UNDERSTANDING SHIKAAPAASHKWH (ᔑᑳᐹᔥᑯᐦ)

Eelgrass Health and Goose Presence in Eastern James Bay

Final Report from the Eeyou Coastal Habitat Comprehensive Research Project (CHCRP)

Submitted to Niskamoon Corporation by Zou Zou Kuzyk, University of Manitoba, on behalf of the Research Consortium

April 16, 2023

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The Eeyou Coastal Habitat Comprehensive Research Project was overseen by Niskamoon Corporation (Robbie Tapiatac, Ernie Rabbitskin, and Marc Dunn) and received guidance from a Steering Committee (members listed in Introduction) and many Cree leaders and community members. We would like to thank all those who participated in this project including the Cree Nation of Chisasibi, Cree Nation of Waskaganish, Cree Nation of Eastmain, Cree Nation of Wemindji, Cree Regional Authority and Cree Nation Government, Cree Trappers' Association, Eeyou Marine Region Wildlife Board, and Canadian Wildlife Service.

This report is dedicated to the coastal Crees of Eeyou Istchee, who have seen dramatic changes in the land and the Cree way of life during their lifetimes. The Eeyou Coastal Habitat Comprehensive Research Project came about through the persistent efforts of the Cree First Nation of Chisasibi to bring to light the dramatic changes in eelgrass and geese they have seen and seek explanations for them. We want to honour the efforts of all community leaders, past and present, to bring attention to these issues.

The Landing by Natasia Mukash. Used with permission

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Preface

In August 2016, an agreement was signed between the Cree Nation Government and Hydro-Québec that mandated Niskamoon Corporation to implement a comprehensive program of research about the ecology of the coastal region of Eeyou lstchee, specifically relationships between eelgrass (*Zostera marina*), Canada Geese, and Cree hunting. The research was to include at least three components: a) distribution and abundance of eelgrass; b) oceanographic conditions of the coastal region of Eeyou Istchee, and c) Cree traditional land use and knowledge of eelgrass and geese. The research was to be overseen by a Steering Committee consisting of representatives of the coastal Cree First Nations of Chisasibi, Wemindji, Eastmain, and Waskaganish; Niskamoon Corporation, Hydro-Québec, and other invited specialists such as the Canadian Wildlife Service. The comprehensive research program came to be called the *Eeyou Coastal Habitat Comprehensive Research Project* (CHCRP). This document is the final integrated report from the researchers that worked within the CHCRP. It was delivered to Niskamoon and the Steering Committee that oversaw implementation of the project in May 2023.

The researchers who worked as a team to prepare this report came from the University of Manitoba, University of British Columbia, University of New Brunswick, and several universities in Québec, including McGill, Université du Québec à Montréal, Institut des sciences de la mer de Rimouski, and Université du Québec à Rimouski. The senior author is Zou Zou Kuzyk, a professor and biogeochemist at the University of Manitoba in Winnipeg MB. For the purposes of this project, Dr. Kuzyk worked closely with specialists in hydrology, coastal zone oceanography, eelgrass ecology and physiology, as well as waterfowl ecology and population dynamics. Lead authors of the report in addition to Dr. Kuzyk include Dr. Mary O'Connor on eelgrass ecology, Dr. Jean-François Giroux on goose population dynamics, Dr. Paul del Giorgio on river hydrology, and Dr. Julián Idrobo on Cree knowledge. Content was contributed by Dr. Fanny Noisette, Caroline Fink-Mercier, Daniela Walch, Dr. Melanie Leblanc, Dr. Michaela de Melo, Dr. Manon Sorais, Dr. Michel Gosselin, Dr. Simon Bélanger, Dr. Urs Neumeier, Dr. Jens Ehn, Dr. Brigitte Leblon, and Dr. Emily Adamczyk. Dr. Melanie Leblanc also served as co-chief editor of the document.

Many researchers had the privilege of working closely with Cree land users on this project. In doing so, we researchers came to understand the importance of Cree culture and knowledge in addressing the research questions. We learned about the depth and breadth of Cree knowledge of the land, the water, the geese, the eelgrass, the people, and all their interconnections and how it is the result of experience passed among Cree people across generations. Cree partners also shared with us the fundamental Cree value of caring for all life, now and for future generations.

The integrated results in this report represent our scientific work over several years, conversations with community members and land users, Cree knowledge documented formally as part of the project, and previously published records and syntheses. Our data collection and analyses use the methods, conventions and language of our training and disciplines. It is this practice that gives our results credibility in science. However, in addition to the Cree knowledge that was formally documented and validated for the project, the research was also influenced by the Cree knowledge and experience that was shared less formally with us. The questions we asked, the locations and times we sampled, even what we sampled, reflect the Cree-driven context of the research program. Our conclusions reflect the evidence interpreted in the context of current scientific understanding *and* inferences drawn from our experiences in the project.

As researchers, we do not speak for the Cree, for Hydro-Québec, for Niskamoon, or for our universities. We speak for ourselves. Although in different contexts, we were all trained in Western scientific traditions, thus what we say here and how we say it are influenced by Western worldviews. In terms of the conclusions of the research, we researchers do not see the significance of every detail in the same way, for many reasons. This document cannot capture the perspective of every researcher and Cree perspective. However, we have made every effort to consider Cree knowledge, values, and understandings as much as we can, and have done our best to build a synthesis grounded in both knowledge systems.

Zou Zou Kuzyk,
on behalf of the researcher consortium

Summary and Key Findings

This report brings together research results from the *Eeyou Coastal Habitat Comprehensive Research Project* (CHCRP), including scientific data and Cree knowledge, and historical information from previously published reports. It reviews and synthesizes information on the health (productivity and extent) of eelgrass meadows along the eastern James Bay coast and implications for goose presence and Cree hunting activities. It focuses on the eelgrass meadows along the east coast of James Bay, between Waskaganish and Cape Jones at the junction with Hudson Bay. Decreases in the distribution and density of eelgrass since the 1980s-90s accompanied by decreases in the waterfowl harvest have been a source of concern to Cree land users especially the Cree Nation of Chisasibi and the investigations reported herein reflect that concern. The report integrates the knowledge from these multiple sources to address the two overarching research questions of the project:

- *What are the main factors affecting the current state of eelgrass along the eastern coast of James Bay?*
- *What is the impact of the current state of eelgrass on waterfowl presence and consequently Cree hunting activities?*

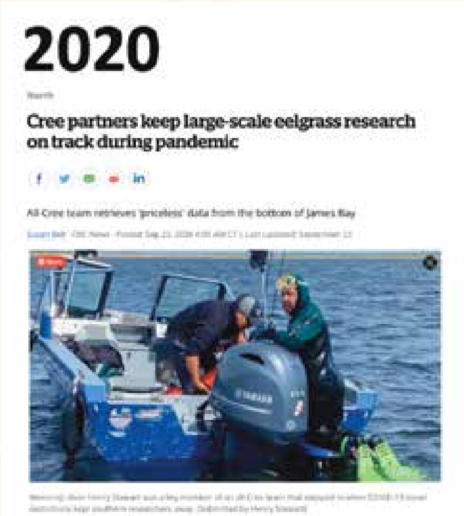
The CHCRP was a Cree-driven project designed and conducted as a collaboration between university researchers and Cree land users. The research drew upon Cree knowledge and experience as well as established scientific methods at every stage. Cree land users worked with researchers to collect samples of river water, coastal water, sediment, and eelgrass, and to survey geese. Cree shared their knowledge during interviews, symposia, and community outreach events.

As directed by the Cree Nation Government and Hydro-Québec, the coastal habitat project was coordinated by Niskamoon Corporation. Niskamoon is a non-profit body established in September 2004 to address environmental and social issues arising from the La Grande hydroelectric development project. That project developed, over a roughly 35-year period between 1978 and 2013, a series of dams, reservoirs, and river diversions towards the La Grande River, which discharges into northeast James Bay near Chisasibi.

In the Eeyou coastal habitat project, Niskamoon established linkages between scientists with a wide range of backgrounds and Cree land users interested in understanding the origins and nature of environmental changes along the James Bay coast. The team of investigators worked closely with

Niskamoon Local Officers (NLOs) and collaborators from the coastal Cree First Nations to conduct the research. The NLOs gained permission and support for the research by contacting the tallyman (traditional family territory manager) and land users of each traditional family hunting ground (e.g., trapline) or trapline along the coast. More than 20 traplines participated in portions of the research, although three (CH4, CH5, CH6) withdrew before the eelgrass health studies were completed.

In this report, discussions of ecological changes or trends in the coastal environment of eastern James Bay consider the La Grande hydroelectric complex, which altered the spatial and seasonal distribution of freshwater inputs to the James Bay coast, as well as large-scale factors that may affect the eelgrass or the geese, such as climate change, land use changes, natural isostatic rebound, and events like wildfires. It is also recognized that current conditions of eelgrass ecosystems could very much depend on their history. Considering both the past and the present provides some perspective for the future.



2020

Cree partners keep large-scale eelgrass research on track during pandemic

All-Cree team retrieves 'priceless' data from the bottom of James Bay

Figure 1. Article in CBC News about the all-Cree team that collected data for the project in 2020 during the global covid-19 pandemic.

Figure 2. Researchers and Cree land users prepare for eelgrass sampling near Wemindji in 2019. Photo credit: G. Mark.

Figure 3. Researchers and Cree land users conduct banding operations at Boatswain Bay in 2018. Photo credit: J.-F. Giroux.

Key Findings

WHAT ARE THE MAIN FACTORS AFFECTING THE CURRENT STATE OF EELGRASS ALONG THE EASTERN COAST OF JAMES BAY?

Eelgrass in eastern James Bay underwent a massive decline in the 1990s and failed to fully recover. The current state of eelgrass meadows along the coast is partly a consequence of these declines. Without large, dense eelgrass beds and meadows to keep the water calm and clear, the coastal waters are frequently turbid with mud stirred up off the bottom. The research results showed that the light available underwater for eelgrass is insufficient for optimal summer eelgrass growth and may reduce winter survival.

Eelgrass recovery is likely further impeded by large-scale stressors associated with climate change. The research showed there has been a browning of James Bay offshore waters over the past two decades, which further reduces the light available underwater for eelgrass. Also, there were extreme weather events, including unusually early ice breakup and warm June water temperatures in the late 1990s, which seem to be stressful for eelgrass; these extreme weather events have become more frequent since the 2000s.

In the La Grande River sector of the coast[1], a third stressor likely affecting some eelgrass beds is the regulated high river flows. Research results showed that both high flows from La Grande and warm water temperatures negatively affect eelgrass beds in this area.

WHAT IS THE IMPACT OF THE CURRENT STATE OF EELGRASS ON WATERFOWL PRESENCE AND CONSEQUENTLY CREE HUNTING ACTIVITIES?

The current poor state of eelgrass reduces the stopovers and use of the coastal habitat by geese, at least during fall. This makes the distribution of the geese less predictable, and impacts Cree hunting activities and associated cultural and socio-economic aspects of Cree society. Additional factors, both local and global, also impact waterfowl presence including changes to waterfowl feeding habits and hunting, and changes in habitat and wildlife distributions due to climate change.

Because the goose migration is ever changing and adjusting to environmental and climate shifts, it is impossible to predict with certainty whether the historically large numbers of Canada Geese that were observed in the 1970s will return.

1 The La Grande sector extends from approximately CH34 in the south to CH5 in the north, although the northern limits are difficult to fully determine due to lack of data collected in this area. Freshwater influence extends to CH7.

Figure 4. First project symposium in Chisasibi in January 2019. Photo credit: Z. Kuzyk.

Figure 5. Photos from the symposium and workshop in Chisasibi in September 2022. Photo credits: M.L. Leblanc.

EELGRASS AND GEESE ARE AN ESSENTIAL PART OF COASTAL CREE CULTURE IN EEYOU ISTCHEE:

Waterfowl hunting is an essential cultural and economic activity for the coastal Cree of Eeyou Istchee. The most important waterfowl are Canada Geese, locally called short necks or *nisk* in Cree. During the 1970s, tens of thousands of short necks would stop and feed along the east coast of James Bay during their northward migration in spring and southward migration in fall.

The stopovers of the geese and thus the coastal Eeyou goose hunt was deeply interconnected with extensive and productive beds of eelgrass (*Zostera marina*), a marine flowering plant that grows in shallow subtidal waters. In fall, the geese fed extensively in eelgrass beds, and on wrack left on the mudflats by the tide and in upland areas on berries. Cree hunters found the geese to be a consistently available resource for many decades and they developed a system involving 'goose bosses' to manage a collective harvest that balanced short-term productivity and the goal of maximizing harvests for the long term.

Figure 6. Canada Geese fall migration along the coast near Chisasibi. Photo credit: M.L. Leblanc.

HEALTHY EELGRASS NEEDS A GOOD ENVIRONMENT:

Historically, eelgrass beds flourished along the Eeyou coast especially north of the Vieux Comptoir (Old Factory) River. They formed large, lush meadows that were considered to be among the most extensive in North America. Eelgrass needs clear waters so that a large amount of sunlight can reach the plants under the water. It also needs salty water and nutrients, but it can usually get enough nutrients from the bottom sediments using its roots. The northeast coastal environment must have provided excellent conditions for eelgrass growth.

Eelgrass that receives enough light and has its roots anchored in good bottom sediments will grow tall and spread and store up energy to survive the winter, which in James Bay extends for many months. Sometimes, diseases, animals, ice scour, or extreme events like storms can reduce eelgrass size and extent by removing or damaging the plants. Isostatic rebound (uplift of the land) can cause eelgrass to shift their distribution to stay submerged under the water. However, eelgrass is known to be tolerant of a wide range of conditions, and able to recover from minor disturbances or natural environmental change.

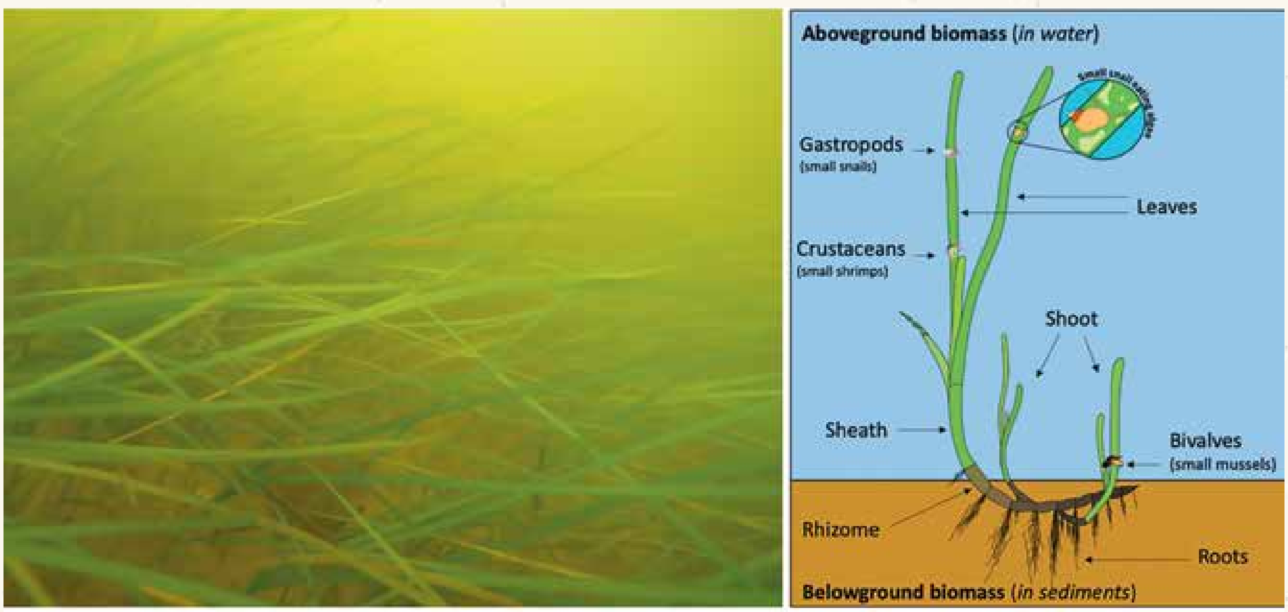


Figure 7. View of eelgrass underwater and diagram showing the parts of the plant. Photo credit: C. Peck. Illustration credit: M.L. Leblanc.

A COASTAL ENVIRONMENT BENEFITS FROM HEALTHY EELGRASS:

Large, dense eelgrass beds and vast meadows like those present in eastern James Bay in the 1970s serve other important functions in coastal ecosystems, in addition to attracting geese. According to the *Migratory Bird Habitat Task Force Report* prepared by community members of Chisasibi, "*A major indicator of healthy eelgrass is aayoshtinuuktícj, which means that as soon as the tide recedes the eelgrass settles and calms the water in the area of the eelgrass beds*".

The calming effect of a dense, healthy eelgrass bed encourages small creatures (snails, small clams, and juvenile fish) to live there and promotes clearer water because the sediment does not get stirred up off the bottom during storms. Eelgrass roots help trap and hold sediment in place. Under these conditions, sunlight can penetrate more deeply into the clear water and the eelgrass is able to grow tall and spread. The more light that reaches the plants, the better it is for growth. Scientists describe this as a '*positive feedback effect'* of healthy eelgrass; that is, healthy eelgrass beds help keep the environment good for themselves and for other eelgrass beds around them, but when they decline, the environment degrades and becomes unfavorable for eelgrass growth

Figure 8. Chisasibi Cree technician Laura-Lee Sam sampling eelgrass. Photo credit: G. Mark.

EELGRASS DECLINED SEVERELY IN JAMES BAY IN THE 1980S AND 90S:

Between 1996 and 1999, an unprecedented, severe reduction in eelgrass occurred that affected the entire coast of eastern James Bay. Cree land users from Chisasibi saw uprooted plants and observed that most of the tall eelgrass growing in deep water had disappeared. In the La Grande sector of the coast, where Hydro-Québec crews had been monitoring eelgrass biomass since 1982, many eelgrass beds all but disappeared, decreasing 94% to 99% compared to 1995 conditions. A large-scale monitoring of eelgrass cover was carried out during summer 1999 all along the coast, after the discovery of the eelgrass losses in Chisasibi. The monitoring crew observed that *many* eelgrass beds had deteriorated.

For some Chisasibi land users, the decline in eelgrass in the late 1990s was not the first decline they had seen: some eelgrass beds in the La Grande sector had declined earlier, during the 1980s and early 1990s. Eelgrass biomass monitoring data collected between 1982 and 1995 in the La Grande sector of the coast showed decreases in the size or density of eelgrass over the period 1982-1995 at three of six sites. There was no eelgrass biomass monitoring in the other sectors of the coast prior to 1995.

As described by Cree land users interviewed for this project, and confirmed by various publications, hydroelectric development caused major coastal environmental changes around Chisasibi between 1978 and 1995. Increased flows of La Grande River led to coastal environmental changes due to increased transport of sediment from the newly flooded reservoirs and riverbank erosion into the bay, and the expansion of the freshwater plume along the coast during winter. As a result, there may have been changes in salinity, temperature, water clarity, and nutrient availability within the coastal areas influenced by La Grande River, each of which may have impacted the eelgrass beds in these areas.

Major climate-driven changes along the eastern James Bay coast first became apparent *during the late 1990s*. Between 1995 and 1998, there were several extremely warm springs, hot, dry summers, and low river flows both from natural rivers and La Grande. The winter of 1997-1998 was exceptional. In January 1998, an ice storm occurred that broke down Hydro-Québec power lines in southern Québec. The spring of 1998 was unusually warm and the sea ice in northeast James Bay broke up in mid-May 1998, almost a month earlier than normal. The coastal waters warmed up rapidly, reaching unprecedented temperatures for June and July.

We conclude that changes caused by La Grande hydroelectric development started to affect eelgrass health in some monitored (and likely some unmonitored) traplines near Chisasibi before regional climate change effects become apparent in the late-1990s. In the late-1990s, climate change started to strongly affect James Bay, and there was a massive loss of eelgrass along the entire Bay. In the La Grande sector, these extreme weather events may have accelerated the decline of eelgrass that had been already weakened by environmental changes resulting from hydroelectric development and related river diversions. The onset of extreme weather events in the late 1990s therefore played a major role in extending the eelgrass decline to the entire eastern James Bay coast, expanding and accelerating the decline that had already started in some Chisasibi traplines.

There is insufficient information to know if early eelgrass declines like those that occurred near Chisasibi before 1998 also occurred in other sectors of the coast. Eelgrass biomass monitoring data from 1982-1995 are limited to the La Grande sector. The La Grande plume does not directly influence coastal waters south of the Chisasibi traplines but the Eastmain sector was affected at least locally by the 1980 river diversion. Some Eastmain land users recall losing eelgrass from the coastline immediately south of the Eastmain River after the river was diverted; they felt the circulation had changed. However, a Cree knowledge study completed in Wemindji in 1995 described eelgrass as stable or even flourishing in parts of that territory.

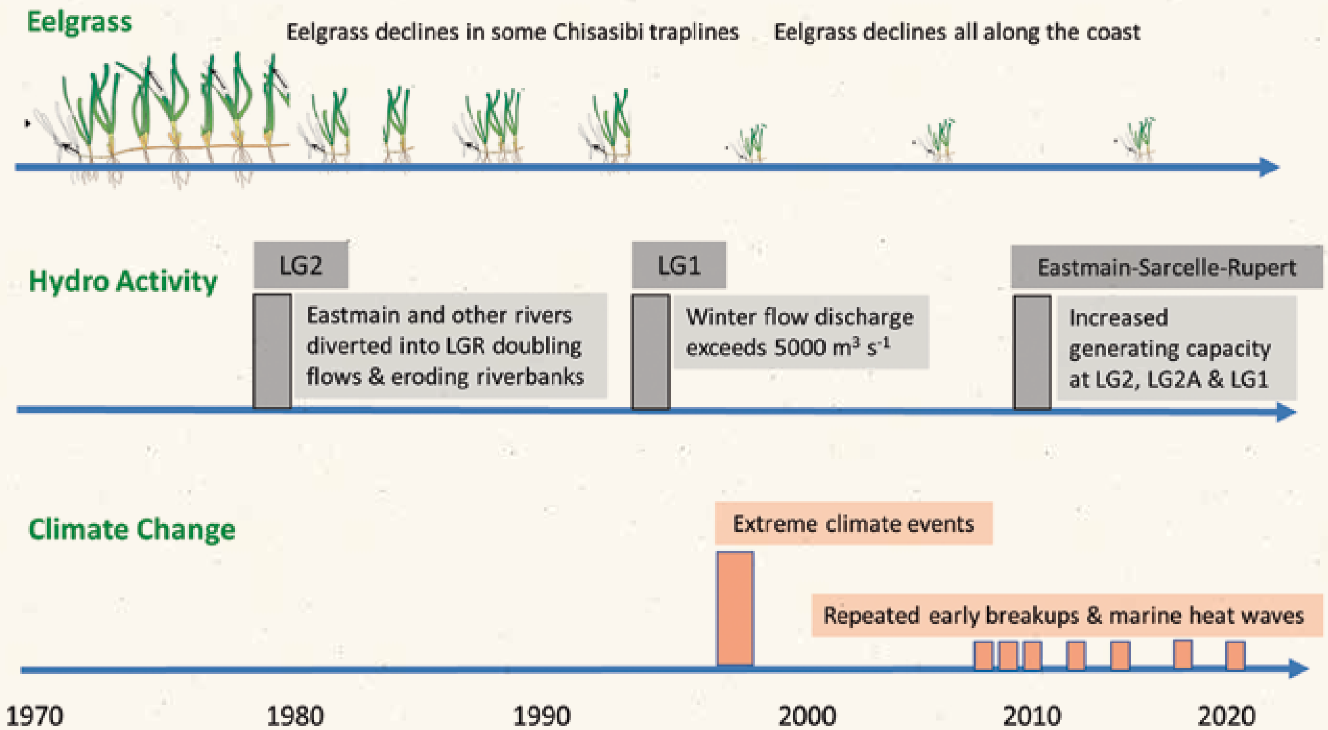


Figure 9. Timeline of eelgrass declines and environmental changes in the Eeyou coastal habitat.

Figure 10. Studying the freshwater plume of the La Grande River during summer and winter. Photo credits: C. Peck, 2019 and J. Ehn, 2016.

Figure 11. Map showing how the winter freshwater plume from the La Grande River has expanded since hydro development. The dashed line shows the extent of the freshwater plume (salinity below 5) in winter 1975-76 and the solid lines show the extent of the plume (salinity below 5, 10, and 15) during winters 2018-2021. Smaller rivers that continue to flow in winter make small areas with salinity below 5. Image credit: U. Neumeier.

Figure 12. Diver on SCUBA examines the eelgrass. Photo credit: E. Lim.

EELGRASS IN JAMES BAY HAVE FAILED TO FULLY RECOVER FROM THE DECLINES:

Eelgrass growth and extent is much less today than it was in the 1970s, 80s, and early 90s. There are small areas where eelgrass is doing better than it is in other areas, but large, dense meadows like those that once covered the large bays like Dead Duck Bay were not seen during the study. There appear to be some dense eelgrass beds in the region north of Chisasibi but the eelgrass team's SCUBA divers did not get permission to make measurements in these areas.

THE CURRENT STATE OF EELGRASS CONTRIBUTES TO LOW GOOSE PRESENCE DURING FALL:

Currently, the eelgrass is rarely more than 1 m tall, much shorter than the 2-m shoots seen in the 1970s-90s, and the eelgrass beds are smaller, patchy, and generally constrained to shallow waters (less than

2.5 m). Beds vary in quality year to year and the total area covered by eelgrass has decreased compared to 1988. *In this poor state, the eelgrass is likely less profitable as a food source for geese compared to the 1970s.*

In addition to changes in eelgrass, goose feeding habits and hunting have changed all along their migration routes and in their wintering range. More long-necked geese now undertake molt migrations through eastern James Bay and may compete with short necks for local resources. Chisasibi and Wemindji Cree also attribute change in goose abundance to changes in local hunting practices and more noise pollution associated with the mechanization of hunting and air traffic in the area. There is increased hunting pressure around some of the remaining eelgrass beds.

We conclude that the loss of large, dense, eelgrass beds partly explains changes in goose distribution along the coast and the negative effects on the fall goose hunt. The geese also changed their migratory habits in response to changes on the land along the bay (drying, more trees, fewer berries), and in the south (use of agriculture lands).

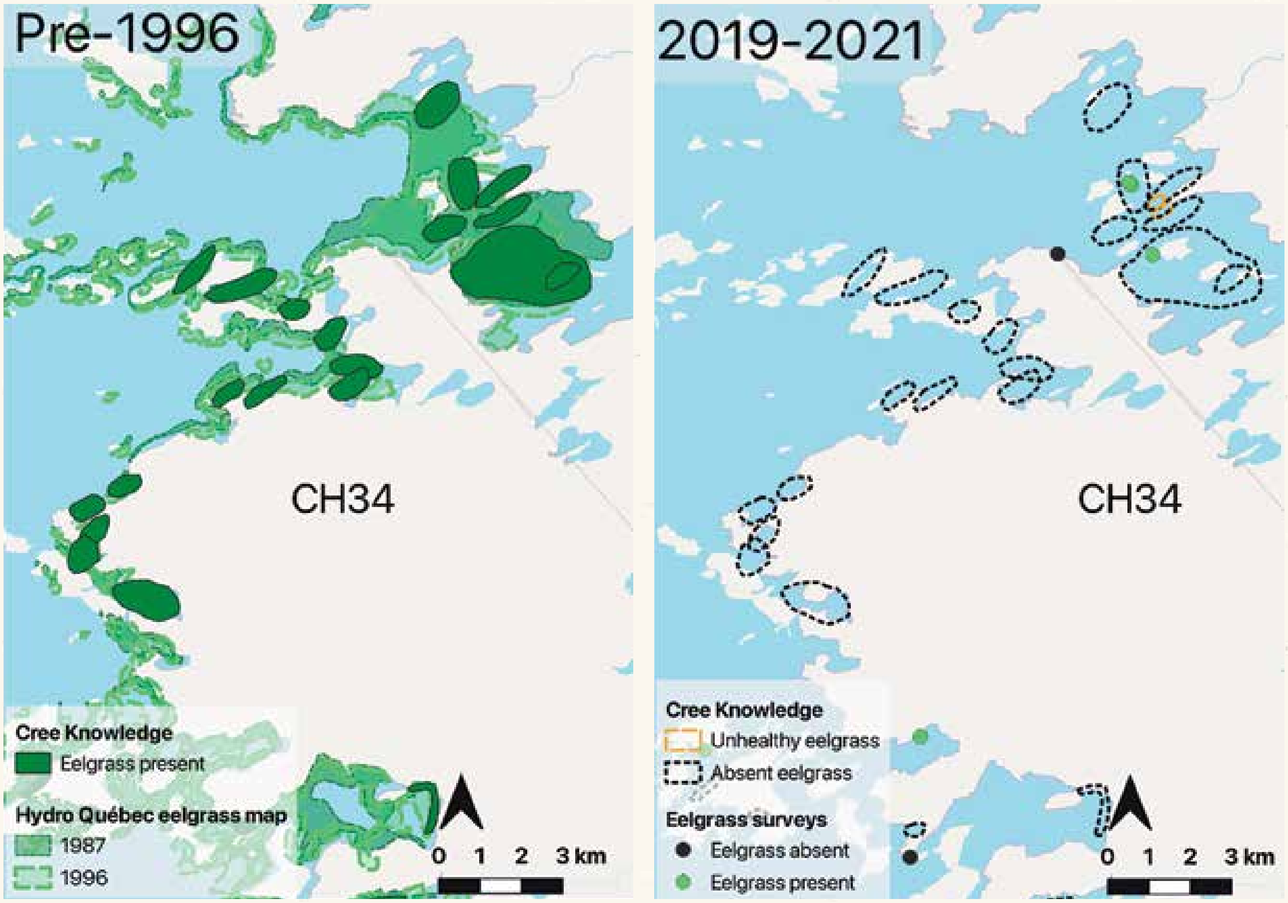


Figure 13. Eelgrass presence in 2019-2021 compared to pre-1996 in trapline CH34 (see full report for additional traplines). The maps include eelgrass beds known to Cree land users, eelgrass extent mapped by Hydro-Québec, and eelgrass absence/presence noted during eelgrass surveys by divers on SCUBA. Illustration credit: M.L. Leblanc.

WHAT IS HOLDING BACK RECOVERY OF THE EELGRASS?

CHCRP results suggest that eelgrass recovery all along the coast is held back by *lasting effects of the eelgrass decline*. The positive feedback effects of healthy eelgrass have been lost. High levels of sediment resuspension now occur that cause *low light availability* under the water during the growing season. Eelgrass needs lots of light during summer, particularly in regions where there are many months of ice cover. When eelgrass does not get enough light during the summer, it is smaller, less dense, and less prepared to survive the winters. It is more vulnerable to stressful conditions such as warmer or fresher waters or low nutrient availability. Also, some areas that lost eelgrass and where the soft sediments were washed away by waves now have a *hard bottom* (seabed). If eelgrass cannot get its roots anchored well into the bottom, it has difficulties rooting and getting nutrients, and it is also at risk of being washed away by currents and storm waves.

The Cree have consistently reported that James Bay rivers and coastal waters have become murkier and more coloured over the years. This observation agrees with published scientific reports that northern inland waters have become increasingly browner and murkier during recent decades as climate has warmed. This is being called a *browning of inland waters*. Using satellite data, we have detected a *browning of James Bay waters* over the past two decades, which may also contribute to low light availability for eelgrass. The browning may be caused by increases in riverine inputs of coloured dissolved organic matter to the Bay. Large variability in ice breakup date from year to year *and* variation in water colour and turbidity cause the light availability for eelgrass to vary four- to five-fold from one growing season to the next.

In the La Grande sector of the coast, *high flows* from the La Grande River may also impede eelgrass recovery. The analysis of eelgrass biomass data from 1982-2009 showed that eelgrass biomass at some beds was reduced after high freshwater discharges from LG1 and warmer spring water temperatures out in the bay. It is also well known that low salinity (less than 5-10, where 0 is pure freshwater and 25 is typical James Bay water) impedes eelgrass growth. Other factors that are not yet quantified such as turbidity caused by sediment erosion could not be tested.

Near Eastmain, nutrient fluxes to the coastal habitat were reduced after the diversion and local sedimentation was changed. There were also temporary effects on turbidity of the river water in the months following an intense forest fire in the Eastmain and Rupert River watersheds in 2013. The fire followed three consecutive years of dry conditions in the southern James Bay watersheds. The oceanography of James Bay is not yet well enough understood to confirm how variations in river discharge alter the various properties of the water out in the bay.

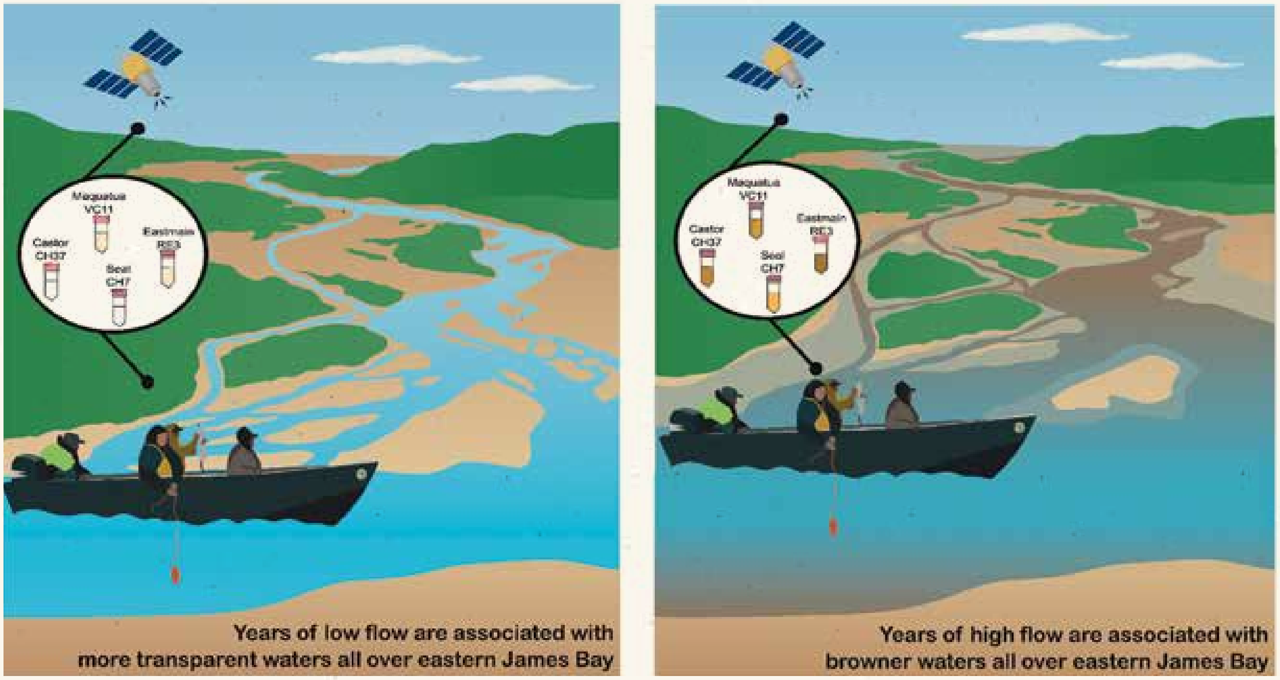


Figure 14. Using satellite data validated by water sampling, we have detected a browning of James Bay waters over the past two decades, which may contribute to low light availability for eelgrass. The browning may be caused by increases in riverine inputs of coloured dissolved organic matter to the Bay. Years of high river inflow are associated with browner waters all over eastern James Bay. Illustration credit: C. Fink-Mercier.

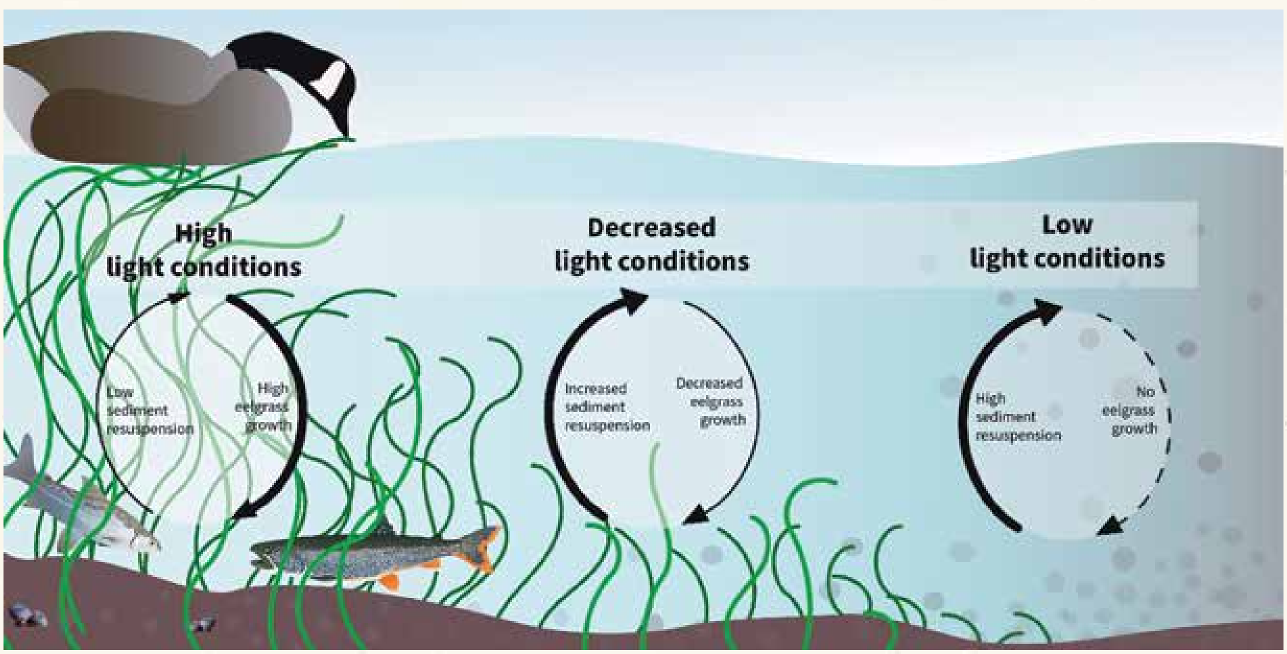


Figure 15. Positive feedback effects of dense eelgrass beds and impacts of eelgrass loss. Healthy eelgrass beds help keep the environment good for themselves and for other eelgrass beds around them by calming the water and preventing the sediment from getting stirred up off the bottom by waves. But when eelgrass declines, the sediment can be stirred up off the bottom (resuspended) by waves, leading to murky water and low light conditions that hold back eelgrass growth. Image credit: M.L. Leblanc.

THIS IS A CRITICAL TIME FOR THE FUTURE OF EELGRASS:

Although more turbid and browner water and other factors work against eelgrass recovery, eelgrass is still found in many areas, still growing, and still providing habitat for fish and birds. However, if human activities in the watershed further disturb the coastal habitat, or if climate change makes inland areas more susceptible to fires and erosion, the health of the eelgrass could decline further, or it could disappear from more areas along the coast.

This research was the first to seek a comprehensive understanding of recent environmental changes in eastern James Bay and impacts of the dam construction and diversion of rivers in the coastal habitat of Eeyou Istchee. Much was accomplished through the dedication of Cree land users, NLOs, and researchers, and the research stimulated a lot of interest in the communities. Unanswered questions remain, particularly about what could facilitate eelgrass recovery and a return to productive fall goose hunts. If the coastal habitat continues to change, it is difficult to predict how geese will adapt or respond to these changes. *Because eelgrass in eastern James Bay has persisted through major environmental changes in the past, perhaps it can recover but much depends on both how the climate varies in the coming years and future coastal management.*

Eelgrass has declined and recovered in other places. From these examples, we know the importance of long-term coastal monitoring and considering ecosystem health in environmental impact assessments and infrastructure development. The coastal habitat of Eeyou Istchee is large and complex. Some eelgrass beds may be more impacted by coastal development and others by climate change, and in places these stressors may interact. Although some impacts associated with climate change can be neither controlled nor avoided, there *is* potential to predict, manage, and mitigate potential effects of hydroelectric and other regional development as they impact coastal ecosystems.

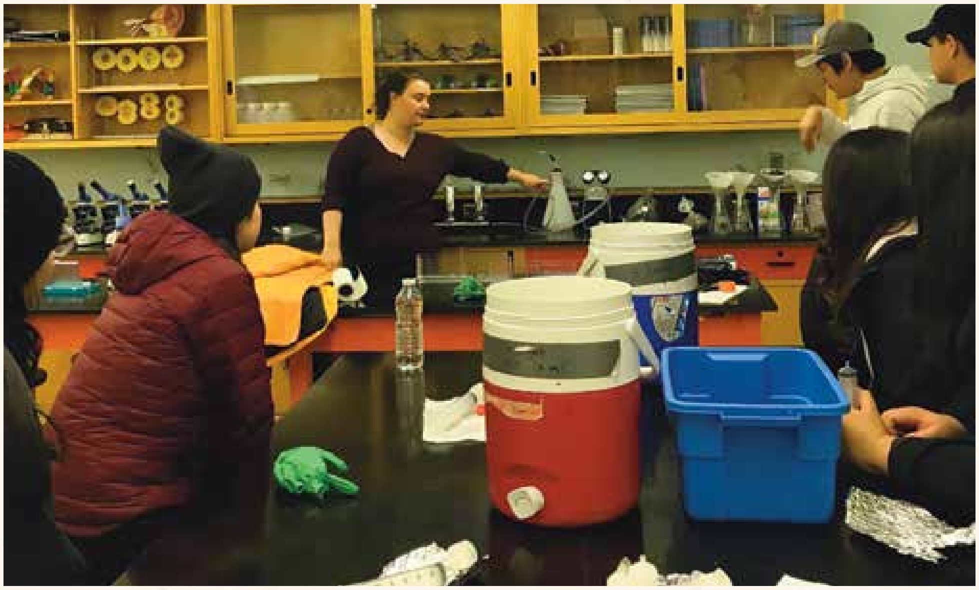


Figure 16. Outreach event demonstrating water sampling in Chisasibi school in 2019. Photo credit: A. Guzzi.

Figure 17. Cree describe eelgrass distribution in Wemindji in 2019 (left). Photo credit: G. Mark.

Figure 18. Outreach event demonstrating river sampling equipment in Chisasibi in 2019. Photo credit: P. del Giorgio.

Recommendations

In view of the importance of healthy coastal ecosystems for fish and wildlife, Cree way of life, and global processes, understanding and protecting the eelgrass ecosystems is important for the long term. It is our expectation that this report will help support future Cree-led monitoring and management. Based on our findings and discussions with Cree community members, we make the following recommendations:

The eelgrass beds are changing, as is the whole coastal ecosystem of the Bay, and even if they do not return to their past condition, these beds will remain very important ecologically. Monitoring the distribution and density of eelgrass meadows is complex and challenging, but vitally important from an ecological standpoint. A suitable monitoring strategy needs to include the following points:

- *Maximize community interest and involvement with local and regional governments and Hydro-Québec support,*
- *Employ several sampling techniques as developed in the CHCRP,*
- *Address knowledge gaps identified over the course of the CHCRP such as the influence of the high winter flows of the La Grande River on eelgrass and the influence of light-sediment resuspension on eelgrass,*
- *Assess eelgrass abundance and conditions annually to quantify spatio-temporal trends,*
- *Assess eelgrass health in areas not surveyed by researchers during the CHCRP especially north of the La Grande River.*

Monitoring the abundance and distribution of migratory waterfowl should include the following points:

- *Maximize community involvement while minimizing impacts on traditional hunting activities,*
- *Assess the changes of goose populations and track harvest success by collecting Canada Geese harvest booklets, determining the proportion of the two subspecies in the harvest (long- and short-necked geese), developing a protocol for the return of goose bands, and promoting the use of CTA's harvest phone app,*
- *Assess how the Cree waterfowl harvest has changed by compiling information on where goose camps operate, and how hunting activities are coordinated,*
- *Address knowledge gaps about the breeding grounds of the short necks hunted in fall along the coast,*
- *Assess the success of different habitat enhancement measures during the fall goose hunt by working closely with land users,*
- *Continue to assess the relationship between geese and coastal habitats, including eelgrass, by building on knowledge already compiled during the first phase.*

Discussions should continue on the feasibility and desirability of site-specific measures to restore eelgrass meadows in selected areas. An eelgrass restoration expert should be called on for advice about feasibility, and requirements for monitoring and evaluation in such an initiative.

Future development activities in the territory should recognize the vulnerability of eelgrass to sediment releases and sediment disturbance that affect water clarity in the coastal environment and if feasible include strategies to minimize and monitor these potential impacts.

Figure 19. A feast of goose and bannock is prepared in a traditional Cree way in 2019. Photo credit: J. Idrobo.

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Introduction

What is the CHCRP and why was it conducted?

The Eeyou Coastal Habitat Comprehensive Research Project (CHCRP) was initiated in 2017 to address long-standing concerns of the coastal Cree of Eeyou Istchee about declines in eelgrass along the eastern coast of James Bay and impacts on goose presence and Cree hunting activities (Figure 1-1). Niskamoon Corporation was mandated by the Cree Nation Government and the Cree Nation of Chisasibi to coordinate the research project. They established a Steering Committee made up of representatives from coastal Cree communities, regional Cree organizations, and Hydro-Québec to oversee the research.

The research addressed two main questions:

- *What are the main factors affecting the current state of eelgrass along the eastern coast of James Bay?*
- *What is the impact of the current state of eelgrass on waterfowl presence and consequently Cree hunting activities?*

The research took place along the coast of Eeyou Istchee in eastern James Bay and involved four coastal communities—Chisasibi, Wemindji, Eastmain, and Waskaganish (Figure 1-2). Niskamoon Local Officers in the communities including Ernie Rabbitskin, Geraldine Mark, Norman and Wilfred Cheezo, Gregory Mayappo, Merlin Whiskeychan, Clarence Happyjack, and Ernest Moses, helped coordinate the research (Table 1-1). Chisasibi technician Laura-Lee Sam assisted with water sampling and processing. Additionally, Cree tallymen and more than 60 Cree land users from 20 traplines helped with the research activities. Interviews about eelgrass, geese, and hunting were conducted with Cree knowledge holders from the four First Nations. Cree land users contributed to collecting observations of the water, sediment, eelgrass, and geese. Researchers accessed sites adjacent to each coastal trapline with the permission of the trapline's tallyman[2] and were guided by land users knowledgeable about each specific coastal area.

2 Traplines CH4, CH5, and CH6 ceased participating in 2019, after which researchers did not access these areas.

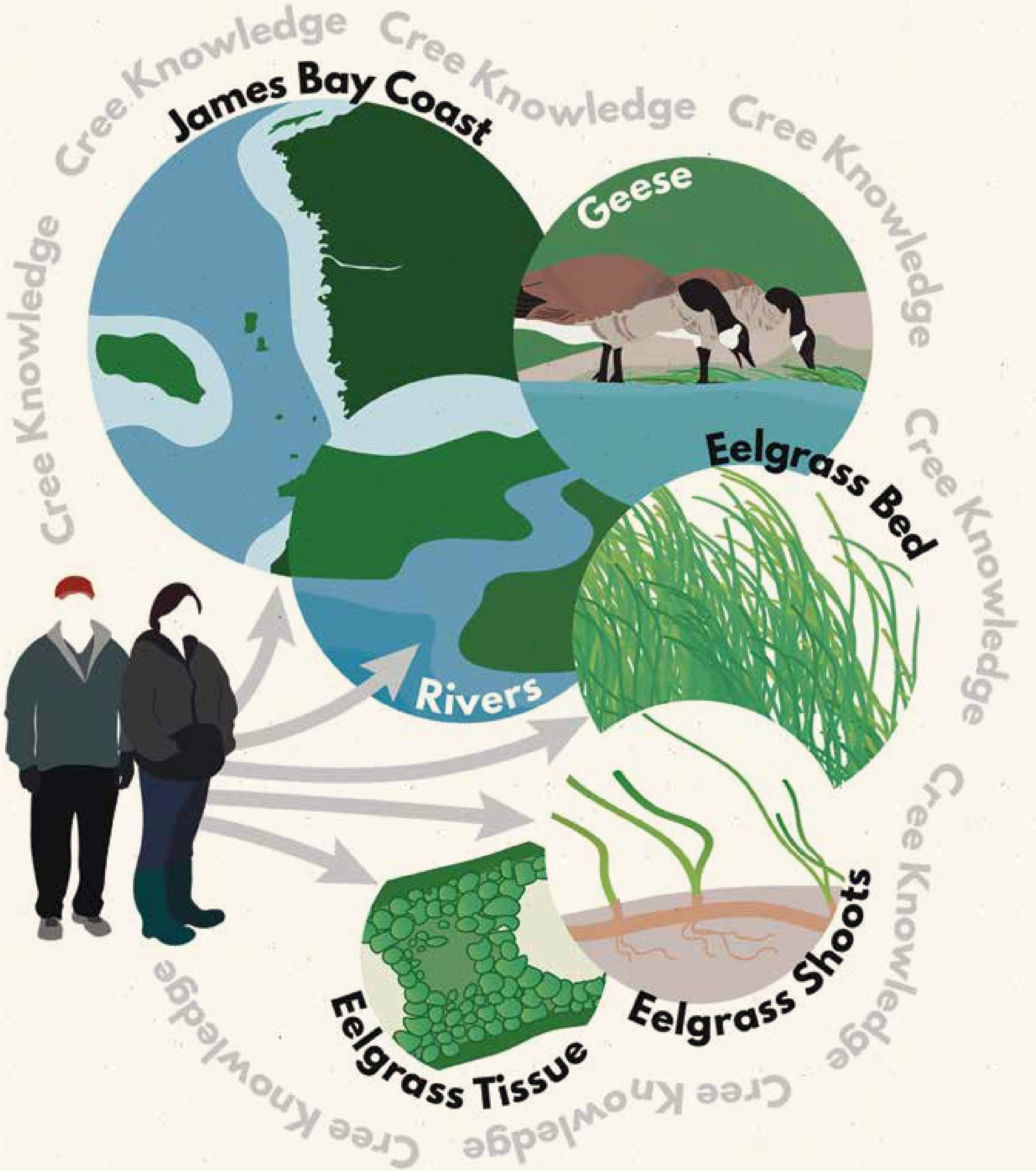


Figure 1-1. Visual overview of the components of the coastal habitat research project: rivers, coastal ocean, eelgrass, geese, and Cree Knowledge. Courtesy: Align Illustration.

