55(1-2), 153-162. DOI: 10.1215/00138282-55.1-2.153.

Whyte K. (2020). Too late for Indigenous climate justice: Ecological and relational tipping points. *Wiley Interdisciplinary Reviews: Climate Change,* 11(1), e603. DOI: 10.1002/wcc.603.

Widdicombe S. and Spicer JI. (2008). Predicting the impact of ocean acidification on benthic biodiversity: What can animal physiology tell us? *Journal of Experimental Marine Biology and Ecology,* 366(1-2), 187-197. DOI: 10.1016/j.jembe.2008.07.024.

Wiencke C. Amsler CD. and Clayton MN. (2014). Macroalgae. In *Biogeographic Atlas of the Southern Ocean*. Scientific Committee on Antarctic Research. Cambridge, United Kingdom. Retrieved online from: https://epic.awi.de/id/eprint/43647/1/Wiencke.pdf.

Wild B. Andersson A. Bröder L. Vonk J. Hugelius G. McClelland JW. *et al.* (2019). Rivers across the Siberian Arctic unearth the patterns of carbon release from thawing permafrost. *Proceedings of the National Academy of Sciences*, 116(21), 10280-10285. DOI: 10.1073/pnas.1811797116.

Williams J. (2012). The impact of climate change on Indigenous people—The implications for the cultural, spiritual, economic and legal rights of Indigenous people. *The International Journal of Human Rights*, 16(4), 648-688. DOI: 10.1080/13642987.2011.632135.

Wilmers CC. Estes JA. Edwards M. Laidre KL. and Konar B. (2012). Do trophic cascades affect the storage and flux of atmospheric carbon? An analysis of sea otters and kelp forests. *Frontiers in Ecology and the Environment,* 10(8), 409-415. DOI: 10.1890/110176.

Wilson NJ. (2019). "Seeing water like a state?": Indigenous water governance through Yukon First Nation self-government agreements. *Geoforum,* 104, 101-113. DOI: 10.1016/j.geoforum.2019.05.003.

Wilson KL. and Lotze HK. (2019). Climate change projections reveal range shifts of eelgrass *Zostera marina* in the Northwest Atlantic. *Marine Ecology Progress Series,* 620, 47-62. DOI: 10.3354/meps12973.

Wilson KL. Skinner MA. and Lotze HK. (2019). Eelgrass (*Zostera marina*) and benthic habitat mapping in Atlantic Canada using high-resolution SPOT 6/7 satellite imagery. *Estuarine, Coastal and Shelf Science*, 226, 106292. DOI: 10.1016/j.ecss.2019.106292.

Wilson E. and Garbary DJ. (2020). Absence of recovery in a degraded eelgrass (*Zostera marina*) bed in Nova Scotia, Canada: Results from a transplant study. *Proceedings of the Nova Scotian Institute of Science (NSIS),* 50(2), 251-267. DOI: 10.15273/pnsis.v50i2.10001.

Wilson N. Parrish CE. Battista T. Wright CW. Costa B. Slocum RK. *et al.* (2022). Mapping seafloor relative reflectance and assessing coral reef morphology with EAARL-B topobathymetric Lidar waveforms. *Estuaries and Coasts*, 45, 923-937. DOI: 10.1007/s12237-019-00652-9.

Windham-Myers L. Cai WJ. Alin SR. Andersson A. Crosswell J. Dunton KH. *et al.* (2018a). Chapter 15: Tidal wetlands and estuaries. In *Second State of the Carbon Cycle Report*. U.S. Global Change Research Program. Washington, DC, USA. Retrieved online from: https://carbon2018.globalchange.gov/chapter/15/.

Windham-Myers L. Crooks S. and Troxler TG. (2018b). A Blue Carbon Primer: The State Of Coastal Wetland Carbon Science, Practice And Policy. *CRC Press*. Boca Raton, USA.

Wollenberg J. Ollerhead J. and Chmura GL. (2018). Rapid carbon accumulation following managed realignment on the Bay of Fundy. *Plos One,* 13(3), e0193930. DOI: 10.1371/journal.pone.0193930.

Wood G. Marzinelli EM. Coleman MA. Campbell AH. Santini NS. Kajlich L. *et al.* (2019). Restoring subtidal marine macrophytes in the Anthropocene: trajectories and future-proofing. *Marine and Freshwater Research*, 70(7), 936-951. DOI: 10.1071/MF18226.

Woosley RJ. and Millero FJ. (2020). Freshening of the western Arctic negates anthropogenic carbon uptake potential. *Limnology and oceanography*, 65(8), 1834-1846. DOI: 10.1002/lno.11421.

World Bank. (2018). Sovereign Blue Bond Issuance: Frequently Asked Questions. *World Bank Group*. Washington, DC, USA. Retrieved online from: https://www.worldbank.org/en/news/feature/2018/10/29/sovereign-blue-bond-issuance-frequently-asked-questions

WWF-Canada. (2020). Living Planet Report Canada: Wildlife at Risk. *World Wildlife Fund Canada.* Toronto, Canada. Retrieved online from: https://wwf.ca/wp-content/uploads/2020/09/WWF-7-x-9-LPRC_Web.pdf.

WWF-Canada. (2022). Blue Carbon in Canada: A Federal Policy Review. *World Wildlife Fund Canada.* Toronto, Ontario. Retrieved online from: https://wwf.ca/wp-content/uploads/2022/11/WWF-Canada_BlueCarbonInCanada-AFederalPolicyReview_Report.pdf.

Wysote T. and Morton E. (2019). 'The depth of the plough': white settler tautologies and pioneer lies. *Settler Colonial Studies,* 9(4), 479-504. DOI: 10.1080/2201473X.2018.1541221.

Youmans J. (2013). Community and Shared Docks: Case Studies from the BC Coast. *Islands Trust.* Victoria, Canada. Retrieved online from: https://islandstrust.bc.ca/document/community-dock-case-studies/.

Zhu L. Lei J. Huguenard K. and Fredriksson DW. (2021). Wave attenuation by suspended canopies with cultivated kelp (*Saccharina latissima*). *Coastal Engineering,* 168, 103947. DOI: 10.1016/j.coastaleng.2021.103947.