Figure 1-2. Coastal Cree communities and First Nations in Eeyou Istchee—Chisasibi, Wemindji, Eastmain, and Waskaganish. Source: EMRWB (2020).

Table 1-1. Research coordinators and research teams for the project.

COMMUNITY/TEAM	TEAM LEADER(S)	TEAM MEMBERS AND AFFILIATIONS
Niskamoon Local Officers and Technicians		
Chisasibi	Ernie Rabbitskin	Laura-Lee Sam
Eastmain	Norman Cheezo, Wilfred Cheezo, and Gregory Mayappo	
Wemindji	Geraldine Mark	
Waskaganish	Ernest Moses, Merlin Whiskeychan, and Clarence Happyjack	
University Researchers		
Traditional Knowledge	Julian Idrobo (UBC)	Alexa Mantifel (UBC)
River team	Paul del Giorgio (UQAM)	Michaela de Melo, Caroline Fink-Mercier, Marie-Laure Gérardin, Serge Paquet, and Alice Parkes (all at UQAM)
Ocean team	Urs Neumeier and Michel Gosselin (ISMER)	Simon Bélanger (UQAR), Huixiang Xie (ISMER), Jean Carlos Montero Sarrano (ISMER), André Rochon (ISMER), Simon Senneville (ISMER), Caroline Fink-Mercier (ISMER), Virginie Galindo (ISMER), Amélie Évrard (ISMER), Daniela Walch (UQAR), Rakesh Kumar Singh (UQAR), Raphael Mabit (UQAR), Rémi Costanzo (ISMER), Félix Lachapelle (UQAR), Valentin Gaillardon (UQAR), Marie-Hélène Carignan (ISMER), Constance Marty (ISMER), Manfred Désiré Bonga Nyetem (ISMER)
	Zou Zou Kuzyk and Jens Ehn (UM)	Christopher Peck, Alessia Guzzi, Madelyn Stocking, Kaushik Gupta, Aura Diaz, Devin Hammett, Stephen Ciastek, David Babb, Alex Crawford, Jennifer Bruneau (all at UM)
Eelgrass team	Mary O'Connor (UBC)	Fanny Noisette (ISMER), Brigitte Leblon (UNB), Armand Larocque (UNB), Lou Richer (ISMER), Kaleigh E. Davis (UBC), Kevin Clyne (UNB), Abraham Olatunji (UNB), Melanie-Louise Leblanc (UBC), Murray Humphries (McGill), Em Lim (UBC), Stéphanie Lacoste (McGill), Del Heal (UBC)
Goose team	Jean-François Giroux (UQAM)	Manon Sorais and Martin Patenaude-Monette (UQAM)

UM - University of Manitoba

UBC - University of British Columbia

UQAM - Université du Québec à Montréal

ISMER - Institut des sciences de la mer de Rimouski

UQAR - Université du Québec à Rimouski

UNB – University of New Brunswick

*For 2017, eelgrass team was Fred Short (UNH), Dante Torio, and Nick Anderson

Five university research teams with different types of expertise were assembled to complete the project (Table 1-1). Detailed team reports may be found on the Niskamoon CHCRP social media page (https://www.facebook.com/EeyouCoastalHabitats/; https://www.eeyoucoastalhabitat.ca/). Briefly, the river team installed new stations to monitor river discharge and conducted fieldwork across several seasons to assess water quality properties in rivers distributed all up and down the coast. The ocean team sampled coastal seawater, ice, and sediment, and monitored currents and key ocean properties like salinity and temperature throughout the coastal habitat during various seasons. They measured bottom depths, sediment properties, nutrients, and light.

The eelgrass team conducted underwater observations and sampling of eelgrass beds. They also conducted experiments to assess the sensitivity of eelgrass to underwater light conditions and nutrients. Using satellite data, they mapped the eelgrass bed distribution and other coastal habitat types.

The goose team assessed the populations of geese that were being harvested by Cree. They also assessed the migrations routes followed by tagged Atlantic population Canada Geese. They used GPS tracking data and aerial surveys to study the kinds of coastal habitats that were being used by migrating geese when they made a stopover in the area.

The Cree Knowledge team documented information shared by Cree land users of all ages about the rivers, coastal waters, eelgrass, geese, and Cree hunting practices both now and in the past. They interviewed Cree community members across all communities. They also worked with land users to capture on paper maps some of the changes in eelgrass beds.

In addition to formally documenting Cree Knowledge for the project, the research team embraced opportunities for knowledge exchange with coastal Cree land users (see photos assembled in Figure 1-3). Community members from all communities actively participated in the research. The communities made unique contributions reflecting differences in their past and present use of the eelgrass habitat for hunting geese. Cree Knowledge was shared with researchers throughout the project at formal meetings, informal meetings, meals shared together in communities, and out in the boats and on the land. This shared knowledge contributed to the design and implementation of studies done by each project team.

CHCRP Research Process

Viewed through a more formal lens, the CHCRP research process included three components essential for designing and interpreting community-driven research (Figure 1-4): co-development, community engagement, and co-validation. The components were not done consecutively but rather reflected a way of working that was repeated year after year. As the relationships strengthened between researchers and Cree land users over time, the components became more effective at improving the quality of the research. Each component also aimed to ensure that the study outputs respected and upheld the two primary principles upon which the agreement was based: academic freedom and support for Indigenous

Figure 1-3. Photos of researchers and community members interacting during the project.

people's self-determination in research. Academic freedom acknowledges researchers' rights to (i) examine data, question assumptions, and be guided by evidence, (ii) submit knowledge and claims to rigorous and public review by peers (experts in the subject matter), and (iii) ensure that funding and other types of partnerships do not put pressures on them (Association of Universities and Colleges of Canada AUCC 2011). The Indigenous self-determination principle recognizes the inherent right to govern the collection, storage, use, and dissemination of data pertaining to Indigenous peoples' knowledge and health, the wildlife they harvest for food, and the environments in which they live (ITK 2019). The validity of both perspectives, academic and Indigenous, was a prerequisite for developing effective academic-community research partnerships.

Research co-development occurred as part of a regular review of proposed research activities by the Steering Committee (SC), which had representatives from the coastal communities (Table 1-2), and during consultations in the communities. The SC provided high-level feedback on researchers' proposed work before the onset of each set of field activities. Upon arriving in the communities, Cree tallymen and land users provided a more detailed review of proposed plans, which, for example, fine-tuned the selection of sampling sites. Strong efforts were made to respect the traditional authority structure, including consulting with the tallyman, goose boss, or other designated Cree land users to co-develop the detailed sampling plans.

Engagement with Cree land users was coordinated by Niskamoon Local Officers (NLO). They facilitated the direct involvement of more than 60 Cree land users in the research. Each coastal community had its own NLO with a mandate to facilitate the inclusion of land users and monitoring activities. The tallyman typically identified the knowledgeable land users to guide outsiders into the nearshore waters and look after their safety as well as share knowledge about eelgrass and waterfowl. The NLOs scheduled the activities and arranged for the land users' involvement on a day-to-day basis. In addition to researchers working closely with Cree land users, on many occasions, researchers had meals or even spent overnight visits at families' traditional cabins out on the traplines. These are places where extended family networks gather for traditional activities such as fishing, berry picking, and especially goose hunting. The hospitality of the tallymen and their families provided opportunities for rich knowledge exchange.

The third component, co-validation of research results, included two distinct review methods. The first review was done among research teams and the CHCRP-SC. Both groups were invited to provide comments on draft manuscripts and reports. The second review procedure involved the co-validation of various sets of results and the overall integrated results through community participation during meetings and consultations. CTA representatives were engaged in all the knowledge validation exercises for this project and the elected Chiefs and Councils received regular updates on the project and the research results as they emerged over 2017–2022. Both review processes, among research teams and CHCRP-SC and with the community, were iterative. The SC review occurred before researchers submitted their work for consideration for publication in a peer-reviewed journal or other media accessible to the broad public. This review process ensured that the SC members were familiar with the research

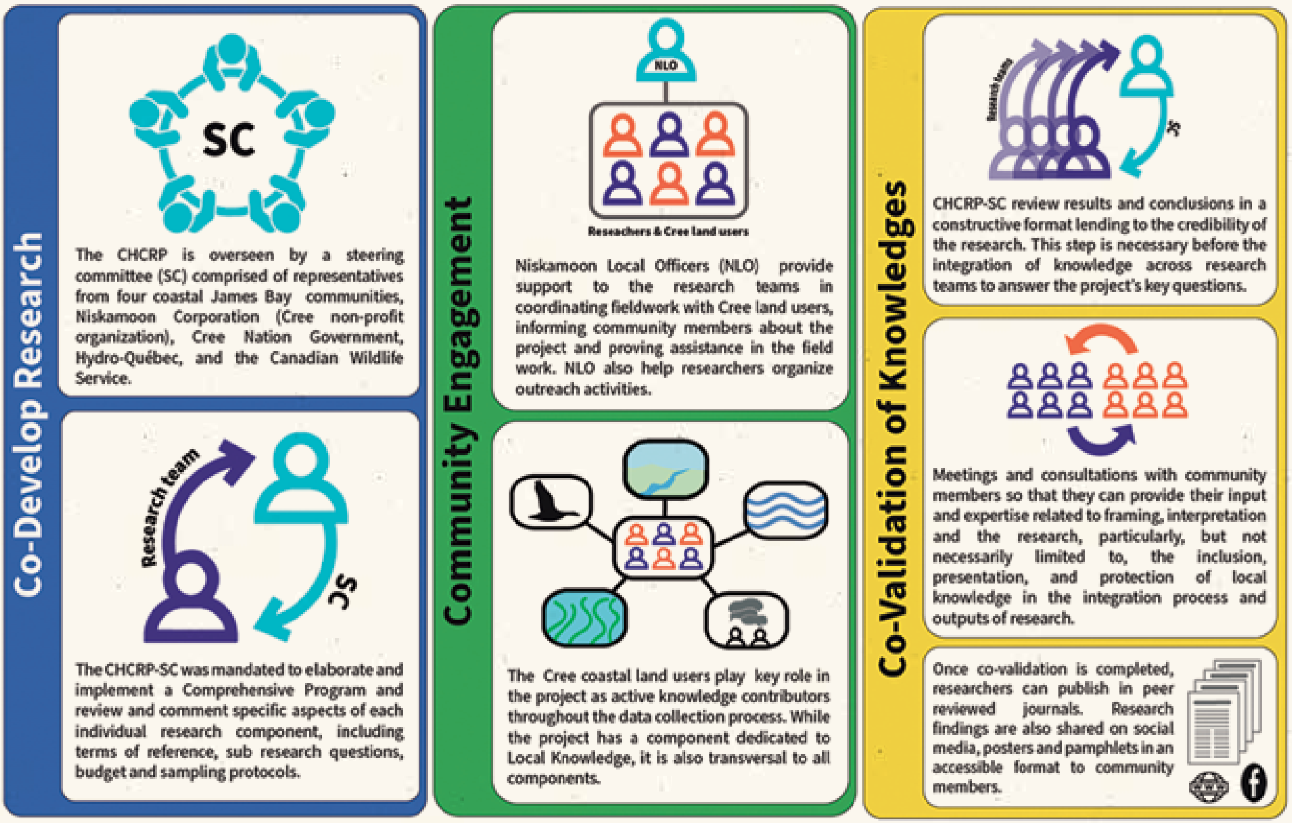


Figure 1-4. Schematic illustrating research approach.

findings as the project went along and could anticipate and help researchers address questions from community members.

During the development of the integration report, preliminary results were co-validated through a series of in-person meetings in the communities in April and August 2022. The integration lead (Kuzyk) and other delegates (Leblanc, Fink-Mercier, O'Connor, Noisette, Sorais, and others) met with groups of Cree land users active in the research and other knowledgeable community members including Elders and tallymen. They also met with community leaders. These meetings were structured to promote discussion between the researchers and community members. Some land users raised points that needed clarification and identified gaps.

A synthesis of the integration results was presented over two days in Chisasibi in September 2022 with members of all the coastal Cree communities in attendance. A pamphlet was distributed in English and Cree to promote discussion and reach a wider audience across the communities (see Appendix A). The Chisasibi radio carried the entire proceedings. The meeting was followed by a half-day workshop or "Cree

Café" to discuss the results and future considerations (see notes in Appendix A). A video was prepared to summarize the findings and will remain hosted on the Eeyou Coastal Habitat social media account at https://www.facebook.com/EeyouCoastalHabitats/.

Table 1-2. Steering Committee members (past and present).

NAME	AFFILIATION
Marc Dunn	Niskamoon Corporation
Robie Tapiatic	Niskamoon Corporation/Cree Nation Government
Ernie Rabbitskin	Niskamoon Corporation
Ernest Moses	Cree Nation of Waskaganish
Clarence Happyjack	Cree Nation of Waskaganish
Normand Cheezo	Cree Nation of Eastmain
Geraldine Mark	Cree Nation of Wemindji
James Bobbish	Cree Nation of Chisasibi
John Lameboy	Cree Nation of Chisasibi
Louie Kanatewat	Cree Nation of Chisasibi
Rodrick Pachano	Cree Nation of Chisasibi
Emily Sinave	Cree Nation Government
Félix Boulanger	EMR Wildlife Board
Jean-Phillippe Gilbert	Hydro-Québec
Alain Tremblay	Hydro-Québec
Carine Durocher	Hydro-Québec
Real Courcelles	Hydro-Québec
Jean Rodrigue	Canadian Wildlife Service
Josée Lefebvre	Canadian Wildlife Service

What is the Integration Report? - A Guide for Readers

This report brings together the scientific results of the research project, Cree Knowledge shared during the project and in previous reports, and historical information contained in various Hydro-Québec reports and government documents dating from the 1970s.

The report has the following structure:

- *The second section provides background about eelgrass, geese, and the coastal habitat of Eeyou Istchee.*
- *The third section describes the potential factors influencing where and how eelgrass grows.*
- *The fourth section describes the condition of eelgrass along the Eeyou coast in the past and at present.*
- *The fifth section describes the coastal habitat characteristics with emphasis on what has changed.*
- *The sixth section discusses the impact of the state of the eelgrass on waterfowl presence and Cree hunting activities.*
- *The final section provides conclusions.*
- *Appendices include the pamphlet and notes of the workshop (Cree Café) that followed the Symposium in Chisasibi in September 2022 (Appendix A); glossary of terms (Appendix B); additional information about the eelgrass mapping efforts along the coast from 1975 to 2014 (Appendix C); additional information about methods used in mapping depth distribution of eelgrass by Autonomous Underwater Vehicle (AUV) (Appendix D); and a list of publications associated with the project (Appendix E).*

Background

Eelgrass, geese, and the coastal habitat of Eeyou Istchee

Eelgrass, which scientists call *Zostera marina* and Cree call *Shkaapaashkw,* is a marine flowering plant that grows submersed in the coastal ocean. Although eelgrass beds are found along Canada's Pacific and Atlantic coasts and in Alaska, there are fewer records of eelgrass along Canada's Arctic and Subarctic coasts (Figure 2-1). The eelgrass meadows along the eastern coast of James Bay were once among the most extensive in North America (Lalumière et al. 1994) and remain the most extensive eelgrass beds documented anywhere across Canada's north.

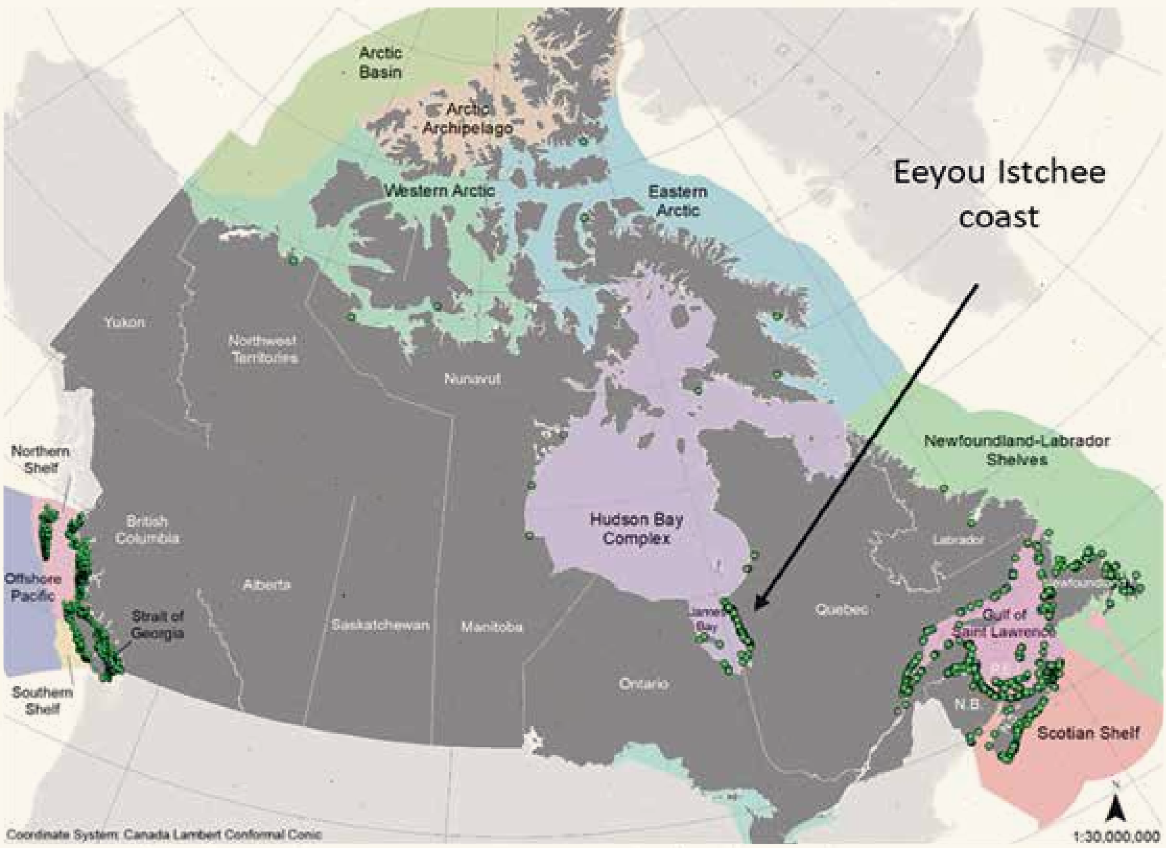


Figure 2-1. Map showing distribution of eelgrass (Zostera marina) in Canada. Points represent locations of published studies or reports where eelgrass meadows have been observed. Source: Murphy et al. (2021).

Eelgrass has long slender green leaves (shoots) that extend upward into the water and reach toward the surface. In shallow water, the shoots may lie along the surface of the water at low tide (cf., Figure 2-2). Eelgrass also has a root and rhizome system in the sediments. Eelgrass flowers, pollinates, and releases seeds under the water and expands vegetatively by spreading its rhizomes beneath the sediment and sending up new shoots. The eelgrass beds in eastern James Bay may grow at water depths of 0.5–4 m (Lalumière et al. 1994).

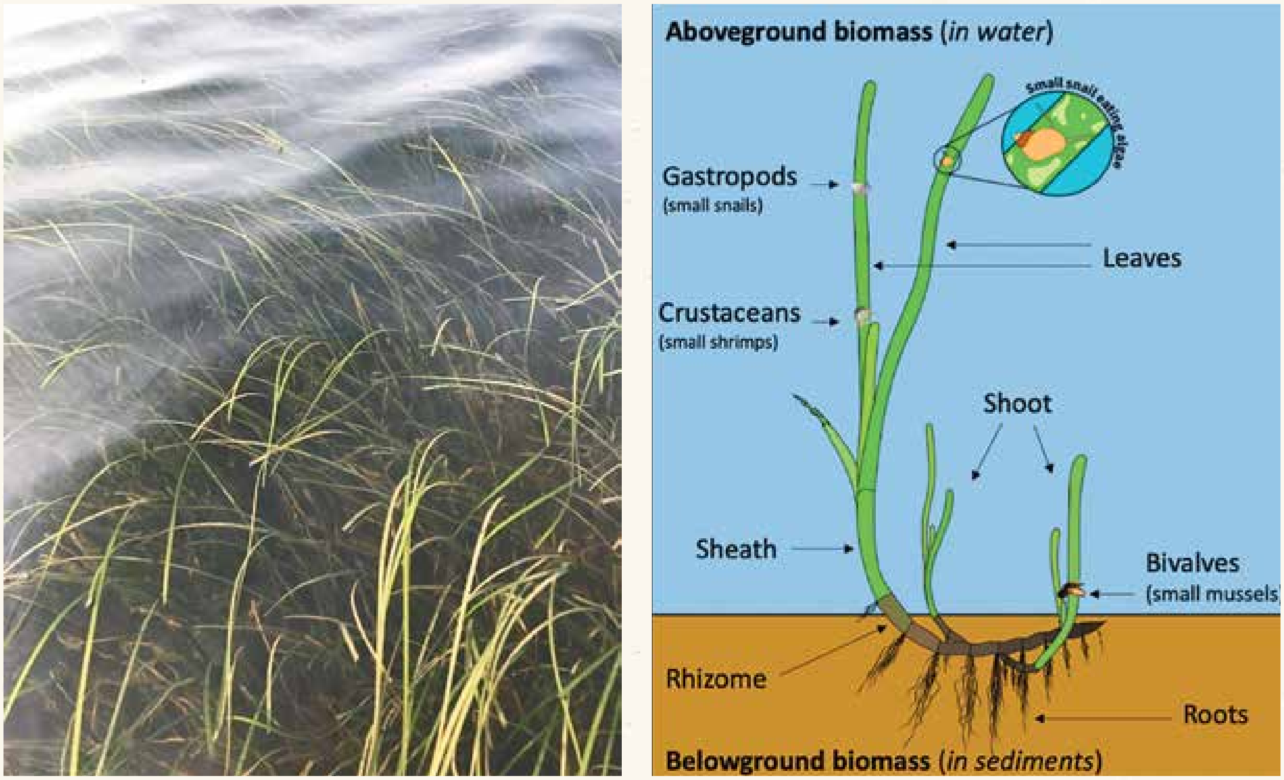


Figure 2-2. Photo of eelgrass in eastern James Bay with the shoots lying along the surface of the water at low tide and diagram showing eelgrass parts.

Wherever eelgrass grows, it is considered a foundation species because it provides habitat for numerous species including mammals, fish, small organisms (invertebrates), algae, waterfowl, and microbes (Figure 2-3) (Larkum et al. 2006; Murphy et al. 2021). Eelgrass has long been considered an important food source for many waterfowl species migrating along coastal zones (Ganter 2000; Kollars et al. 2017; Murphy et al. 2021) and is recognized as an Ecological Significant Species in eastern Canada by the federal government (DFO 2009). Eelgrass-reliant waterfowl populations tend to closely track the abundance of this resource during migration, and abrupt changes in eelgrass availability have been known to significantly alter the timing and location of their stopover behavior (Kollars et al. 2017). Waterfowl populations known to rely on eelgrass as a food source include the Black Brant (*Branta* *bernicla nigricans*) on the west coast of North America (Moore et al. 2004) and the Atlantic Brant (*Branta bernicla hrota*) on the east coast (Ladin et al. 2011; Ladin et al. 2014). Some populations of Canada Geese (*Branta canadensis*), like those staging in Nova Scotia, also heavily rely on eelgrass during the fall migration (Hanson 2004; Seymour et al. 2002). Waterfowl and eelgrass may have reciprocal relationships. Indeed, both scientific (Shaughnessy et al. 2021; Unsworth et al. 2015) and Indigenous knowledge sources (Ettinger and Lajoie 1995; Turner 2020) suggest that eelgrass meadows benefit from moderate disturbances associated with waterfowl grazing. On the other hand, overgrazing by waterfowl may result in long-term reduction of eelgrass biomass and coverage (Kollars et al. 2017).

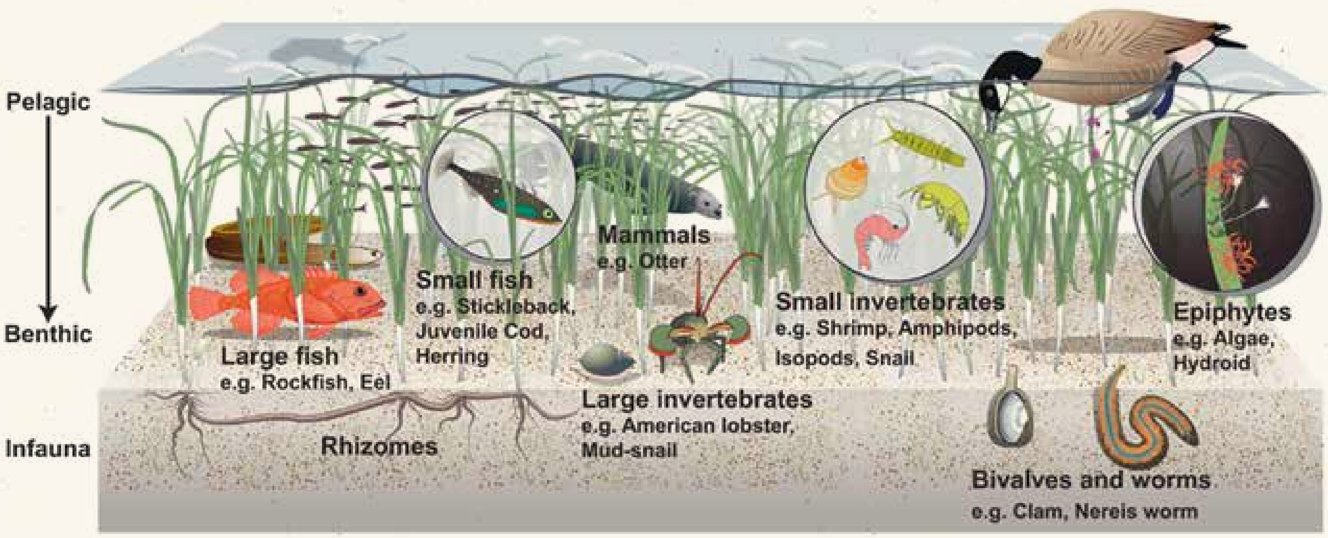


Figure 2-3. Illustration of a Canadian eelgrass meadow with simplified species assemblages representing the kinds of animals found in all meadows, with specific species found in the Pacific, Atlantic, and James Bay. Illustration © Sylvia Heredia. Source: Murphy et al. (2021).

In eastern James Bay, the eelgrass beds are a nursery for juvenile fish and even more importantly support tens of thousands of migrating waterfowl, especially geese (Curtis and Allen 1976; Dignard and Service 1991; Ettinger and Lajoie 1995; Lajoie and Cuciurean 1994). The coastal Cree have long emphasised the importance of healthy eelgrass in shaping the stopover sites of Canada Geese. Four populations of geese contribute to the coastal Cree harvest at the present time, including the Atlantic Flyway Resident Population, Mississippi Flyway Giant Population, Southern Hudson Bay Population, and Atlantic Population (Giroux et al. 2022). Each goose population has different fecundity and mortality rates that influence its size and ultimately hunting success.

Geese from the Atlantic Population, which breed in the Subarctic (Figure 2-4), are locally called 'short-necked geese' (or 'short-necks') and are the focus of the traditional subsistence hunt (Berkes et al. 1994; Prevett et al. 1983). The short-necks, which extensively used the eelgrass habitat in the 1970s (Curtis and Allen 1976), are now the focus of concern about the impact of the eelgrass decline. Another important waterfowl species is the Atlantic Brant (*Branta bernicla hrota*). Brant is an Arctic-breeding migratory waterfowl species that relies heavily on eelgrass for food during migration and overwintering (Ganter 2000; Kollars et al. 2017; Reed et al. 1996). The Atlantic Brant nests on Southampton Island and around the Foxe Basin in the eastern Canadian Arctic and overwinters along the eastern coast of the U.S., from Massachusetts to North Carolina (Ganter 2000). Unlike other species of geese, Atlantic Brants rely on eelgrass during migration, preferring coastal estuaries, shorelines, and lagoons for feeding (Ladin et al. 2011; CWSWC 2022).

For more than a decade, Cree have observed a reduction in the number of short-necked geese and Brant along the east coast of James Bay and consequently lower hunting success (Peloquin and Berkes 2009). The low numbers of geese have persisted year after year; it is not simply the natural year to year variation that occurs when the seasons change too abruptly, or some other factor that causes the geese to fly over the territory too high or at night. Already in the 1970s some elders raised concerns that geese may have changed their migration routes towards inland areas due to increased hunting and disturbance along the coast (Berkes 1978; Scott 1979; Scott 1983). However, between the 1980s and 2000s, it seemed to get worse. The major ecological changes and their impacts on Cree culture and way of life were brought forward by Chisasibi Cree (Cree Nation of Chisasibi 2015; FOPO 2008). The many questions that remain today about the current state of the coastal habitat and the causes of the past changes motivated the current research.

In addition to providing benthic habitat, shelter for fish, and stopover sites for migrating geese, eelgrass beds in eastern James Bay likely provide a large number of ecosystem services including buffering waves during storms (Barbier 2017; Barbier et al. 2011), improving water quality and clarity (Orth et al. 2020), and carbon storage and sequestration (Fourqurean et al. 2012).

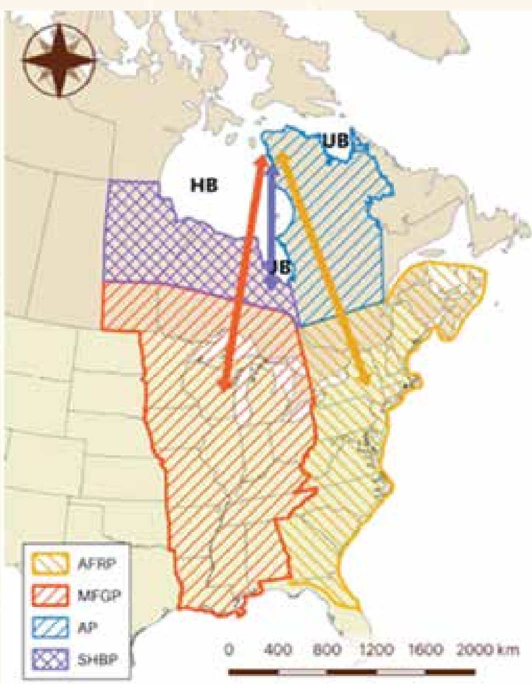


Figure 2-4. Breeding ranges of the four populations of Canada Geese harvested along the eastern coast of James Bay: AFRP: Atlantic Flyway Resident Population; MFGP: Mississippi Flyway Giant Population; AP: Atlantic Population; SHBP: Southern Hudson Bay Population. Arrows represent molt migration movements. Source: Giroux et al. (2022).

According to the *Migratory Bird Habitat Task Force Report* prepared by community members from Chisasibi, "*A major indicator of healthy eelgrass is aayoshtinuuktícj, which means that as soon as the tide recedes the eelgrass settles and calms the water in the area of the eelgrass beds.*" Scientists describe healthy eelgrass as having a *positive feedback effect* on the environment: healthy eelgrass alters the environment in a way that helps more eelgrass to grow.

The figure below (Figure 2-5) illustrates how this feedback process from healthy eelgrass works. It contrasts the differences in water clarity and thus underwater light availability between an area with healthy eelgrass and little to no eelgrass. The former environment (with healthy eelgrass) will have clear water and low levels of sediment in the water column (high water clarity). Because eelgrass needs relatively high light levels in the water to grow well, the calm, clear water within healthy eelgrass beds promotes further growth and spreading of eelgrass. In contrast, at unvegetated muddy areas of James Bay, the waters can be quite turbid on windy, ice-free, days because bottom sediments easily undergo resuspension, i.e., get stirred up off the bottom by waves. Sediment suspended in the water makes the water look turbid or dirty (i.e., causes low water clarity). The suspended sediment blocks the sunlight from reaching eelgrass and other underwater plants. Turbid water will not let much light pass through, thereby slowing down eelgrass growth. Sediment resuspension also makes it difficult for seedlings to get properly anchored to the bottom because the remaining sediment is usually very compact.

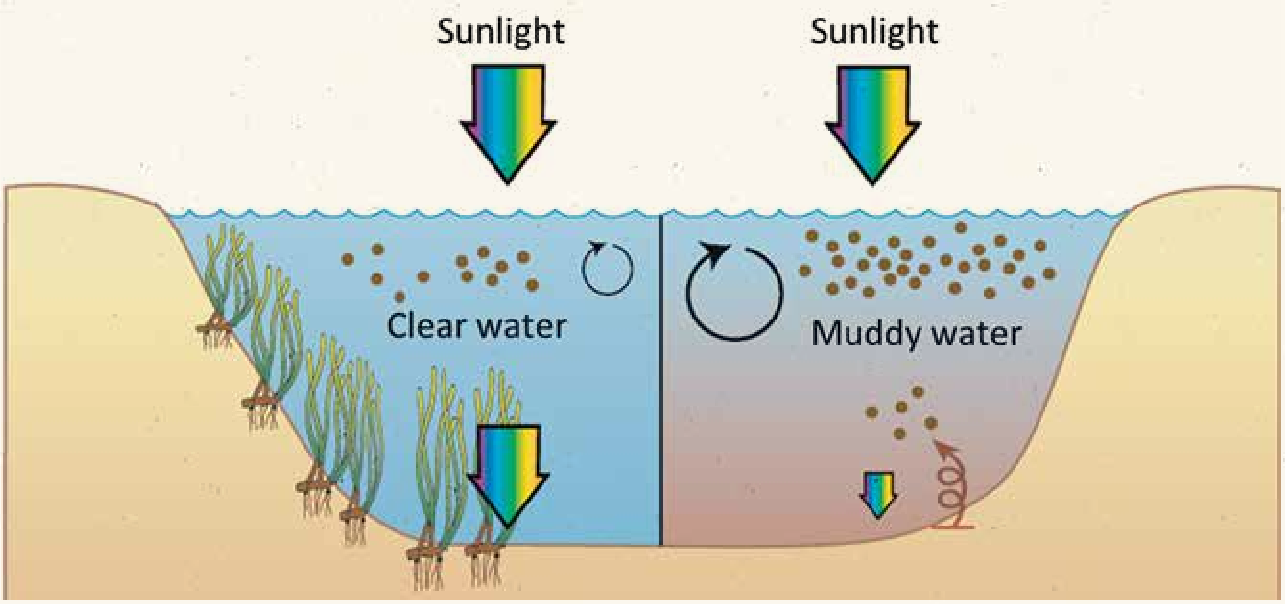


Figure 2-5. Eelgrass and its effect on the environment. Large dense eelgrass beds keep the water clear. Water slows down when it hits the eelgrass shoots. This reduces wave energy (circular arrow) and allows sediment (brown dots) to fall out of the water column onto the bottom (seabed). When sediment is on the bottom and not suspended in the water, less of the sunlight gets blocked. There is more light reaching the eelgrass shoots, which is important for optimum eelgrass growth. When there is no eelgrass, the waves cause sediment to be resuspended off the bottom and into the water column (curly arrow), leading to muddy waters that do not let the sunlight through. Modified from https://www.rimonitoring.org/eelgrass-beds/.

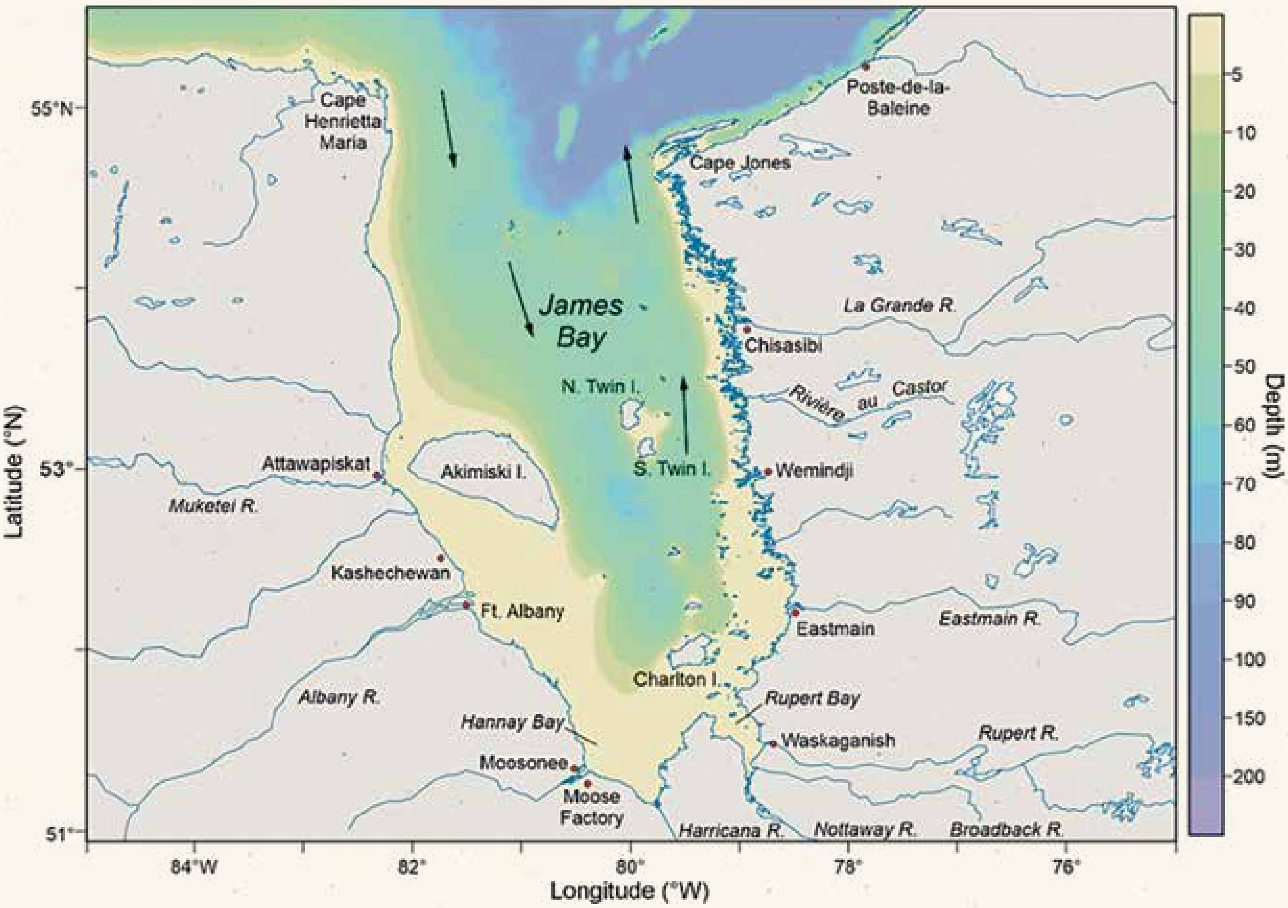
Physical environment of James Bay

CIRCULATION AND SURFACE WATERS

James Bay extends over an area of more than 68,000 km^2. Seawater with a salinity of 28–30 flows into James Bay from Hudson Bay along the northwest coast and below the surface and exits James Bay mostly along the northeast coast (Figure 2-6). Based on available measurements and increasingly sophisticated ocean models, there is probably some seasonal variation in the circulation patterns of the surface waters. In spring and early summer, there may be a brief reversal of flow where water flows out of James Bay along the northwest coast as well as the northeast coast (Ridenour et al. 2019). This is because of the large amounts of river discharge into James Bay at that time of year (Meilleur et al. 2023; Ridenour et al. 2019). The subsurface inflow to James Bay from Hudson Bay to replace the surface waters that flow out (i.e., estuarine circulation) is believed to be stronger during summer as well, although no measurements have been reported since the 1970s (El-Sabh and Koutitonsky 1977; Prinsenberg 1980; Prinsenberg 1984; Prinsenberg 1986; Ridenour et al. 2019; Saucier et al. 2004).

At a very large scale, the offshore waters of James Bay have higher ambient salinity in the north and lower salinity in the south (Figure 2-7). This spatial pattern is present during both winter and summer and reflects the exchange with Hudson Bay and the influence of river inflow and sea ice melt (Ingram and Prinsenberg 1998; Prinsenberg 1986). During winter, surface waters throughout the whole bay have higher salinity than during summer (compare Figure 2-7a and b) because the process of sea ice formation releases salt (brine) into the water beneath the ice. Sea ice melt makes surface waters fresher during spring and summer. In addition to local ice melt, which is maximum in May–June, sea ice melt in southern Hudson Bay may influence northern James Bay waters during the summer months (Prinsenberg 1984).

Another factor in the large-scale salinity distribution is the large amount of river discharge that enters James Bay at the south end and along the east coast (Déry et al. 2011; Déry et al. 2016). Distinct areas of low salinity near river mouths—called river plumes—can be seen in Figure 2-7. The largest of these features is the plume of the La Grande River, which is the largest river discharging to James Bay and has higher than natural discharge since the 1970s due to hydroelectric development (dams and diversions).



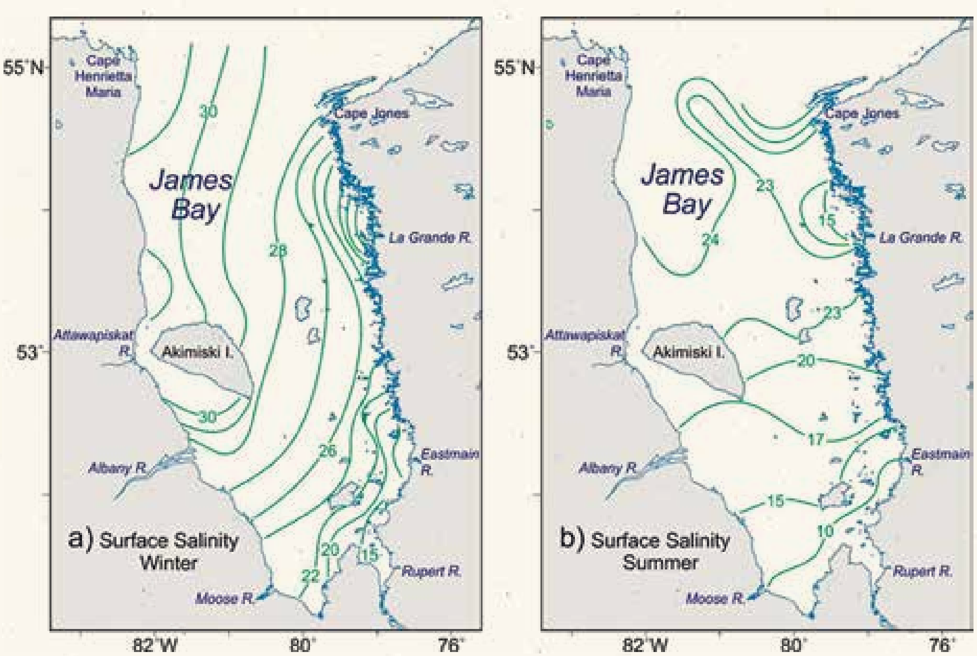


Figure 2-6 (top). Bathymetric map of James Bay. Arrows show general northward surface water circulation.

Figure 2-7 (left). Typical surface salinity distributions in James Bay in winter (a) and summer (b) as drawn in Ingram and Prinsenberg (1998).

SEA ICE

Sea ice is an important feature of James Bay affecting water salinity and temperature, transporting sediments, and dictating the length of the growing season for eelgrass because it blocks incoming sunlight leading to dark conditions in the water below. During winter, James Bay is fully covered by sea ice, which is mostly mobile pack ice that covers and slowly drifts around in the offshore waters (Figure 2-8). The ice forms during November–December, virtually covers the bay during January–April, and melts during May–June. However, sometimes sea ice persists in northern areas up to July. This can be ice that drifts into James Bay from southern Hudson Bay, where large, thick, and dirty (sediment-laden) ice floes often end up concentrated along the coast (cf., Barber et al. 2021). Landfast ice, i.e., ice attached to the land, rims the shoreline of James Bay and extends out about 15–25 km in many places (Figure 2-9). Immediately beyond the outer edge of the landfast ice is a flaw lead that is intermittently open, depending on the currents and winds (Messier et al. 1989; Peck et al. 2022).

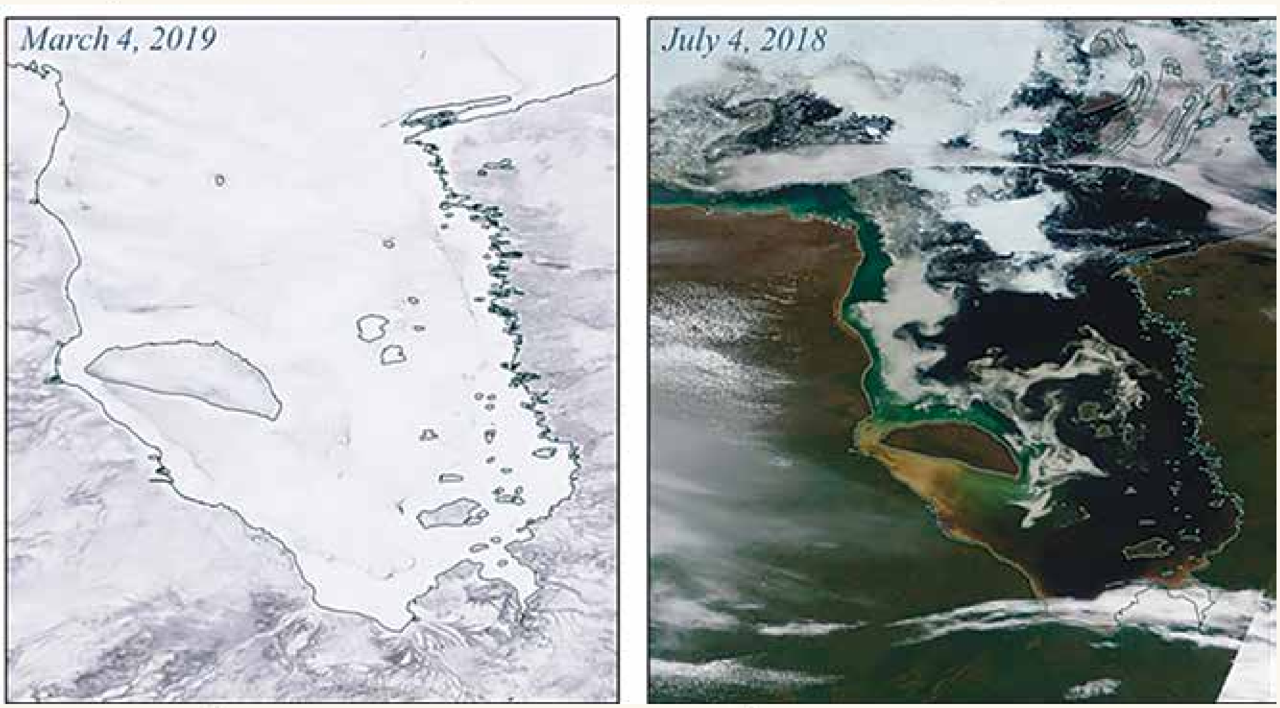


Figure 2-8. MODIS Worldview satellite images of the ice in James Bay on March 4, 2019 (left) and July 4, 2018 (right). Outlined area is shown in more detail in the following figure.

Figure 2-9. Landfast ice in the La Grande sector of the coast. The pack ice has drifted westward opening a lead along the outer edge of the landfast ice. Open water along the La Grande River appears black in the image. Source: MODIS Worldview image for April 8, 2019.

GEOMORPHOLOGY AND COASTAL ENVIRONMENTS

As evident on satellite imagery (cf., Figure 2-10), the west and east coastlines of James Bay have strikingly different forms (geomorphology). On the west side of the bay, most of the bedrock is limestone and the coast is linear and dominated by gently sloping tidal flats and marshes (Douglas 1973). The east coast of James Bay, which has Canadian Shield rocks, is morphologically complex with numerous small bays, inlets, and islands, especially north of Eastmain. Several large bays, protected by peninsulas and islands, are present in the Chisasibi area (Dead Duck Bay, Bay of Many Islands). South of Eastmain, the coastline has a few large open embayments including Rupert Bay. The Eastern Swampy and Moose Cree living along the western shore of James Bay (James Bay Lowlands) call the bay "winipīhk" or wînipêkw (ᐧᐄᓂᐯᒄ; https://dictionary.moosecree.atlas), which means muddy, brackish waters. The principal source of the muddy (i.e., turbid) appearance of the bay's waters is the resuspension of very fine-grained, glacial silt and clay sediments from shallow areas and shoals and lateral transport of these sediments in the water column until they settle out in deeper, quieter areas (Kuzyk et al. 2009).

Figure 2-10. Satellite image of James Bay from August 15, 2022. The pale yellow coloured areas along the west coast are shallow mudflats. Swirling pale yellow and blue coloured features are turbid waters carrying fine-grained resuspended sediments. River discharge that appears dark brown is rich in coloured dissolved organic matter (CDOM). Several rivers are labelled.

Note that the light brown areas in the satellite image are shallow (we are seeing the bottom or seabed), while the pale blue colours are parcels of water with high concentrations of suspended sediment (high turbidity). Currents give them a swirling appearance. Turbid waters are relatively common in the nearshore environment of western James Bay, generated mostly by wave-driven sediment resuspension over the extensive shallow mud flats.

RIVERS

The rivers connect the coastal marine environment of James Bay with the watersheds that surround the bay and deliver nutrients, organic matter, and sediments, in addition to freshwater. Although many large rivers discharge to James Bay, the La Grande River is the largest river by far and its annual discharge increased with the re-routing of flows from the Eastmain and Caniapiscau River systems (Phase I of development) and later the Rupert River (most recent phase). According to data compiled by Déry et al. (2016), during the periods 1964–1973 and 1974–1983, the La Grande River had an average annual discharge of about 60 $km^3 yr^{-1}$ (Figure 2-11). During the period of 1984–1993, the average annual discharge increased to 96 $km^3 yr^{-1}$; and from 2004–2013, the average annual discharge was about 110 $km^3 yr^{-1}$. The next largest river in the James Bay watershed is the Moose River of southwestern James Bay that has an average annual discharge of about 40 $km^3 yr^{-1}$ (Déry et al. 2016).

Under natural conditions, meaning without dams or diversions, James Bay rivers have their highest flow discharges during spring following snow melt. The La Grande River discharge also followed this seasonal pattern prior to development (Hernández-Henríquez et al. 2010) (see grey bars in Figure 2-12). After development during the period of 1984–2004, the highest flows occurred during December, January, February, and March (see hatched bars in Figure 2-12). A reconstruction suggests that *in the absence of development*, natural flows for the 1984–2004 period *would have followed similar* seasonality to the pre-development period (see black bars in Figure 2-12).

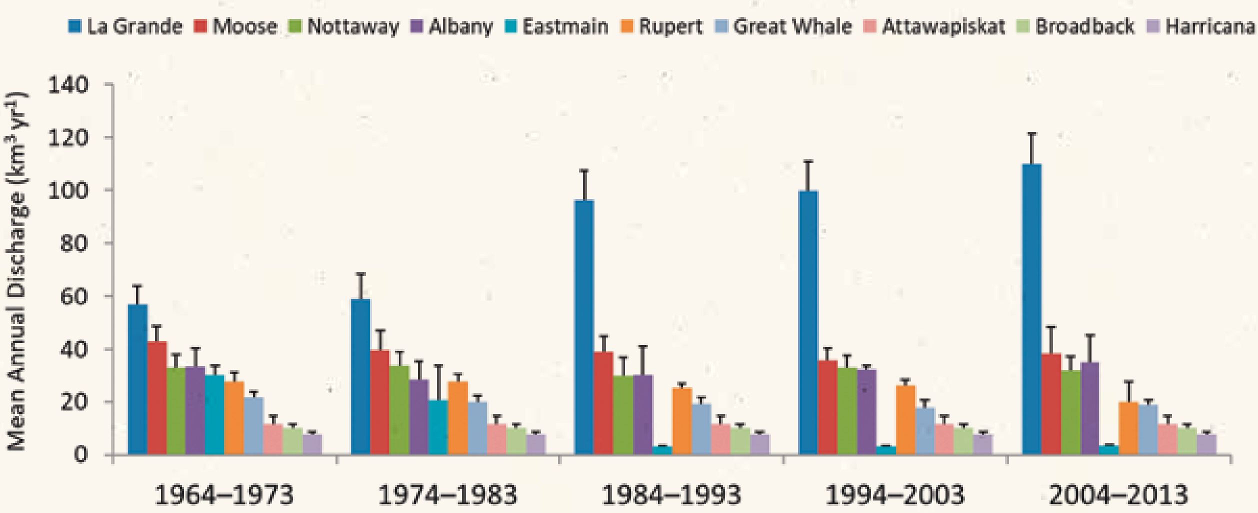


Figure 2-11. Average annual river discharge for ten major rivers discharging to James Bay based on data presented by Déry et al. (2016).

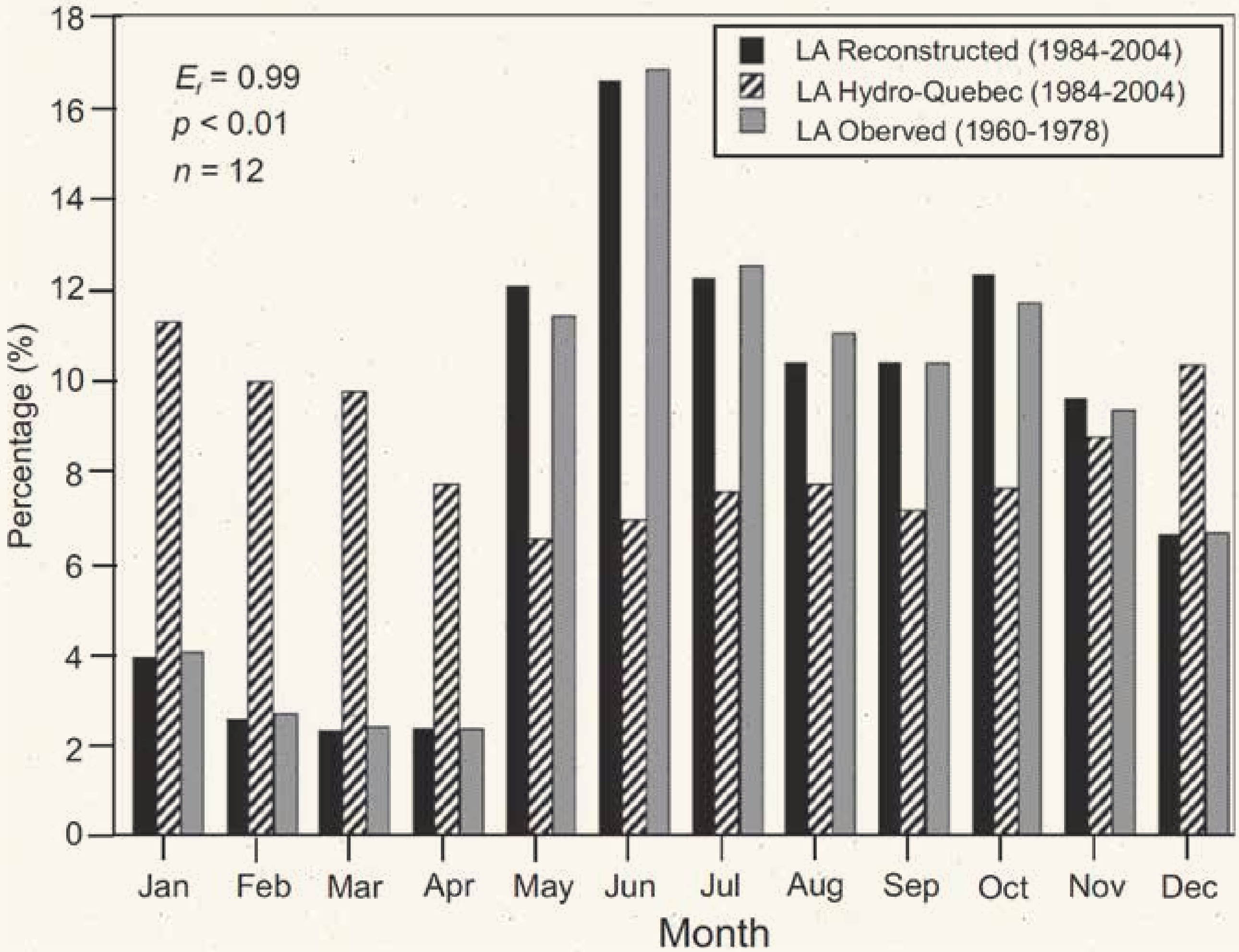


Figure 2-12. Average monthly discharge from La Grande expressed as a percentage of total annual discharge. Grey bars show a period of natural flow (LA Observed (1960–1978)) and hatched bars show a period after development (LA Hydro-Québec (1984–2004)). Black bars show a reconstruction of what natural flows would have been for 1984–2004 without development. Source: Hernández-Henríquez et al. (2010).

Different rivers have different natural water properties depending on the properties of their watershed. Rivers that flow through the clay belt in Quebec tend to be rich in clay (suspended sediment), whereas those rivers draining peatlands and wetlands tend to be clear but coloured because of coloured dissolved organic matter (CDOM) (Cummings 1968; de Melo et al. 2022). In fact, many of the rivers that discharge into southern James Bay carry high concentrations of CDOM, whereas rivers in northeastern James Bay were naturally lower in CDOM (de Melo et al. 2022). In satellite imagery of James Bay like that shown in Figure 2-10, river plumes rich in CDOM can be seen as dark brownish waters extending from the land into the coastal environment. The Albany River and the Moose River that drain the wetlands (James Bay Lowlands) of western James Bay have high concentrations of CDOM, for example.

CDOM can be detected using satellite-borne sensors as well as lab measurements of water samples (Bélanger et al. 2022; Mabit et al. 2022) and provides a convenient way of tracing river water as it mixes with seawater (Meilleur et al. 2023). CDOM also absorbs sunlight and limits the depth to which light can penetrate down through the water column. This is significant for determining how much light is available under the water for eelgrass.

SEDIMENT DYNAMICS AND ISOSTATIC REBOUND

A fundamental control on the sediment dynamics in James Bay over the long term is the rapid rate of residual glacio-isostatic rebound, which is uplifting the land mass around James Bay at a rate of 1–2 cm per year (Pendea et al. 2010). This causes new land to emerge from the sea (cf., Figure 2-13). Recent estimates of rates of uplift near Waskaganish are as large as 2–3 cm per year (Florin Pendea, pers. Comm., Dec 2022). The land has been rising since the immense Laurentide Ice Sheet melted and withdrew less than 8,000 years ago (Martini 1986). What this means in the underwater environment is that James Bay coastal waters are steadily becoming shallower. Fine mud that accumulated long ago at deeper locations is gradually getting lifted up to shallower areas, where it may be more strongly affected by waves and currents. This process is called sediment resuspension and, in the long term, affects water clarity in near-shore environments, especially in open areas. In seasonally ice-covered areas like James Bay, ice scouring combined with strong tidal currents can furthermore exacerbate sediment erosion, resuspension, and transport (Hequette et al. 1999). In sheltered locations like bays, especially those with eelgrass, sediments may be deposited rather than eroded, and eelgrass rhizomes help stabilize the sediments that settle to the bottom.

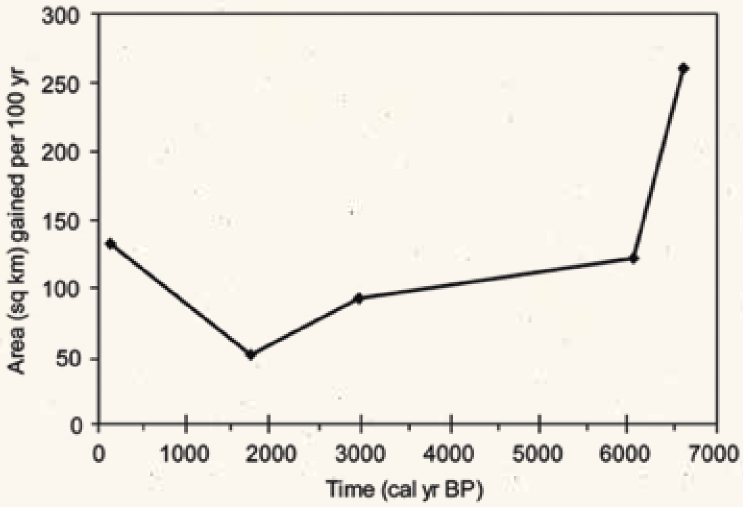


Figure 2-13. Rate of land area that has emerged during the last 7,000 years in eastern James Bay due to isostatic rebound. Source: Pendea et al. (2010).

Figure 2-14. Views of the La Grande River during summer (first photo), La Grande River during winter (second photo), Broadback River in fall (third photo), and Eastmain River in fall (fourth photo). Photo credit: C. Fink-Mercier

Another consequence of isostatic rebound is that the lower reaches of the rivers cut through thick glacial sediments close to the coast. High riverbanks composed of glacial sediments can be seen in places including the La Grande River near Chisasibi (Figure 2-14). The glacial and glaciomarine sediments are left over from the period after deglaciation when the low-lying land was inundated by the Tyrrell Sea (Cummings 1968; d'Anglejan 1982; Pendea et al. 2010). Some of the glacial sediments in the riverbanks are vulnerable to erosion during high water levels (Demers et al. 2014; Locat and St-Gelais 2014; Torrance 2014).

HYDROELECTRIC DEVELOPMENT

River flow is the fundamental control of the size, shape, and structure of a river (Zeiringer et al. 2018). In every free-flowing river, there is a dynamic balance between the movement of water and the movement of sediment (Dunne and Leopold 1978). The shape of the river and the locations of sediment erosion and deposition reflect the natural flows and sediment loads of the river. When flow alteration occurs, a river must adjust, which generally involves new patterns of erosion and deposition or both. Dam installation on a river generally means that sediments moving downstream from the watershed will get captured above the dam in the reservoir, while fine sediment in the downstream section will be eroded (Zeiringer et al. 2018).

In Eeyou Istchee, the James Bay Hydroelectric Development Project began in the 1970s. The development was "an immense undertaking" (Awashish 2018) that brought about major shifts in regional hydrology. The diversion of several rivers and the development of a series of dams (cf., Figure 2-15) served to concentrate flows in the La Grande River (also called the La Grande Complex) enabling power generation in response to hydroelectric demand (de Melo et al. 2022; Déry et al. 2011; Déry et al. 2016). The first phase of the development was completed from 1973–1985. Three generating stations were built, Robert-Bourassa (LG2), La Grande-3 (LG3), and La Grande-4 (LG4), each with its own reservoir. Note that the La Grande 2 (LG2) reservoir, powerhouse, and dam have been named Robert-Bourassa since October 1996 but in this report, we use the designation LG2. Two partial river diversions were completed forming the Caniapiscau Reservoir, at the head of the La Grande Complex, and the Opinaca Reservoir (Schetagne et al. 2005). Flow from the Caniapiscau and Eastmain-Opinaca Rivers was rerouted to the LG2 Reservoir, substantially increasing La Grande discharge between 1980 and 1984 (Messier et al. 1986). Eastmain River flows were reduced by about 90% after 1980 (Figure 2-16).

Phase II of the development, which began in 1987, involved the construction of five generating stations: La Grande-1 (LG1), La Grande-2-A (LG2A), Laforge-1, Laforge-2 and Brisay, and two new reservoirs (LG1 and Laforge 1). The generating stations were commissioned between 1991 and 1996. After considering a change to the location of LG1, it was decided to complete the development at km 37 (approximately 37 km from the bay), and LG1 was commissioned in 1994–1995 (Schetagne et al. 2005). Construction of the additional powerhouse at LG2 (LG2A) required some design changes for LG1 (addition of two units). These changes brought about by Phase II of the development represented a sufficient modification to the initial La Grande Complex design (sometimes called 'sur-équipement'; (Roche 1982; Roche 1985) that required new government approvals and agreements with the Cree. The "over-equipment" of LG1 and the addition of the LG2A generating station raised the peak discharge capacity and allowed discharge to vary substantially on 24-hour and weekly cycles. Winter discharge

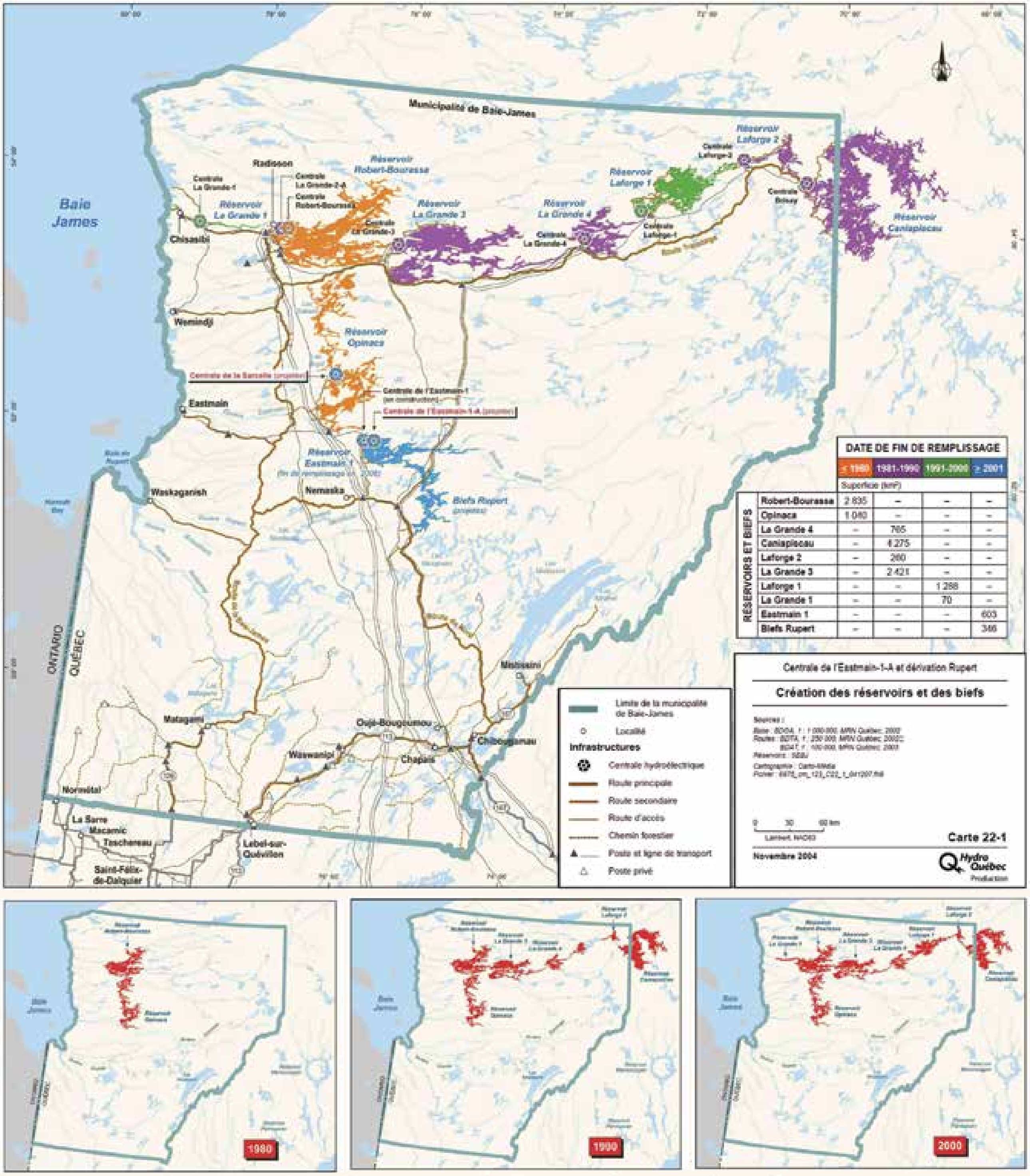


Figure 2-15. Hydro-Québec map depicting the development of dams and reservoirs in Eeyou Istchee. Source: Société d'énergie de la Baie James and Hydro-Québec (2004).

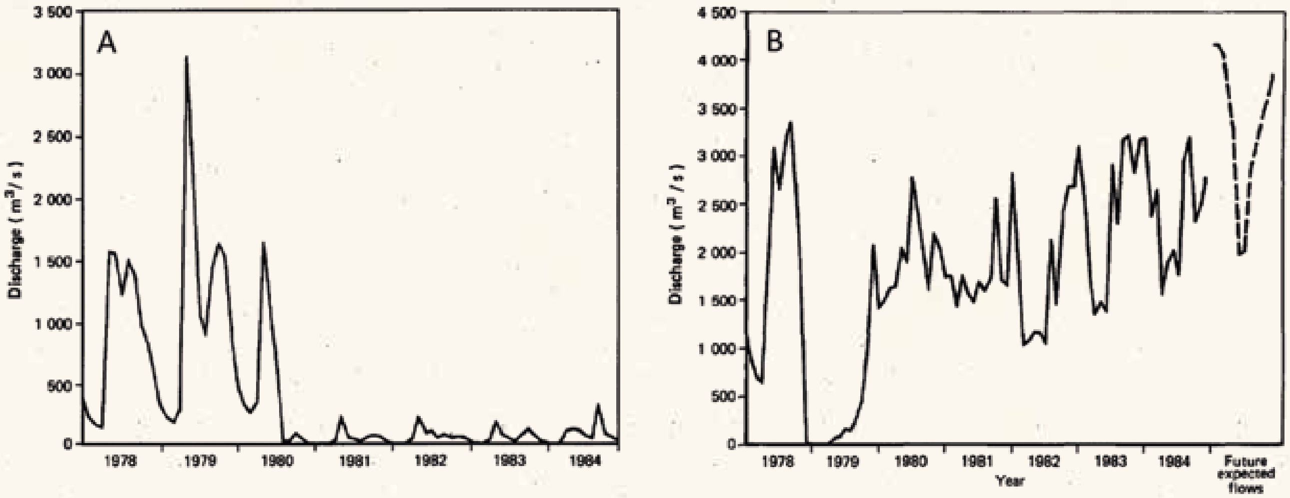


Figure 2-16. Effects of hydroelectric development on the discharge of (A) Eastmain River and (B) La Grande River between 1978 and 1984. Source: Messier et al. (1986).

was most affected and flows regularly varied up to 5000 $m^3 s^{-1}$ for the first time during winter of 1994 (Lemieux and Lalumière 1994).

The third phase of development was completed between 2009–2012 and involved a partial diversion of the Rupert River into the La Grande Complex. Whereas the pre-development discharge of the Rupert River averaged about 845 $m^3 s^{-1}$, the post-development discharge averages about 395 $m^3 s^{-1}$ (de Melo et al. 2022). With the Rupert diversion, the mean annual discharge from the La Grande River has begun to regularly exceed 3170 $m^3 s^{-1}$ during the past 10–15 years and reached as high as 4090 $m^3 s^{-1}$ in 2013 (Déry et al. 2016).

CLIMATE CHANGE

The greater Hudson Bay region including James Bay has warmed progressively over the past three decades. Cree community members have reported profound changes in air temperatures and drying up of berry bushes during hot dry summers. Coastal Cree have described how it is now often late into the year before the ice in the lower reaches of the rivers and along the coast is safe for travelling. Climatological studies have documented significant warming trends in the James Bay region in recent years (Gagnon and Gough 2005b). Projections for the James Bay region suggest an increase in minimum daily temperatures of around 4.5°C, an increase in maximum daily temperatures of around 2.5°C, and a 15% increase in precipitation by 2050 (Guay et al. 2015).

Impacts of climate change in the greater Hudson Bay marine system include a roughly three-week increase in the open water season on average across Hudson Bay (Hochheim and Barber 2014), a

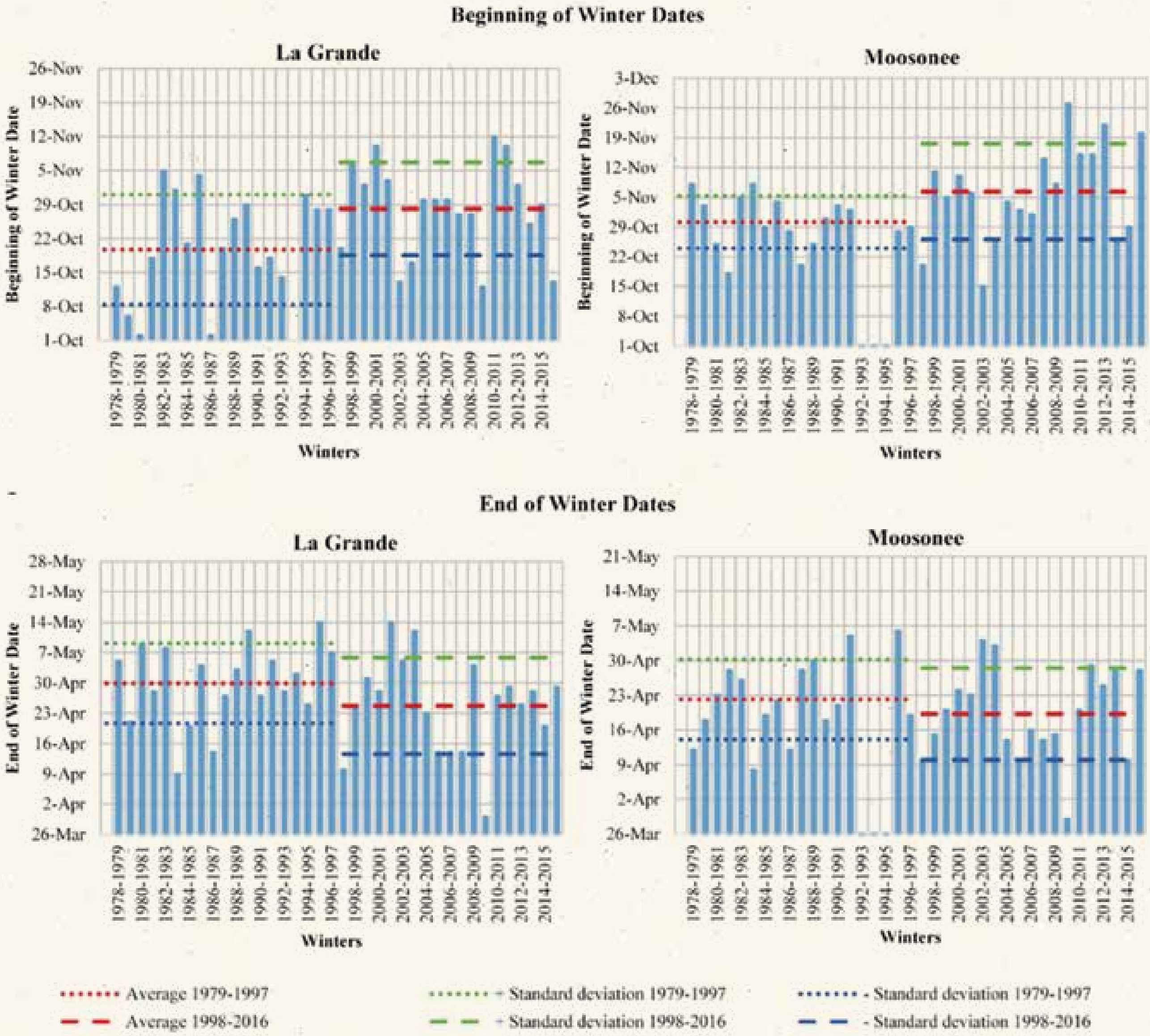


Figure 2-17. Estimated average dates for the beginning of winter (freeze up) and end of winter for two periods, 1979–1997 (red dotted lines) and 1998–2016 (red dashed lines), at La Grande and Moosonee. Green and blue lines show upper and lower limits (one standard deviation) around the averages. Source: Taha et al. (2019).

decrease in sea ice extent in eastern Hudson Bay since the early 1980s (Kowal et al. 2017), earlier fast ice breakup dates throughout Hudson Bay and James Bay (Galbraith and Larouche 2011; Gupta et al. 2022; Taha et al. 2019), and warming of sea surface temperatures (Brand et al. 2014; Galbraith and Larouche 2011). Ice-free periods are gradually getting longer in James Bay because of both early breakup and delayed freeze-up. Taha et al. (2019) performed an analysis of air temperature trends for James Bay for the periods 1979–1997 and 1998–2016 using Environment Canada records from weather stations at La Grande and Moosonee on the southwest coast (Environment Canada 2017). Their analysis showed that the beginning of winter as defined by several consecutive days of below-zero temperatures and the start of freeze-up (Svensson et al. 1989) has been delayed by about nine days on average at La Grande and seven days at Moosonee (Figure 2-17). In addition to this delay in freeze up, the overall winter air temperatures were approximately 1°C warmer during the recent period at both sites (Taha et al. 2019).

Climate change also is known to be affecting air temperatures, vegetation, and forest fires in the eastern James Bay watersheds. CHCRP researchers used climate data available online (https://climate.weather.gc.ca/historical_data/search_historic_data_e.html) to seek evidence of trends in total precipitation (rain +

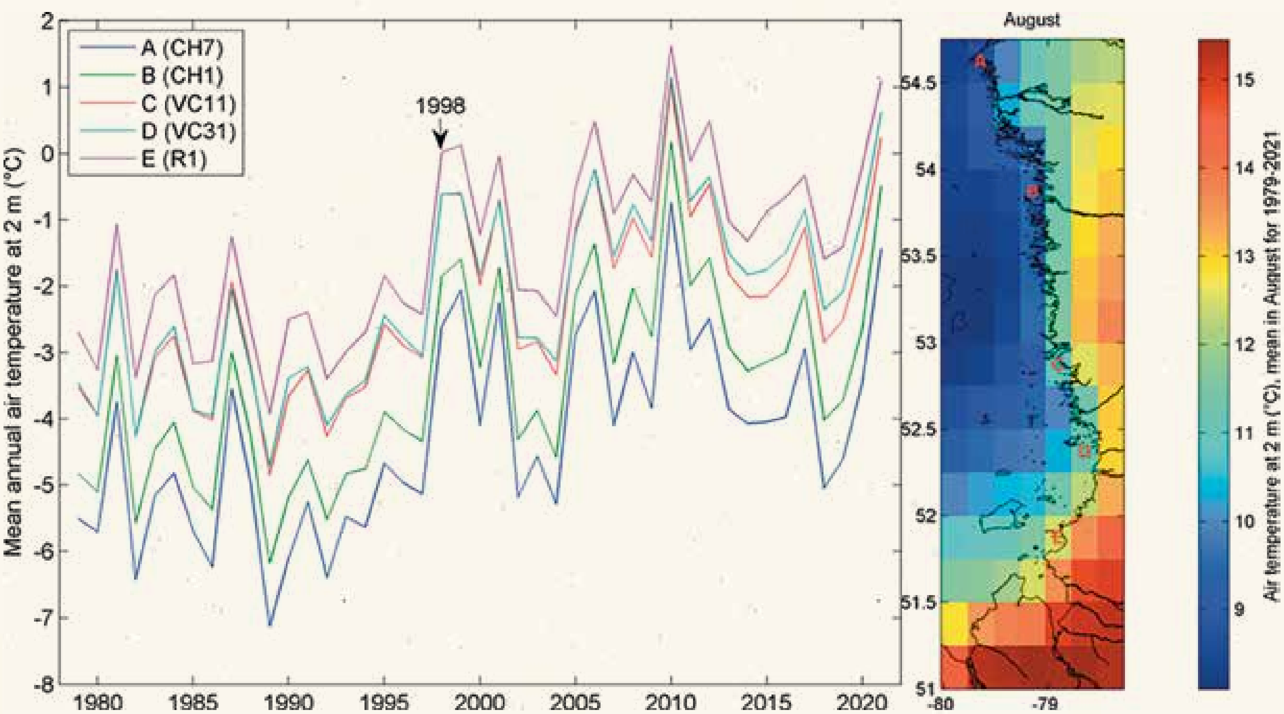


Figure 2-18. Average annual air temperatures from the reanalysis product ERA5 2 m for grid points A to E as shown on the map. Source: Costanzo (2022).

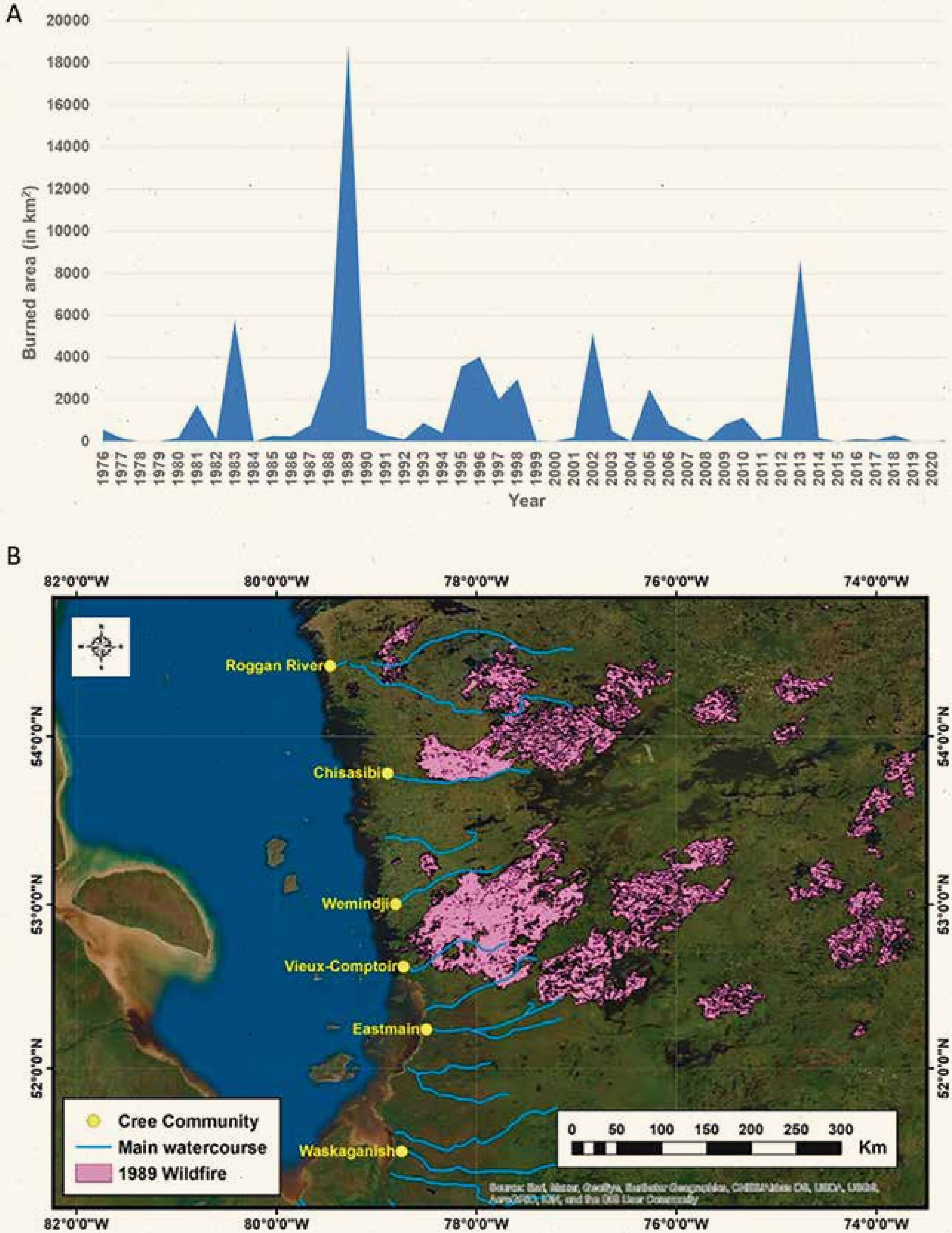


Figure 2-19. A) Evolution of the annual burned areas extracted from the forest fire map of the Quebec Ministry of Forests, Wildlife and Parks website (https://mffp.gouv.qc.ca/). B) Distribution of the 1989 wildfires in Eeyou Istchee as extracted from the forest fire map of the Quebec Ministry of Forests, Wildlife and Parks website (https://mffp.gouv.qc.ca/). After Clyne (2022).

snow in mm) and air temperatures for the region. The analysis was conducted using data for the closest station to eastern James Bay that had long-term data available, which was La Grande Riviere A (from 1976 to 2020). The precipitation data reveal a long dry period between 1993 to 1998 and a trend in increasing frequency of wet years over the past two decades. The air temperature records indicated a hot period between 1997 to 2001 and a trend of increasing air temperatures over the past 2.5 decades (de Melo et al., in prep.). Separately, the team examined an atmospheric reanalysis of the global climate produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) using a combination of historical observations and modelling called "ERA5". The ERA5 reanalysis dataset combined weather observations at fixed stations across the globe, remote sensing products, and climate and ocean model simulations (https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.3803). Air temperature time series were plotted for five locations along the eastern James Bay coast (Figure 2-18). The increase in mean annual air temperature calculated with a standard regression over 1979 to 2021 was 0.067, 0.073, 0.067, 0.076, and 0.072 °C/year, for various grid point locations (A, B, C, D, and E, respectively) along the eastern James Bay coast.

Climate warming combined with the particularly rapid isostatic rebound means that the region's coastal vegetation and landforms change rapidly. Climate-driven changes in the watersheds of northern Quebec include the northward advancement of the tree lines in recent decades and the rapid degradation of the discontinuous or scattered permafrost that occurs in the northern portions of the Cree territory (Bhiry et al. 2011). Warm springs and hot and dry summers that lead to low river runoff also tend to be associated with more intense forest fires. One such fire occurred across much of the territory in 1989 and a second one occurred along the Eastmain River in 2013 (Figure 2-19). Intense fires can destroy some or all the vegetation and leaf litter cover leading to more soil erosion from the landscape (Shakesby and Doerr 2006). A modelling study found that fires typically caused modest increases (6.5%–13.1%) in sediment and organic matter yields at river outlets, with larger increases possible in small catchments (Loiselle et al. 2020).

Cree governance of lands and resources

Cree have inhabited the territory they call Eeyou Istchee for thousands of years and consider themselves the guardians, stewards, and custodians of this land (Awashish 2018). Various agreements have touched on the protection of Cree rights related to traditional subsistence activities and natural resources management, research, and monitoring. The James Bay and Northern Quebec Agreement or JBNQA (1975), followed by several successive agreements (e.g., Agreement respecting a New Relationship between the Cree Nation and the Government of Quebec, 2002; Agreement concerning a New Relationship between the Government of Canada and the Crees of Eeyou Istchee, 2007), defined much of the political and institutional framework for land use, management of natural resources, and environmental research and monitoring in the region. The JBNQA was negotiated following several court proceedings after hydroelectric development was initiated in the region, but it served in some ways also as a land claim settlement and is considered the first co-management agreement in Canada (White 2020). For example, the JBNQA and associated agreements specify categories of lands within which Cree have exclusive wildlife harvesting rights and other lands that are in the Quebec public domain; they also allocate land to the First Nations communities in the territory. The Eeyou Istchee–James Bay Regional Government has responsibilities of a municipal nature for other lands. The Cree Nation Government (CNG) functions as a regional-level government for Cree society for Eeyou Istchee as a whole. There is also a regional Cree Trappers' Association (CTA), which was incorporated following the signing of the JBNQA as a not-for-profit organization with a role in protecting the knowledge and culture associated with traditional hunting and trapping activities, promoting knowledge sharing, and developing ongoing research and monitoring related to the environment and environmental change (Awashish 2018).

The Eeyou Marine Region Land Claims Agreement (EMRLCA), sometimes called the 'Offshore agreement' was signed in 2012 and led to the establishment of three EMR bodies including the Wildlife Board, Impact Review Board, and the EMR Planning Commission. These bodies have different roles and responsibilities for the offshore waters of eastern James Bay. The EMR Wildlife Board is the main instrument of wildlife management in the EMR and is responsible for identifying wildlife research priorities and promoting and encouraging related research. However, many coastal land users are part of local Cree Trappers' committees, which help support traditional subsistence harvesting activities through various programs, and the CTA works closely with the EMR Wildlife Board via local CTA-EMR Officers.

Many previous reports and academic publications emphasize that traditional subsistence activities remain exceptionally important to the Cree (cf., Awashish 2018; Royer 2016). Awashish (2018) describes Eeyou Istchee as "*the foundation of our identity, governance, history, heritage, culture and way of life, spirituality and Eeyou Eedouwin (Eeyou way of doing things). It is the Eeyou homeland of yesterday, today and tomorrow*." Traditional Eeyou Law (*Eeyou Weeshou-Wehwun*) and Traditional Eeyou Hunting Law (*Eeyou Indoh-ho Weeshou-Wehwun*) provide a framework of good practices based on Cree worldview that guide the management and stewardship in Eeyou Itschee hunting territories (CTA, 2009). The Cree 'trapline' system, which corresponds to communal and family hunting territories and is traditionally called "*Indoh-hoh Istchee*", extends throughout Eeyou Istchee (Awashish 2018). The JBNQA defines a Cree trapline as "an area where harvesting activities are by tradition carried out under the supervision of a Cree tallyman". A "tallyman" is "*a Cree person recognized by a Cree community as responsible for the supervision of harvesting activity on a Cree trapline*" (Awashish 2018). According to the traditional system, the tallyman would bear many responsibilities in relation to a territory, including control of access and sharing of resources, and sharing of information, history, and traditional knowledge (Awashish 2018).

For traplines located along the coastline in Eeyou Istchee, which number at least 25 (Figure 2-20), there is a second traditional authority called the 'goose boss' (*Paasd-heejeh Oujemaaou*) (Awashish 2018). The goose boss is typically a well-respected experienced hunter with detailed knowledge of the coastal habitat. He has central responsibility for managing the goose hunt and deciding who hunts where, when,

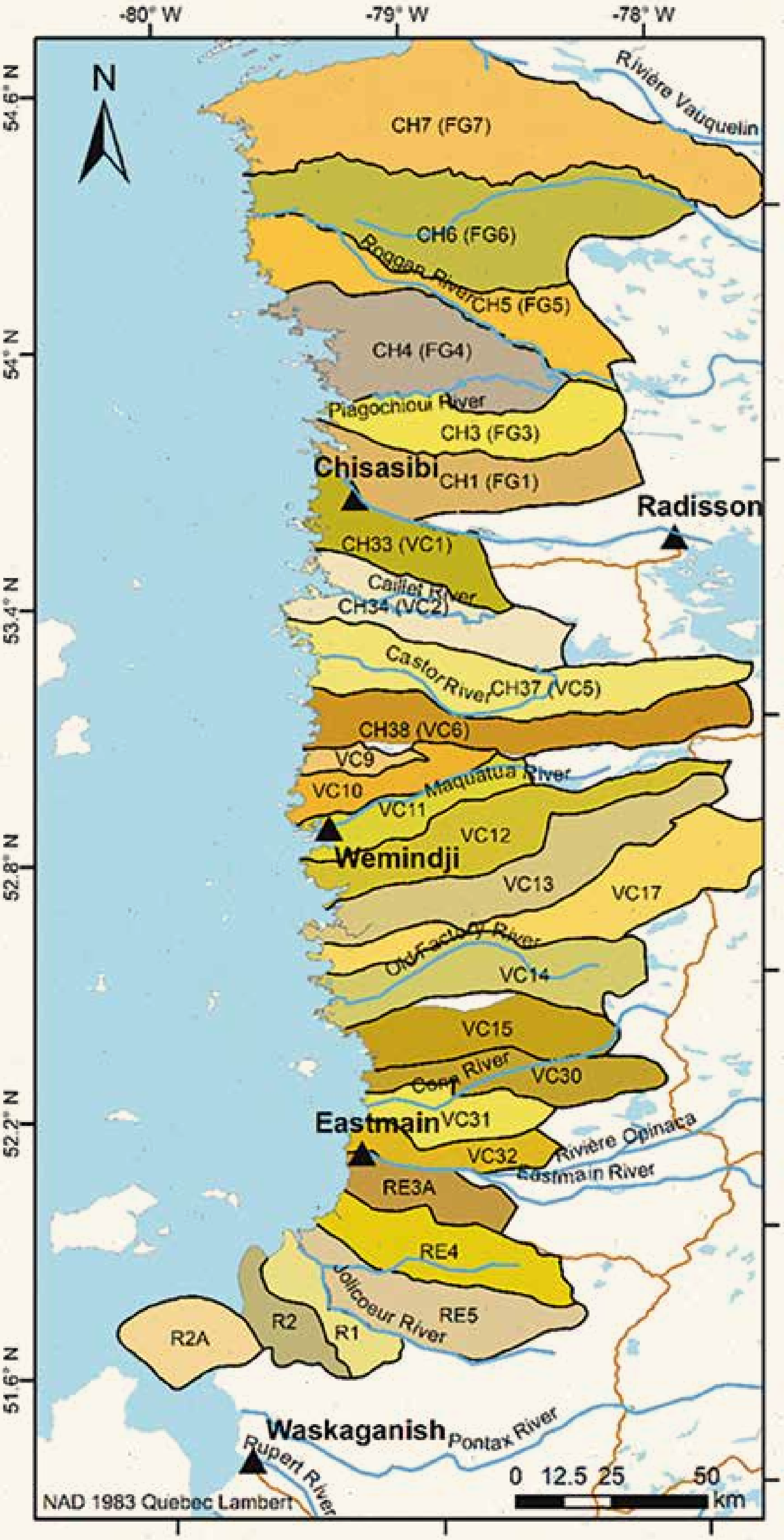


Figure 2-20. Map showing coastal traplines in Eeyou Istchee between R^2A in the south near Waskaganish and CH7 along the coast north of Chisasibi.

Figure 2-21. Miichuuap, by Eeyou artist Natasia Mukash. Used with permission of the artist. See additional work at https://linktr.ee/paintedstone.

and how on his territory or a certain portion of the coast or trapline (Scott 1983). This role speaks to the significance of Canada Geese in the Cree subsistence harvest, particularly for communities along the James Bay coast (Peloquin and Berkes 2009). As documented in the 1970s, short-necked geese were the biggest catch of all harvested species and had the highest return relative to hunting effort in Chisasibi (Berkes 1977; Berkes 1978; Berkes 1986). Comparable information about the Cree harvest is not available today. Many traditional arts and crafts depict geese, and today, geese and the coastal habitat remain prominent in artwork produced and displayed in the coastal Cree communities (cf., Figure 2-21).

Coastal habitat concerns

Four coastal communities participated in the research project: Chisasibi, Wemindji, Eastmain, and Waskaganish. Chisasibi Cree have long expressed concern about the health of the eelgrass ecosystems and the impacts of the eelgrass on goose presence and Cree hunting. Chisasibi community members worked with biologists studying the coastal ecosystems during the 1970s (Berkes 1977; Berkes 1979; Berkes 1982; Curtis and Allen 1976). Some elder hunters expressed concern that the dams would impact the eelgrass (John Lameboy, pers. Comm., 2022). Being located originally on Fort George Island and then relocating to the south shore of the La Grande River, community members have paid close attention to the changes in the river, particularly since the development of LG1 ~37 km upstream (e.g., high winter flows, riverbank erosion, and loss of river ice).

In 2006, the Cree Nation of Chisasibi (CNC) solicited input on the eelgrass problem from internationally recognized expert Dr. Fred Short (Short 2008). Representatives from Chisasibi testified about the eelgrass decline and loss of geese to the House of Commons *Standing Committee on Fisheries and Oceans* on March 4, 2008 (FOPO 2008). In the following years, the CNC compiled Cree Knowledge about eelgrass and geese in a document entitled the *Migratory Birds Habitat Task Force Report (Cree Nation of Chisasibi 2015)* and established a community-based research institute, Chisasibi Eeyou Resource and Research Institute (CERRI; https://www.cerri.ca/).

In contrast to Chisasibi, the documented Cree traditional knowledge of eelgrass beds in Eastmain revolves around the role of eelgrass as fish habitat (Lajoie and Cuciurean, 1994). Wemindji Cree land users answered questions about eelgrass ecology and distribution for a report prepared by the Cree Regional Authority in the 1990s (Ettinger et al. 1995). They also have shared their knowledge with academics for several publications related to resource management and ecosystem dynamics (cf., Peloquin and Berkes 2009; Scott 2020) and marine protected area planning (cf., Mulrennan et al. 2019).

Niskamoon Corporation, which administered the CHCRP between 2017 and 2022 (including a COVID-19 delay), was established in September 2004 from an agreement between the Grand Council of the Crees, the Cree Regional Authority, the nine Cree communities, the Société de l'énergie de la Baie James (SEBJ), and Hydro-Québec. Niskamoon has administered and managed many Cree–Hydro-Québec agreements and programs related to remedial works during the past two decades and employs several regional coordinators and a representative in each community. For this project, Niskamoon convened and chaired the Steering Committee, which brought together representatives of all the regional organizations with a role in the governance of lands and resources.

Factors affecting eelgrass growth

Although eelgrass can grow in a wide range of conditions, there are limits to the environments it can tolerate and environmental conditions under which it does better or worse (see, for example, recent reviews on eelgrass health and ecology across Canada: (Dickey 2015; Murphy et al. 2021). Understanding the light, nutrient, water, and sediment conditions eelgrass needs for sustained growth and survival can help to identify environmental changes that may threaten eelgrass growth and survival in the future. Globally, eelgrass is found throughout the northern hemisphere, in both the Pacific Ocean and the Atlantic Ocean, from about 30°N to the Arctic (McRoy 1970a; Short 2007). However, it is excluded from locations where the duration of the ice-covered season is too long or the water is too muddy and/or too fresh, such as large river deltas, glacial fjords, and high arctic environments (McRoy 1969; McRoy 1970b). Eelgrass generally grows in clear, colourless, shallow, coastal marine waters in sheltered bays or estuaries where the current is not too strong and there is not too much exposure to large ocean waves. Within a given region, eelgrass distribution at local scales tends to be uneven: some areas may have no eelgrass, some areas may have small or sparse beds, and some areas may have vast dense eelgrass meadows. Boundaries also change over time, moving around with changing features of the local environment (such as ice scour). The distribution of eelgrass from one stretch of coastline to the next depends on a suitable physical setting (water depth and slope of the seabed, sediment type, wave exposure, and dynamics of ice cover). How well the eelgrass grow at these locations depends on the environmental conditions from year to year (light availability, nutrients, wave energy, water temperature and salinity).

As described further below, eelgrass requires soft, organic- and nutrient-rich sediments to expand its rhizomes and obtain nutrients, and for seedlings to establish themselves. Soft sediment texture, appropriate composition (some mud and organic matter), and slow accumulation of deposited material are important for the establishment of seedlings and nutrient uptake for growth. Sediments also have their own microbial community, which controls the rate at which nutrients are produced through the breakdown of organic matter and the production of other compounds like sulfides. Regardless of whether the underground roots and rhizomes survive over the winter period, eelgrass also can spread and reproduce from seeds, provided the seedlings can get established and get sufficient good conditions to grow. Eelgrass can take up nutrients through their leaves *and* roots. Even when the nutrient concentrations in the water are low, typically the sediments in an eelgrass bed will contain lots of nutrients.

In general, light and nutrients are major factors affecting eelgrass growth that have been implicated in eelgrass declines and recoveries all around the world (Hauxwell et al. 2003; Krause-Jensen et al. 2021; Wong et al. 2021). Water in James Bay comes from Hudson Bay and is generally very low in nutrients (Anderson and Roff 1980). However, in established eelgrass beds that are trapping sediment, eelgrass can access nutrients from the sediment as well as the water column, and sediment nutrients are up to ten times higher than water column nutrients (Noisette et al., in prep.). Eelgrass also generally has high light requirements for growth (McMahon et al. 2013; Orth et al. 2006; Ralph et al. 2007).

Water depth, wave energy, and ice scour

Physical factors like water depth, wave energy, and ice scour fundamentally determine where eelgrass can grow and whether its distribution is continuous or discontinuous (patchy eelgrass bed) within a bay or along a coastline. Often, the distribution of eelgrass along a stretch of coastline is spread out in detached beds, a result of environmental restrictions (too great a water depth, inappropriate sediment type, too much exposure to wave action or ice action) (McRoy 1970a; Short 2007). By growing in shallow water, eelgrass shoots may be able to reach the surface at low tide and experience optimum conditions of light and warmth for growth. However, if eelgrass grows in very shallow waters, it is more likely to get disturbed by storm waves, scoured by the ice (Pascal et al. 2020), or buried under sediment that washes in off the adjacent land.

In places like Alaska, the greatest expanses of eelgrass occur in large, shallow lagoons, where the shallow slope of the bottom means that a large continuous area has the right water depths for eelgrass. In these cases, the eelgrass community forms a vast meadow. These are the conditions under which the largest eelgrass meadow in North America, in Izembek Lagoon, has developed (McRoy 1970b). In bays with a steeper depth profile, the eelgrass is limited to growing in a narrow belt between shallower water, where there is too much disturbance by storm waves and ice, and deeper water, where the light availability and/or water temperature are less than ideal. "Fetch", which is the distance over which wind can travel across open water, determines the size of the waves that impinge on the coastal area and hence the wave-driven currents and coastal erosion. In a report prepared in Eastmain, it was noted that eelgrass beds are more often found along stretches of coast with southern exposure because the greatest fetch is towards the north and west; furthermore, eelgrass beds often have elongated shapes that are explained by the NE-SW orientation of bedrock features and till ridges that offer some protection from waves (Lajoie and Cuciurean 1994).

Sediment properties

The bottom sediments are an integral part of an eelgrass ecosystem and there is a reciprocal relationship between eelgrass and bottom sediments (Figure 3-1). Eelgrass needs to be anchored to the sediment on the ocean bottom and able to take up nutrients from it. The rhizomes and roots of eelgrass tend to intertwine, forming a mat that prevents the shoots from being washed away by storm waves and tide action. This means that the sediments cannot be too hard (as in compacted sand or clay) for eelgrass roots and rhizomes to penetrate. Eelgrass typically grows in soft, sandy to muddy sediment, but it can grow in gravel provided it contains enough decaying plant matter to supply nutrients to the eelgrass roots. When sediments are accumulating organic matter—dead eelgrass, algal matter, and other organic material transported in the water or washed off the land—this material gets broken down by microbes to continually supply nutrients to eelgrass roots. The processes within the sediments need to be occurring at a regular rate that the eelgrass is accustomed to and major perturbations such as sediment addition, extreme changes in salinity, or major warming of the waters could potentially lead to changes that increase the production of toxic materials like sulfides. Muddy sediments might supply more nutrients, but they can make the water turbid when disturbed, and it is critical for eelgrass that they have enough clear water that allows the sunlight to pass through.

According to observations by an eelgrass monitoring team in 1987 (Lalumière 1987), dense eelgrass meadows in eastern James Bay have low currents and are sites of accumulation of organic matter. The sediments in the dense meadows exposed to weak currents are richer in fine muddy sediment, organic matter, and nutrients. The sediments underlying discontinuous or fragmented eelgrass beds or areas of low eelgrass cover are eroding, at least slowly, and supplying sediment and other materials to adjacent areas.

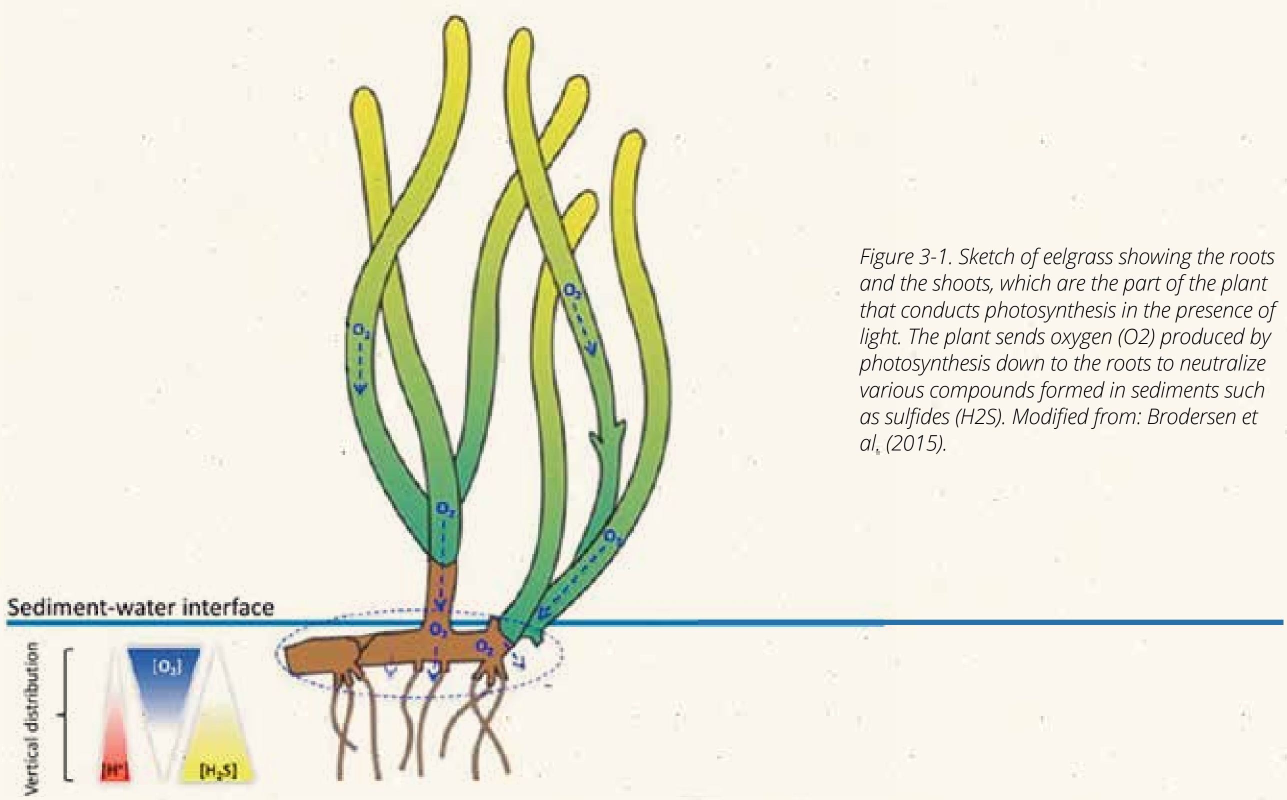


Figure 3-1. Sketch of eelgrass showing the roots and the shoots, which are the part of the plant that conducts photosynthesis in the presence of light. The plant sends oxygen (O2) produced by photosynthesis down to the roots to neutralize various compounds formed in sediments such as sulfides (H2S). Modified from: Brodersen et al. (2015).

Light

Light is important for summer eelgrass growth and winter survival, and eelgrass need a relatively high amount of light compared to other non-vascular plants like algae (Lee et al. 2007). In James Bay, the summer is critically important because the winters are long and dark and very little light penetrates through the snow and ice cover to reach the water column below. Thus, the eelgrass need light in early summer to grow and then after growth slows down, they continue to need light to store sugars to survive the winter (Figure 3-2). Eelgrass likely begins its spring growth under the ice cover in May and early June once the snow melts and the bare or melt-pond-covered ice surface lets light pass through (McRoy 1969). The plants can grow more rapidly after the ice melts and more light reaches the water column. Eelgrass can grow very rapidly during the long summer days of July (Lalumière et al. 1994; Short 2008). In James Bay, eelgrass reportedly reaches its maximum annual biomass in September and thereafter declining day length, waterfowl grazing, lower water temperatures, and later new ice formation start to reduce plant biomass and slow the plants' growth (Lalumière et al. 1994; Short 2008). During summer, the plants expand vegetatively and flower and produce seeds (Lalumière et al. 1994; Short 2008). They also store up energy in the form of starches in their rhizomes to help them last through the winter season when there is not enough light for photosynthesis (Soisson et al. 2018). To be perennial and continue to grow from one year to the next, the plants need to store energy to survive and maintain themselves throughout winter (i.e., they convert the starches to energy through the process of respiration; see Appendix B for a glossary of terms).

During the open water growing season, light availability for eelgrass depends on the depth of the overlying water and water clarity. Water clarity can be reduced by turbidity, i.e., cloudiness caused by particulate matter suspended in the water column, and by water colour, which is caused by dissolved substances (Figure 3-3). In coastal areas, the particles causing turbidity can be micro/macroalgae, particulate organic matter delivered by rivers, or sediment resuspended off the bottom (Lee et al. 2007; Ralph et al. 2007). Eelgrass also can be shaded by epiphytic algae that grow on the eelgrass shoots. At extremely high densities of eelgrass, shading by eelgrass itself may occur and decrease the light availability (Backman and Barilotti 1976; Orth and Moore 1983; Sand-Jensen 1977). It is well documented that poor water clarity can lead to a decrease in eelgrass photosynthesis even if eelgrass are able to adjust their photosynthetic capacity to a certain extent (Dennison and Alberte 1982; Ralph et al. 2007). Eelgrass may acclimate to light availability across depth gradients by decreasing shoot size and density (Enríquez and Pantoja-Reyes 2005; Ruiz Fernandez and Romero 2001), which can reduce self-shading and respiratory demand (Collier et al. 2007; Enríquez and Pantoja-Reyes 2005; Krause-Jensen et al. 2000). Eelgrass also can alter its colour, i.e., chlorophyll *a* content (Abal et al. 1994), and make other physiological adaptations to adjust to lower light (Mazzella and Alberte 1986; Ralph et al. 2007; Ruiz Fernandez and Romero 2001). However, acclimation has its limits. Low photosynthesis because of lack of light may lead to a breakdown of the ability of the plants to maintain an oxygen shield around their roots (Figure 3-1), which may lead to sulfide toxicity and rotting of the roots, affecting the whole plant.

If there is a sustained period of low light availability, especially during the eelgrass growing season (e.g., spring and summer), eelgrass plants may be unable to store enough energy to survive colder months, causing declines (Burke et al. 1996). Burke et al. (1996) highlighted that spring is an important time for both the growth and storage of carbohydrate reserves and turbidity during this springtime 'window of opportunity' may jeopardize subsequent survival because, with inadequate reserves, the plants cannot maintain a positive carbon balance during the rest of the year. Diminished starch content at the beginning of the growing season leads to a lower regrowth potential after severe winters (Soisson et al. 2018).

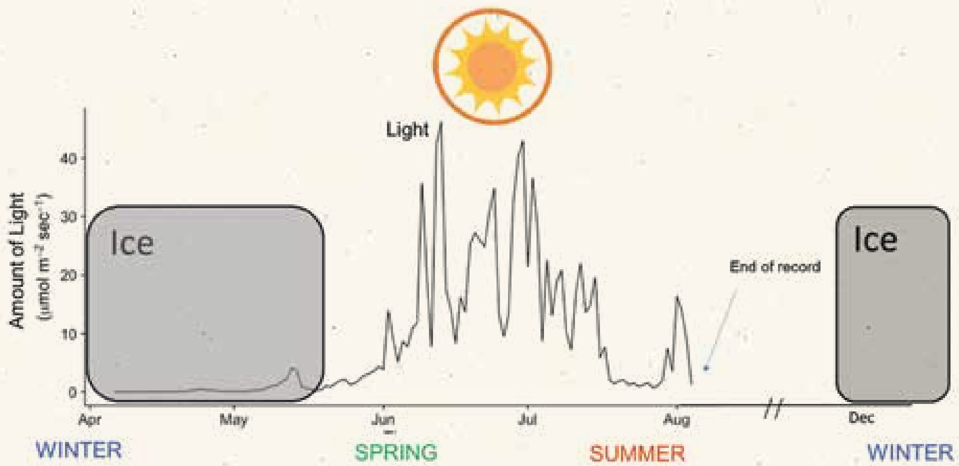


Figure 3-2. Seasonality of light and eelgrass growth. The light record was collected at a CH33 eelgrass meadow between April and August 2019.

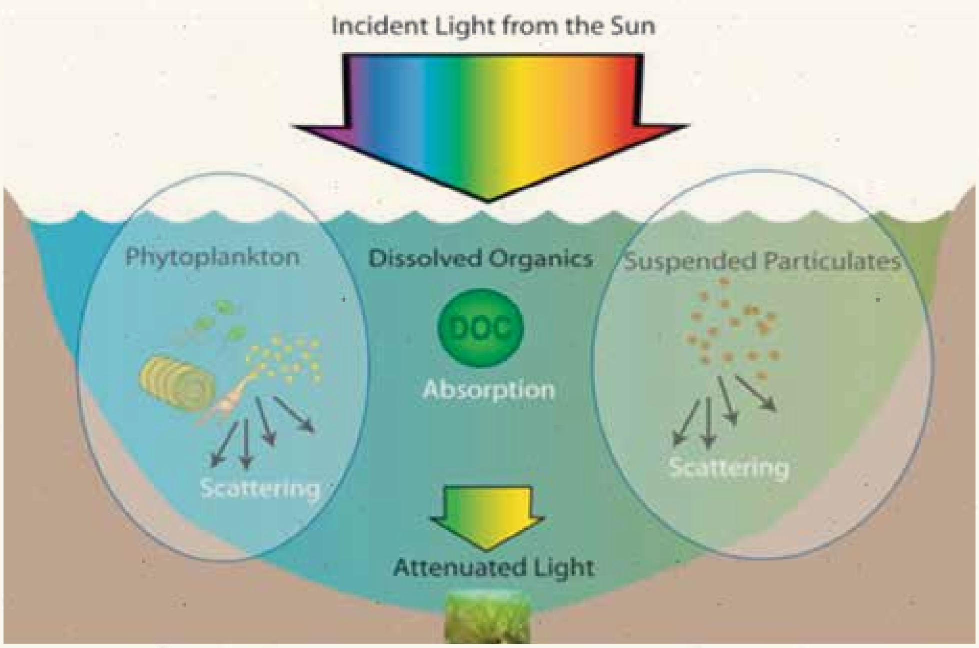


Figure 3-3. Factors affecting the light available underwater when there is no ice cover.

Nutrients and carbon

Eelgrass uses nutrients, such as nitrogen (N) and phosphorus (P), and carbon (C) to grow, maintain biomass, and reproduce. Eelgrass requires C, N, and P for photosynthesis and building amino and nucleic acids (Duarte 1990; Romero et al. 2006).

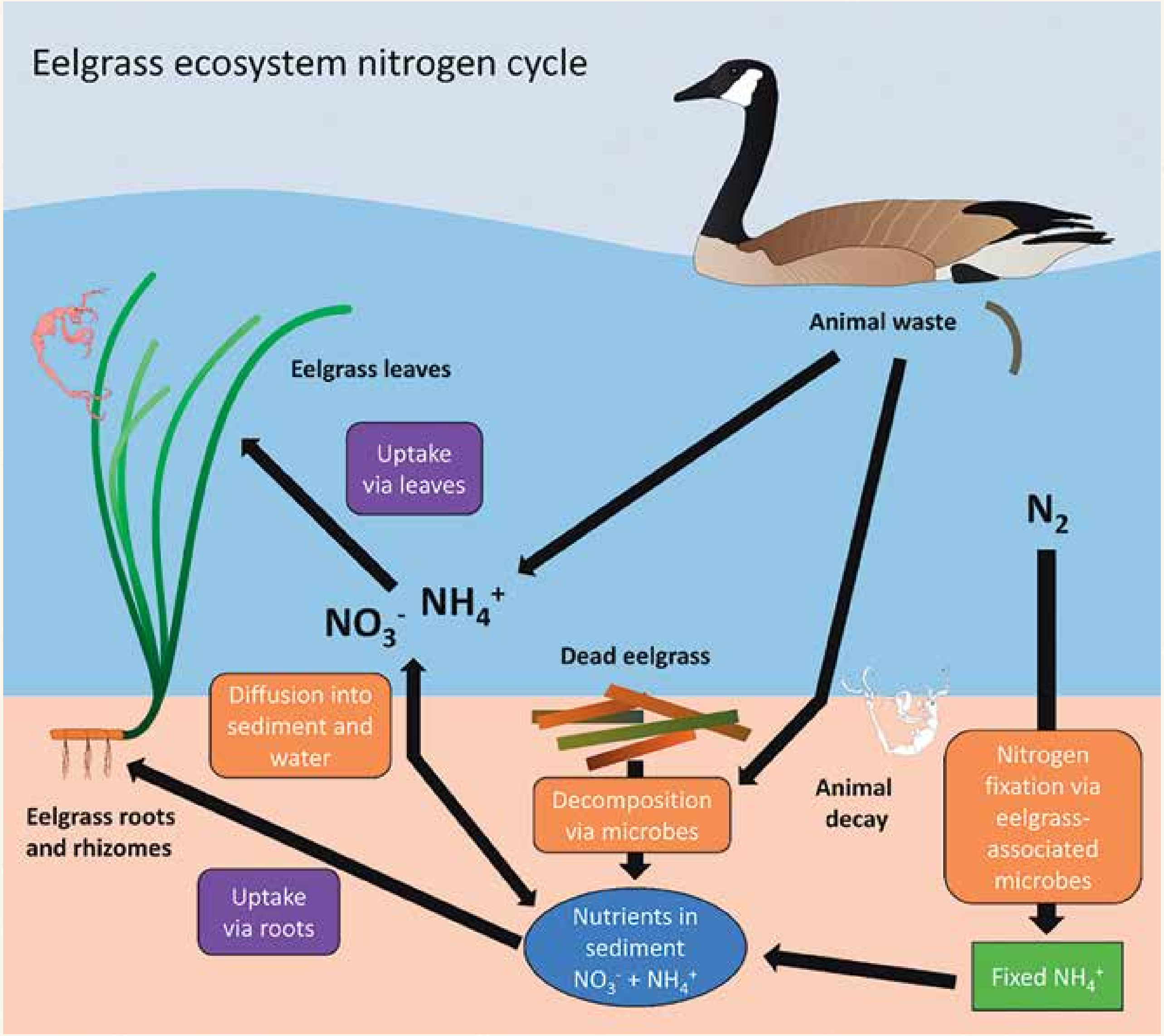


Figure 3-4. Eelgrass ecosystem nitrogen cycle. Orange boxes represent chemical pathways between water and sediment, green and blue boxes represent different stages of ammonia, and purple boxes represent nitrogen acquisition. Arrows represent flow of different chemical processes. Modified from: Adamczyk (2022).

NITROGEN

Ammonium (NH4+) and nitrate (NO3-) are the primary forms of nitrogen (N) that eelgrass uses (Iizumi 1975). The majority of N required for eelgrass growth is obtained in sediment pore water (water wedged in the sediments) in the form of ammonium, and water column nitrate is utilized by eelgrass leaves when available (Figure 3-4) (Iizumi and Hattori 1982; Zimmerman et al. 1987). Waterfowl that graze on eelgrass, including Brant Geese, can release nitrogen-rich faecal matter into eelgrass ecosystems, thereby contributing to eelgrass growth (Shaughnessy et al. 2021). Eelgrass growth can become nutrient-limited due to competition with phytoplankton, epiphytic algae, and macroalgae (Pedersen and Borum 1992), and eelgrass tissue-N content of <1.8% dry weight is considered very nutrient-limited (Duarte 1990). Nutrient limitation often occurs during the summer when photosynthesizing organisms compete for resources and when maximal photosynthetic rates are reached (Pedersen and Borum 1992).

PHOSPHORUS

Although phosphorus (P) often limits the growth of plants in freshwater ecosystems and near river mouths (inner estuaries), it is rarely a limiting element in marine systems because ocean waters are replete with phosphate (PO43-). In addition to the seawater supply of phosphorus, eelgrass uses pore water (PO43-) as its primary source of P, analogous to N acquisition (Short 1987). Eelgrass can experience P limitation, and eelgrass tissue-P content of <0.20% dry weight is considered P limited (Duarte 1990). However, in the salty settings where eelgrass is found, P limitation usually occurs when inorganic phosphate binds to carbonate sediments, limiting the availability of dissolved inorganic phosphate (Koch 2001). This process occurs more commonly in tropical and subtropical regions where carbonate sediments are present (Fourqurean et al. 1992a; Fourqurean et al. 1992b; Short 1987).

CARBON

Dissolved inorganic carbon (C) is essential for eelgrass photosynthesis but it is very rare that it is the element potentially limiting growth. Coastal seawater contains a lot of inorganic carbon through, for example, exchanges of carbon dioxide (CO2) with the atmosphere. Eelgrass can use CO2 and other forms of dissolved inorganic carbon such as bicarbonate (HCO^{3}-) to reduce C through photosynthesis, but it primarily uses HCO^{3}- (Beer 1989; Beer and Rehnberg 1997; Invers et al. 2001; Sand-Jensen and Gordon 1984). Eelgrass tissue C:N:P ratios can vary and represent nutrient availability; usually, C constitutes about 30–40% of eelgrass tissue dry weight compared to N (1–4%) and P (0.1–1.0%) (Duarte 1990).

Temperature

Although the optimal temperature for eelgrass growth is between 15–23°C (Lee et al. 2007; Ralph et al. 2007), it also grows well over a wide range of temperatures (10°C–25°C) and survives in temperatures from 0°C to 35°C (DFO 2009). For instance, eelgrass in the Mediterranean Sea can grow at 30°C (Sfriso and Francesco Ghetti 1998) and it can also survive under sea ice in Japan, growing in seawater below 0°C but above the freezing point of seawater (Watanabe et al. 2005). Different physiological processes within eelgrass have different temperature sensitivities. The average optimal temperature for eelgrass *photosynthesis* is 23.3 ±1.8°C, which is greater than the optimal temperature for eelgrass *growth* (Lee et al. 2007). The optimal temperature for eelgrass growth and photosynthesis are different because temperature also regulates respiration, nutrient uptake rates, flowering, and leaf senescence (Bulthuis 1987; Lee et al. 2007; Marsh et al. 1986).

Higher water temperatures (25–40°C) can decrease eelgrass photosynthesis capabilities, increase respiration, and result in a negative carbon balance due to photosynthesis limitation, which can lead to a decrease in biomass, leaf production, and growth (Hammer et al. 2018; Lee et al. 2007). Sustained periods of high-water temperatures can result in eelgrass die-off events, such as those having occurred in Chesapeake Bay, VA, USA in the summer when water temperatures exceeded 28°C (Moore and Jarvis 2008; Shields et al. 2019) and the Gulf of California (McMillan 1983; Meling-López and Ibarra-Obando 1999; Muñiz-Salazar et al. 2005; Phillips and Backman 1983). Experimental studies have shown that not only extreme summer marine heat waves, but also unusually warm winter-to-spring conditions, can have severe effects on eelgrass. Premature water warming in spring was found to accelerate the consumption of energy reserves, which are low following winter and even lower if the previous summer suffered bad light conditions. Then it can trigger early flowering, which led to high mortality in the following months (Sawall et al. 2021).

Salinity

According to a review by Fisheries and Oceans Canada (DFO 2009), eelgrass has an optimal salinity range between 20 and 26 for photosynthesis but is tolerant of salinity levels of 5–35 and even pure freshwater (salinity ~0) for short periods of time (Biebl and McRoy 1971). However, eelgrass growth, survival, seed germination, and reproduction can be negatively affected at the extreme ends of this salinity range (Biebl and McRoy 1971; Kamermans et al. 1999; Phillips et al. 1983; Sand-Jensen and Borum 1983). Though eelgrass can grow in low (2–5) and high salinity (35–40) at the mouths of rivers and marine coastlines respectively (Den Hartog 1970), low salinity in the range of 2.5–5 decreased eelgrass growth, thereby decreasing overall biomass, and increased eelgrass mortality (Nejrup and Pedersen 2008). Eelgrass exposed to a salinity range of 10–35 experienced similar growth performance. The consequences of fluctuating salinity for eelgrass health were studied in southern France. During the first three years of low salinity (5–15), the eelgrass meadow progressively contracted and in the fourth year, it suddenly disappeared (Charpentier et al. 2005). Rather than a direct effect of low salinity, the eelgrass decline was attributed to higher turbidity resulting from a lack of flocculation and particle settling in low salinity water. The study was conducted in Vaccarès Lagoon, where sediments are frequently resuspended by strong winds. When the salinity was lowest, the concentration of suspended particulate matter (SPM) was about 10 times higher than in the original state, which is attributed to a lack of particle aggregation and flocculation of suspended solids and hence much slower sinking of particles to the seabed and much higher water turbidity.

Warming and other effects of climate change

Because of the poor conditions for eelgrass growth under sea ice (low light availability, possibly low dissolved oxygen), eelgrass biologists working in places like Alaska and Greenland have speculated that reduced ice conditions could permit northward extension of the present eelgrass range (McRoy 1969; McRoy 1970b). However, according to a recent study, warm winter-to-spring conditions have a negative impact on eelgrass biomass because an early warming accelerates the depletion of eelgrass energy reserves (Sawall et al. 2021). Another study showed a lag effect between summer temperatures and eelgrass presence, with above-average summer temperatures linked to a decrease in the probability of eelgrass presence the following year (Plaisted et al. 2022). Also, early ice breakup can expose shoots to strong winds and waves, increasing mortality from spring ice scouring. Spring is when ice scouring is most intensive in southeast Hudson Bay and presumably James Bay because when the coastal area is mainly ice-free, winds cause the ice floes to drift around and run up against the seabed in shallow areas (Hequette et al. 1999). Ice scour is regarded as a major cause of eelgrass mortality in ice-covered regions (Ward et al. 1997; Wium-Andersen and Borum 1984), including eastern James Bay (Lalumière et al. 1994), and furthermore remobilizes seabed sediment contributing to turbid water (Hequette et al. 1999).

Past and present eelgrass condition in eastern James Bay

Cree description of pre-hydro condition of the eelgrass

Cree have rich traditional knowledge of the coastal habitat developed through hunting and trapping in their territory over generations. This knowledge was shared during interviews conducted for the CHCRP and in various past testimonials and reports (Cree Nation of Chisasibi 2015; FOPO 2008). According to these sources, dense eelgrass beds have long been very important feeding habitats for Canada Geese and Atlantic Brant; important habitat for other bird species such as Red-throated Loon (*Gavia stellata*), Arctic Tern (*Sterna paradisaea*) and Black Guillemot (*Cepphus grylle*); and important spawning and nursery habitats for many fish species (Cree Nation of Chisasibi 2015; FOPO 2008). Goose hunting and fishing activities in southern James Bay required detailed knowledge of the size, distribution, and density of the eelgrass beds (Ettinger and Lajoie 1995; Lajoie and Cuciurean 1994).

In past publications and reports, coastal Cree described eelgrass as historically plentiful and, in many places, sufficiently tall and dense that they would stop a motorboat and get caught around the propeller (CGW 2017). Cree land users described how the long eelgrass would float on the surface of the water during low tide, thereby calming the waves (Cree Nation of Chisasibi 2015). Dense eelgrass beds would be avoided when Cree were travelling the coast to fish.

Additionally, when eelgrass beds were large and dense, washed-up eelgrass would accumulate on the shoreline, forming wrack piles or lines (cf., Figure 4-1). The accumulation of washed-up eelgrass is therefore a very good indicator of dense eelgrass beds nearby. In the Migratory Bird Habitat Task Force report (Cree Nation of Chisasibi 2015), it is stated that:

"Cree elders have recounted that in the past, canoes could be pulled up on low stacks of eelgrass for protection against abrasive rocks. Fox traps were set in windrows of dried eelgrass contouring the tide line, as mice using them for shelter would attract foxes and other predators. Hunters would

temporarily store harvested geese in heaped eelgrass since cool damp conditions within the pile would protect carcasses from the sun. Cree elders recall observing caribou digging through the outer dried layer of eelgrass windrows to reach the fresher green eelgrass within."

The same report also states that from the Cree perspective, "*healthy eelgrass plants are identified by their dark, rich green color and very long blades. In contrast, unhealthy eelgrass plants are described as being yellowish or pale green, shorter, slow-growing, and occurring in patchy, and less dense beds. Unhealthy eelgrass plants are said to be commonly found in low salinity or in shallow, cold water*".

In the interviews conducted for this study (2018-2021), the Cree gave the following description of the eelgrass they were familiar with before the declines:

- *Leaves were long (up to 3 m) and deep green in colour*
- *Eelgrass beds were large and dense*
- *Abundant in late summer and fall*
- *Short necks and brants were often seen feeding on it*
- *Used to calm the water where present*
- *Floated above water in the low tide (looked like an oil slick)*
- *Propellers used to get stuck with eelgrass leaves and wash ashore*

These conditions contrast with many properties of the eelgrass ecosystems today:

- *Current eelgrass is short (no more than 1.5 m) and discoloured (yellowish and brown)*
- *Eelgrass beds are sparse and thin*
- *Beds are scarce*
- *Short necks are rarely seen feeding on eelgrass, Brants don't come in the fall*
- *Eelgrass shoots are no longer seen floating*
- *Eelgrass is no longer stuck in propellers*

As part of the CHCRP, Cree land users shared their knowledge of the spatial distribution of eelgrass along the coast and how it has changed. According to detailed maps drawn by the land users, under historic conditions, some of the shallow, protected bays near Chisasibi, such as Dead Duck Bay in CH34 were almost entirely covered by eelgrass beds (cf., Figure 4-2). Eelgrass extended along a large fraction of the coast in CH38. In each of CH37, CH33, and CH7, there were six or more major eelgrass beds. Traplines close to the mouth of the La Grande River had just a few major eelgrass beds. Cree land users from Wemindji and Eastmain similarly produced maps depicting many major eelgrass meadows distributed along the coastal areas of their traplines before the declines (Figure 4-3). Implicit in how the

Figure 4-1. Thick piles of eelgrass debris (wrack) that were a common sight along the shoreline of eastern James Bay before the eelgrass declines (Roche ltée, 1982).

Cree depicted the eelgrass beds on these maps is that under the initial conditions, major eelgrass beds were consistently present in the same shallow protected areas year after year, for many decades. Cree land users knew precisely where to find the major eelgrass beds and they were reliable features for organizing the goose hunt.

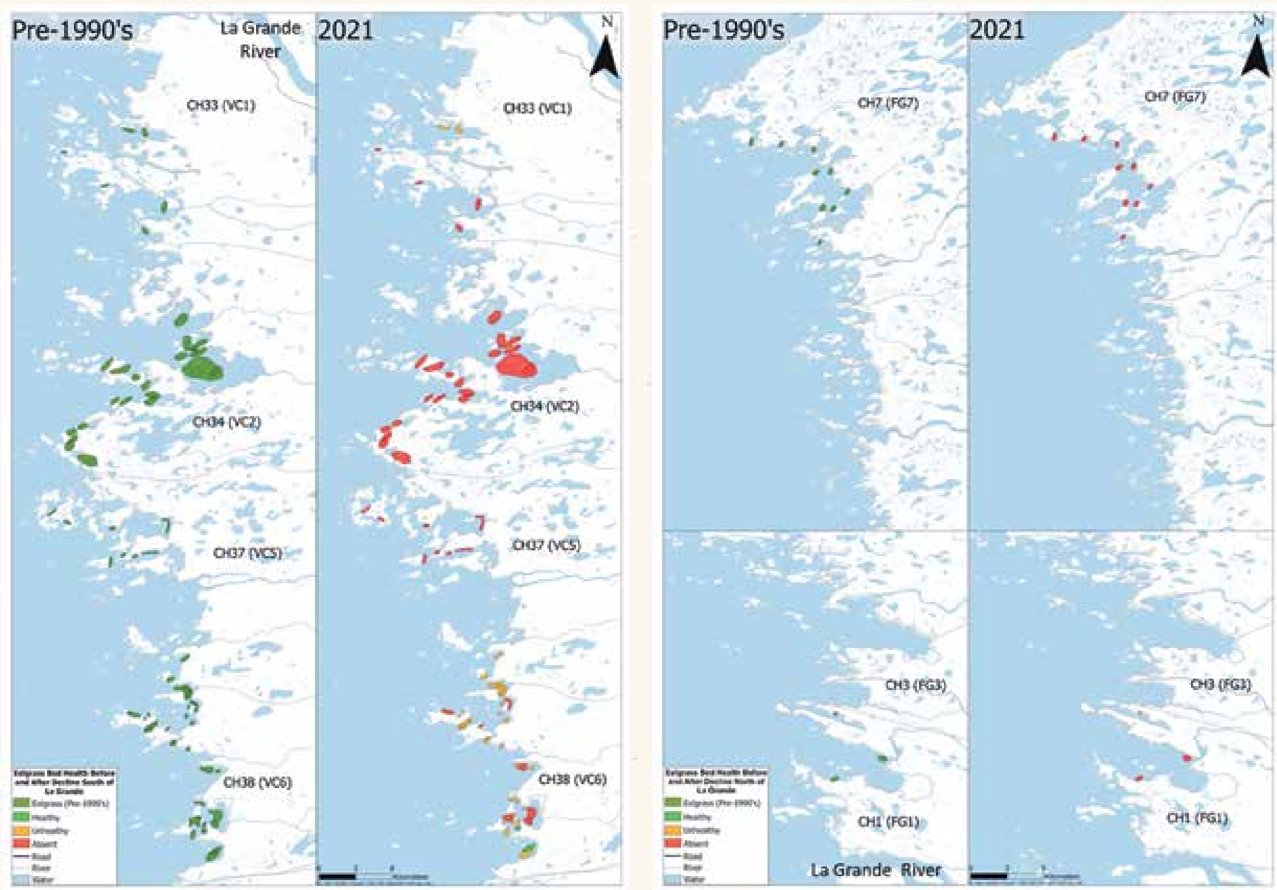


Figure 4-2. Eelgrass distribution near Chisasibi under initial conditions pre-1990s (left) and in 2021 (right) as mapped by Cree land users. Source: Idrobo et al. (in prep.).

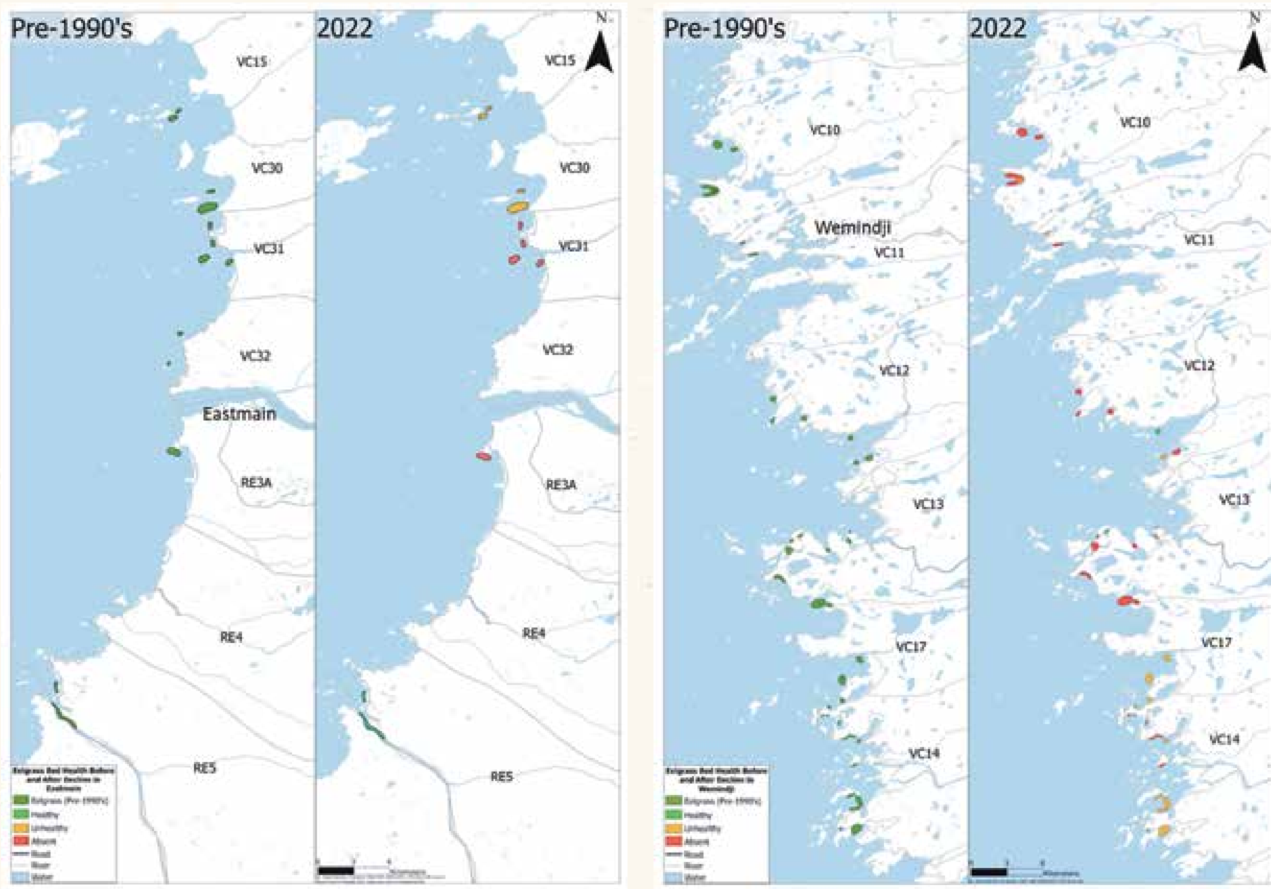


Figure 4-3. Eelgrass distribution near Wemindji (left) and Eastmain (right) under initial conditions pre-1990s and in 2022 as mapped by Cree land users. Source: Idrobo et al. (in prep.).

Scientific observations of eelgrass in the 1970s

The first scientific study of the eelgrass ecosystems and their use by geese along the Eeyou coast was conducted by the Canadian Wildlife Service between fall of 1971 and summer of 1975. During summers of 1974 and 1975, that team mapped the eelgrass distribution along the coast by flying helicopter surveys at low tide when the eelgrass beds were most visible, marking beds on maps and air photos, and stopping frequently to verify the observations on the ground. Local Cree, including George Lameboy, tallyman of CH5, and his uncle, were part of this survey effort. The map (reproduced in Figure 4-4) issued as a result of this effort shows a large amount of eelgrass along the coast, especially north of the Castor River, although the map states it is *not intended to depict every location* where eelgrass existed but rather just the major beds (Curtis and Allen 1976). The coastline north and south of Seal River (Rivière au Phoque), a bay near Roggan River, most of Bay of Many Islands (CH4), and Dead Duck Bay (CH34), were all sites of major meadows with high eelgrass cover (>70% of the seabed cover by eelgrass). The map also shows several large individual eelgrass meadows distributed along the coast between Wemindji and Eastmain near Baie du Vieux Comptoir (Old Factory Bay).

In addition to mapping the eelgrass beds, Curtis and Allen (1976) estimated the *aboveground biomass production* of the eelgrass beds. They described the eelgrass as "extremely productive" and estimated that the average biomass was 100–400 g m^{-2}, not including root production (i.e., aboveground biomass).

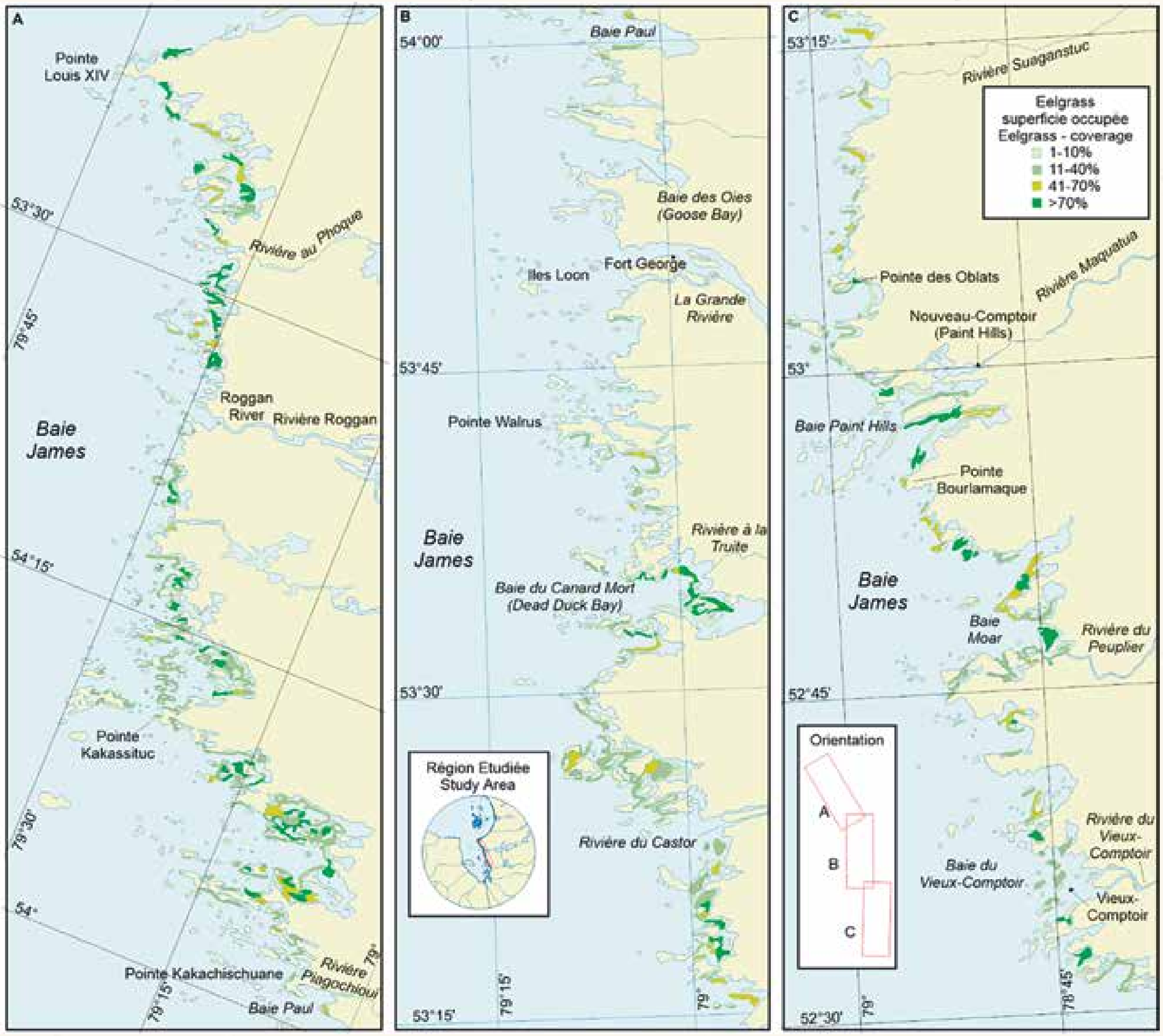


Figure 4-4. Reproduction of the map of the distribution of major eelgrass beds along the east James Bay coast based on helicopter and ground surveys during summers of 1974 and 1975 by the Canadian Wildlife Service. Modified from Curtis and Allen (1976).

Eelgrass monitoring 1982–2009 and comparison to 2019

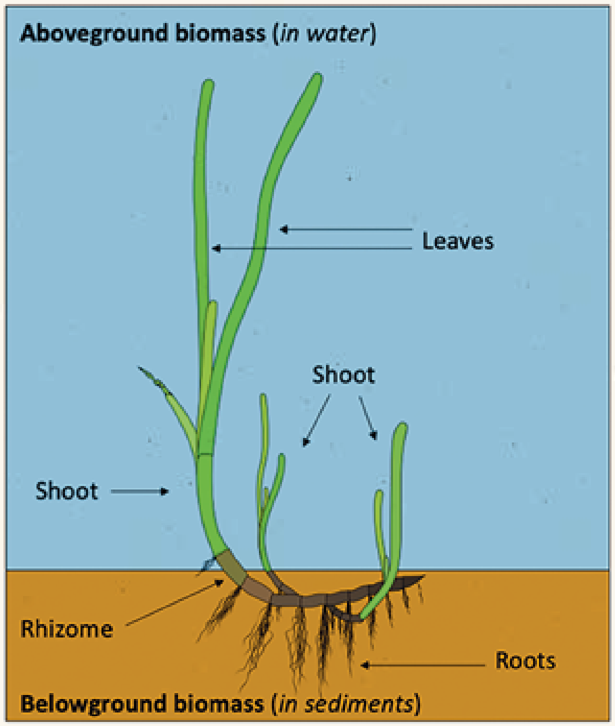
DESCRIPTION OF EELGRASS MONITORING METHODS

Various types of eelgrass monitoring have been conducted along the Eeyou coast over the past forty years. Eelgrass *biomass monitoring* was a main method employed between 1982 and 2009, and again in the CHCRP (2019). Biomass monitoring is the 'gold standard' for eelgrass monitoring programs because the underwater observations made by SCUBA supply a tremendous richness of qualitative information (e.g., shoot colour and overall appearance, growth habit, water colour and turbidity, surface sediment characteristics) as well as samples that can be processed to obtain quantitative data (e.g., shoot length, width, shoot density, rhizome length, biodiversity of the associated community of other organisms, etc.). Figure 4-5 illustrates the parts of the eelgrass that are sampled in order to assess the 'aboveground biomass' of eelgrass. 'Aboveground biomass' refers to the mass (weight) of the shoots and other green parts of the plants and excludes the belowground portions (roots and rhizomes). The right side of the figure shows how 'aboveground biomass' was determined during the CHCRP. Divers on SCUBA collected all the shoots and other green parts of the plants growing within a 0.0625 square-meter footprint on the seabed. Then the team washed this material, dried it in a warm oven, and weighed it. This is a standard method for determining eelgrass biomass.

A second common method of monitoring eelgrass is using 'eelgrass cover', which is assessed visually. Eelgrass cover is a qualitative or semi-quantitative assessment of the percentage of the seabed covered by eelgrass. However, eelgrass cover can be assessed much more quickly by divers than samples can be collected for determination of eelgrass biomass so eelgrass cover is often used for large-scale eelgrass surveys and developing eelgrass maps. Eelgrass cover also may be assessed without diving by collecting photos and videos (see, for example, Short et al. 2017 and Anderson, 2022).

OVERVIEW AND TIMELINE OF EELGRASS MONITORING PROGRAMS

The *earliest* eelgrass biomass monitoring along the eastern coast of James Bay was conducted in 1982 by biologists from Roche Associés guided by two members of the Cree Nation of Chisasibi on behalf of SEBJ in 1982 (Figure 4-6). Roche repeated the eelgrass biomass monitoring in 1985. Between 1986 and 1999, eelgrass biomass monitoring continued to be conducted at many of the same stations and additional sites. Some beds were visited almost annually between 1985 and 1995, while other beds were revisited at longer intervals. Detailed observations of the eelgrass beds, sediments, and benthic community were completed in CH4 in 1987. Annual reports were prepared to present the eelgrass biomass and shoot density data. However, after 1987, most of the monitoring was less detailed (sediments were no longer assessed, no details on eelgrass length, biodiversity, or water quality). The last biomass monitoring event associated with assessing the impacts of La Grande development was completed in 2009. Eelgrass biomass was next assessed as part of the CHCRP during 2019–2021.



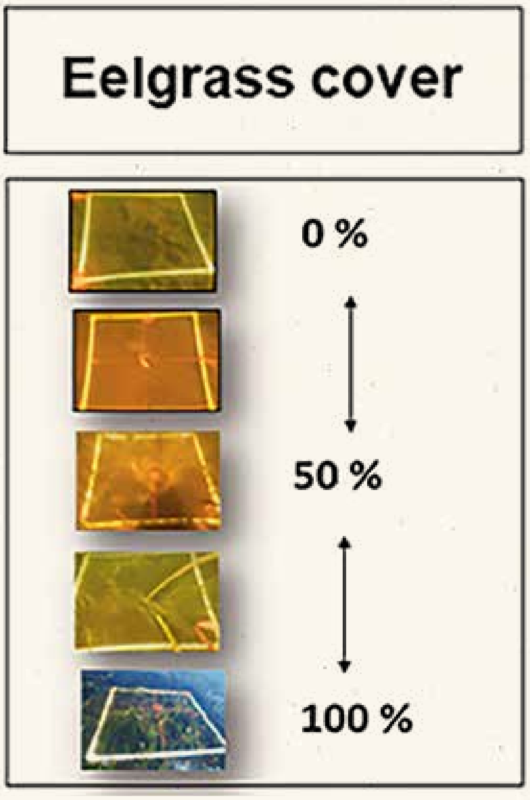


Figure 4-5. Illustration of eelgrass monitoring methods. The upper panel shows what is meant by the term 'aboveground biomass' (shoots and other green parts of the eelgrass found in the water rather than belowground in the sediment). The schematic shows how aboveground biomass was determined in the CHCRP. All the eelgrass shoots growing in an area of one square were collected by divers, dried in an oven, and then weighed giving a weight per unit area of seabed (g m^2). The lower panel shows how eelgrass cover is evaluated. Source: Leblanc et al. (2022).

Figure 4-7 shows the locations of early eelgrass monitoring. The monitoring sites were all located in the La Grande sector of the coast. The monitoring sought to assess the impacts of the first phase of La Grande hydroelectric development and allow anticipation of impacts potentially associated with additional modification of flows during subsequent phases of development (Roche 1982; Roche 1985).

Figure 4-8 provides a visual summary of the data obtained from the biomass sampling programs between 1982 and 2009. Total biomass was determined at only a few sampling sites and only during 1984, 1985, and 1986. Aboveground biomass was determined at a larger number of sites repeatedly between 1982 and 2009.

As part of the CHCRP, the eelgrass biomass monitoring data spanning 1982–2009 for the six stations near Chisasibi were compiled and analyzed together with new eelgrass biomass observations obtained in 2019 (see Leblanc et al. 2022). These results are discussed at the end of this section after describing the reported eelgrass observations across 1982–2009.

Alongside the eelgrass biomass sampling by divers on SCUBA, SEBJ and Hydro-Québec also undertook to map the distribution of eelgrass several times between 1982 and 1996 (see Appendix C for details). The 1986/1987 map was the first to show the shape and extent of the coastline and eelgrass beds in greater detail. A 1991 map was completed to compare to the 1986/1987 maps. These maps also were compared to Cree land user descriptions of eelgrass distribution when interviews were conducted by the Cree Regional Authority in Eastmain and Wemindji in 1994 and 1995, respectively (Ettinger and Lajoie 1995; Lajoie and Cuciurean 1994). Another map was produced in 1996 showing the distribution of eelgrass along the eastern coast of James Bay based on data from the eelgrass monitoring program (Figure 4-9). The total area of eelgrass beds represented on this map was 197 km^2.

OBSERVATIONS DURING EARLY EELGRASS MONITORING

Below we provide a summary of eelgrass and coastal habitat observations between 1982 and 2009 based on the eelgrass monitoring reports prepared for SEBJ and Hydro-Québec. The observations add to the understanding of historical variability and change in eelgrass condition and how the variability and change was perceived within the context of the monitoring program. In addition to describing the eelgrass condition, the reports also provide a picture of the physical environment and habitat characteristics in the 1980s and early 1990s. The historical data was compiled and re-analyzed as part of the CHCRP project (Leblanc et al. 2022). Here we provide a detailed account of how eelgrass abundances have changed over the course of the monitoring period.

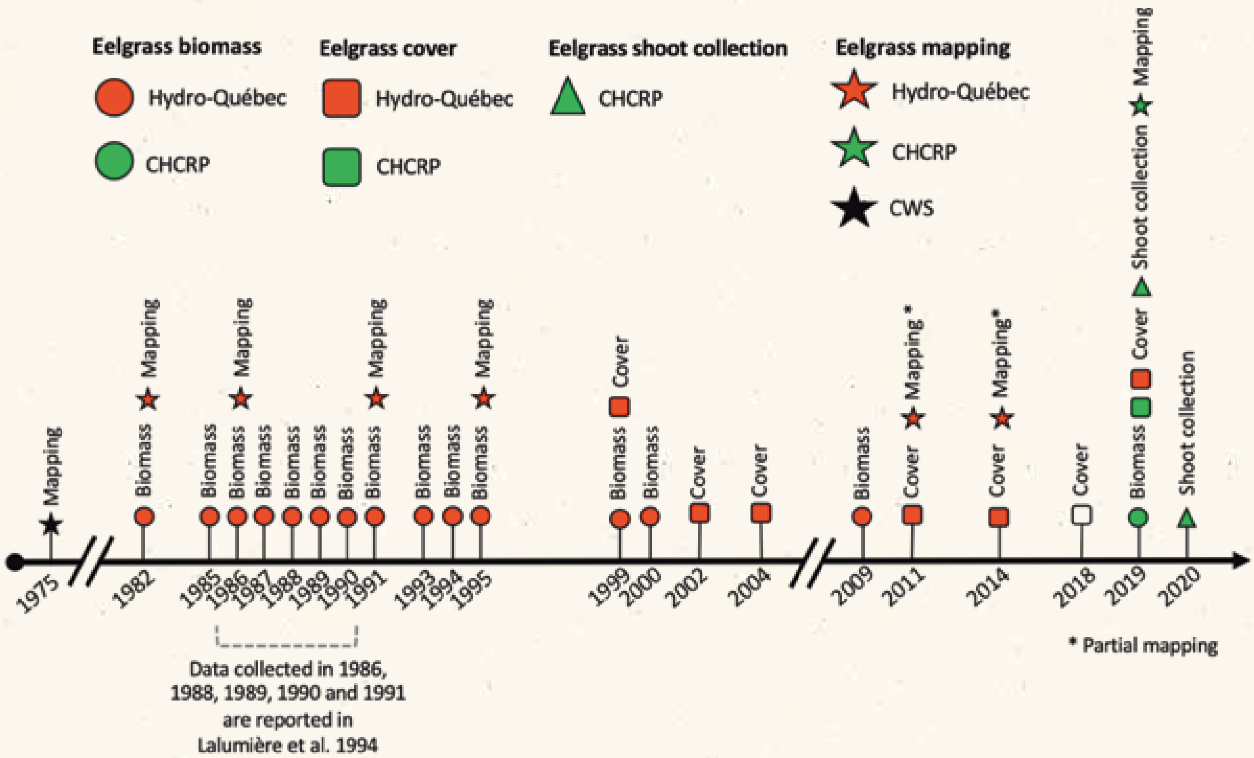


Figure 4-6. Timeline of different types of eelgrass monitoring along the coast. SCWS refers to the Canadian Wildlife Service, which conducted eelgrass surveys in the 1970s.

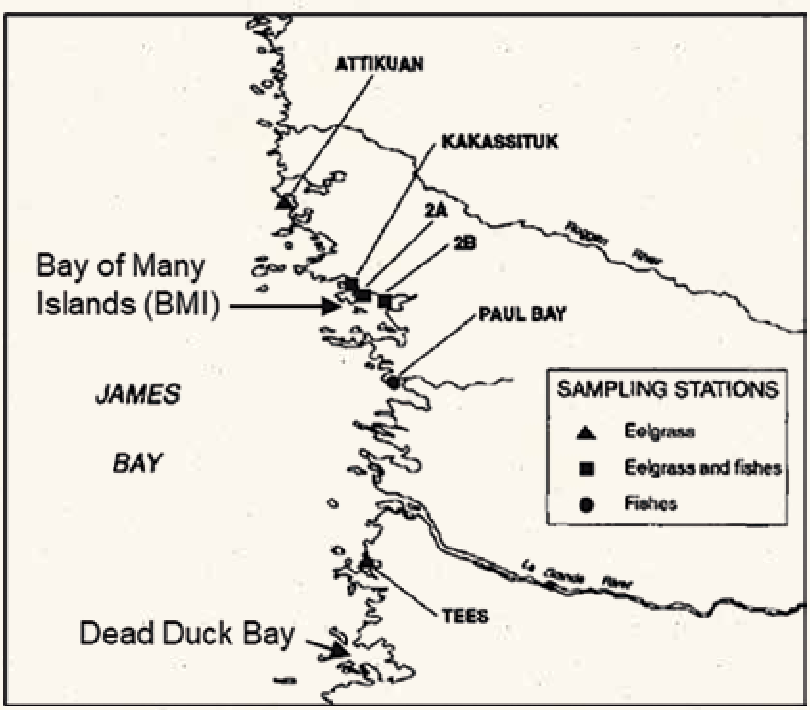


Figure 4-7. Map of eelgrass biomass sampling stations during the 1980s and 1990s (Attikuan, Kakassituk, and Tees). Elsewhere in this document, these areas are referred to by the trapline numbers CH4, CH5, and CH33, respectively. Stations were added in the Bay of Many Islands (BMI; also CH4) and Dead Duck Bay (elsewhere CH34). Modified from Lalumière et al. (1994).

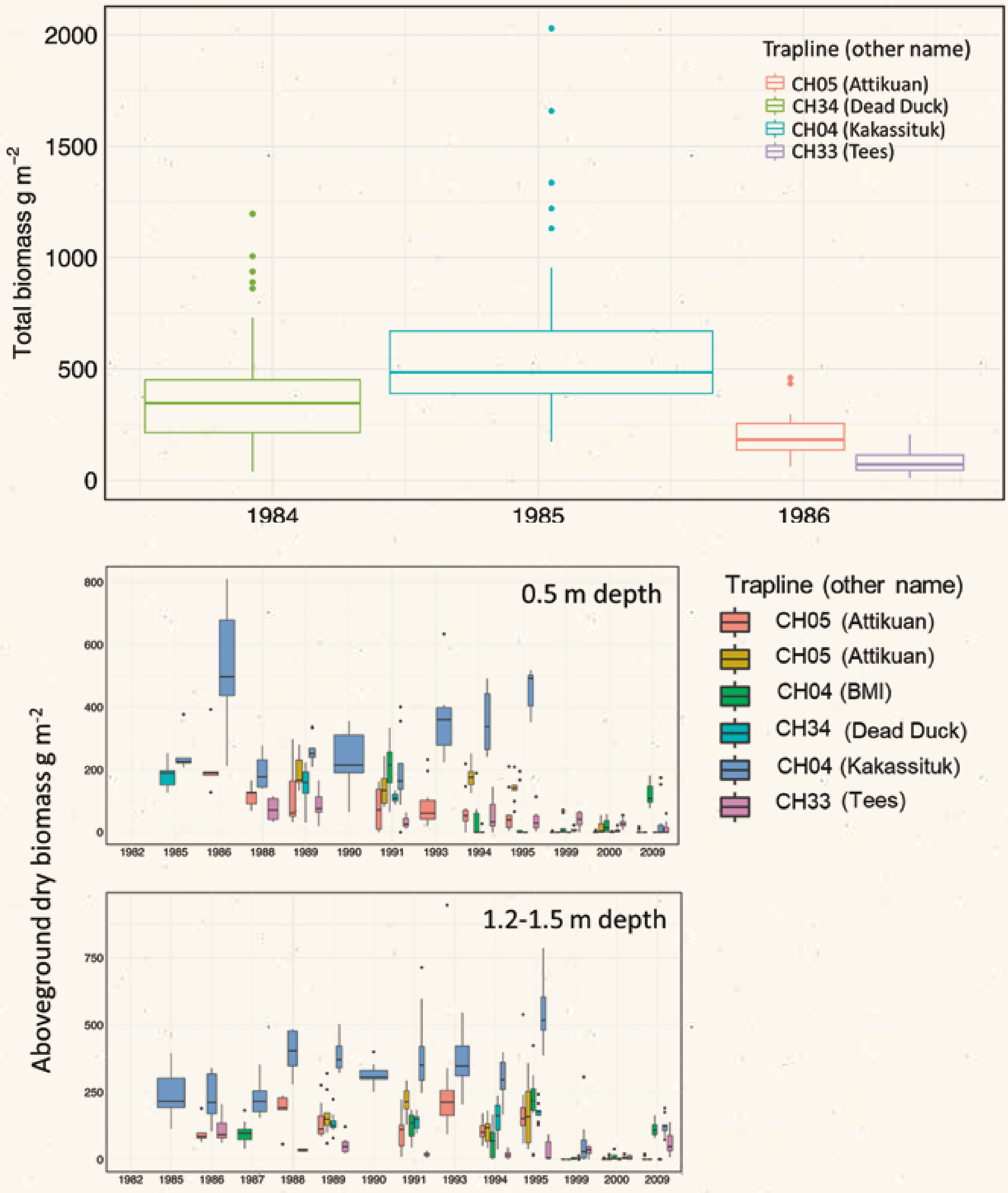


Figure 4-8. Summary of the total biomass (top panel) and aboveground biomass data (bottom panel) from eelgrass biomass monitoring at the six stations in the La Grande River sector of the coast from 1982 to 2009. Each station is represented by a different colour. Modified from data in Leblanc et al. (2022).

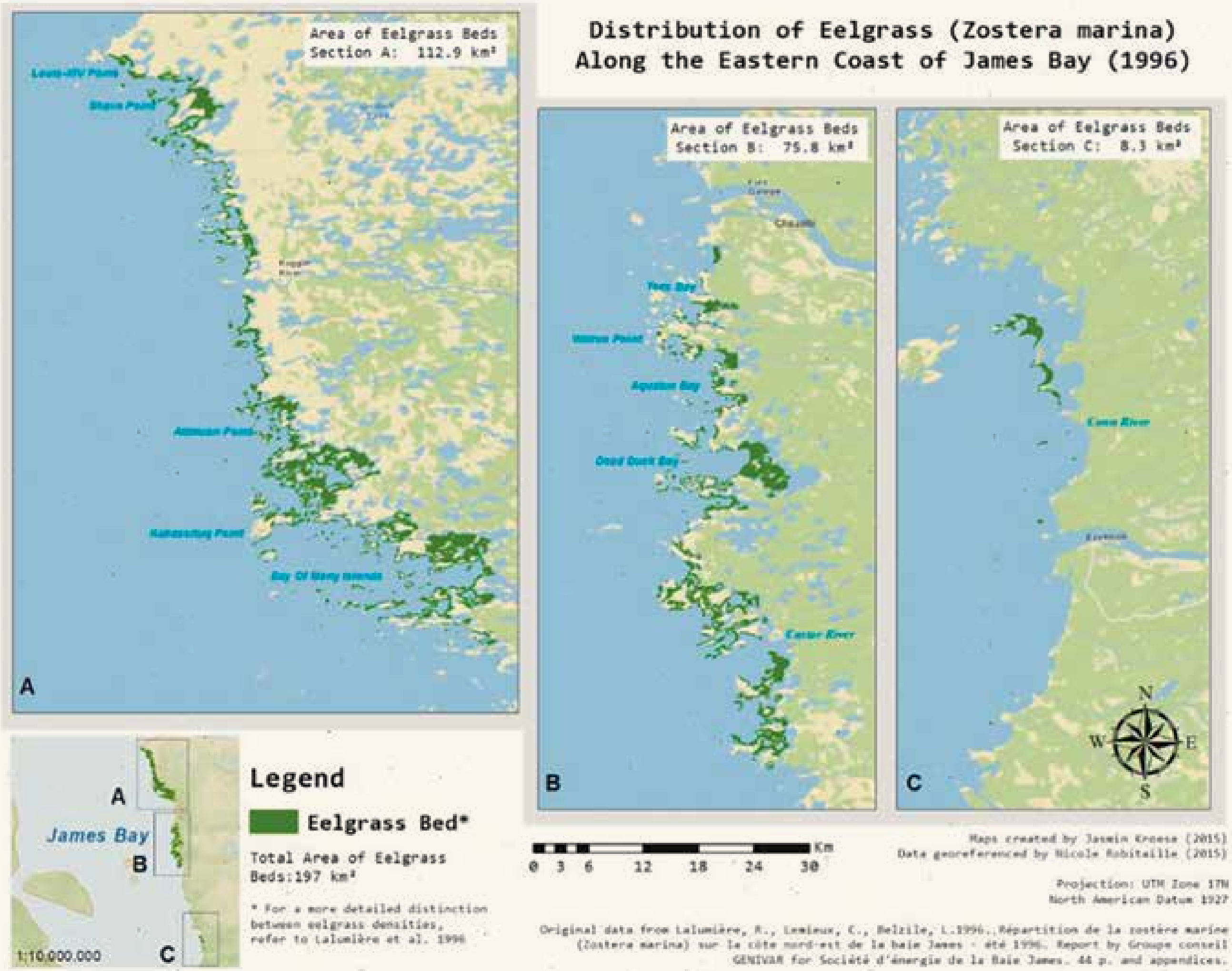


Figure 4-9. Map showing distribution of eelgrass along the eastern coast of James Bay in 1996 based on data from the eelgrass monitoring program. Source: Cree Nation of Chisasibi (2015).

1982

The 1982 monitoring team reported that eelgrass beds were still abundant despite the initial (1978–1981) flow alterations to the La Grande River. A large-scale survey of the northeast coast revealed that eelgrass was present all along the northeast coast of James Bay except for the area between Goose Bay and Tees Bay (Roche 1982). The team described and photographed large and thick piles of eelgrass debris (wrack) along the shoreline of the Bay of Many Islands (see Figure 4-1). Eelgrass *total biomass* and cover were assessed in relation to water and sediment properties at three sites in 1982: one in CH4 (referred to as Kakassituk Point in the HQ reports; see Figure 4-7), a second in CH34 (referred as Dead Duck Bay in the HQ reports; about 30 km south of the river mouth), and the third *outside* the presumed influence of the La Grande River in CH38 (near Comb Islands). Note that because of the methods used for the sampling in 1982, the total biomass results are not directly comparable to later measurements and the 1982 results are not shown alongside the other data in Figure 4-8.

In 1982, the monitoring team remarked that the CH4 and CH34 sites near Chisasibi contained extensive eelgrass meadows with high eelgrass cover *and* high biomass. There were long shoots (2 m) and lush growth (high shoot density). At CH4, eelgrass cover was 70%–100% in places and total biomass in these places was 552–2,031 g m^{-2}. Areas of high cover and high biomass occurred at various water depths. At CH34, eelgrass cover was low (5%–25%) in a shallow area of 0.5 m but high (50%–75%) in a deeper zone of 0.7 m. Total biomass averaged 923 g m^{-2} in the deeper, high-cover area. The shallow area had large numbers of shoots up to 4,625 shoots m^{-2}, but these shoots were very short and fine, whereas the shoots in 0.7 m were fine but very long (2 m) and vigorously growing. At the Comb Islands site in CH38, total biomass was lower at 363 g m^{-2} in 0.7 m of water and 420 g m^{-2} in 1.7 m of water.

In comparison to eelgrass biomass documented at sites across the northern hemisphere, the biomass observed at CH4 and CH34 in 1982 is similar to the best biomass seen anywhere. One point of comparison is the Izembek Lagoon on the Alaska Peninsula, one of the most extensive eelgrass meadows in North America. That lagoon had total biomass of 1,510 g m^{-2} (McRoy 1970b), similar to CH4 and CH34. In the Izembek Lagoon, the high biomass was the product of short plants (13 to 48 cm) growing at high shoot densities (mean, 4,576 shoots m^{-2}). In James Bay, the high biomass was controlled by both shoot length and shoot density because many long shoots were present and growing at relatively high density.

1985

In 1985, the 1982 eelgrass monitoring site in CH38 (Comb Islands) was not revisited due to bad weather. Two other sites (CH4 and CH34) were revisited. The opinion of the eelgrass monitoring team in 1985 was that eelgrass biomass but not cover had declined at both Kakassituq Point (CH4) and Dead Duck Bay (CH34) compared to 1982. At the revisited CH4 sites, eelgrass biomass that had been 1,124 g m^{-2} in 1982 was only 455 g m^{-2} in 1985 (Roche 1985), representing a 59% decrease. The biomass was low regardless of water depth. Only one shallow (0.5 m) subarea still had 75%–100% eelgrass cover and high shoot densities (≥ 1,100 shoots m^{-2}, maximum 1,575 shoots m^{-2}). In CH34, eelgrass biomass that had been 690 g m^{-2} in 1982 was only 348 g m^{-2} in 1985, representing a 49% decrease. The monitoring team also noted differences in shoot density and proportion of reproductive shoots, and plants with “rotting roots” (Roche 1985). The team observed higher water turbidity during monitoring and noted that eelgrass beds identified in Paul Bay in 1982 were either impossible to observe due to murky water or had disappeared between the 1982 and 1985 field surveys.

1986 TO 1996

Summer 1986 marked the beginning of nearly annual eelgrass biomass monitoring at some locations. Instead of *total biomass*, only *aboveground biomass* was collected. Eelgrass biomass sampling was conducted at three stations in 1986 (called Attikuan I, Kakassituq, and Tees Bay), one station in 1987 (Kakassituq), and then three stations again in 1988 (Attikuan I, Kakassituq, and Tees Bay). In 1989, the first sampling was conducted at a set of six stations (Attikuan I, Attikuan II, Kakassituq, Many Islands, Tees Bay, and Dead Duck), which subsequently came to be known as the 'six permanent stations'. Three or four depths per station were sampled (Lemieux et al. 2000). In 1987, eelgrass biomass at beds at Kakassituq (CH4) at a water depth of 1.5 m was noted as being 325 g m^{-2}, compared to 460 g m^{-2} in 1986, and 482 g m^{-2} in 1985 (Lalumière 1987). The results for the three stations sampled repeatedly between 1986 and 1991 (including the CH4 site) were analyzed in a scientific publication (Lalumière et al. 1994). The eelgrass meadows in eastern James Bay were described as "extensive" (> 250 km^2), extending down to water depths of 4.0 m (referenced to mean low water level), and having biomass as high as 675 g m^{-2} and shoot densities as high as 1,500 m^{-2} (Lalumière et al. 1994).

In summer 1994, the first complete monitoring of the six permanent stations after the commissioning of LG2A and the beginning of regular winter flows of 5,000 $m^3 s^{-1}$ was completed (Lemieux and Lalumière 1994). Note that LG2A was commissioned in 1992 but turbine flows in the winter of 1992–1993 were lower than expected so monitoring activities in summer 1993 were reduced. The monitoring report notes that in summer 1994, eelgrass biomass and shoot density at all depths at the CH5-A site decreased significantly compared to 1993. At both 0.5 m and 1.0 m depths, there were downward trends in biomass over 1986–1994. At the CH4-A site, eelgrass biomass and shoot density also decreased at 0.5 m and 1.0 m in 1994 compared to 1993 but were higher than during some of the early years of monitoring. At the CH4-B site, eelgrass biomass and shoot density at 0.5 m, 1.0 m, and 1.5 m were significantly lower than at the last monitoring event in 1991, and at 0.5 m, 6 of 10 sample plots were free of eelgrass. At the CH33 site, the report notes that the 1994 biomass and shoot density at 0.5 m was not different from previous years but at 1.0 and 1.5 m, there were slight decreases in eelgrass biomass and shoot production. It is noted that these decreases extended what appeared to be a downward trend in eelgrass production since monitoring began. Biomass values in 1988, 1989, 1991, and 1994 were not half the ~110 g m^{-2} value observed at the 1.5 m depth at Tees Bay in 1986. At the CH34 site, eelgrass biomass and density decreased sharply at 0.5 m depth with 80% of the sampling plots having no eelgrass at all.

In summer 1995, eelgrass sampling was again conducted following the design used during earlier surveys. This was the first year of sampling following the start-up of the LG1 power plant, and the second year following the start-up of the LG2A power station. The report describes that growing conditions were better in summer 1995 than in 1994 and that 1995 eelgrass production reflected the better conditions. A global decreasing trend in dry biomass production had occurred in shallow water (0.5 and 1.0 m) at all stations, except Kakassituq since the implementation of the monitoring program, which was attributed to factors unrelated to La Grande river discharge (Lalumière and Lemieux 1995).

1999

In 1999, Hydro-Québec carried on the eelgrass biomass monitoring program, completing the third sampling survey after the commissioning of the LG-2A power station. They described a 'massive' decline in eelgrass biomass. At five of the six permanent stations, eelgrass biomass was found to have decreased by 94 to 99% in comparison with the previous monitoring surveys (Genivar 1999). The only exception was Tees Bay, which already had low biomass (9 g m^{-2}) in 1995 and was at 39 g m^{-2} in 1999.

After the massive decline was observed by the monitoring team, sampling was conducted by divers on SCUBA at more than 100 points (called verification points) between Manitounuk Sound (southeast Hudson Bay) and Strutton Islands (40 km north of Rupert Bay). The eelgrass cover observed by the divers was compared to the eelgrass cover as mapped in 1996 (i.e., Figure 4-9). The results showed that the eelgrass cover all along the coast in 1999 was well below that mapped in 1992 and 1996 (Genivar 1999; Lemieux et al. 2000). The report describes that on the whole, eelgrass beds had disappeared from offshore areas, with only a few shoots remaining nearer to shore (Genivar 1999; Lemieux et al. 2000).

On October 26, 1999, a meeting was held with Elder Coasters from Chisasibi. The report describes that although participants were used to seeing eelgrass disappear in very shallow areas due to isostatic rebound, a decline had never been witnessed before in deeper waters. The notes also state that:

"the recent decline started in 1997. It was noticeable in shallow bays at that time. Grass got yellowish and there were black spots at the tip of some leaves. There was evidence of ice scouring on the roots for the past 3 years in shallow waters; it was noticeable in springtime, after the ice melt."

"there were no eelgrass stuck in the ice for the last 2 years, confirming that there was no eelgrass in shallow embayments."

POST-1999

The sampling of the six permanent eelgrass stations and the large-scale survey of eelgrass along the coast (i.e., verification points) was repeated in 2000. Eelgrass conditions were like those in 1999 with some beds showing minor increases (Bay of Many Islands) and others decreases (Tees Bay) compared to 1999. Some sites that had average biomass of 500 g m^{-2} or greater in the 1980s had a biomass of <10 g m^{-2} in 1999 and 2000. It was thought that in places, rhizomes in the periphery of the remaining eelgrass patches were expanding across the bare substrate left by the eelgrass loss.

The next eelgrass biomass monitoring event occurred nine years later. The six permanent monitoring stations were visited in summer 2009 in the context of an environmental follow-up program for the Eastmain-1-A and Sarcelle powerhouses and the Rupert diversion project. The results varied, with some sites (such as Attikuan) showing essentially "no recovery" compared to 1999/2000, and others (such as Bay of Many Islands in CH4) showing "partial recovery" (Genivar 2010).

STATISTICAL ANALYSIS OF EELGRASS CHANGE

Leblanc et al. (2022) completed a comprehensive review and data assimilation exercise to analyze the historical shoot density and aboveground biomass data (1982 to 2009) as well as eelgrass cover data and compare it to new data from sites revisited in 2019 as part of the CHCRP (see Figure 4-10 for locations). The study aimed to answer the three following questions: 1) do observations from systematic monitoring of eelgrass meadows reflect a gradual or drastic decline; 2) if a decline is detectable in the monitoring data, is it possible to attribute changes in eelgrass meadows to local or large-scale environmental drivers; and 3) has monitoring indicated recovery of eelgrass following the decline?

The study showed that in recent years (2019 and 2020), eelgrass aboveground biomass and density in eastern James Bay have been less abundant than in the past. According to Leblanc et al. (2022), there was a statistically significant decline in shoot density *and* aboveground biomass sometime between 1995 and 1999 at four of the permanent eelgrass biomass monitoring sites in both shallow and deeper water (site 1 in CH5, site 2 in CH04, site 3 in CH33, and site 6 in CH34 in Figure 4-11)). Visual inspection of the time series for sites 1 and 6 suggests a gradual decline started in the 1980s, whereas sites 2 and 3 show a more rapid decline that occurred after 1995. In site 3, density and aboveground biomass varied interannually but were highest between 1993 and 1995. Sites 4 and 5 showed some declining trends, albeit of lesser magnitude and no clear breakpoint. Comparing historical observations to 2019, it was found that across all the sites, the average eelgrass shoot density in 2019 was significantly lower than the density in 1995 (Figure 4-12). Similarly, compared to 1995, the 2019 aboveground biomass was significantly lower than the aboveground biomass (Figure 4-12b). Using the 1996 eelgrass cover map as a reference, the number of sites with eelgrass cover >50% was significantly lower in 1999 and remained low in 2019 but slightly higher than in 1999 (Figure 4-13). Finally, modelling the eelgrass data with available environmental data for 1982–2019 revealed associations between low eelgrass biomass at some of the monitored beds near Chisasibi and high freshwater discharge from the La Grande River as well as warmer spring water temperatures along the coast (Leblanc et al. 2022).

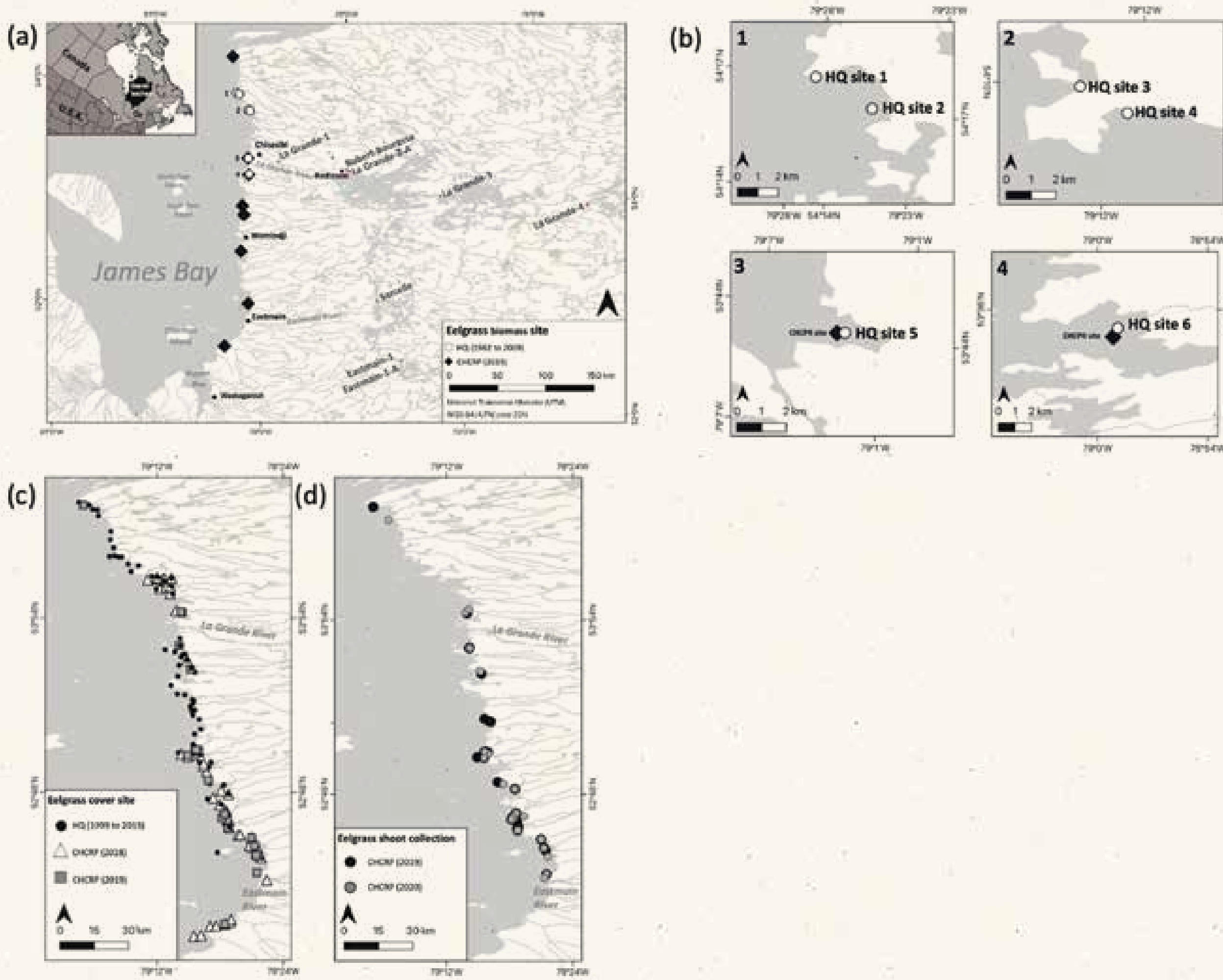


Figure 4-10. Panels (a) and (b) show locations where eelgrass biomass was collected from 1982 to 2019 (HQ: Hydro-Québec; CHCRP: Coastal habitat comprehensive research program), panel (c) shows locations where eelgrass shoots were collected in 2019 and 2020 to assess eelgrass length, and panel (d) shows locations where eelgrass cover was assessed between 1999 and 2019. Source: Leblanc et al. (2022).

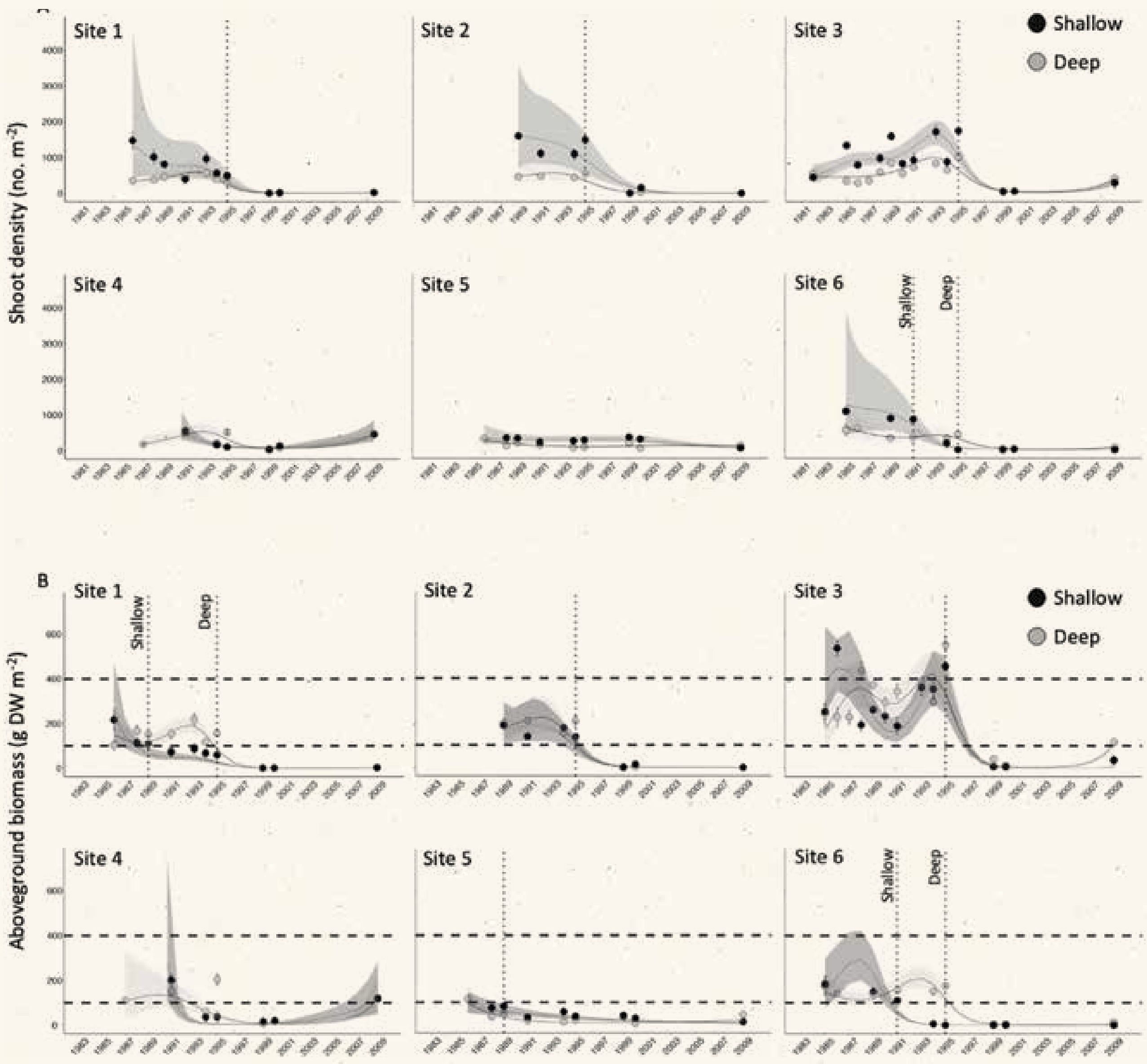


Figure 4-11. Time series of eelgrass shoot density and aboveground biomass at six monitoring sites located in northeastern James Bay (mean ±SE) from 1982 to 2009. The fitted line (shaded areas) shows predicted values (95% confidence intervals) based on statistical models developed by Leblanc et al. (2022). Vertical lines show significant (p <0.05) breakpoints point in time series; vertical line with no label indicating the same breakpoint for both shallow and deep eelgrass. In panel B, dashed gray horizontal lines indicate aboveground biomass range measured prior to the hydroelectric development (100 to 400 g dry weight m^{-2}, Curtis, 1974-75). Source: Leblanc et al. (2022).

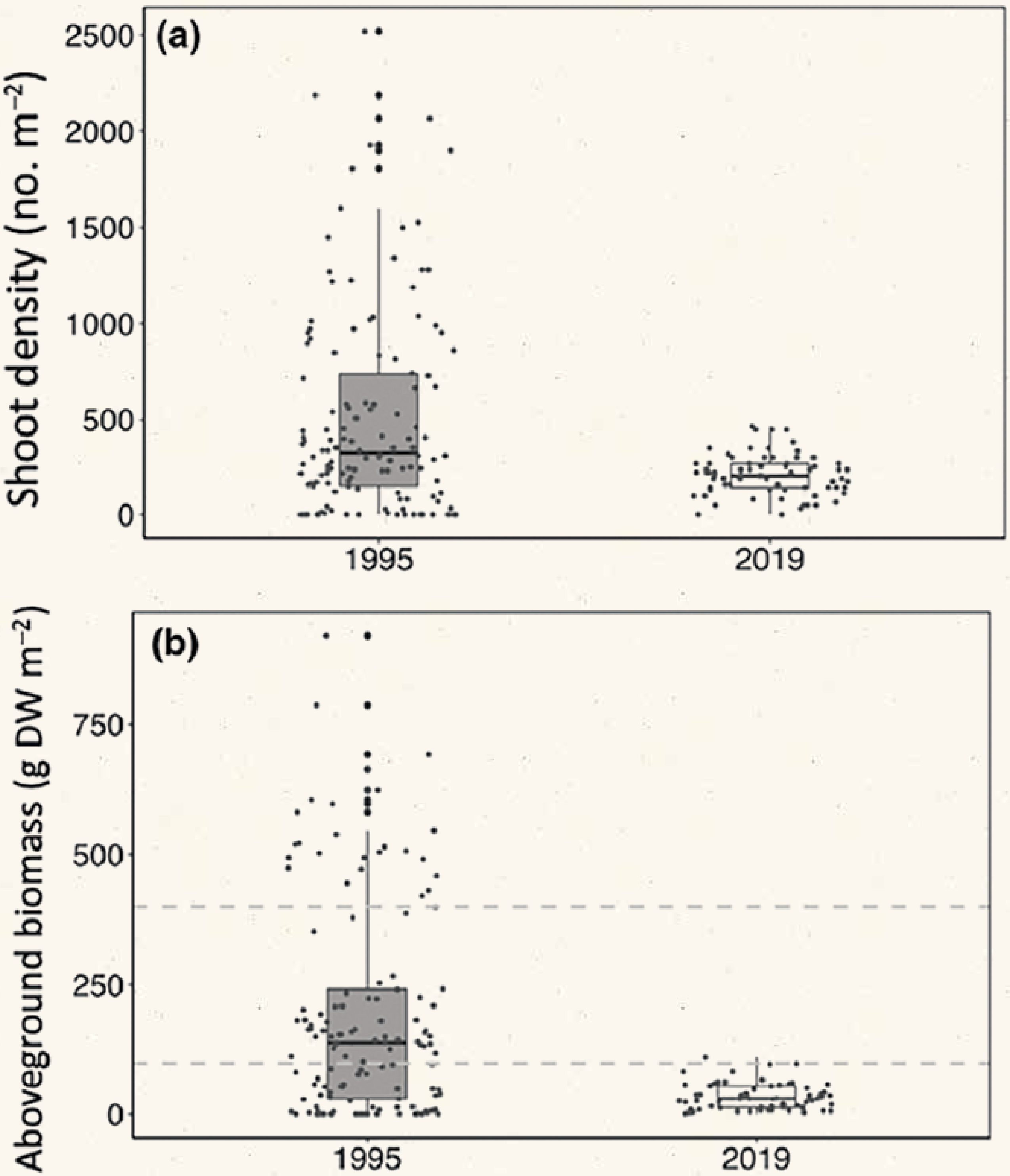


Figure 4-12. Boxplot of (a) eelgrass shoot density and (b) aboveground biomass in 1995 (n = 6), prior to the eelgrass drastic decline, and in 2019 (n = 8). Dashed gray horizontal lines in panel b indicate aboveground biomass range measured prior to the hydroelectric development (100–400 g dry weight m^{-2}; Curtis, 1974–1975). Eelgrass biomass in both years was collected in August. Source: Leblanc et al. (2022).

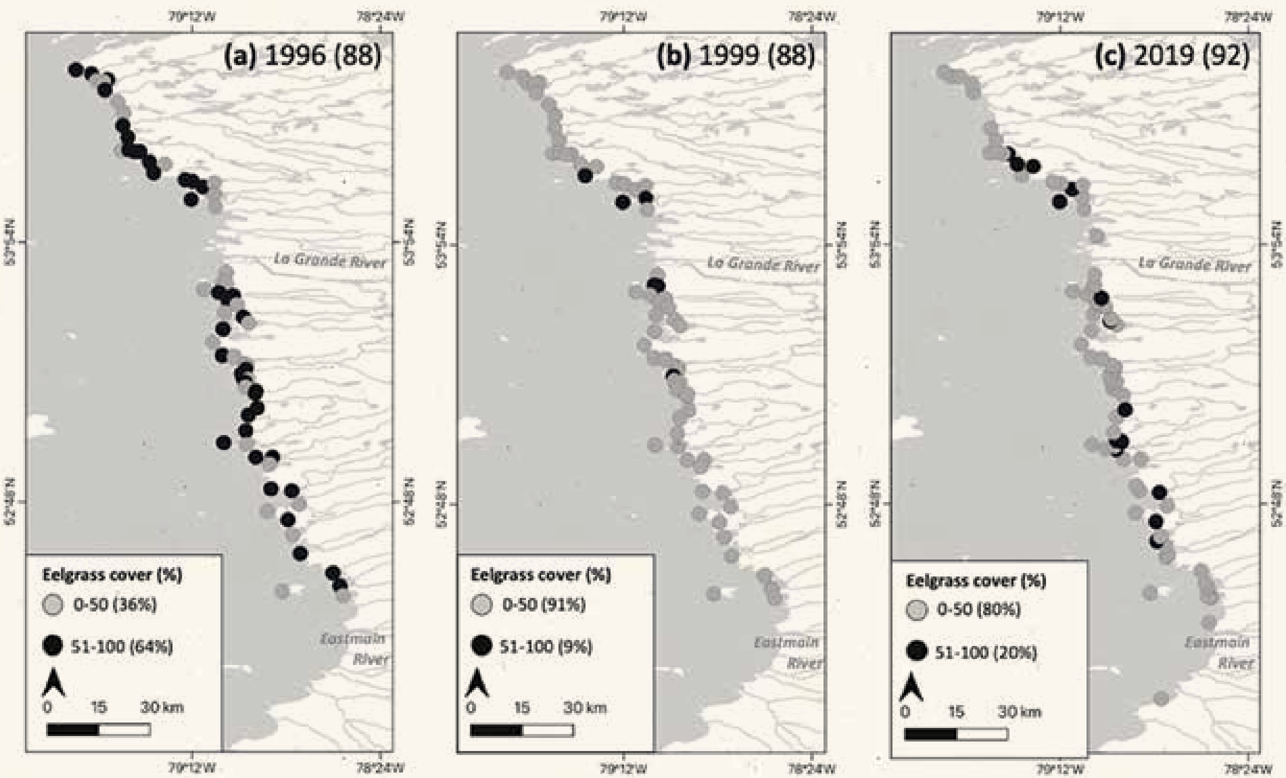


Figure 4-13. The number and location of HQ cover survey sites with eelgrass cover >50% and eelgrass cover <50% based on (a) on the 1996 eelgrass distribution map (Lemieux et al. 1999), (b) surveys conducted in 1999 (Lemieux et al. 1999), and (c) surveys in 2019 HQ and CHCRP combined. Source: Leblanc et al. (2022).

Eelgrass ecology and health assessment 2019–2021

OVERVIEW

To assess the present health of eelgrass, the CHCRP eelgrass team surveyed eelgrass along the eastern coast of James Bay during the summers of 2019–2021 (Figure 4-14). They surveyed a total of 124 sites spanning most coastal traplines. Traplines were accessed by Cree boat with the permission and support of the tallyman and land users for each trapline. Three traplines (CH4, CH5, CH6) were not included in the 2019–2021 survey because of a lack of permission. The team sampled eelgrass, algae, and associated invertebrates in a standard 25 x 25 cm sampling unit. They also conducted experiments to test the effects of light and nutrients on eelgrass growth.

At no site visited during the 2019–2021 survey was the eelgrass as long or as thick as it used to be. The eelgrass observed underwater was generally short and sparse, and often the shoots had coatings of

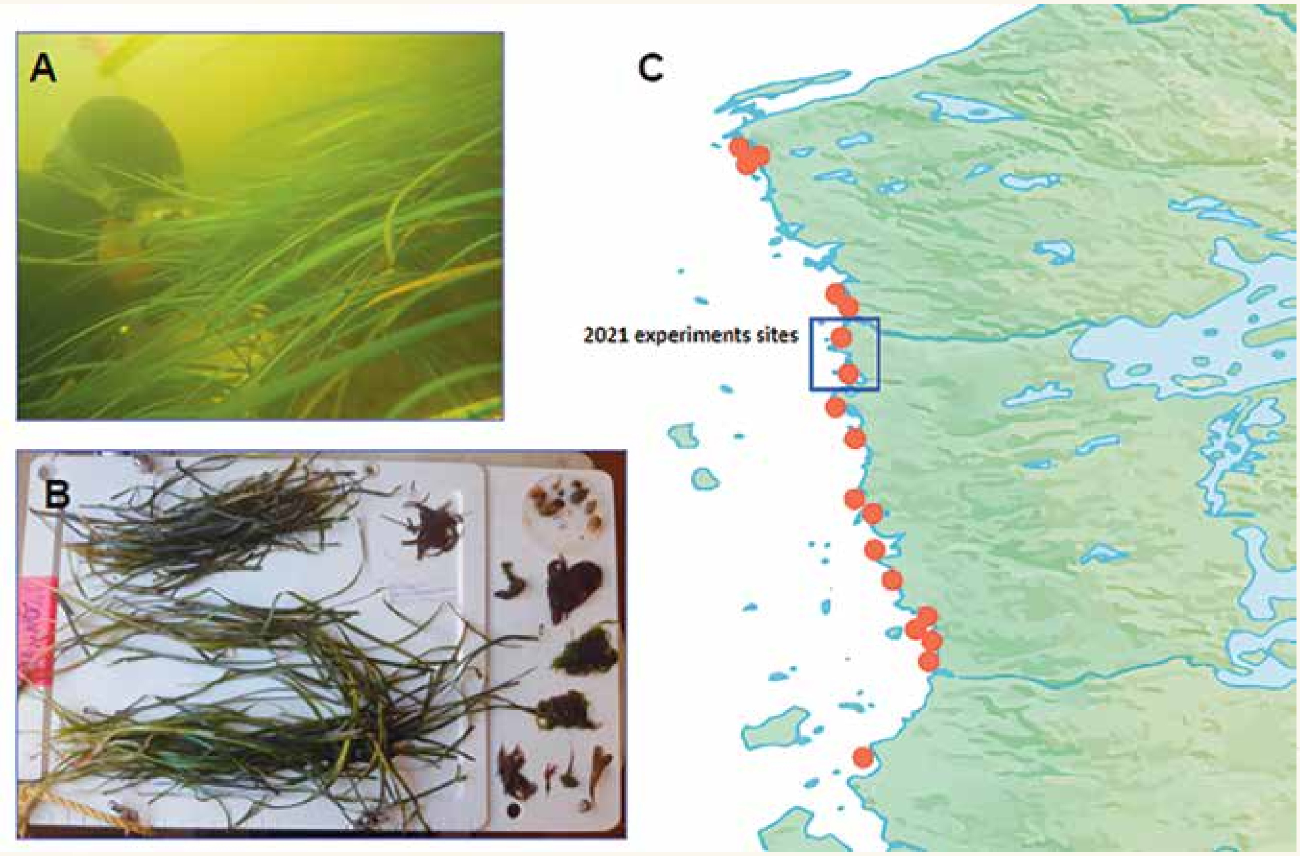


Figure 4-14. (A) Collecting eelgrass samples via SCUBA. (B) Eelgrass and associated algae and epifaunal invertebrates collected using a 25 x 25 cm quadrat. (C) Site locations along the eastern shore of James Bay.

silt or algae (Figures 4-15). We focused the divers' underwater observations at sites that were known to the Cree as *once* having had notable eelgrass so we *likely* observed most of the best meadows. Note, however, that a few isolated patches of long, dense eelgrass were observed in a few locations such as a protected location in the northern part of Dead Duck Bay (CH34). These were small discrete patches rather than meadows covering the entire bay like they used to. Underwater video images collected by Cree land users and Fred Short's team in 2017–2018 (Short et al. 2019) and analyzed by Anderson (Anderson 2020) showed similar results. Most eelgrass along the coast was in poor condition but there were a few isolated areas of long dense eelgrass (cf., Figure 4-16). One of these areas was at the eastern end of the Bay of Many Islands (CH4).

Despite the poor overall condition of the eelgrass, still, we wanted to know where eelgrass is present and where it is absent, and where it is doing better in a relative sense, i.e., growing taller or thicker than in other places. We took measurements of eelgrass at 41 sites in 2019, 26 sites in 2020, and 13 sites in 2021.

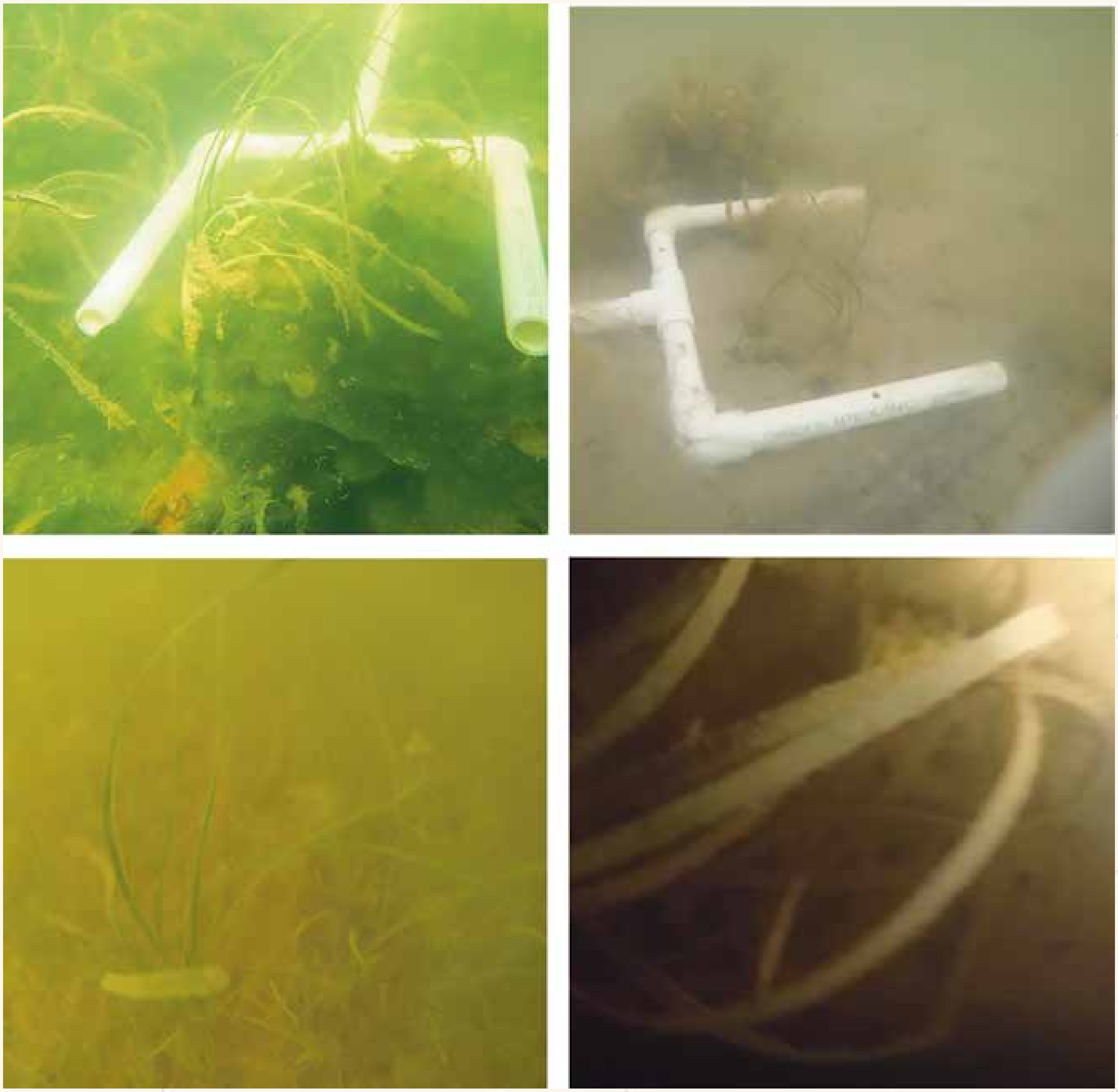


Figure 4-15. Underwater photos of eelgrass taken by divers during the summer and by GoPro camera (bottom right) during the winter under the ice.

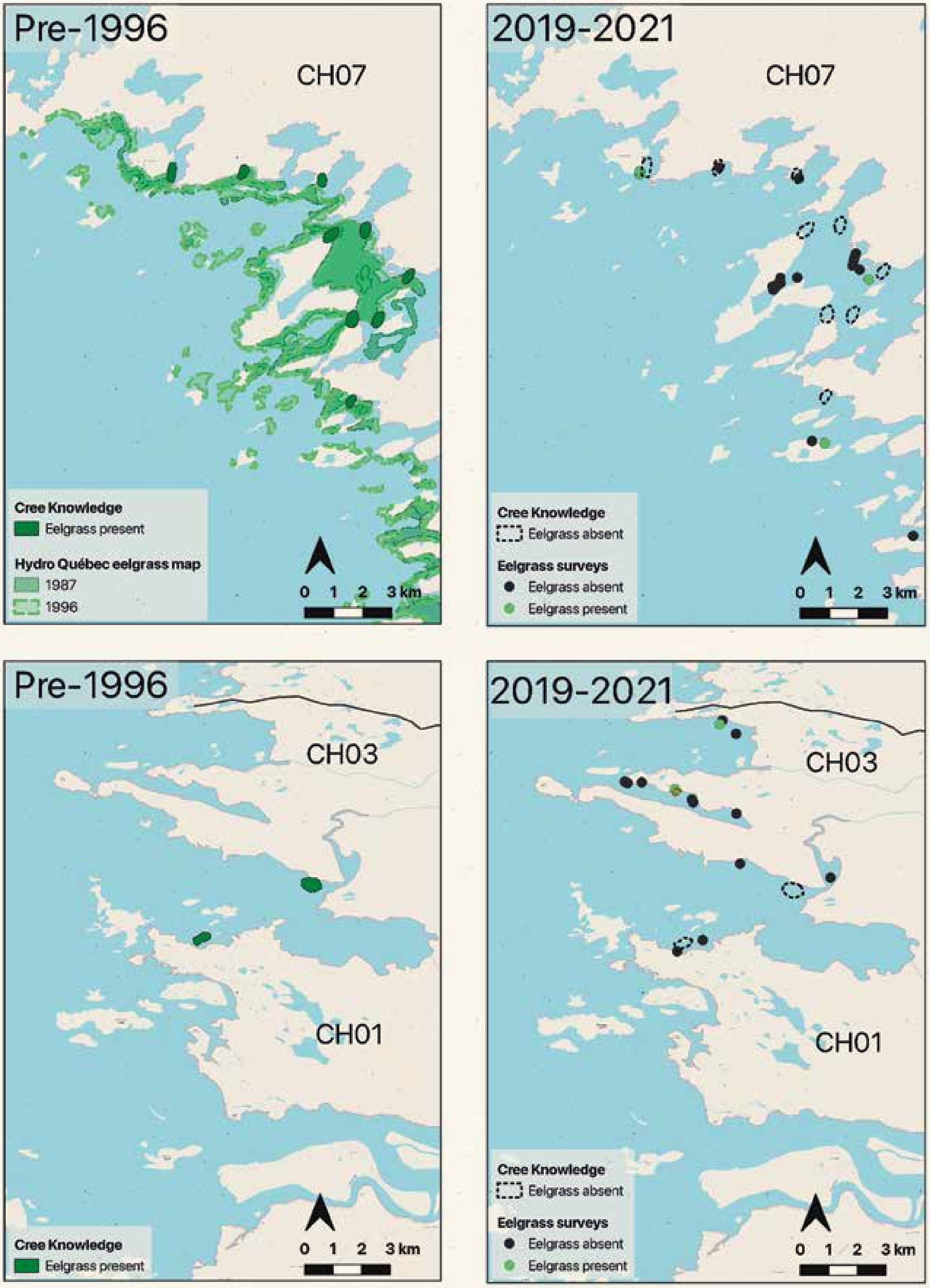
Figure 4-16. Underwater photos of eelgrass taken by GoPro camera by Fred Short's team during 2017–2018. Credit: Short et al. (2019).

Although the dataset of detailed, replicated measurements of eelgrass biomass at 80 sites is the first of its kind for eastern James Bay, it is important to note that it contains geographic data gaps (e.g., CH4, CH5, CH6) and also that the large-scale sampling design led to lower temporal resolution for any particular location. Furthermore, what we can say about where eelgrass is doing well, and where it is not, is influenced by how we chose to visit sites. Choices about where to go were essential—the coastline is large and travel by canoe is highly weather dependent. Even when we were there for several weeks in the summer, we could only visit a few places on a good day. We chose sites according to the following three factors: 1) sites where land users told us eelgrass used to grow, and was still there recently (most sites); 2) sites where eelgrass used to grow and has not been growing recently (some sites); and 3) sites where land users said they did not know if eelgrass ever grew (a few). This is a stratified approach to site selection that reflects our collaboration with the land users. This collaboration is a clear strength for this project, and it allows us to describe the current state of eelgrass in what are likely some of the best meadows (except CH4, CH5, and CH6). However, from a scientific perspective, our sampling method limits what we can say. For example, it is not a stratified random sampling design. This means that we cannot demonstrate using statistical methods *why* eelgrass grows where it does because we did not sample a full enough set of sites to get enough data at places where eelgrass is *not* growing. There are many places where eelgrass is not growing at all, where it used to grow (Figure 4-17). This may be said with high confidence because, in our surveys, we assessed eelgrass absence either on SCUBA or by snorkeling and looking underwater for eelgrass for at least 20 minutes. There are additional limitations to our ability to explain variations in how well the eelgrass is growing that have to do with the recent history of decline and recovery, and we explain those below.

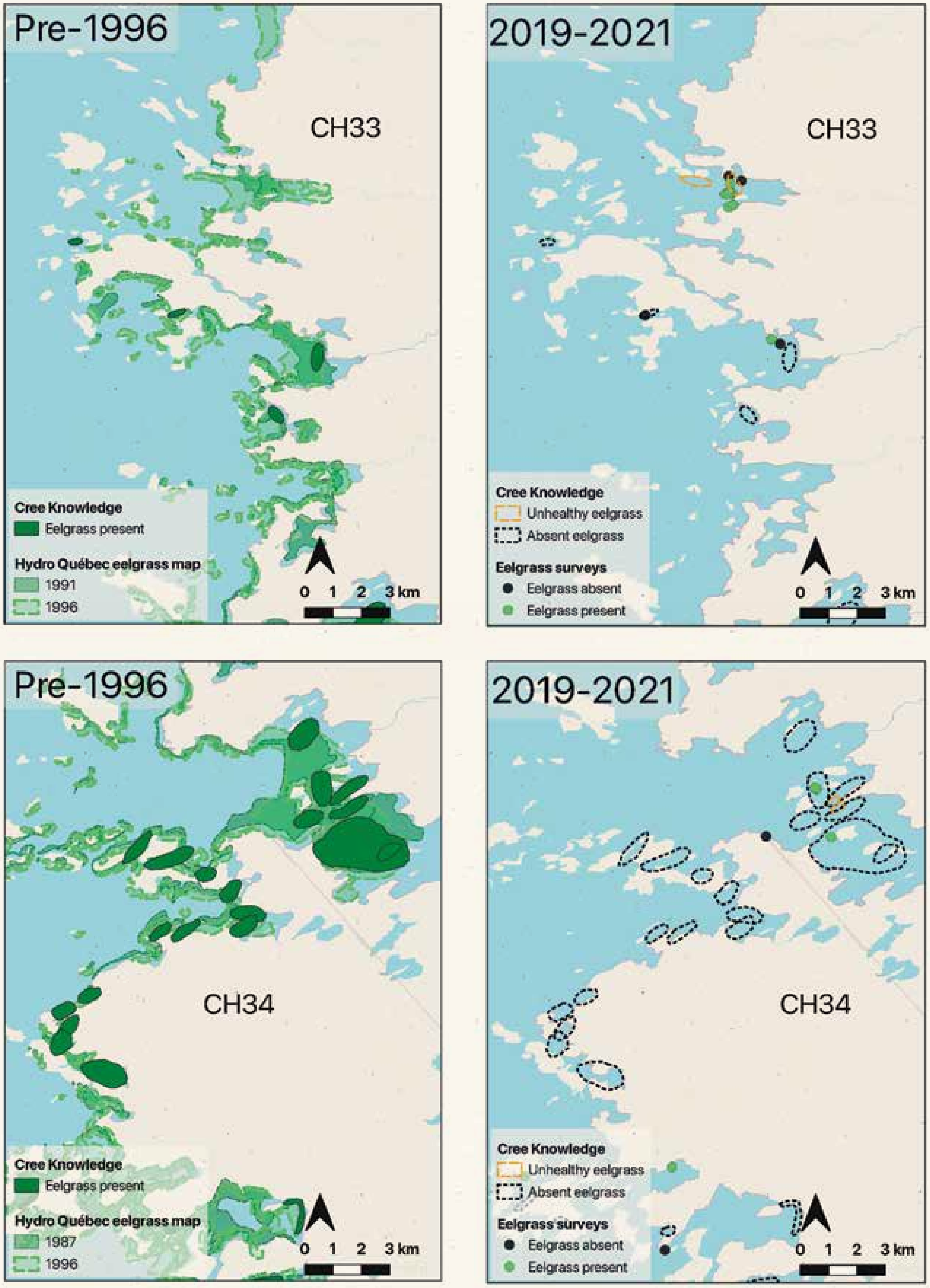
WHERE WAS EELGRASS PRESENT AND WHERE WAS IT ABSENT?

In 2019–2021, we observed eelgrass growing at far fewer locations than described for the pre-1990s period by the Cree or documented by Hydro-Québec surveys in 1991 or 1996. Figure 4-17 shows these comparisons (eelgrass presence pre-1996 vs. 2019-2021) for all the studied traplines using 13 map panels with the traplines ordered from north (CH07) to south (R01).

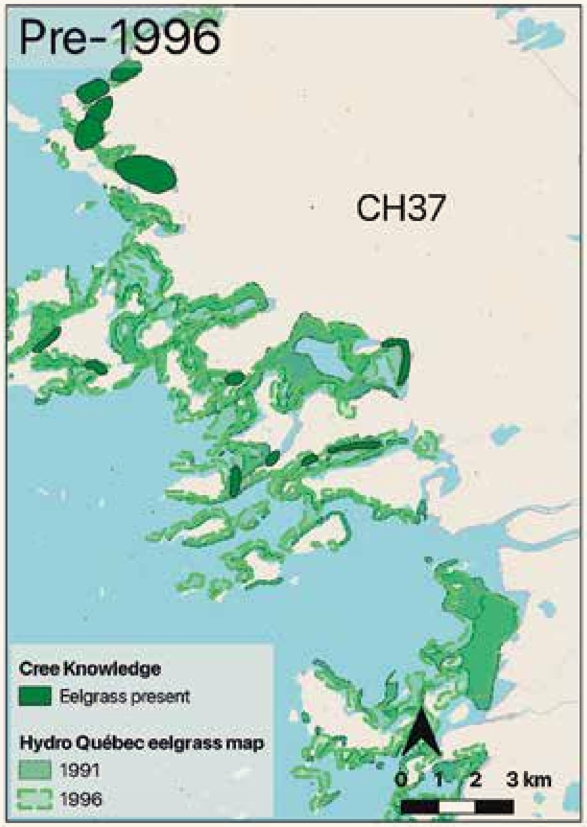
As shown on the maps, we visited sites with land users where eelgrass used to grow well. At many of these sites, there was no eelgrass and/or such small sparse eelgrass that the Cree land users consider it 'absent'. For example, at CH07, eelgrass used to be widespread and there were many significant eelgrass beds that were well known to the Cree (Figure 4-17, dark green areas in the left panel). In 2021, eelgrass was absent at most sites (Figure 4-17, black dashed lines and filled circles in the right panel). Eelgrass was present at just three sites. Another example is CH34 (Dead Duck Bay). There used to be eelgrass meadows extending across most of Dead Duck Bay but in 2022, there were only isolated patches of eelgrass (Figure 4-17).



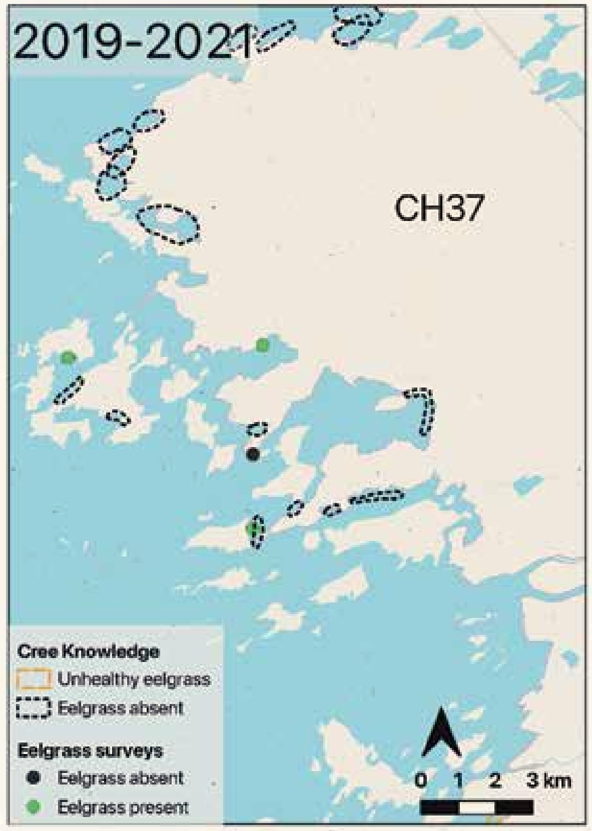
Pre-1996
CH07
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1987
1996
0 1 2 3 km
2019-2021
CH07
Cree Knowledge
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km
Pre-1996
CH03
CH01
Cree Knowledge
Eelgrass present
0 1 2 3 km
2019-2021
CH03
CH01
Cree Knowledge
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km



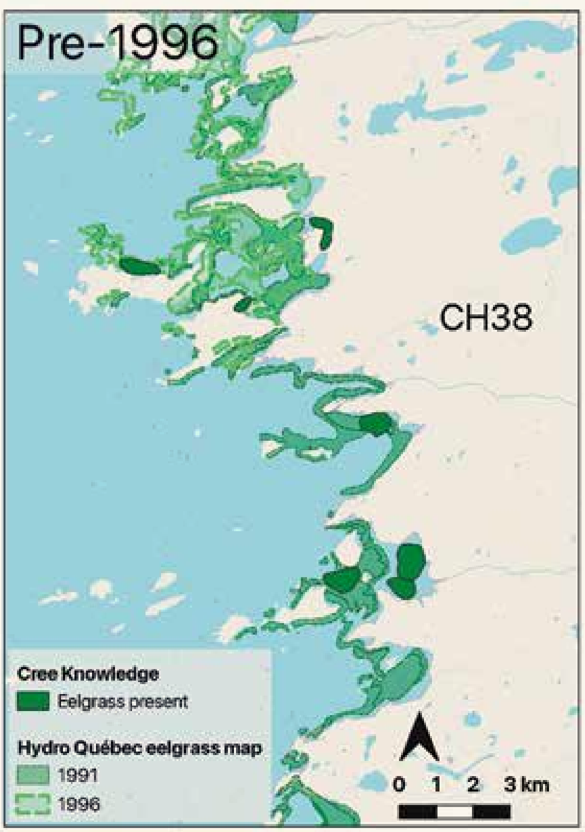
Pre-1996
CH33
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
CH33
Cree Knowledge
Unhealthy eelgrass
Absent eelgrass
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km
Pre-1996
CH34
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1987
1996
0 1 2 3 km
2019-2021
CH34
Cree Knowledge
Unhealthy eelgrass
Absent eelgrass
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km



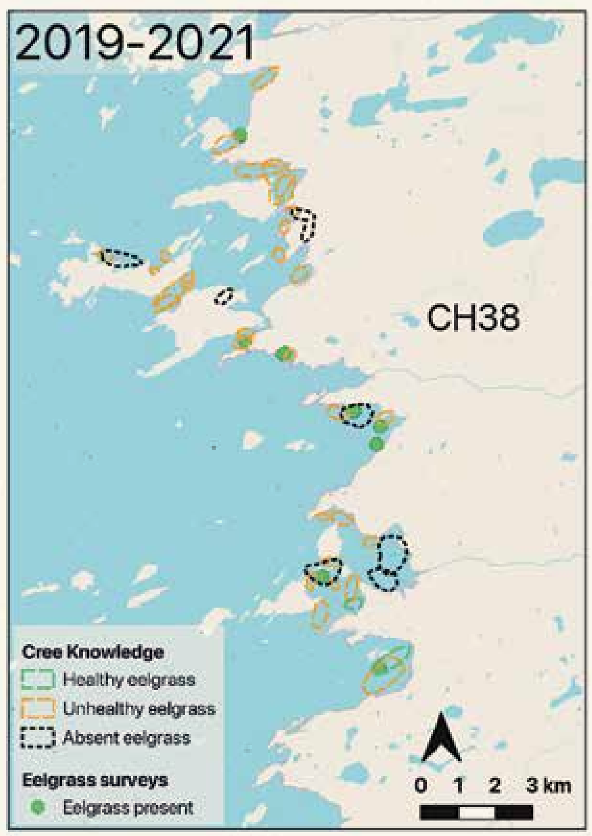
Pre-1996
CH37
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km



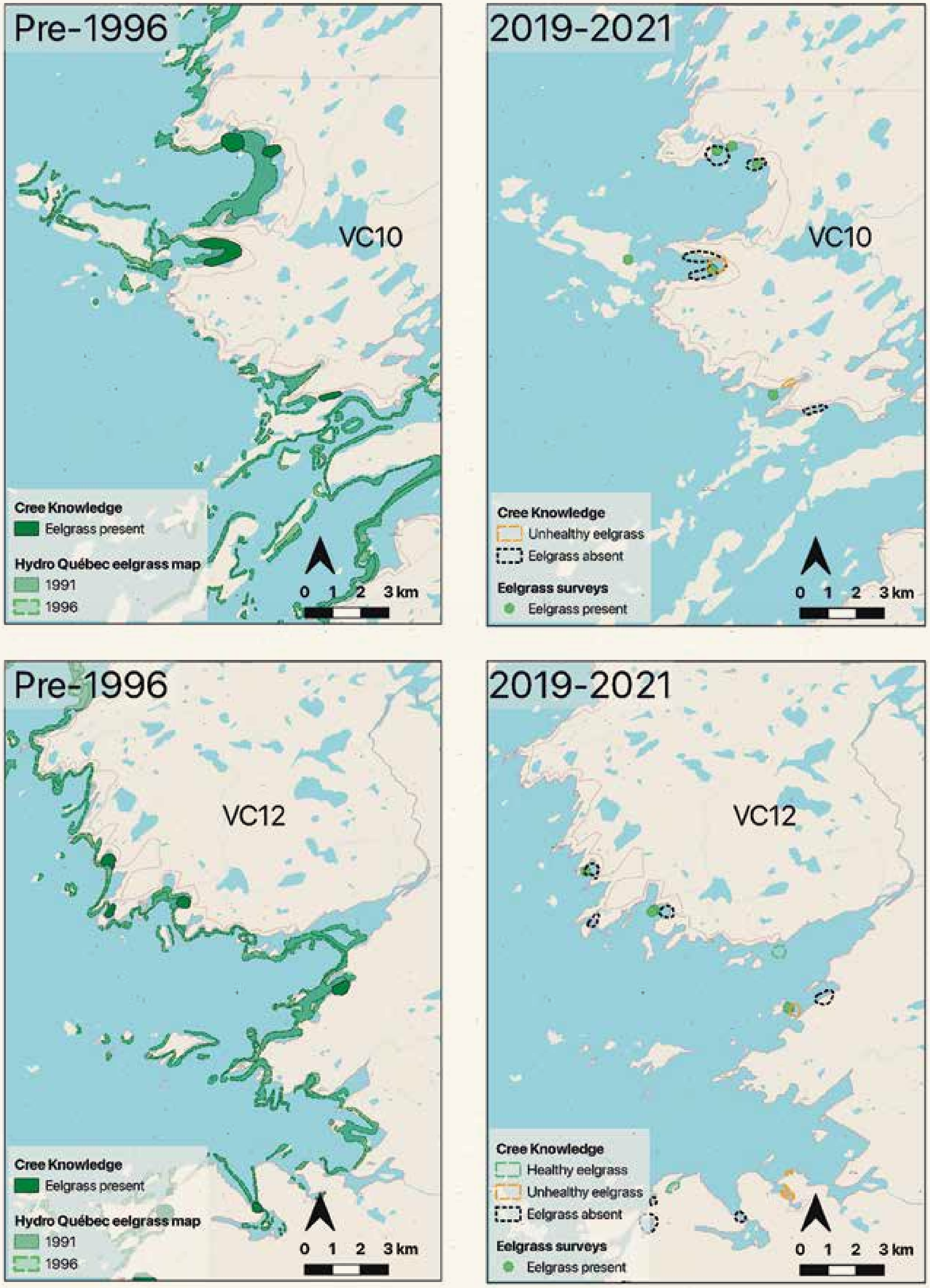
2019-2021
CH37
Cree Knowledge
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km



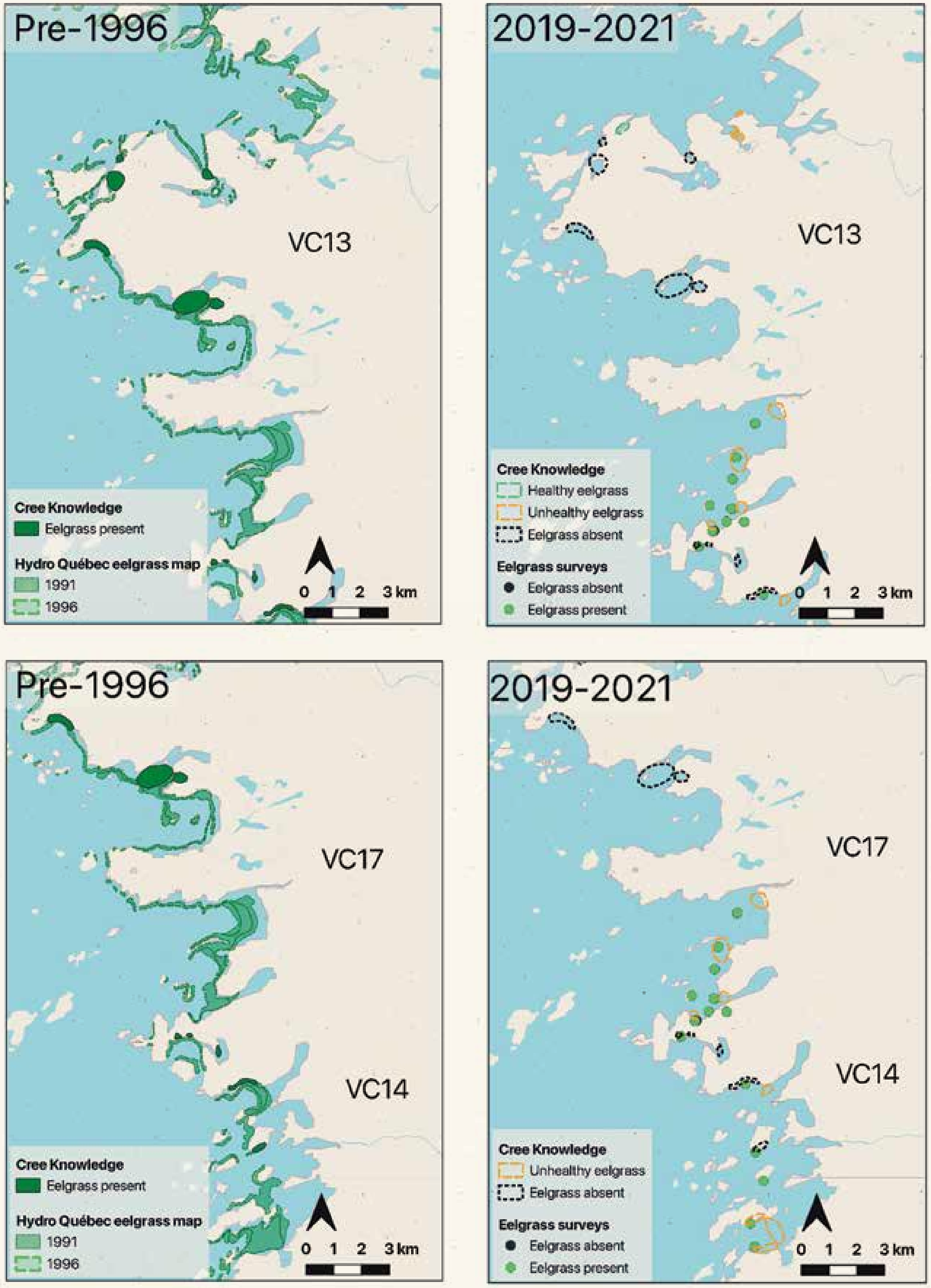
Pre-1996
CH38
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km

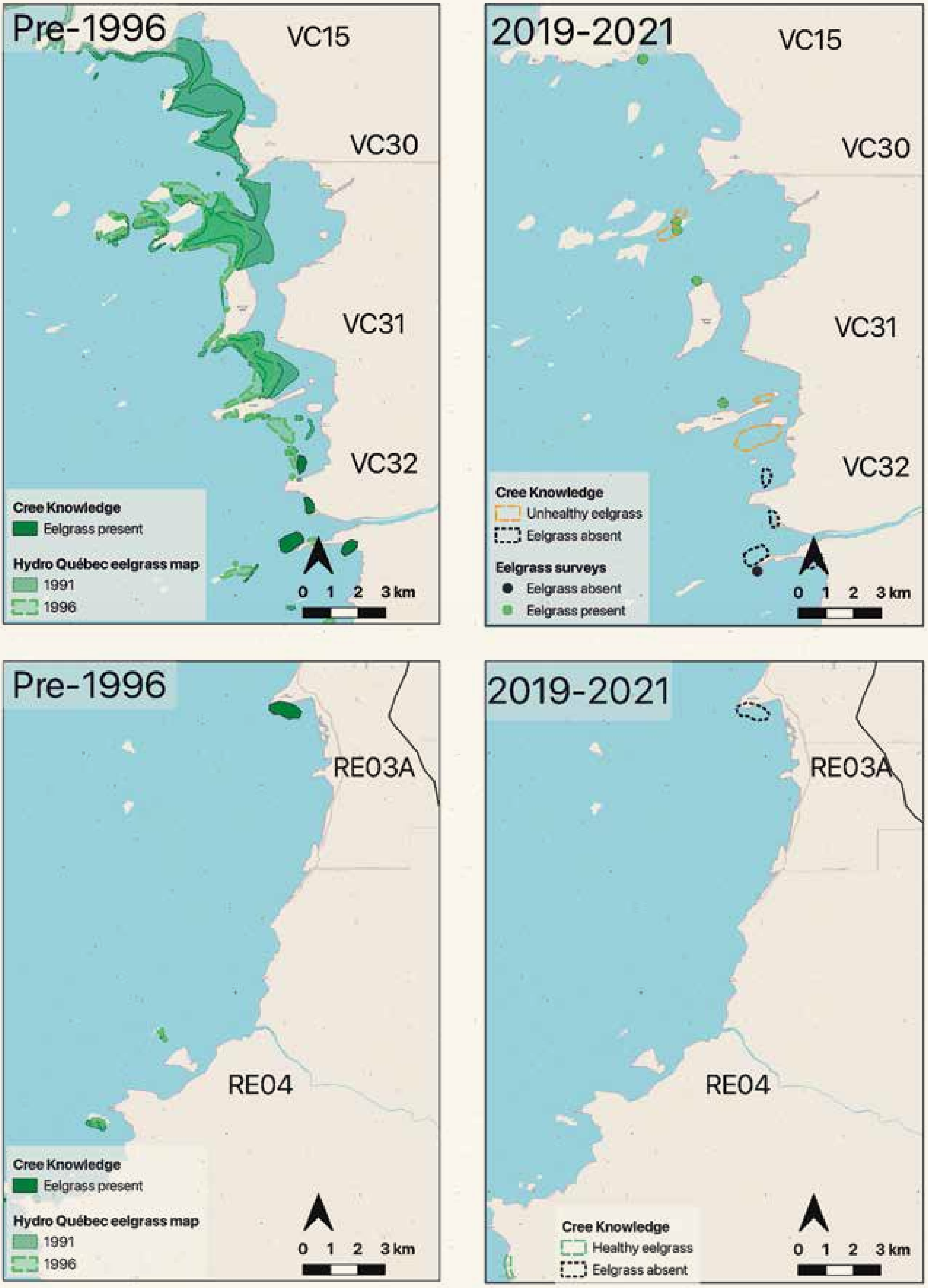


2019-2021
CH38
Cree Knowledge
Healthy eelgrass
Unhealthy eelgrass
Absent eelgrass
Eelgrass surveys
Eelgrass present
0 1 2 3 km



Pre-1996
VC10
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
VC10
Cree Knowledge
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass present
0 1 2 3 km
Pre-1996
VC12
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
VC12
Cree Knowledge
Healthy eelgrass
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass present
0 1 2 3 km


Pre-1996
VC13
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
VC13
Cree Knowledge
Healthy eelgrass
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km
Pre-1996
VC17
VC14
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
VC17
VC14
Cree Knowledge
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km



Pre-1996
VC15
VC30
VC31
VC32
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
VC15
VC30
VC31
VC32
Cree Knowledge
Unhealthy eelgrass
Eelgrass absent
Eelgrass surveys
Eelgrass absent
Eelgrass present
0 1 2 3 km
Pre-1996
RE03A
RE04
Cree Knowledge
Eelgrass present
Hydro Québec eelgrass map
1991
1996
0 1 2 3 km
2019-2021
RE03A
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Cree Knowledge
Healthy eelgrass
Eelgrass absent
0 1 2 3 km

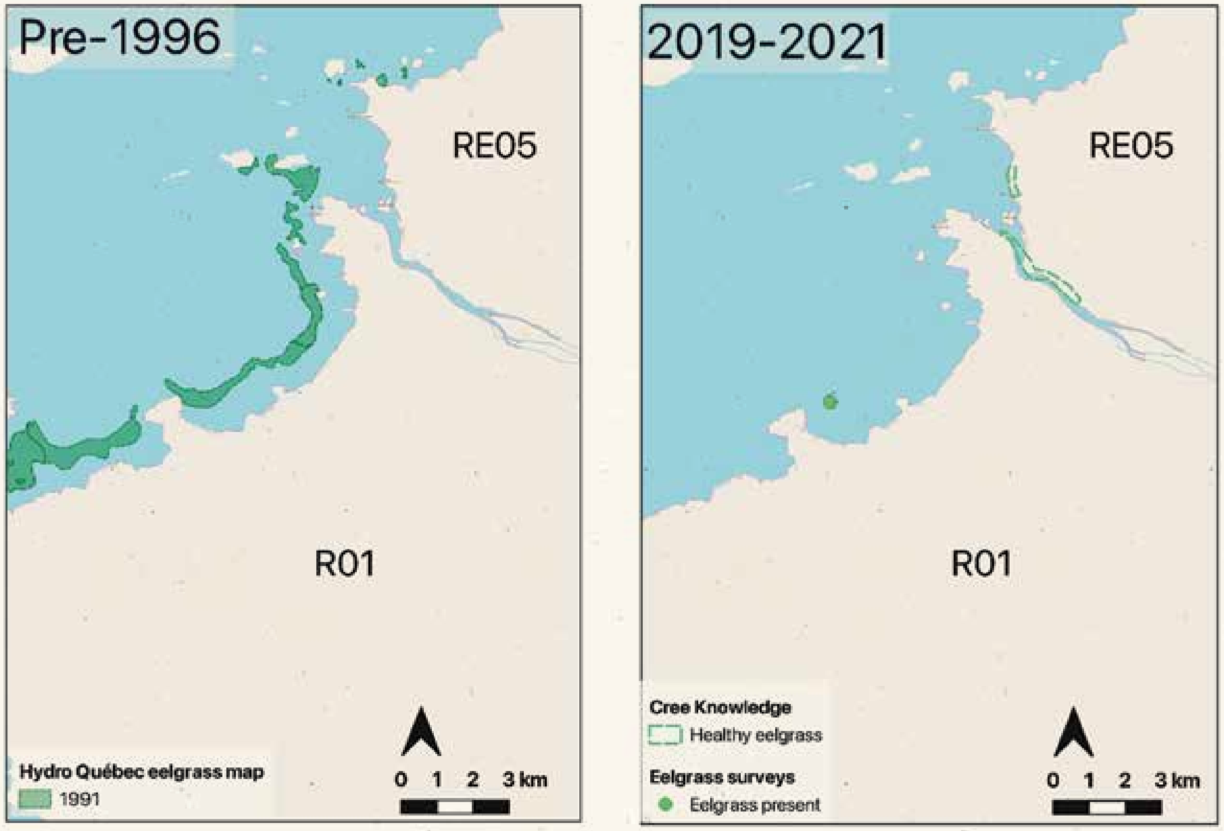


Figure 4-17. Eelgrass presence and absence based on Cree knowledge and eelgrass team surveys from 2019–2021 compared to previous distributions pre-1996. Past data sources include Cree knowledge documented during the CHCRP and Hydro-Québec eelgrass distribution maps produced in 1987, 1991, and 1996. The east coast is shown across 13 map panels from north to south.

It has been suggested that eelgrass might be present or absent due to a single aspect, or factor, in the environment. Although we think this simple explanation is unlikely (Section 5), we tested several hypotheses for various present-day factors that could be associated with eelgrass presence or absence, or eelgrass recovery. These factors can be grouped into two types: landscape features, such as exposure to waves or proximity to rivers, and environmental conditions, such as water temperature, salinity, ice breakup dates, turbidity, or other temporally dynamic conditions that could have delayed effects on eelgrass loss and recovery (Section 5).

The landscape features are most straightforward to interpret because they would be constant over time scales of days to weeks. We tested a measure of exposure to waves, REI, that estimates how much exposure to wind-driven wave energy a site would have had based on its fetch and the preceding 8 years of wind data from Environment and Climate Change Canada (see Eelgrass team report for full methods). Including observations from 2019, 2020, and 2021, and sites that we visited at least 50 days after ice melt (to exclude observations earlier in the growing season when eelgrass is very small and easy to miss), we found that eelgrass was present and absent across a similar range of exposure levels. However, there tended to be slightly higher levels of exposure where eelgrass was present (Figure 4-18, left panel, t-test: $t = -3.54$, $df = 50.0$, $p < 0.001$). This difference suggests a possible positive association between exposure to wind-driven waves and eelgrass persistence. Some of the sites with the lowest exposure were those in CH3 (Figure 4-17B), and some of the sites with the highest exposure were in CH7 (Figure 4-17A) and VC30 (Figure 4-17D). We also tested whether the ice breakup date was associated with eelgrass presence. We found that ice breakup date had a smaller but significant effect on eelgrass presence and absence, with earlier ice breakup dates positively associated with eelgrass presence (Figure 4-18, right panel, t-test: $t = 2.70$, $df = 80.30$, $p < 0.05$). We think these two physical factors, ice breakup and wave exposure, affect sediment resuspension and light availability. Ice breakup dates did not vary significantly across sites with different degrees of wave exposure.

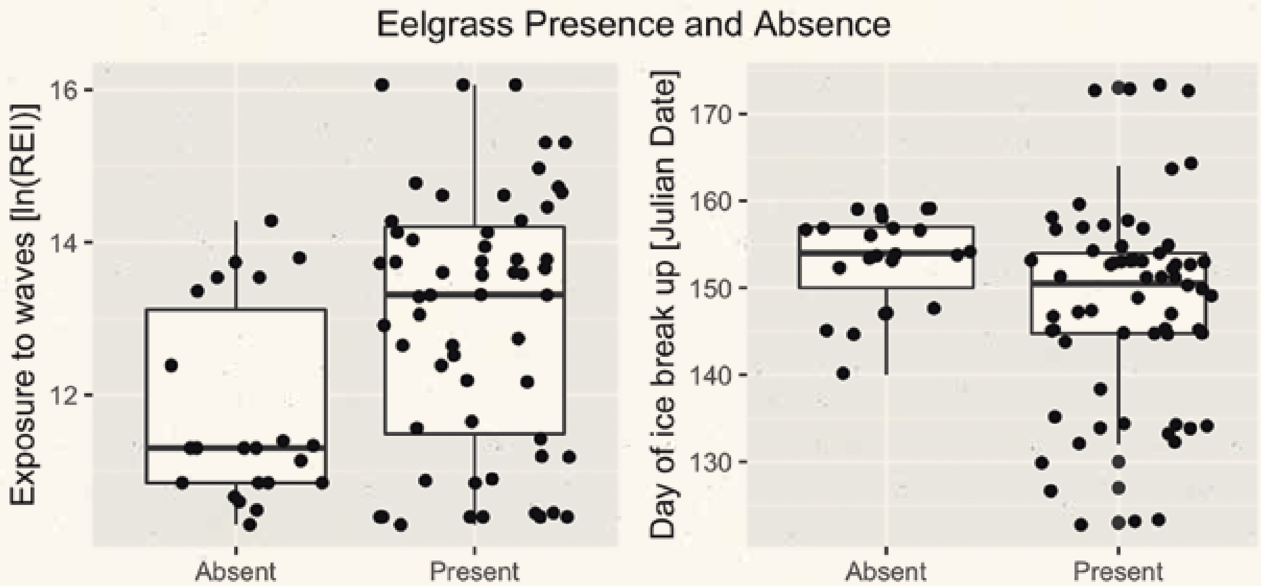


Figure 4-18. Eelgrass presence (n = 76) and absence (n = 30) varied somewhat with exposure to wind-driven waves (left panel) and ice breakup date (right panel).

WHAT WAS THE EELGRASS LIKE?

When we did observe eelgrass, detailed measurements of the plants demonstrate that its length (Figure 4-19), density (Figure 4-20), and biomass (Figure 4-21) were well below historical levels and varied quite a lot within and among sites. The eelgrass that we observed ranged in size from very tiny shoots to shoots up to approximately 1 m in length (Figure 4-19). Based on the measurement of 1,439 shoots across 14 traplines, the length of the longest shoots (also called canopy height) was much smaller in 2019–2021 than the biggest shoots of ~250 cm documented in 1988–1991 dive surveys near Chisasibi (Lalumière et al. 1994). The traplines with the longest eelgrass, when we visited in 2019, were VC10, VC17, and CH34. In 2020, CH33, CH3 and CH7 had the longest eelgrass (Figure 4-19). This difference reflects the fact that from year to year (between 2019, 2020, and 2021), eelgrass varied in size even at the same site. CH34, CH33, and VC12 had the most *consistent* eelgrass over time. One thing that affects eelgrass length in the data is the date we visited the site, relative to when the ice melted. Because we measured shoot length at each site on just one date each year, we also needed to consider how far into the growing period it was (i.e., the number of days that had elapsed between the date we visited the site and the date of ice melt). Statistical analysis revealed that the growing period had *some* effect but not a consistent effect on the size of eelgrass: more days to grow was associated with longer eelgrass in 2019, but not in 2020 or 2021.

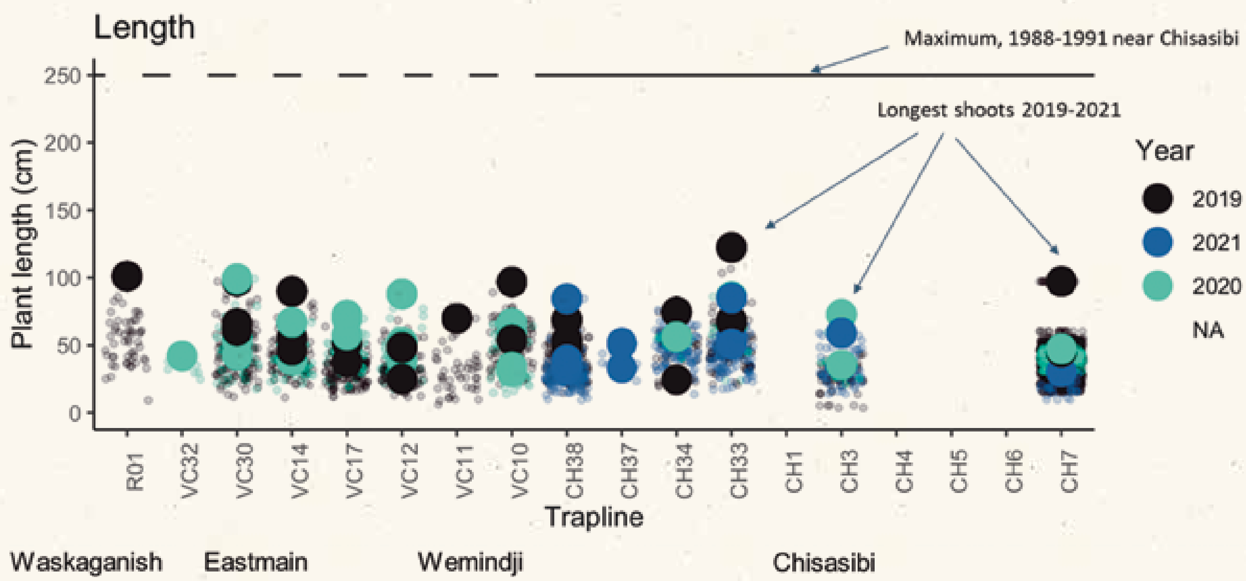


Figure 4-19. Eelgrass shoot lengths. A) Horizontal line shows the biggest shoots documented in 1988-1991 dive surveys (Lalumiere 1994) near Chisasibi. Source: O'Connor et al. (in prep.).

Shoot density and biomass are additional measures of eelgrass bed health that may be made by divers on SCUBA. The densest eelgrass beds observed had densities of nearly 400 shoots m^2 at CH34 in 2021 (Figure 4-20). We observed densities greater than 200 shoots m^2 at three other traplines: R01, VC17, and VC30. The lowest densities we observed were at CH7 in 2021 and CH3 in 2019 and 2021. These low-density meadows in CH7 are areas known to historically have had high abundance; we do not have historical records of large meadows in CH3.

Aboveground biomass, which depends on both shoot length and density, was assessed across numerous sites in 2019 (Figure 4-21). Similar to density, aboveground biomass was highest at CH34 at more than 60 g m^{-2}. At about half the remaining sites, the aboveground biomass was in the 30–40 g m^{-2} range and at the remaining sites it was less than 20 g m^{-2}.

Of the 11 sites sampled for density in 2019, we were able to revisit and resample four sites in 2021 (CH3, CH33, CH34, and CH7). We found that CH3 and CH33 had similar densities in 2021 as in 2019, while CH34 had a higher density in 2021, and CH7 had a much lower density in 2021. Thus, shoot density did not vary consistently between the two summers.

Based on the water samples we collected on the days we visited the sites to sample eelgrass density, there were positive relationships between eelgrass bed density and warmer, more highly coloured water as indicated by concentrations of CDOM (Figure 4-22). Warmer water was highly correlated with higher CDOM ($R^2 = 0.72$), higher SPM ($R^2 = 0.42$), and lower salinity ($R^2 = 0.64$). We do not know whether these water properties are representative of these sites throughout the growing period. We suspect that the warmer, more coloured water is indicative of more summertime conditions, further advanced into the growing season, which we associate with larger plants and denser beds.

HOW WELL WAS EELGRASS GROWING?

Most of our observations are on eelgrass size or density, but we also want to know how well eelgrass is growing. This can help us understand whether it is small because it grows slowly and runs out of time in the growing season or whether it is small for other reasons. We were able to directly measure growth rates at two sites in 2021 (Davis et al, *in prep*). Growth rates were measured on plants growing in the field underwater over a period of approximately 2 weeks, and growth was measured as an increase in shoot surface area in units of cm^2 per day. We found that at these two sites in CH33 and CH34, shoots were growing very quickly during July—between 1 and 12 cm^2 per day (Figure 4-23). These rates correspond to linear shoot growth rates of about 0.5 to 1.0 cm per day, which compares favourably with growth rates of eelgrass elsewhere. We suspect that July is the peak growing season in eastern James Bay and that eelgrass is capable of growing quite quickly at that time provided the growing conditions are good.

By comparing various morphometric measurements against the directly measured growth rates, we found that the length of the sheath, which is part of the shoot, was a good proxy for growth rate. Furthermore, we found that there was a positive correlation between sheath length, which reflects recent growth rates, and the length of internode 2 on the plant's rhizome (root) (Figure 4-24; adjusted $R = 0.12$, $p = 0.0015$). The internode 2 length reflects growth rates in the recent past (1–2 months). This relationship allowed us to estimate growth rates for other sites where we were not able to measure growth directly and did not have measurements of sheath length. Using both these growth rate proxies (sheath length, rhizome node length), we tested whether different summer water conditions were associated with different rates of eelgrass growth (Table 4-1). Among the strongest results were *positive* associations between recent shoot growth rates and salinity (i.e., better growth at higher salinity) and *negative* associations between growth rates and water temperature and suspended particulate matter or SPM (Figure 4-25). Warmer water temperatures

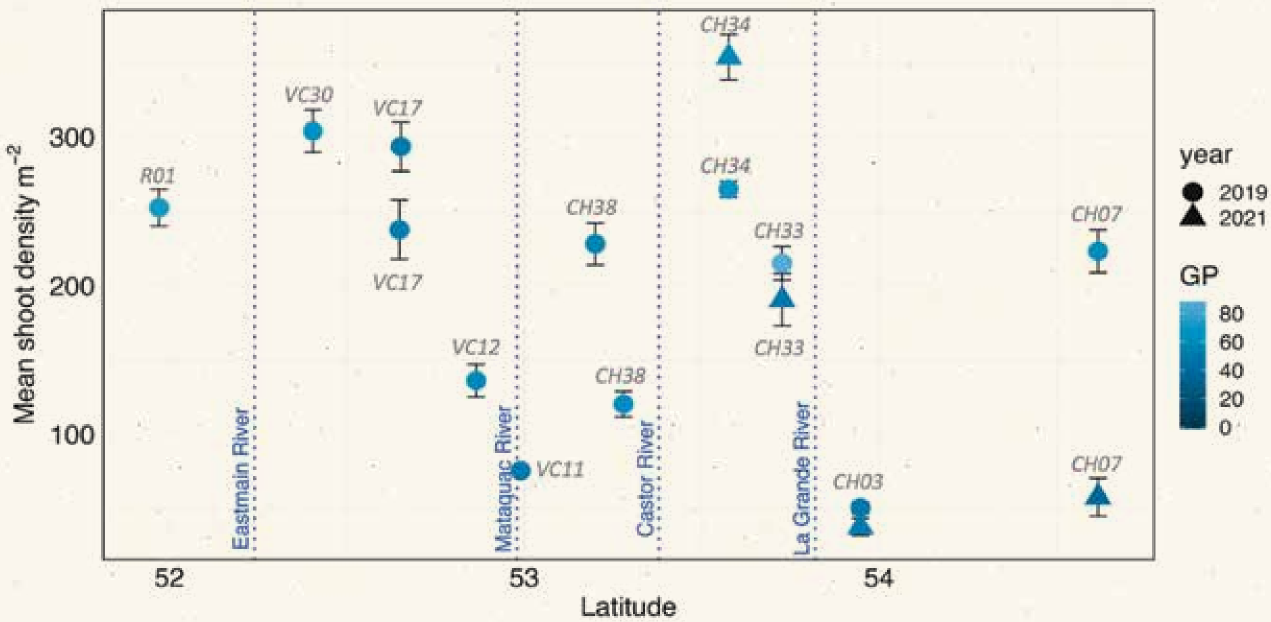


Figure 4-20. Density of eelgrass shoots at sites sampled by divers in 2019 and 2021. Blue colours show how much of the growth period (GP) had elapsed when each site was sampled.

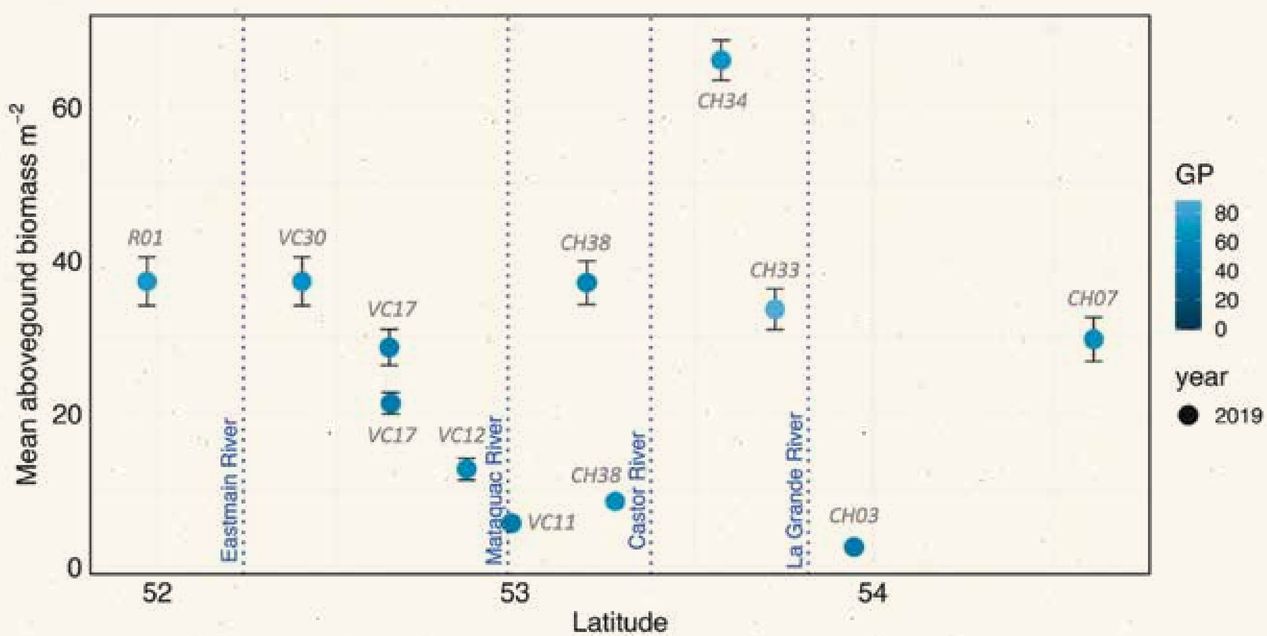


Figure 4-21. Above-ground biomass at sites sampled in 2019. Blue colours show how much of the growth period (GP) had elapsed when each site was sampled.

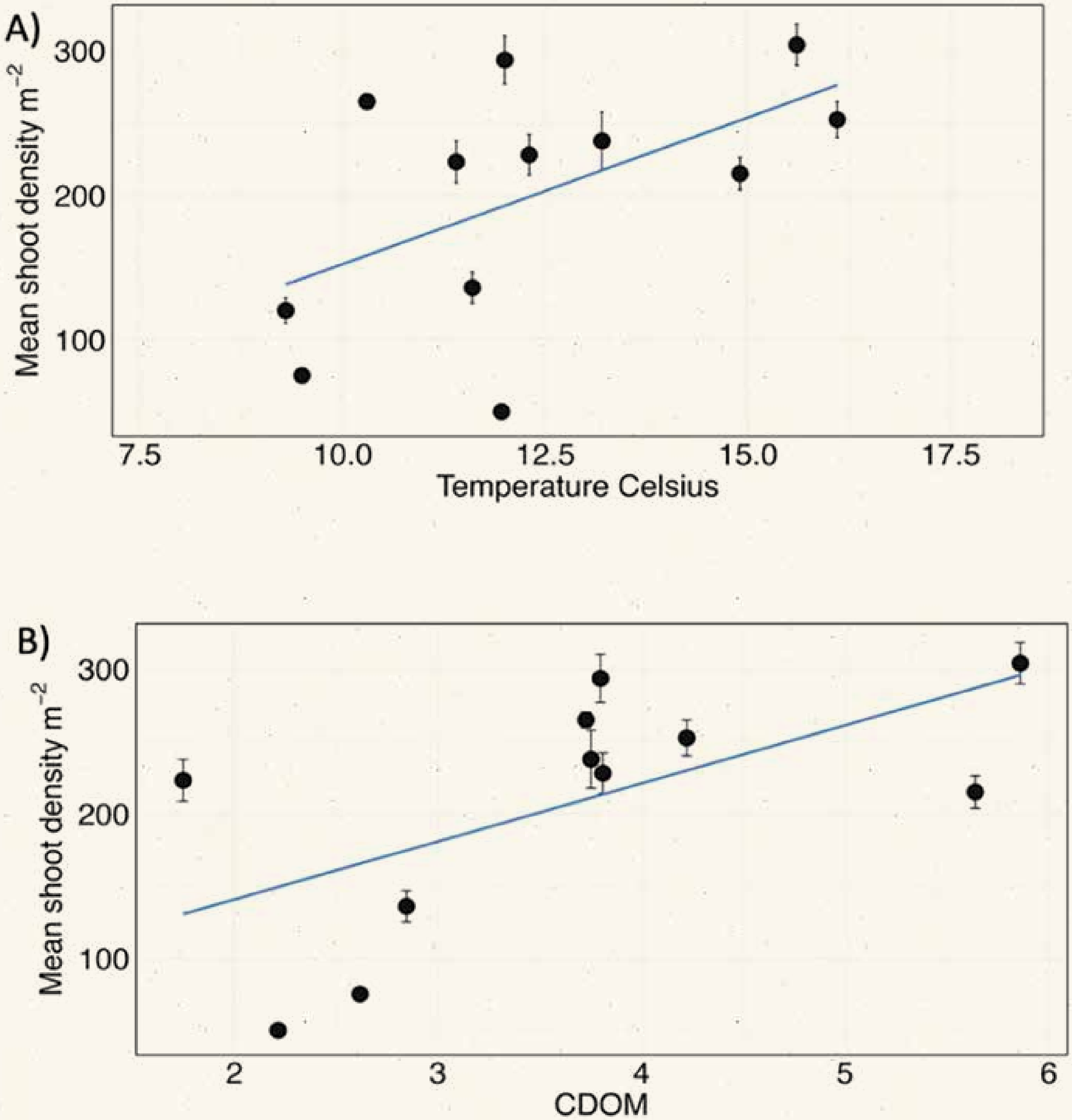


Figure 4-22. Relationships between shoot density and (A) water temperature and (B) CDOM. Units for CDOM are m-1 and represent the absorption at 350 nm.

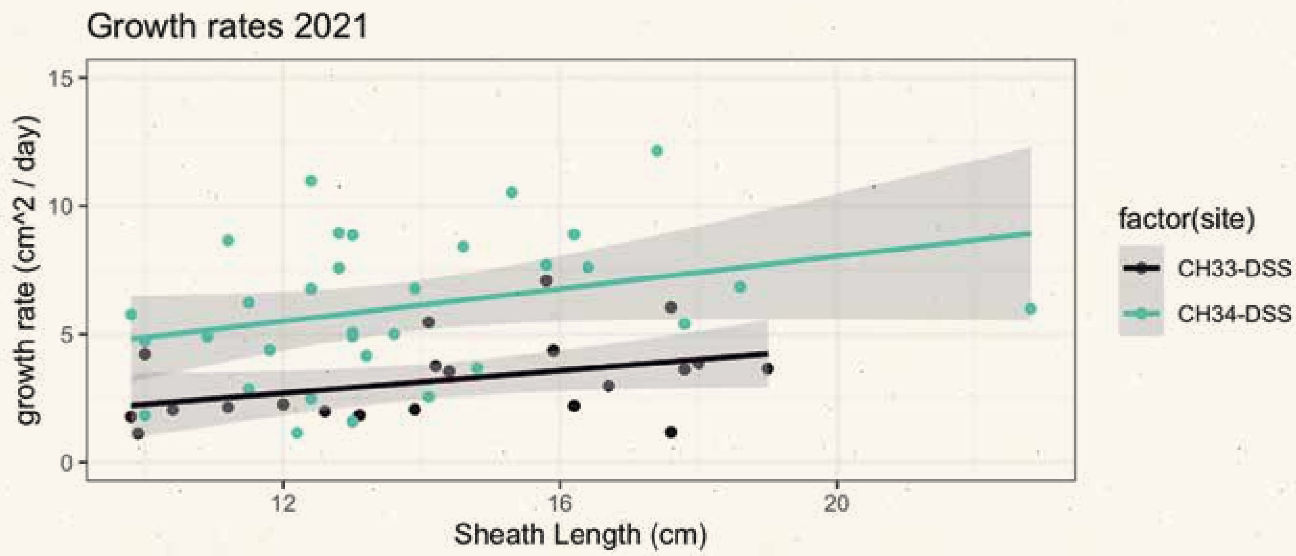


Figure 4-23. Eelgrass growth rates measured at sites in CH33 and CH34. Source: Davis et al. (in prep.).

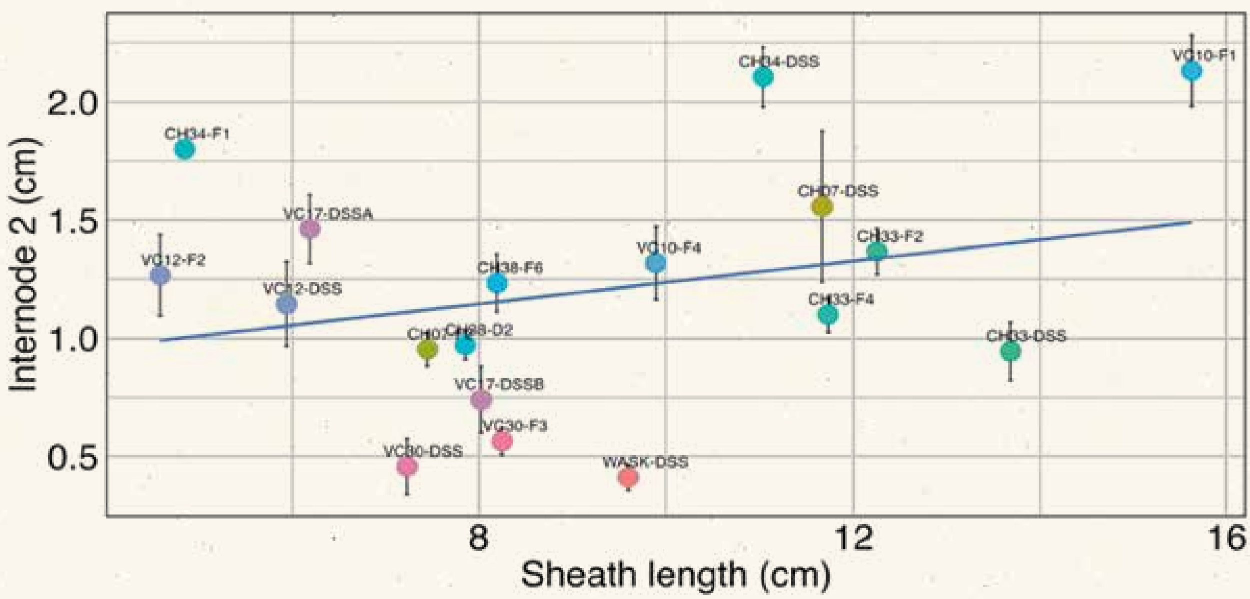


Figure 4-24. Relationship between two morphological proxies of growth rate, the sheath length (cm) and the length of internode 2 (cm). Source: O'Connor et al. (in prep.).

were closely correlated with higher CDOM (adjusted $R^2 = 0.55$) and both likely reflect the advancement of the summer growing season. The tendency for higher growth rates at higher salinity is consistent with the general understanding that eelgrass thrives in saltier water.

Table 4-1. Relationships between eelgrass properties and water parameters measured on the day of eelgrass collection at sampling sites in 2019. We used linear regressions and here show the adjusted R values. Adjusted R above 0.10 suggests a possible relationship between the water parameter and eelgrass measurement. Non-significant statistical relationship between a water parameter and eelgrass measurement is indicated with NS (non-significant).

	ABOVEGROUND BIOMASS (G M^{-2})	SHOOT DENSITY (M^{-2})	LENGTH (CM)	RHIZOME INTERNODE 2 GROWTH RATE
Salinity	NS	NS	0	0.2
Water Temp (°C)	0.03	0.11	0.04	0.18
CDOM (m^{-1})	0.08	0.16	0.06	0.01
SPM (mg L^{-1})	NS	0.02	0	0.19
Turbidity (NTU)	NS	NS	0.02	0.03
Nutrients in water column (µmol L^{-1}) *	0.01	0.01	0.00	NS
Nutrients in sediments (µmol L^{-1})*	0.03	0.05	0.04	NS
Chl *a* (µg L^{-1})	0.03	0.02	0.05	0.13

*nitrate+nitrite corrected for salinity

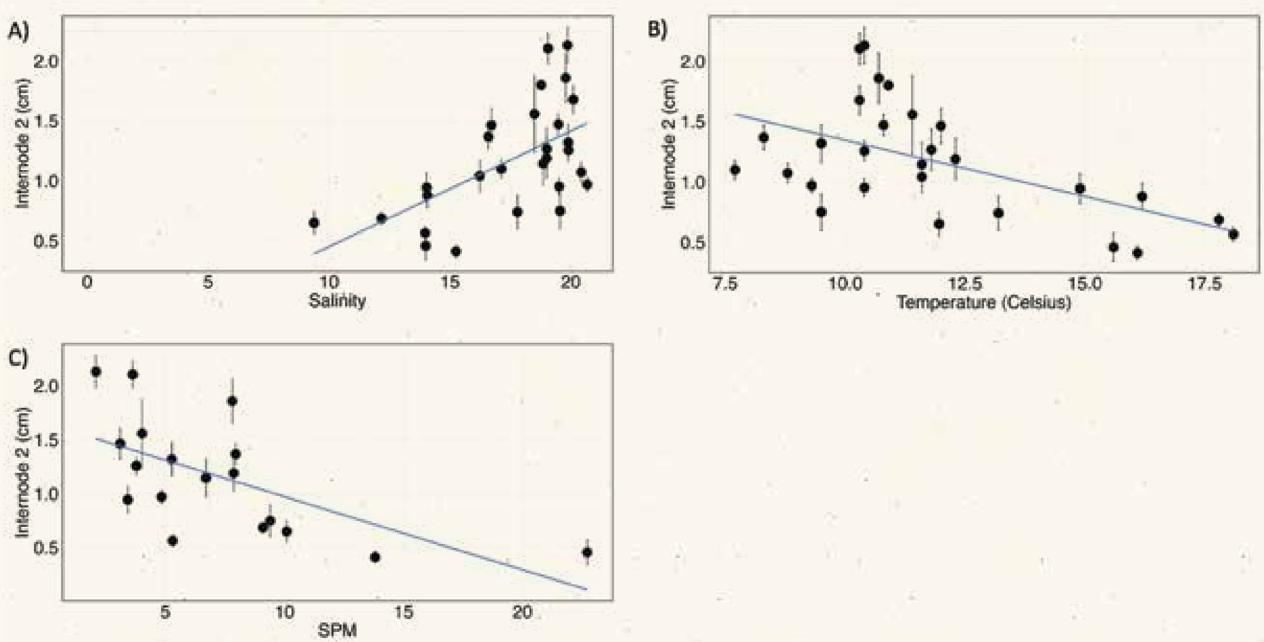


Figure 4-25. Relationships between (A) salinity, (B) water temperature, and (C) SPM (units of mg L^{-1}) and the recent growth rates of eelgrass estimated from length of internode 2 on the rhizome.

WINTER GROWTH AND SURVIVAL

At many sites, we collected rhizomes (roots) that indicated that eelgrass was surviving the winter and even growing during winter under the ice. Using rhizome morphology, we were able to reconstruct growth in winter in a similar manner to growth rates in summer, i.e., using internode length. We found that shoot growth in winter under ice (cm rhizome/node) was much slower than summer growth—rates of 0.2 to 0.7 cm of rhizome per internode length compared to rates between 1 and 2 cm/node during summer—but also *positively related* to the summer growth rate of the plant (Figure 4-26). These results highlight the importance of considering the environmental conditions during winter under the ice as well as during the growing season because poor growth under the ice may lead to less growth in summer. Altogether, we learned that eelgrass growth is likely affected by environmental conditions year around. We saw evidence of fast growth in the six weeks or so preceding our sampling at CH34-DSS and VC10-F1, and even more recent fast growth (preceding four weeks or so) at CH33 sites and CH7 (high sheath length values).

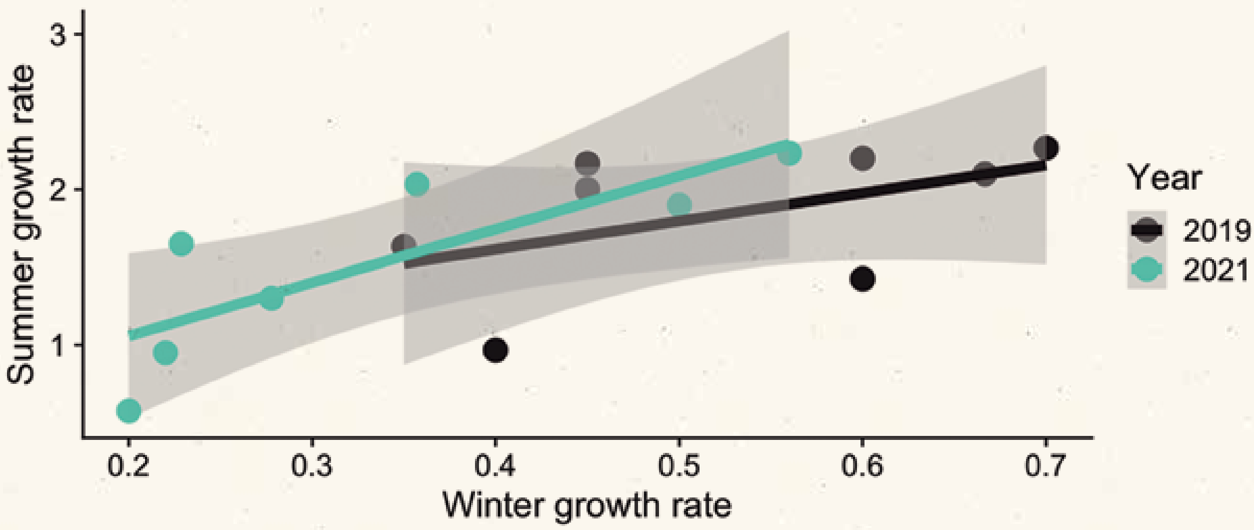


Figure 4-26. Relationship between growth rate during winter and growth rate during summer. Growth rates are the summer internode length (cm) and the previous winter internode length (cm). Source: O'Connor et al. (in prep.).

EELGRASS INVERTEBRATE COMMUNITY

Despite the smaller size and sparse growth habit of the current eelgrass beds, the divers' observations confirm that they still provide habitat for a wide variety of invertebrates including shrimp, amphipods, isopods, and snails (Figure 4-27). We observed invertebrate assemblages typical of eelgrass meadows elsewhere (Duffy et al. 2015; Gross et al. 2022), with a mix of crustaceans, snails, and worms. Crustaceans and some of the larger worms (annelids) are good food for fish.

Notably, we did observe a few species typical of freshwater environments, which were nonetheless abundant in several of the eelgrass meadows. These species are chironomids, a type of insect larvae. They were quite abundant at sites in CH3, CH33, CH38, VC12, VC30, and R01 (*Insecta* group; Figure 4-28). Their presence is an indication of persistent freshwater in these eelgrass meadows related to nearby rivers.

Figure 4-27. Examples of invertebrates living in and around the eelgrass and collected by the divers on SCUBA. Source: O'Connor et al. (in prep.).

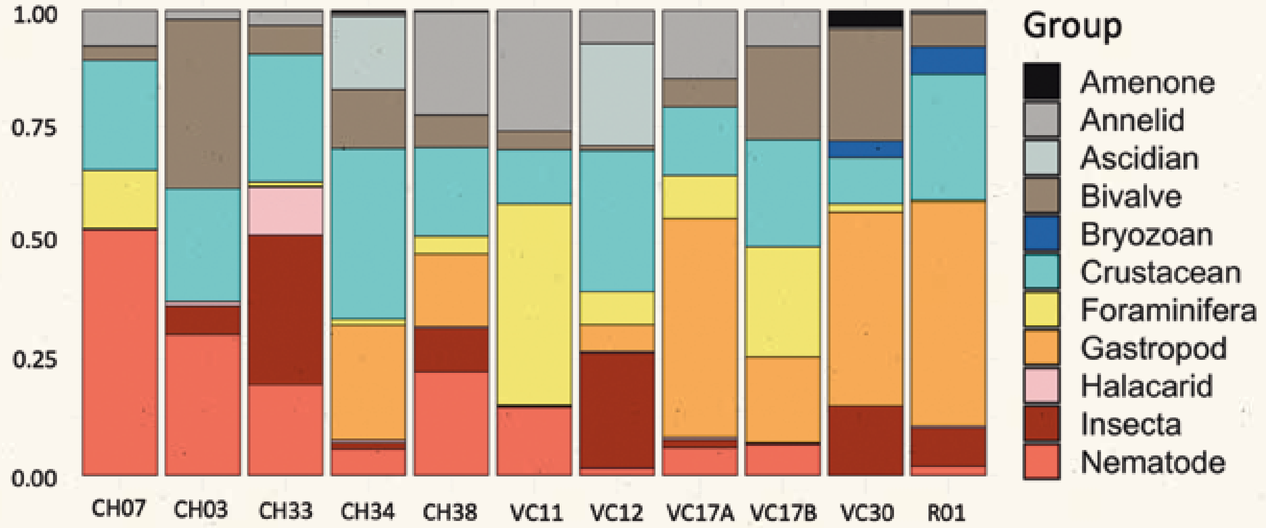


Figure 4-28. Fractional abundance of 11 taxonomic groups in each dive site. Gastropods are snails, nematodes and annelids are worms, crustaceans include shrimp-like animals. Foraminifera are signs of more ocean water and insects are signals of more freshwater. Source: Leblanc et al. (in prep).

EELGRASS PHYSIOLOGICAL INDICATORS

To study eelgrass health, we used different chemical indicators and measurements in leaves and roots. These measurements help us see how the plant is doing in terms of storing energy and obtaining sufficient nutrients. If these properties were monitored consecutively for several years, the results could reveal locations that are persistently better (or worse) for eelgrass growth and show whether there are important inter-annual differences between "good" and "bad" growing seasons.

Eelgrass stores energy reserves (measured as C content) in the roots and uses this energy to grow and survive in less favorable conditions (i.e., winter season). Carbon content in eelgrass roots from CH7 and CH3 traplines was lower than in the other traplines in 2021 (Figure 4-29), indicating that eelgrass from these traplines had lower energy reserves for new growth in the spring. Nitrogen (measured as N content) in leaves is an indicator of whether the plant is obtaining enough nutrients. Eelgrass that are nitrogen-deficient have nitrogen values below 1.8% (Short and McRoy 1984). The eelgrass nitrogen values in eastern James Bay were typically above 1.8% (Figure 4-29, middle panel), suggesting that eelgrass growth is not limited by nutrients. Lastly, nitrogen isotopic ratios (measured as delta 15N ratio; Figure 4-29, lower panel) in eelgrass shoots can help determine if eelgrass are taking up nutrients from the water column or sediments (Lepoint et al. 2004). Except for eelgrass in CH7, delta 15N ratio values were low, indicating that the nutrients are taken up from sediments. CH7 has a very sandy seabed that may not contain many nutrients. Therefore, at this location, eelgrass growth may be limited by low nutrient availability in the water column.

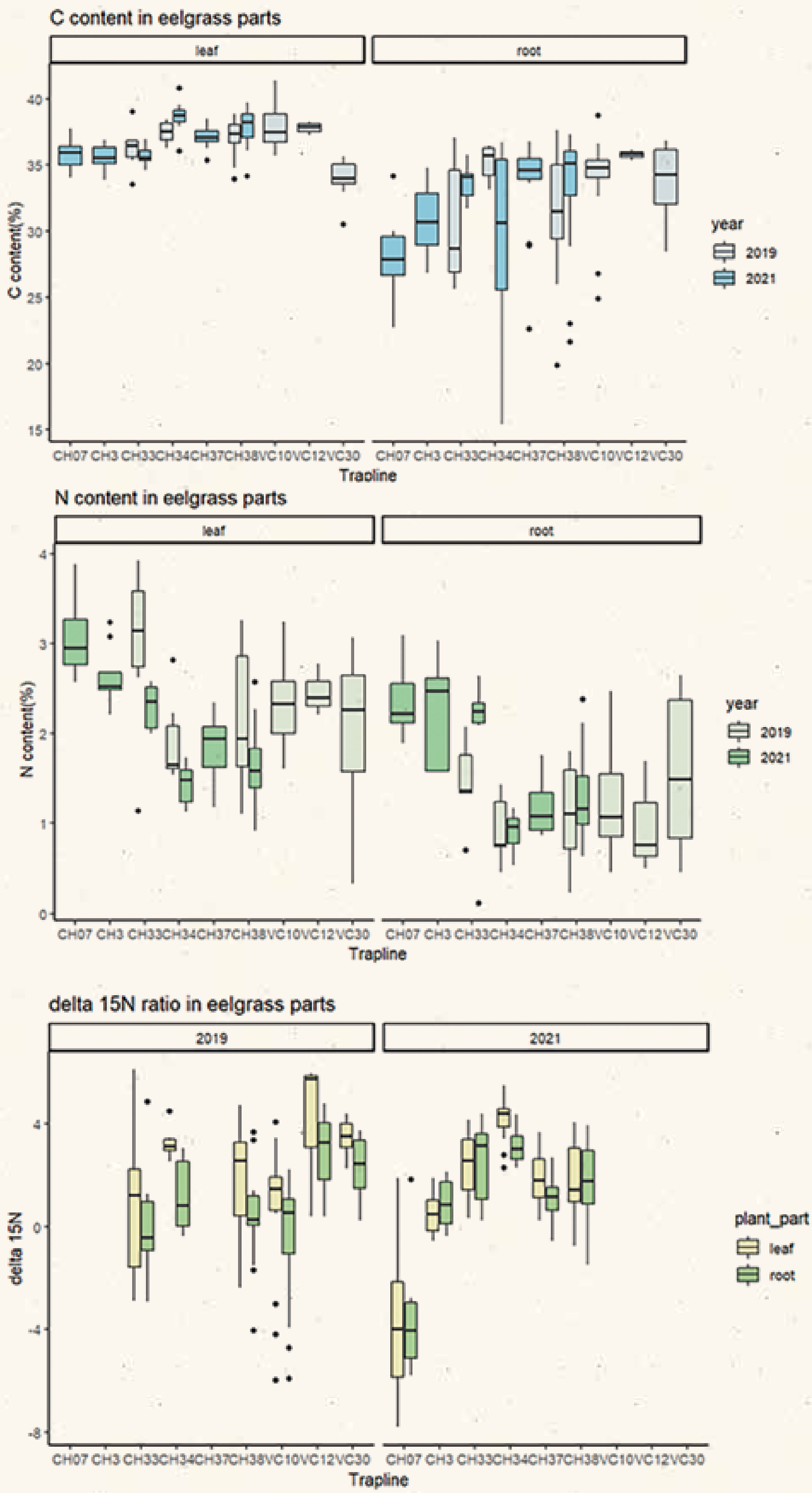


Figure 4-29. Eelgrass physiology results indicating the energy reserve and nutrient status of the eelgrass: C content (top), N content (middle), and delta 15N ratio (bottom) across traplines. Source: Richer et al. (in prep.).

LIGHT AND NUTRIENT EXPERIMENTS

To test whether the light and nutrient levels in the water could be limiting eelgrass growth, we conducted experiments on eelgrass from two eelgrass beds in CH33 and CH34, where eelgrass was observed to be relatively healthy relative to other areas yet still well below historical sizes. To test for nutrient limitation, we experimentally manipulated water column nutrient concentration in the beds and compared eelgrass growth in manipulated (high-nutrient concentration) and controlled (ambient-nutrient concentration) locations at each site (Figure 4-30). Divers on SCUBA measured eelgrass growth rates using a standard growth measurement protocol (Short and Duarte 2001). Overall, the experiment demonstrated that eelgrass shoots are growing quickly in both beds. We found no effect, either positive or negative, of nutrient addition on eelgrass growth rate (Figure 4-31). We did find a positive effect of nutrient addition on epiphyte accumulation rate suggesting that algae growth is limited by low nutrient availability in the water column. Because the addition of nutrients to the water did not improve eelgrass growth, we conclude that the eelgrass takes up enough nutrients from the sediments at these locations. The concentration of nitrogen (measured as ammonium) in the sediments was about 10 times higher than in the water column (Figure 4-32), which is consistent with the conclusion that the sediments supply nutrients to the eelgrass.

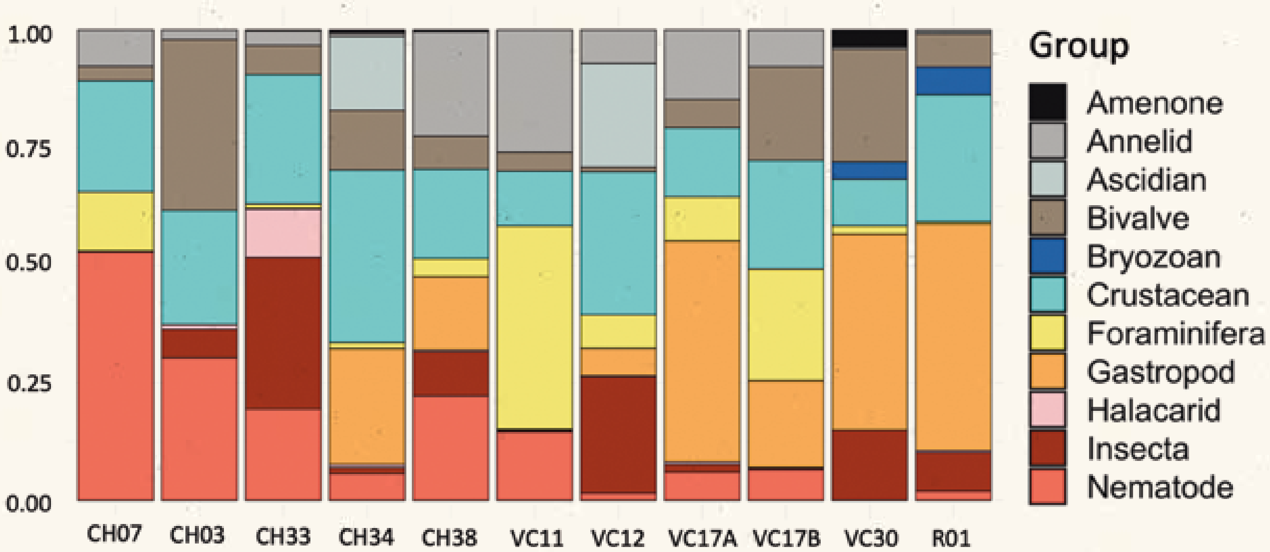


Figure 4-30. Experimental design for nutrient and light experiments. Within the eelgrass meadow (shown as green rectangle), each square represents an experimental location and was marked by a white pole (see diagrams B and C). Half of these locations received nutrient addition by way of small bags of fertilizer (shown by orange circles and see diagram C). Sun icons indicate examples of random sampling locations for eelgrass shoots, which were brought back to the research facility for light exposure experiments. Source: Davis et al. (in prep.).

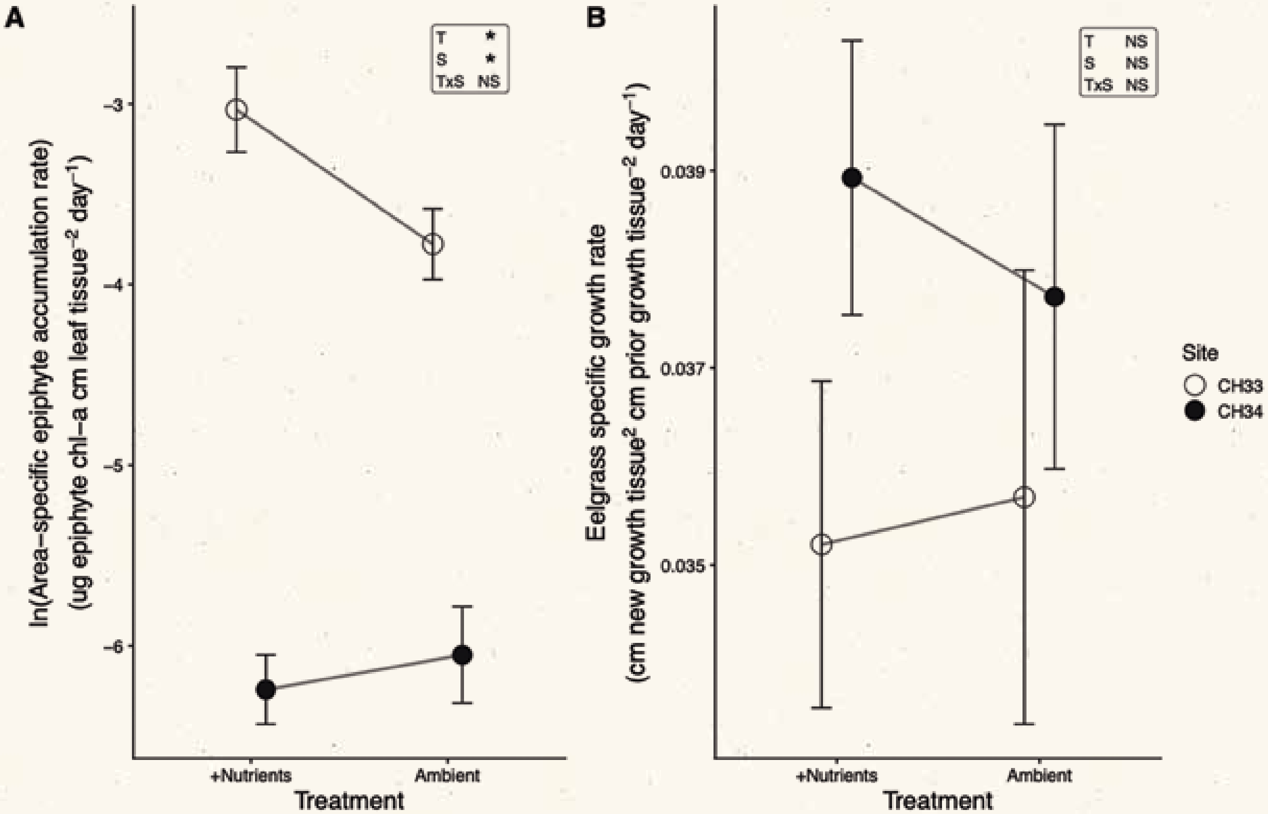


Figure 4-31. Experimental results for nutrient addition experiment. A) effects on epiphytes (logged area-specific epiphyte accumulation rate); B) effects on eelgrass (area-specific growth rate at each site). Panel legends indicate statistical results as significant (asterisk) or not significant (NS), where T = treatment, S = site, and TxS = treatment by site interaction. Source: Davis et al. (in prep.).

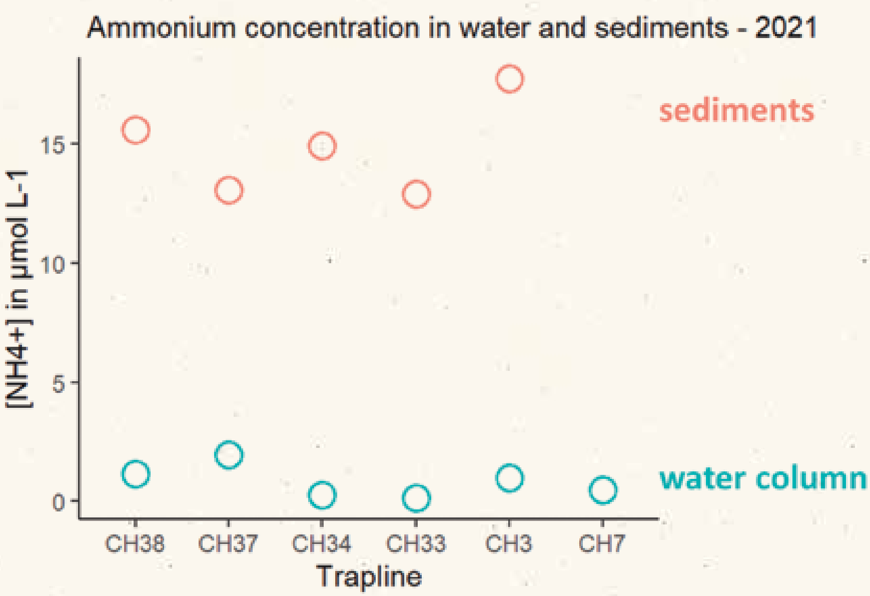


Figure 4-32. Concentrations of nitrogen measured as ammonium in sediments and the water column. Source: Davis et al. (in prep.).

To test for light limitation, we collected shoots from each eelgrass bed, brought them back to the field lab in Chisasibi, and experimentally manipulated light levels to test how the shoots responded. We found that eelgrass at both sites had high light requirements, i.e., they were not adjusted to be able to grow well in a low-light environment.

Evidence that low light was limiting growth at CH34 was obtained by combining the knowledge about the light requirements of the eelgrass with the light record collected at a CH34 eelgrass bed between April and August 2019 (Ehn, unpublished data). We found that light levels passed the minimum requirement for growth on 84% of the days where we measured light, but there was only sufficient light to *maximize growth* on 10% of these days (Figure 4-33). The results suggest that low light is holding back eelgrass growth during the summer. If growth is held back by low light, likely other important processes like storing carbon as energy for the winter *also* are being held back.

Severe and chronic light limitation can have consequences for eelgrass growth and survival (Bertelli and Unsworth 2018). These effects can vary throughout the ice-free season. Early in the growth season, eelgrass utilize light to synthesize new shoots and grow quickly. Light limitation during this period can reduce growth rate, leaf area, and density, leading to shorter, narrower, and/or thinner leaves (Bertelli and Unsworth 2018; Schubert et al. 2018). Late in the growing season, eelgrass shoots utilize light to accumulate energy as carbon (carbohydrates) for winter survival in the dark (Olesen et al. 2015). Light limitation during this period reduces these stores, threatening under-ice survival and early growth in the next season (Bulthuis 1987; Marsh et al. 1986).

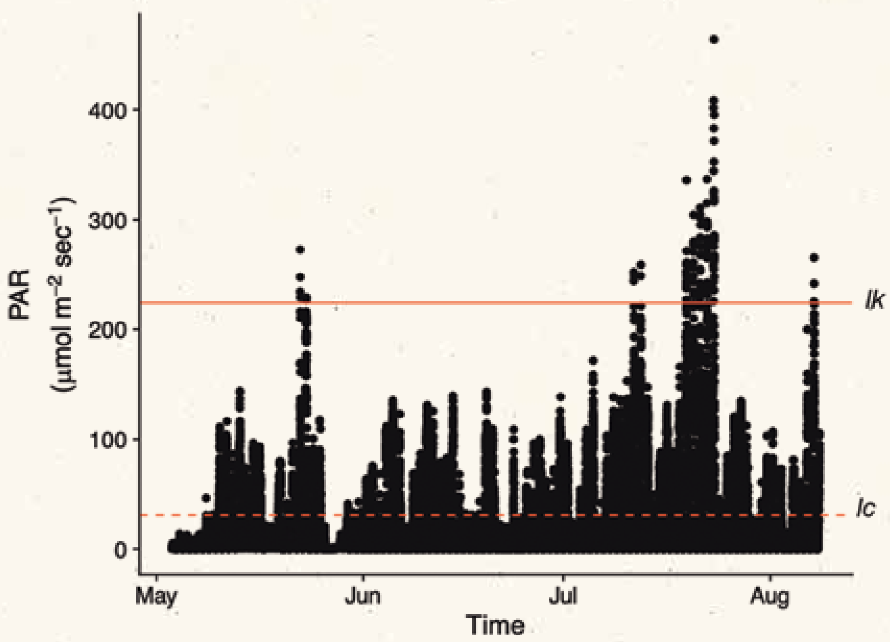
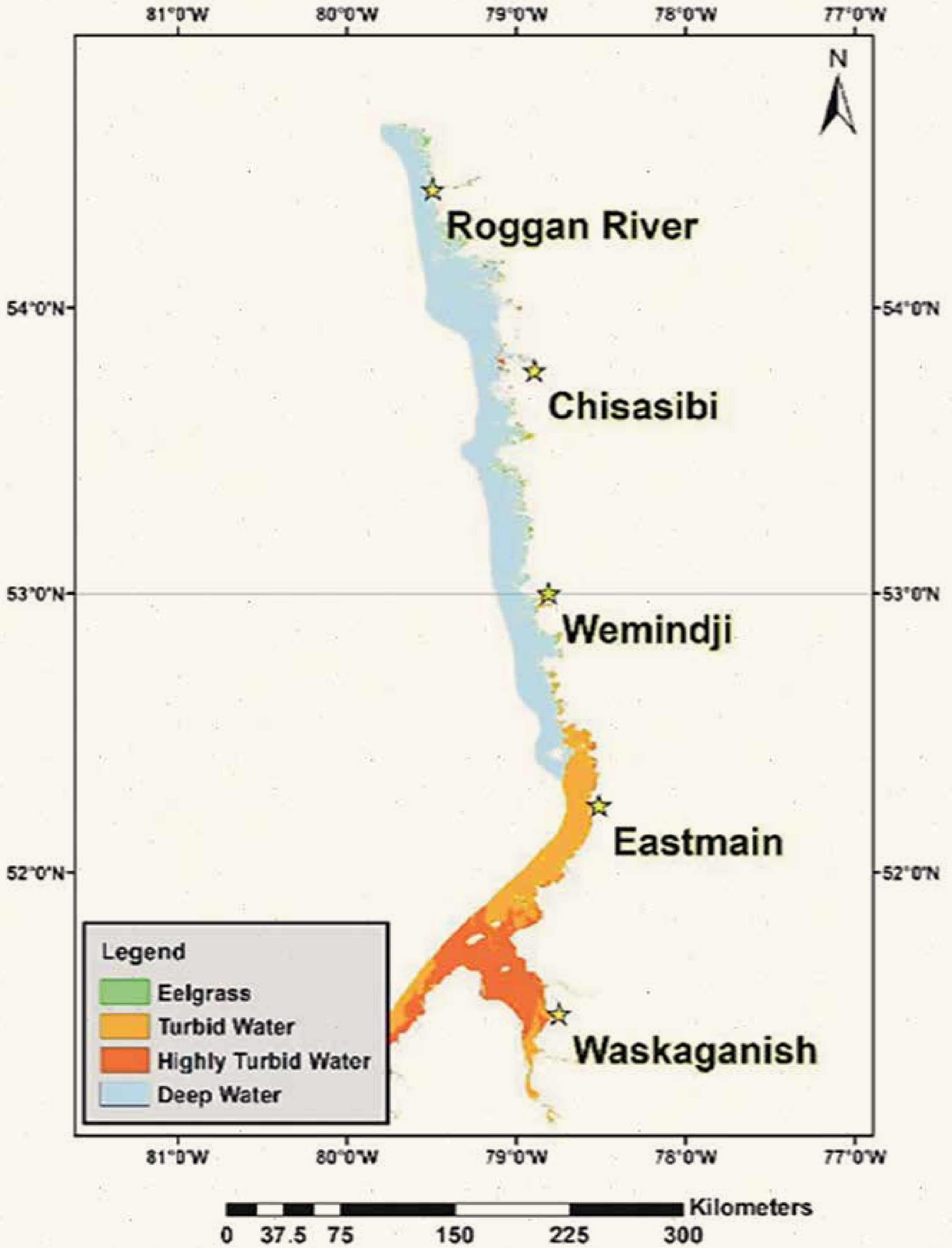


Figure 4-33. Light (measured as Photosynthetically Active Radiation or PAR) at CH34 compared to light requirements of eelgrass. The minimum requirement for growth (compensation point, Ic) is shown by the dotted red line and the light requirement to maximize growth (saturating irradiance, Ik) is shown by the solid red line. Source: Davis et al. (in prep).

Mapping reconstruction of changes in eelgrass cover

Recent eelgrass mapping efforts were completed as part of the CHCRP using Landsat imagery (2019) (Clyne et al. 2021) and subsequently extended into a historical reconstruction of changes in eelgrass bed distribution by comparison of Landsat-8 (2019) and Landsat-5 (1988, 1991, and 1996) (Clyne 2022). The 2019 map showed similar eelgrass distribution to past mapping efforts, with the largest beds still located north of the Castor River (Figure 4-34; Clyne et al. 2021). Note that the Landsat imagery itself cannot distinguish one form of underwater vegetation from another, i.e., eelgrass from algae. The image classification made use of CHCRP field observations of eelgrass cover, but the resulting eelgrass distribution still needs Cree land user validation, which was postponed because of COVID-19. Water turbidity made mapping eelgrass beds impossible in some areas, particularly near Eastmain and Waskaganish (Clyne et al. 2021).

For the historical reconstruction (Clyne 2022), image classifications were evaluated for accuracy using data generated from digitized versions of Hydro-Québec's eelgrass distribution maps for the 1988, 1991, and 1996 years (described in Appendix C) and from the CHCRP field data in 2019. The total area classified as eelgrass appeared to decrease over the study period (1988–2019). There were variable extents of turbid water in the various years but particularly notable turbidity in 1991 and 1996. Some areas such as the Bay of Many Islands, north of Chisasibi in CH4, appeared to consistently hold large eelgrass meadows through all four years, whereas temporal trends were less apparent south of Chisasibi, where turbid water did not allow mapping eelgrass beds (Clyne 2022). Some areas, for example Dead Duck Bay (CH34), showed turbid water during all four classification years. Comparison between the classified Landsat imagery and the aerial photographs for the 1988 and 1996 years showed that eelgrass was present in all areas identified on the classified images, indicating that the classifier is suitable for detecting the presence of large beds at relatively smaller scales (images were at a relative scale of approximately 1:10,000). However, as shown in Figure 4-35, the edges of the eelgrass meadows did not perfectly match because of a difference in spatial resolution between the classified image and the aerial photograph and eelgrass is frequently mapped just outside the aerial photo limits. The difference between the classified image and the aerial photograph was more pronounced for all the sites where turbid water was mapped on the classified image. In these sites, the eelgrass extent seems to be overestimated relative to the aerial photograph extent. The implication here is that there are real challenges to comparing maps of eelgrass extent made from different sources of information including satellite imagery of different spatial resolution.


81°0'W
80°0'W
79°0'W
78°0'W
77°0'W
N
Roggan River
54°0'N
Chisasibi
53°0'N
Wemindji
Eastmain
52°0'N
Waskaganish
Legend
Eelgrass
Turbid Water
Highly Turbid Water
Deep Water
Kilometers
0
37.5
75
150
225
300

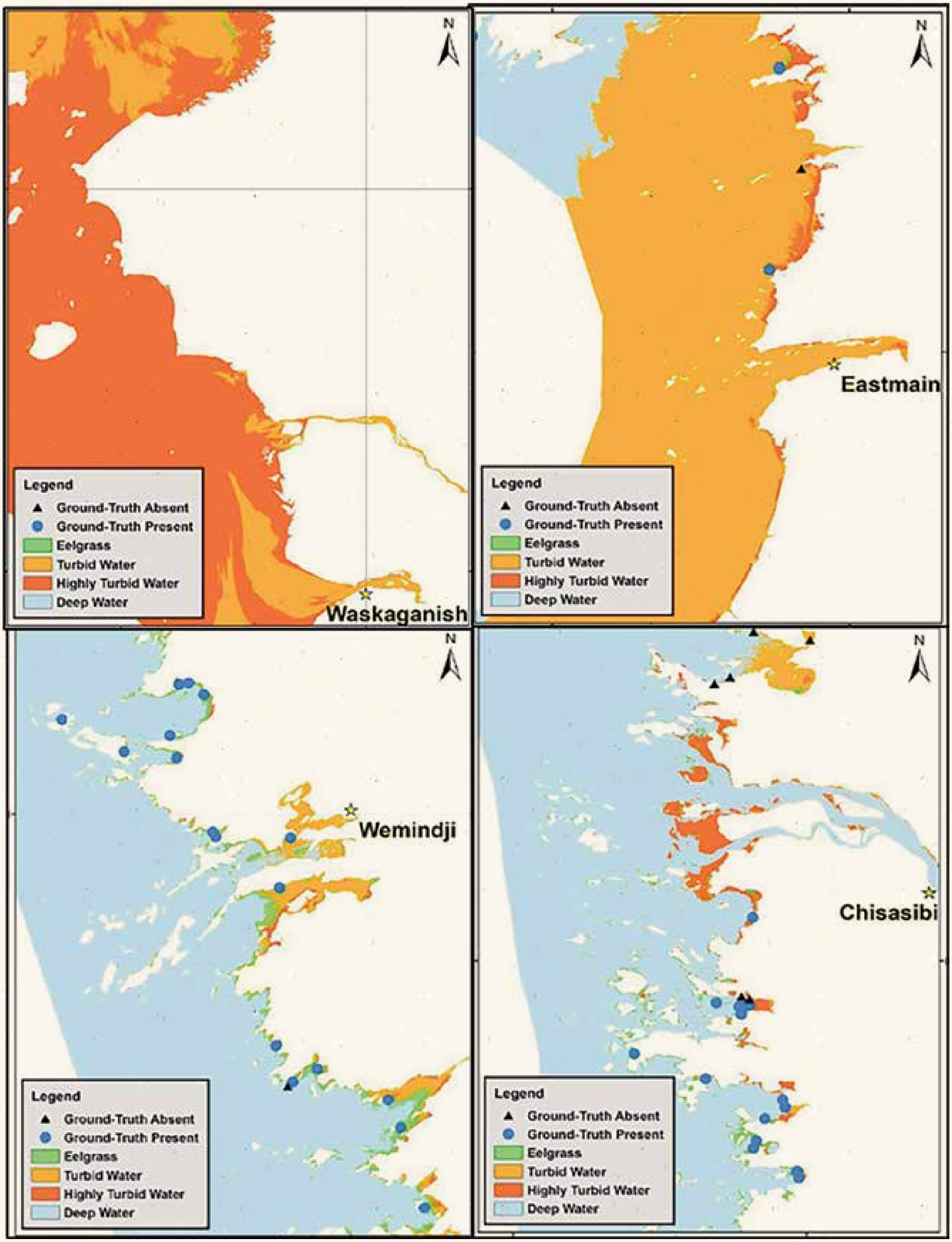


Figure 4-34. Classified images for the Eeyou coast (top panel) and coastlines near the communities (lower panel). Source: Clyne et al. (2021).

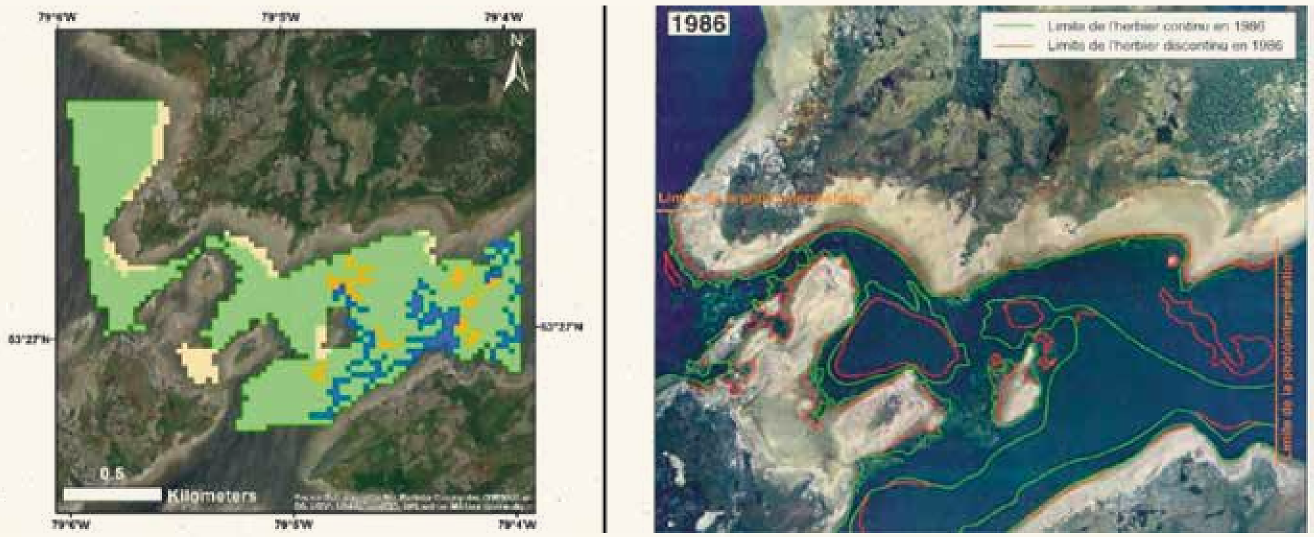


Figure 4-35. Example of the comparison between the classified Landsat imagery of 1988 and the aerial photographs of 1986 for the limits of eelgrass distribution at a selected site. In the left image, pixels were classified as eelgrass (green), turbid water (orange), or deep water (blue). Green lines on the aerial photos represent the extent of continuous eelgrass beds, while the red lines represent the discontinuous bed extent. Source: Clyne (2022).

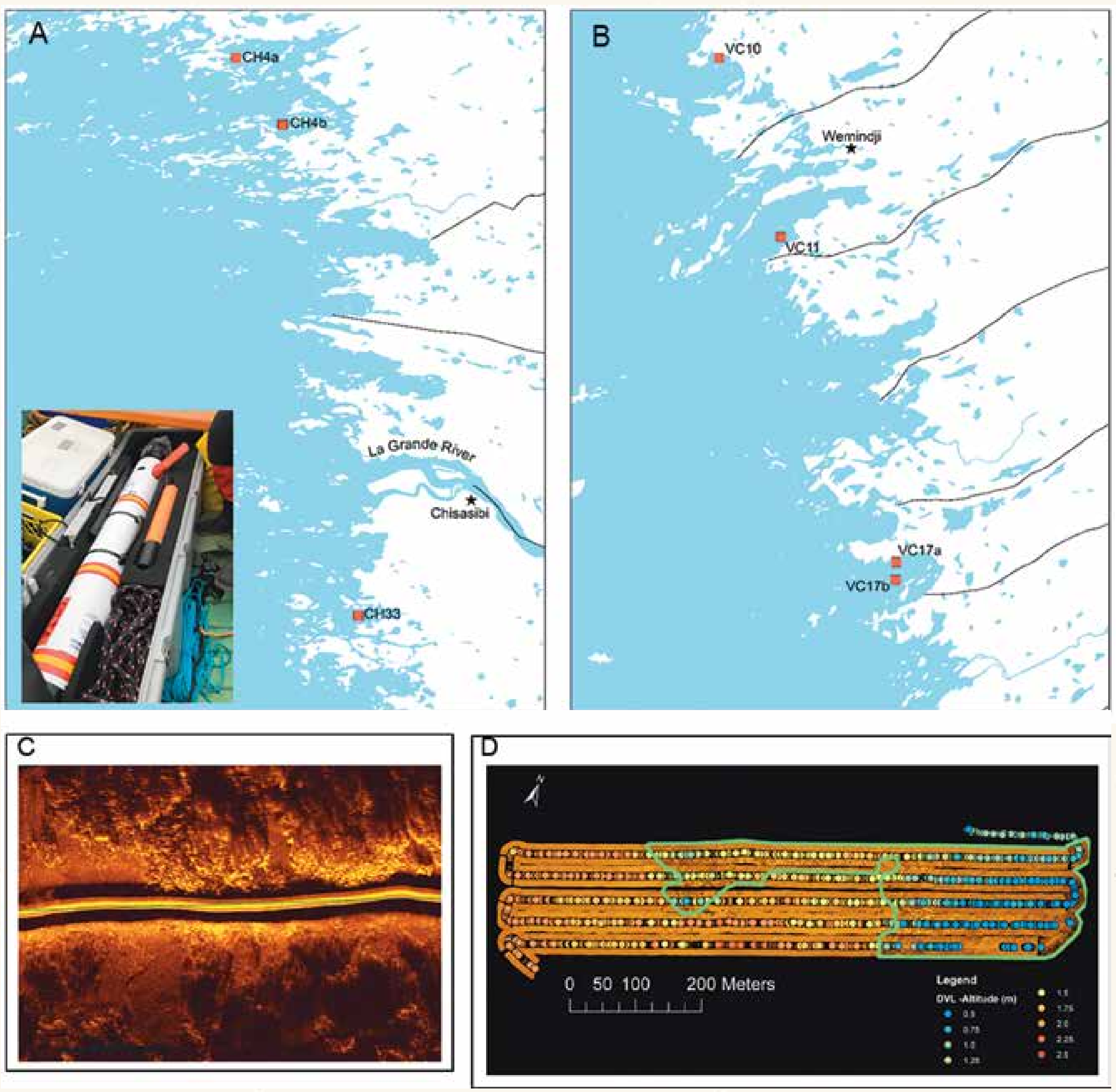
Depth distribution of eelgrass

Eelgrass often exhibit a 'bell-shaped' depth distribution, with ice scour and wave disturbance limiting their abundance in shallow water and low light limiting the maximum depth at which they are found (Duarte 1991; Krause-Jensen et al. 2000). In places with very low turbidity and high light penetration through the water column, eelgrass may grow in very deep water (beyond 10 meters), whereas, in highly turbid areas, eelgrass may be limited to growing in less than 2 m. In eastern James Bay, the depth distribution of eelgrass was historically 0.5–4.0 m (Lalumière et al. 1994).

During the CHCRP, information about the water depth distribution of eelgrass was obtained by conducting surveys with a side-scan sonar mounted on an Autonomous Underwater Vehicle (AUV). The AUV was equipped with a Klein side-scan sonar, a conductivity and temperature sensor, and a 10-beam Doppler Velocity Logger (DVL) which is used for underwater navigation and to determine the distance of the AUV to the seafloor.

Eelgrass or other underwater vegetation is quite distinctive on side scan sonar imagery (see, for example, the image inset in Figure 4-36). As the AUV also collected water depth data, we were able to plot depth on top of the side-scan data and compare it with different classes of seabed type. A grid with squares of 20 m by 20 m was overlaid on the side-scan sonar data and each square was assigned a colour depending on the coverage of eelgrass; green or continuous (<70% coverage), yellow or patchy (20–70% coverage), red or bare sediment (<20% coverage) (see Appendix D for details).

The results across three Chisasibi and four Wemindji traplines showed that large eelgrass beds were *very rarely* found deeper than 2 m and usually shallower than 1 m. Deeper areas had patchy eelgrass and/or bare seabed. There were some differences among traplines. For example, compared to the other sites, CH4a, CH33, and VC10 had a stronger contribution of continuous eelgrass cover in areas deeper than 1 m compared to CH4b, VC11, VC17a, and VC17b.



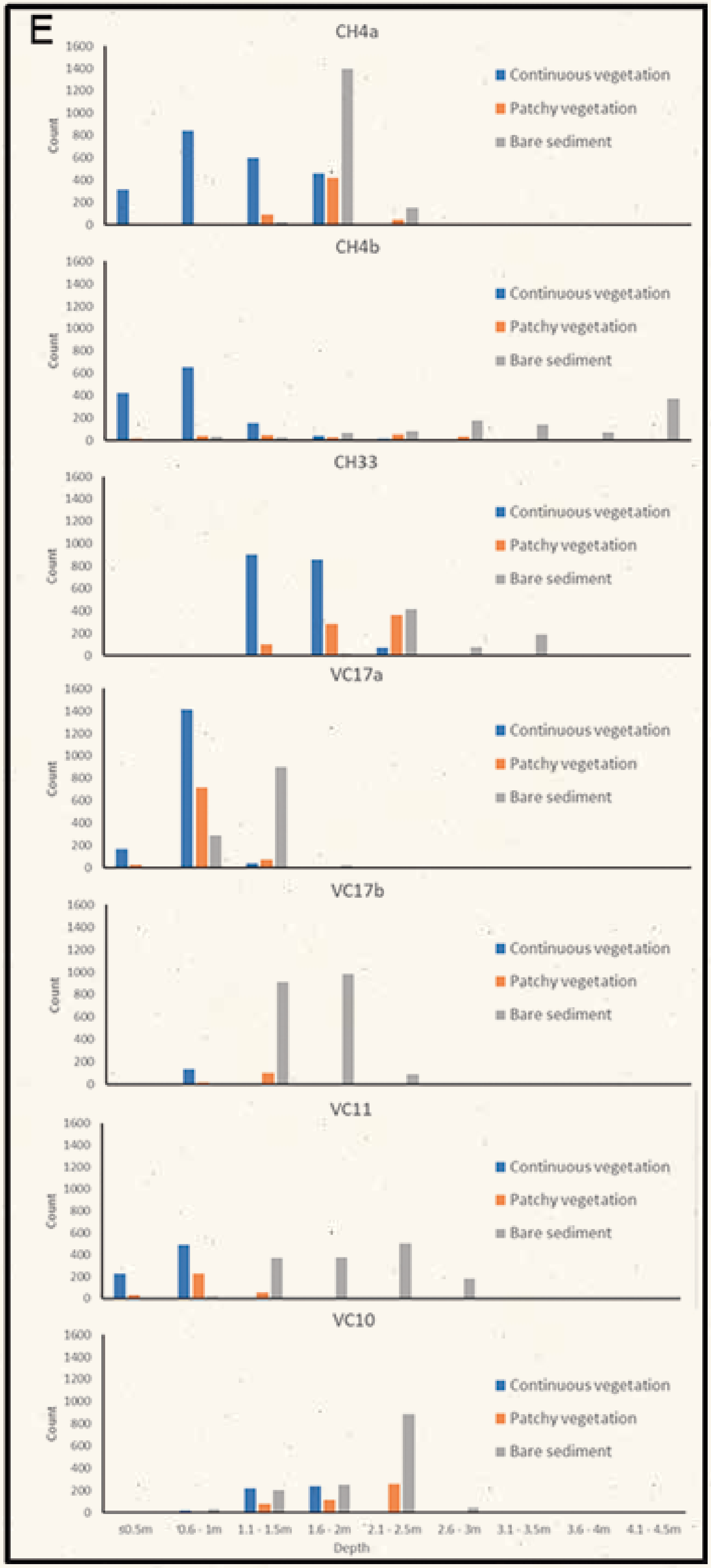


Figure 4-36. Map of the sites surveyed by the AUV and processed in Chisasibi traplines (A) and Wemindji traplines (B). Panel C shows an example of eelgrass on a side-scan sonar image collected by the AUV. The stripe in the middle is the travel path of the AUV along which no side-scan data are collected but water depths are logged. Panel D shows the measured water depths along the AUV track (coloured dots). An eelgrass bed is outlined. AUV is shown in the inset photo. Panel E shows depth distributions. Source: Peck et al. (in prep.).

Coastal habitat characteristics and environmental factors that have undergone change

Cree observations of change

Cree from Eeyou Istchee identify salinity, riverbank erosion, seabed consistency, reduced water clarity, and the presence of slime and algae as elements of the coastal habitat that changed before and after the eelgrass decline and possibly influence eelgrass recovery (Table 5-1). Some environmental changes have been observed by Cree in all communities and other changes are specific to certain communities.

SALINITY NEAR LA GRANDE RIVER

Cree from most coastal traplines in Chisasibi and some Wemindji traplines consider that the water along the coast changed from what they consider “normal” to “less salty than before” after the eelgrass decline. They attribute such a change to the increase of freshwater outflow of the La Grande River after the La Grande hydroelectric complex began to operate, more particularly after the commissioning of the LG1 dam in 1994–1995.

Before: La Grande River didn’t flow much, so there was a lot of salt water. Hunting up Seal River was good because salt water went in for a while. Eelgrass grew while the bay was still salty (CH7, Freddy Scipio, 2019).

After: There’s freshwater coming from the dam affecting the salinity in the bay. Lots of freshwater flowing out hurts the salt water (CH7, Freddy Scipio, 2019).

“The elders say that the water is not as salty anymore. These are impacts from the hydro project. When we first noticed the eelgrass disappearing, the elders said it was related to the hydro project” (VC09, Ryan Swallow and David Matches, 2019).

Indicators of such lower salinity include the fact that the bay does not smell like brine anymore, seals sink immediately after being shot year-round, salt stopped building up on the surface of seagoing vessels and outboard motors, and seawater stopped hurting people's eyes when riding boats in the bay. Although more intense in the Chisasibi area, Cree report lower salinity from the northernmost areas of James Bay (Cape Jones, CH7) to the south of Wemindji (VC13). No changes of this kind are reported in Eastmain and Waskaganish. Cree from Chisasibi relate lower salinity to the current state of eelgrass and other changes to the Eeyou Istchee marine coastal environment:

"I know that nothing can really grow along the coast when there is too much freshwater [...]. Because of the freshwater coming in the eelgrass does not grow and the waterfowl is deeply affected by this" (CH07, Freddy Scipio, 2019).

"The eelgrass has turned yellow too. Healthy eelgrass is dark green. Because there is more freshwater in the bay eelgrass is not as healthy as it used to be. One way we can tell there is less salt in the water is that we used to have white faces from saltwater after riding our boats in the bay. We don't get that because the water is not salty anymore." (CH33, John E. Sam, 2019).

RELEASES OF SILT FROM RIVERBANK EROSION

Compounding the effects of reduced salinity, land users also associate the increased flow of La Grande River's discharge with riverbank erosion and the release of silt or "dead land" into the bay. Cree land users described seeing sections of riverbank that had collapsed into the river floating down to the bay, sometimes getting 'hung up' midstream in view of Chisasibi for a period before breaking up and being conveyed further downstream. While deposited sediment may affect sediment properties on the seabed, suspended sediment contributes to the murkiness in the water.

"Ever since the dam was commissioned, the bay freezes late. When I check the currents beneath the ice, the water flow is already strong. It's like that all winter, the freshwater is always flowing strong. These strong flows cause erosion on the riverbank, especially in the winter when hydro opens the dam and the water 'slams the land'" (CH7, Freddy Scipio, 2019).

HARDENING OF THE SEABED

Land users from all the coastal traplines in Chisasibi (except CH3 and CH34), Wemindji (except VC9, VC12, and VC13), and three traplines in Eastmain (VC14, VC32, RE03A) indicate that the seabed in and around eelgrass meadows used to be soft and sticky mud before the eelgrass decline. Those reporting seabed hardening remember that it was hard to walk on the seabed near the shore and that paddles and canoes used to get stuck in the mud. Land users associate the hardening of the seabed with the continuous accumulation of silt. For them, it is unlikely for eelgrass to grow back under those conditions:

"The seabed used to be soft. Our paddles used to get stuck in the mud. When the sand and grit that comes from the dam mixes with the mud the seabed hardens" (CH33, Eddie Sam, 2019).

"Before the hydroelectric development project, the substrate where eelgrass used to grow was soft. We had a hard time when we wanted to go out because the bottom was so sticky. Our paddles got stuck when we wanted to push our canoes towards the open water. This used to happen in the days before the hydroelectric project. Now it is hard in the same place" (CH38, Louie Kanatewat, 2019).

"Before my dad passed away, we used to go out in the boat. There is a place where we couldn't go through in the boats with the motor. We had to stop and push the boat there. It used to be soft. My dad mentioned, around 15–20 years ago [circa 2007 – 2012]*, that it turned hard, that it was not soft anymore. It's changing that way. The bottom is so hard that the eelgrass won't grow. Now we see it, the eelgrass is not there anymore"* (CH37, Adrian Chiskamish, 2019).

Land users from southern Wemindji report no changes to the hardness of the seabed in their areas:

"The mud hasn't changed much" (VC12, Sinclair, Clarence and Irene Mistacheesik, 2019).

"The bottom of the sea remains soft" (VC13, Ernie Hughboy, 2019).

WATER COLOUR AND CLARITY (MURKINESS) OUT IN THE BAY

Land users along the Chisasibi and Wemindji coasts have seen the coastal waters transform from clear and blue to murky (unclear) and brown between the late 1980s and the early 1990s in Chisasibi and between the late 1990s to the early 2000s in Wemindji. Land users associate those changes with the decline of eelgrass: "*The water is not as clear as it used to when there was eelgrass. Eelgrass likes clear water, now you don't have that*" (CH38, Louie Kanatewat 2019). Murkier waters are reported from the northernmost trapline (CH7) to the southern Wemindji trapline (VC17). Land users from trapline VC17 report that the water only gets murky on windy days. Land users from the VC15 and VC32 in Eastmain also report murkier waters in their area.

"In 1986 and 1987, we observed a colour change in the water to yellow brown. And then in the early 1990s, everything (i.e., all the eelgrass in my trapline) disappeared."
(CH 33, John E. Sam, 1 July, 2021).

"30 to 40 years ago we could see the bottom even at 20 feet. Now, you cannot see through the water, not even at 5 feet" (CH3, Andrew Rupert, 2019).

"We think water quality is the reason why eelgrass doesn't grow anymore, that's what we blame. The water is not good or clear anymore" (CH7, Freddy Scipio, 2019).

"The water is not as clear as before. Now it looks like as if something is mixed in with the water, now it is darker and murkier" (VC10, Rene Atsynia, 2019).

"Yes, the water is muddy now. You could see the bottom along the shorelines back in 1990s. We started seeing most of the changes started around from the late 1990s to the early 2000s. All the debris goes flowing to the James Bay area. More debris is coming from the river" (VC09, Jerry Kikabat, 2019).

SLIME AND ALGAE

Land users from some traplines from the mouth of La Grande River (CH3) in Chisasibi to southern Wemindji (VC17) also report that white and brown slime and green algae started to build up on eelgrass and on surfaces below the high tide level around the same time eelgrass began to decline. Land users associate this new biofilm with limited eelgrass growth and see it as a safety concern:

"There's a brown slime building up on everything below the water. It affects the eelgrass turning it yellow" (CH01, Malcom House and Judy House, 2019).

"We have seen green material too. When we set nets at Governor Island we get a lot of green algae in them. Everything is green, even the rocks on the shore. When we shake our nets, everything comes off" (CH33, John E. Sam, 2019).

"The rocks also look different. A brown film or slime is covering the rocks. I see it a lot at my camp" (CH3, Andrew Rupert, 2019).

Table 5-1. Regional perspective on changes in the coastal habitat detected by Cree land users. Source: Idrobo et al. (in prep).

TRAPLINE	SALINITY	SEABED CONSISTENCY	WATER CLARITY	SLIME AND ALGAE
Chisasibi				
CH7	Less salty	Hardened	Murky	
CH6, 5, 4 did not participate in the study				
CH3	Less salty		Murky	Slime/algae
CH1	Less salty	Hardened	Murky	
CH33	Less salty		Murky	
CH34	Less salty		Murky	
CH37	Less salty	Hardened	Murky	

TRAPLINE	SALINITY	SEABED CONSISTENCY	WATER CLARITY	SLIME AND ALGAE
CH38				
Wemindji				
VC09				Slime and algae
VC10		Hardened		
VC11				
VC12		No change		Slime/algae
VC13	Ambivalent			
VC17	No change	Hardened	When windy	
VC14	No change	Hardened		
Eastmain				
VC15			Murky	No change
VC30				
VC31				
VC32		Hardened	Murky	
RE03A				
RE04				
RE05				
Waskaganish				
R01		No change	No change	
R02				
R02A				
R03				

Timelines of change in Chisasibi

Table 5-2 summarizes the descriptions that Cree knowledge holders shared during the project about the timeline of the eelgrass decline in Chisasibi (Idrobo et al., in prep.). The timeline references stages of the hydroelectric development and other benchmarks. Cree land users communicated that the eelgrass decline in eastern James Bay and associated changes in waterfowl abundance and distribution coincided with the construction of hydroelectric infrastructure and the beginning of its operation in the region. Interviews with Cree knowledge holders, from the southernmost (CH38) to the northernmost (CH7) traplines in Chisasibi, suggest that eelgrass declined drastically after the commissioning of LG1. The pace and onset of the decline differ among traplines (Table 5-3); in some places, the eelgrass declines started in the late 1980s and early 1990s, in others the declines were apparent only after 1995. In some traplines, the eelgrass decline was gradual, in others the eelgrass declines were abrupt. Some eelgrass declines that had begun during the 1980s accelerated during the 1990s while others did not. A summary of Chisasibi land user knowledge in the *Chisasibi Migratory Birds Habitat Task Force Report (Cree Nation of Chisasibi 2015)* describes the eelgrass declines as having been gradual during the 1980s and early 1990s and then becoming "massive" during 1998 and 1999: "*The last year we had eelgrass was 1998*." According to one participant, "*My grandfathers always talked about many things that had to do with hunting and not once did they mention a time when there was no eelgrass.*"

During interviews conducted for this project, Chisasibi land users also shared the following:

"There have been vast changes in hunting activities since the hydro development project started in the early 1970s. We noticed vast changes in the early 1990s when LG1 started to operate. The waterfowl disappeared on account that the eelgrass was disappearing. That is when it started having a hard time getting geese, especially in the fall as they primarily feed on eelgrass and berries. We started feeling the changes in the 1970s, but they became much stronger in the 1990s." (CH38, Louie Kanatewat, 2019).

"I've seen a lot of eelgrass before, but not much today. Since the late 1980s, it seems eelgrass stopped growing. After that, we hardly got any geese in the fall. Since the construction of the dam, we started to feel its impacts. We think that the dam is the reason why the eelgrass stopped growing. Since the dam started working, the dead land (sediment) that flows down to the bay covers everything. That is why eelgrass is not growing anymore, because of the dead soil that comes down from inland." (CH33, John E. Sam, 2019).

Table 5-2. Summary of Cree timeline for eelgrass and goose decline based on interviews in Chisasibi. Source: Idrobo et al. (in prep.).

DECADE	HYDROELECTRIC DEVELOPMENT EVENT[1]	CREE PERCEPTION OF ENVIRONMENTAL CHANGE[2]
1970s	Hydroelectric development announced in James Bay (April 1971) Signing of JBNQA (November 1975) Commissioning of LG2 (October 1979)	Eelgrass and waterfowl are abundant
1980s	LG2 is fully operational (December 1981)	Eelgrass and waterfowl are abundant
1990s	Commissioning of LG2A (1991-92) Commissioning of LG1 (1994-95)	First signs of eelgrass and waterfowl decline (late 1980s–early 1990s)

1 Hydroelectric development timeline based on (Hornig 1999) and (Hydro-Québec 2010).

2 Cree perspective of environmental change based on interviews with Eeyou Istchee Cree land users, tallymen, and Elders.

Table 5-3. Description of the eelgrass decline at specific traplines in Chisasibi based on interviews conducted for this project. Source: Idrobo et al. (in prep.).

TRAPLINE	START OF THE DECLINE	TYPE OF DECLINE	NOTE
CH7	Already declining in 1988, still growing in 1995	Gradual	Around 1998-1999 was the last time I really hunted. [...]. Few years after that, when I came back hunting, that's when I saw that the eelgrass was declining. Then nobody really went hunting in the fall anymore, because there was not much geese to hunt (CH07, Reggie Scipio, 2019).
CH3			*Participatory mapping showed there is no record of eelgrass in this trapline.*
CH33	Disappeared in 1986	Sudden crash	Eelgrass collapsed in 1986. That's the year when people began to notice the drastic decline (CH33, John E. Sam, 2019).
CH37	Late 1990s	Gradual	No information available.
CH38	Late 1990s	Gradual	In the late 1990s. The process was gradual (CH38, Jimmy Kanatewat, 2019).

TIMELINES OF CHANGE IN EASTMAIN AND WEMINDJI

In interviews conducted for this study, Eastmain Cree reported that eelgrass beds were lost from the coastal area immediately south of the Eastmain River after diversion. The Cree we interviewed in Eastmain also associated a change in water colour with the diversion: "*Water quality and appearance has also changed drastically. In the Bay water changed from "navy blue" to "chocolate milk" colour after the diversion*" (VC31, Donald Gilpin, 2019). In the *Voices from the Bay* report published in the 1990s, Eastmain Cree reported an increase in the turbidity along the coast near the Eastmain River outlet associated with weakening currents after the diversion (McDonald et al. 1997). A Cree Knowledge report for Eastmain put together by the Cree Regional Authority (Lajoie and Cuciurean, 1994) described good concentrations of eelgrass in places during the 1990s, and one land user noted an increase in Brant. A total of 23 eelgrass beds were drawn on a map by Eastmain Cree, ranging in size from 5 ha to 200 ha and in one case 540 ha, but with most eelgrass beds smaller than 100 ha. The eelgrass beds tended to be distributed in the southern part of the study area, near the Jolicoeur River estuary and from the Conn River north to Point d'Aiguebelle just south of Vieux Comptoir River (Lajoie and Cuciurean 1994).

Wemindji Cree interviewed for this project emphasized that the late 1990s and early 2000s were the periods of major change in the eelgrass. A Cree Knowledge study completed in Wemindji in 1995 (Ettinger and Lajoie 1995) stated "*the Cree informants have found that eelgrass seems to be spreading in their territory, with the possible exception of several shallow areas in which it appears to be declining*." This report was based on interviews with Cree hunters familiar with the coast and possessing long-term knowledge of local environmental conditions and a participatory mapping exercise, in which eelgrass beds were drawn by hunters onto paper maps (scale 1:50,000). Data were later digitized and input into a geographical information system to produce colour maps at 1:220,000 and to compare with the maps generated by Hydro-Québec. A total of 117 eelgrass beds were mapped in the Wemindji area for a total surface area of 38 km^2, compared to 66 km^2 reported in the Hydro-Québec data dating back to 1991, of which 38 km^2 were identified as high-density eelgrass beds.

Wemindji Cree emphasized the role of climate change in bringing about environmental change. In the *Voices from the Bay* report (McDonald et al. 1997), Cree land users are quoted as saying:

> *"The weather has been changing a lot since the late 1970s. It's not as cold in the wintertime, and after freeze-up you have to wait a long time before you can travel on the ice. And people say the ice is not as thick as it used to be, even out in the Bay. In late February I put out my fish nets, five kilometers from here, I was surprised that the ice was very thin, it was about this thin (~30 cm), it used to be about 1 meter thick. It makes it easier for digging a hole in the ice" (JM).*

> *"Freeze-up takes longer, we must wait a long time before going on ice (in the fall), and then in spring ice goes out really fast, too fast" (LU).*

Scientific observations of change

CHANGES IN REGIONAL HYDROLOGY AND TRENDS IN RIVER DISCHARGE

As mentioned in section 2 of this report, rivers are prominent features of the coastal environment of eastern James Bay. Any significant changes in timing or amount of river discharge may bring about changes in coastal habitat at local to regional scales, depending on the magnitude of change. The development of the large hydropower complex in Eeyou Istchee that started in the 1970s was amongst the largest power generation projects in North America. Between the 1970s and 2013, a total of eight reservoirs and 11 generating stations were developed in the La Grande watershed (Table 5-4; Hydro-Québec 2023). These structures brought regulated flow regimes to all the major rivers along the east coast of James Bay (Eastmain, Rupert, La Grande) and resulted in major shifts in regional hydrology (de Melo et al. 2022; Déry et al. 2011; Déry et al. 2016). Flow from the Eastmain, Opinaca, and Rupert Rivers was diverted northward to increase the discharge of the reservoirs that were built along the La Grande River. The Eastmain-Opinaca diversions added about 830 m^3 s1 to La Grande River in northeast James Bay and removed this freshwater input from southern James Bay (Roy and Messier 1989; Déry et al. 2016). The diversion of the Caniapiscau River, which naturally discharged through the Koksoak River into Ungava Bay on Hudson Strait, *further* increased the net freshwater input to northeastern James Bay by around 750 m^3 s^{-1} (Roy and Messier 1989; Déry et al. 2016). In total, the diversion of waters from the Eastmain, Opinaca, Rupert, and Caniapiscau drainage basins between the 1970s and 2012 increased the annual average flow of La Grande River slightly more than two-fold, from a pre-development natural flow of 1,700 m^3 s1 to about 2,800 m^3 s1 in 1985 following phase I of development and values exceeding 4,000 m^3 s1 during the past ten years (Figure 5-1; (de Melo et al. 2022). The overall increasing pattern in discharge in La Grande River is not driven by a regional increase in runoff but rather by the successive developments. This may be seen in the lack of relationship between the Normalized Runoff Anomaly (NRA; the standardized discharge) of La Grande River versus that of three major free-flowing rivers in James Bay (Figure 5-2). This figure makes the point that there is very little synchrony or correspondence between the annual patterns of discharge of La Grande and the other rivers in eastern James Bay, which are themselves very synchronized. In contrast to La Grande, other major rivers show no obvious increase in discharge over the past decades (see discussion in next section).

Table 5-4. Hydroelectric generating stations in the La Grande watershed as of January 1, 2023. Source: https://www.hydroquebec.com/generation/generating-stations.html.

NAME	RIVER OR OTHER WATERCOURSE	TYPE	INSTALLED CAPACITY (MW)	NUMBER OF UNITS	HEAD[1] (M)	COMMISSION DATE[2]
Eastmain-1-A	Eastmain	Reservoir	768	3	63	2011-2012
Brisay	Caniapiscau	Reservoir	469	2	37.5	1993

Eastmain-1	Eastmain	Reservoir	480	3	63	2006
La Grande-1 (LG1)	La Grande	Run-of-river	1436	12	27.5	1994-1995
La Grande-2-A	La Grande	Reservoir	2106	6	138.5	1991-1992
La Grande-3	La Grande	Reservoir	2417	12	79	1982-1984
La Grande-4	La Grande	Reservoir	2779	9	116.7	1984-1986
Laforge-1	Laforge	Reservoir	878	6	57.3	1993-1994
Laforge-2	Laforge	Run-of-river	319	2	27.4	1996
Robert-Bourassa (LG2)	La Grande	Reservoir	5616	16	137.16	1979-1981
Sarcelle	Eastmain	Run-of-river	150	3	8.7 to 16.1	2013

1 The head of water shown corresponds to the largest value (greatest height), if there are several values. The head varies with each generating unit. Refurbishment work may therefore change the water head value.

2 Year of commissioning of first and last generating unit in each facility.

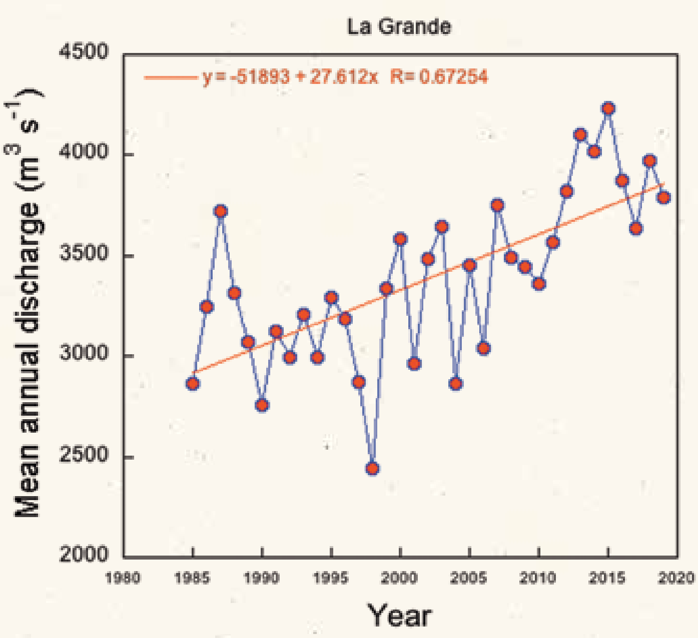


Figure 5-1. Increase in annual freshwater discharge from La Grande River between 1985 and 2020. Source: P. del Giorgio, pers. comm.

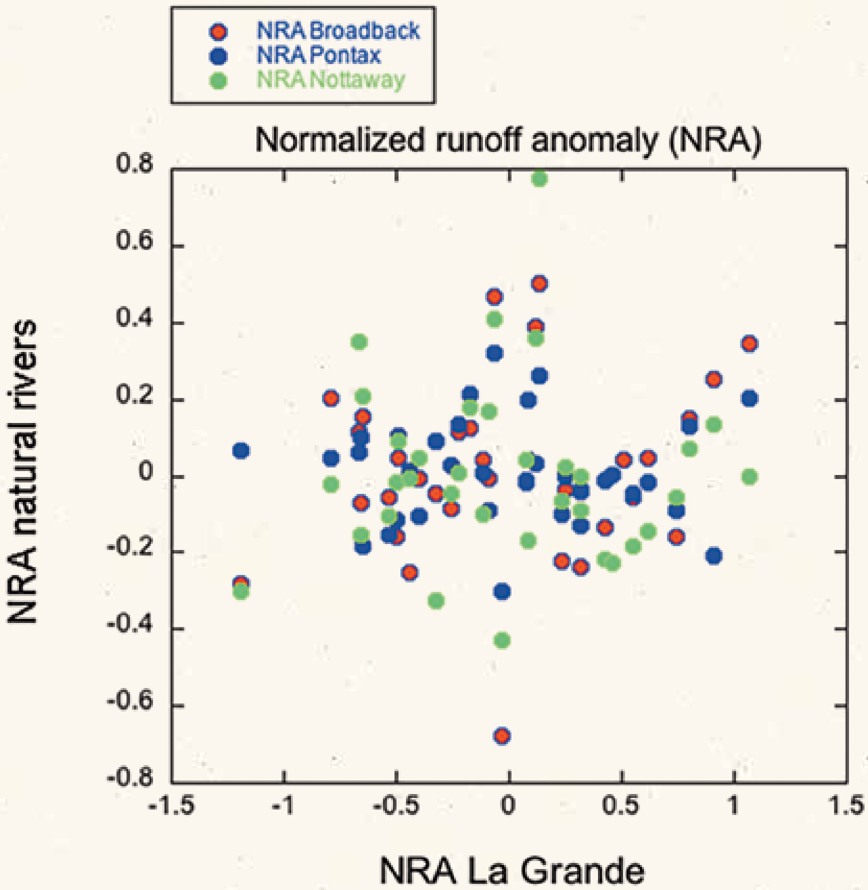


Figure 5-2. Normalized Runoff Anomaly (NRA; the standardized discharge no units) of La Grande River versus that of three major free-flowing rivers in James Bay showing that the discharges vary independently because of the flow regulation of La Grande. Source: P. del Giorgio, pers. comm.

New discharge data for 13 eastern James Bay Rivers collected during the CHCRP show that La Grande River dominates the regional river discharge throughout the year with the exception of May and June (spring runoff), when the combined discharge of all other rivers exceeds that of La Grande (Figure 5-3). In the figure, it is also apparent that the regulated flow regime from the La Grande River to meet hydropower demand has "reversed" the natural hydrograph (pattern of seasonality of flow). Whereas natural free-flowing rivers have their highest flows during spring, the La Grande River has its highest flows during winter (December, January, February) and lowest flows during spring and summer. The La Grande River discharge during recent winters of about 5,000 $m^3 s^{-1}$ (Peck et al. 2022) represents a roughly ten-fold increase from the natural flows of 520 and 460 $m^3 s^{-1}$ during winters 1975 and 1976, respectively (Ingram and Larouche 1987a). As discussed below, the reversed seasonality means the La Grande River now delivers a large fraction of its freshwater, heat, nutrients, carbon, and sediments to eastern James Bay during the winter (ice-covered) period rather than during the growing season for eelgrass and other plants.

In addition to the long-term increase in flow and the reversed seasonality, the La Grande also experienced several periods of irregular flow during the development of the hydroelectric complex. La

Grande River discharge was interrupted quite substantially on several occasions between the fall of 1978 and the summer of 1982. For example, to fill the LG2 reservoir, in fall 1978, the flow of the La Grande was reduced to a few tens of $m^3 s^{-1}$ (Figure 2-16), which is a fraction of the minimum yearly natural flow of 340 $m^3 s^{-1}$ (Environment Canada 1975 as cited in Berkes 1982). The small residual flow was supplied mainly from tributaries downstream of LG2 (Berkes 1982). River flow was gradually restored between June and November 1979 and in winter 1980, the first substantial increases in flow began.

The CHCRP did not analyze data on short-term variations in river flows, but it is well known that substantial variations in lower La Grande River discharge have occurred since the construction of LG2A and LG1 on 24-hour as well as weekly cycles. This is related to patterns of hydroelectric demand. The effect of flow variation is seen in Chisasibi as a raising and lowering of the water level in the river by a metre or more on daily to weekly time scales. During winter, ice along the riverbanks is 'hanging', perched well above the surface of the river, during periods of low water level.

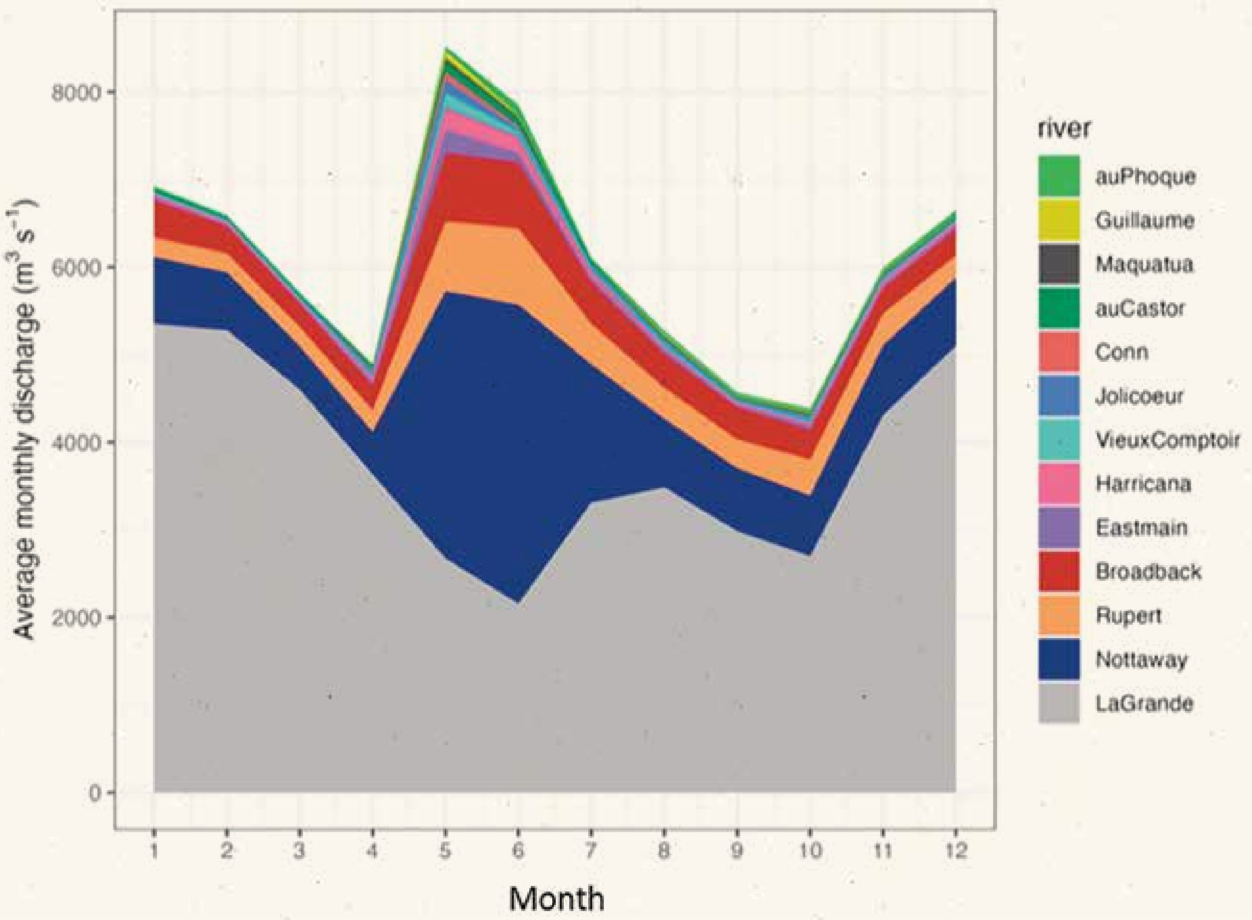


Figure 5-3. Average monthly discharge in 2019 for 13 rivers draining into eastern James Bay. May and June (months 5 and 6) reflect spring snow melt and river runoff.

The hydroelectric development also affected many other rivers in addition to La Grande. The diversion of the Eastmain River into the La Grande Complex meant that the Eastmain River discharge at the river mouth was abruptly and permanently reduced by about 90% (see Figure 2-16). The natural discharge of the Eastmain River that was about 900 m^3 s1 during 1964–1973 (Déry et al. 2016) now is less than 70 m^3 s1 and represents only a small fraction of the total discharge to the eastern James Bay coast (de Melo et al. 2022). The partial diversion of the Rupert River into the La Grande Complex by way of the Eastmain watershed resulted in a ~50% reduction of the Rupert River discharge from 845 m^3 s1 to 395 m^3 s1 after 2012 (de Melo et al. 2022).

There has been some debate about whether climate change has caused changes in *natural, free-flowing* river discharge to James Bay during recent decades. A recent study reported increasing trends in river discharge to the combined eastern Hudson Bay/James Bay region (Déry et al. 2016). However, the authors of the study concluded that the increases were *likely* explained by the Caniapiscau diversion to the La Grande River system, i.e., hydro development, rather than climate change. They noted that few rivers in east James Bay had available discharge data leading to large uncertainties in the climate-driven temporal trends.

Analysis of discharge patterns for free-running rivers, as well as dammed rivers, was completed for the CHCRP. One approach used globally modelled precipitation data for the period of 1951–2021. Time series were obtained by adding up the precipitation data from ERA5, the global reanalysis dataset produced by ECMWF (Costanzo 2022). The results of this work showed that hydroelectric development was the dominant driver of change in river discharge to James Bay over the period from 1951 to 2021. Figure 5-4 shows the estimated annual freshwater discharge for the large watershed sectors of James Bay over the 1951 to 2021 period from this work. The northeast sector, which contains the La Grande shows large increases as a result of the river diversions and reservoir filling in the early 1980s. The southeast sector of James Bay shows a coincident decrease after 1980 due to the diversion of the Eastmain-Opinaca. The changes in discharge were essentially due to adjustments in the sizes of the drainage basin: The same dataset suggests that *without hydroelectric development* the discharge of southeast James Bay and northeast James Bay watersheds would have changed only very slowly, i.e., (0.155% and 0.001%, respectively, over the entire 70 year period of 1951–2021; (Costanzo 2022). These findings agree with previous reports that climate change has *not* caused changes in *free-flowing river* discharge to eastern James Bay during recent decades (Guay et al. 2015; Stadnyk et al. 2021).

A separate analysis used observations (discharge data) to assess temporal trends in natural river discharge into eastern James Bay. Discharge data were obtained from hydrometric stations including newly installed stations and historical hydrometric stations for the Roggan, Eastmain, La Grande (before diversion), and Pontax Rivers, which are publicly available on the web (https://wateroffice.ec.gc.ca/google_map/google_map_e.html?map_type=historical&search_type=province&province=QC). Historical discharge data for the La Grande River, Eastmain-Opinaca, and Rupert Rivers before diversion were made available by Hydro-Québec (see de Melo et al. (2022) for details). This independent analysis confirmed that there has been no overall temporal trend in natural river discharge into eastern James Bay during recent decades, although there have been extreme years of unusually low and high discharge (de Melo et al., in prep.).

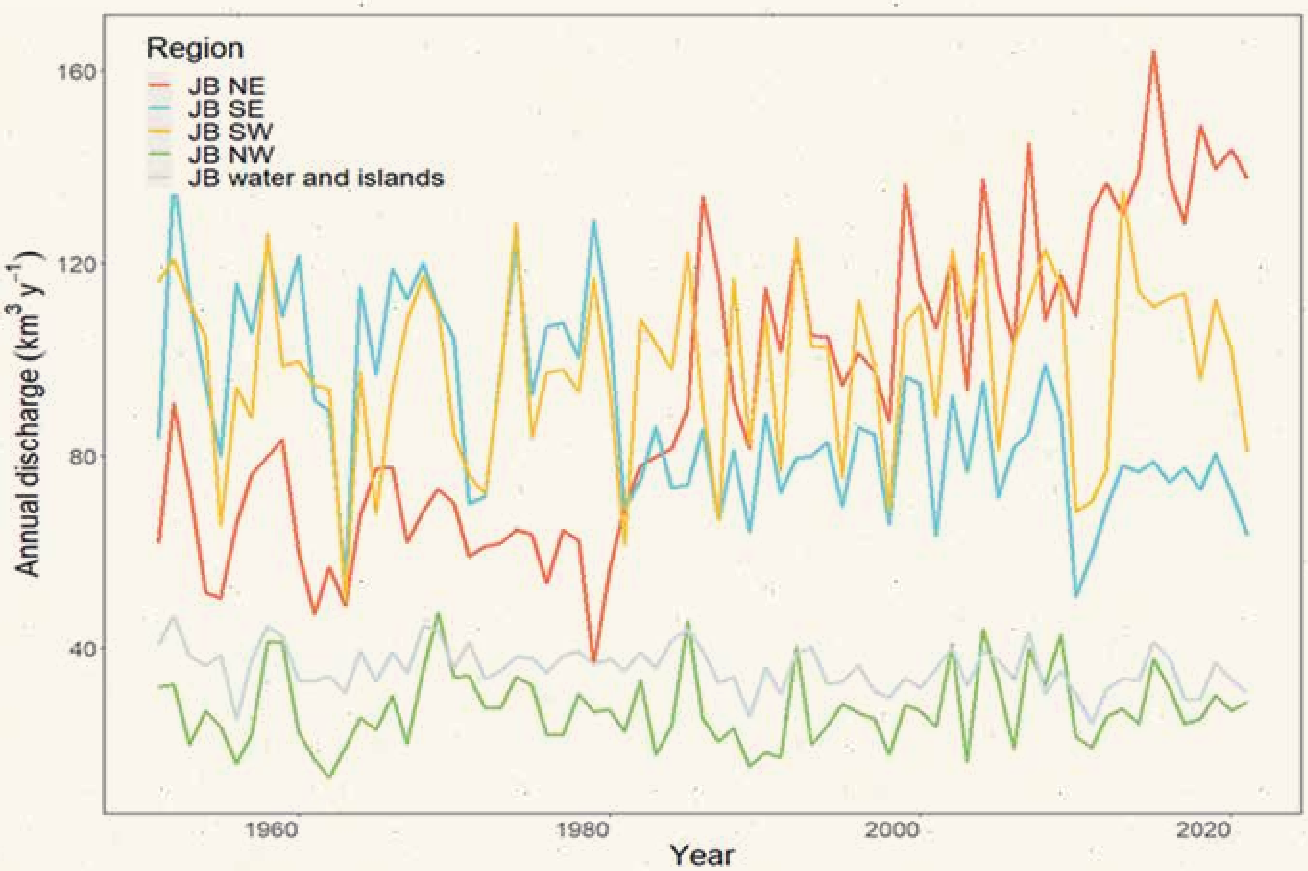


Figure 5-4. Annual freshwater discharge estimated for the large watershed sectors of the JB over the 1951 to 2021 time period. The data considers river diversions and reservoir filling due to the JB Project. JB NE = Northeast JB; JB SE = Southeast JB; JB SW = Southwest JB; JB NW = Northwest JB; JB water and islands = JB marine water and islands. Source: Costanzo (2022).

CHANGES IN RIVER WATER QUALITY AND FLUXES

In addition to freshwater, the rivers of the James Bay watershed deliver heat, nutrients, carbon, CDOM, and sediments to coastal waters. CHCRP researchers reviewed historical reports and collected and analyzed new data to assess water quality in La Grande River and evaluate how water properties have changed, as well as how the deliveries (fluxes) of different materials to James Bay have changed, with the large changes in La Grande River flows. They also collected new water quality data from 18 rivers across the territory (Figure 5-5).

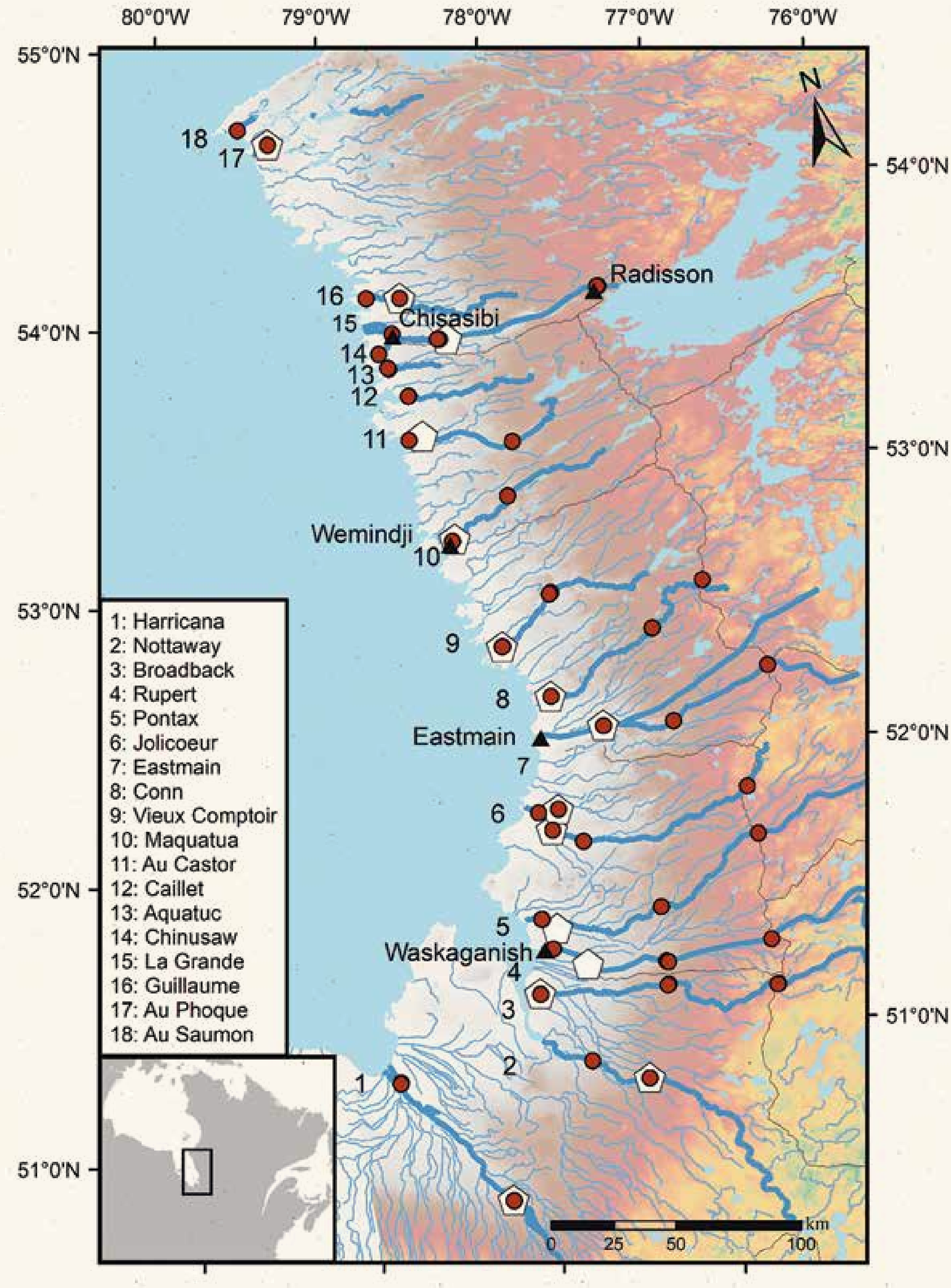


Figure 5-5. Map of the 18 rivers sampled over five field campaigns during the CHCRP. White pentagon symbols show locations of 15 hydrometric stations that were installed. In 2019, the station on the Harricana was lost and a second station was installed on the second channel of the Jolicoeur leaving 14 operating stations on 13 different rivers at the present time.

CHANGES IN LA GRANDE

Limited water quality monitoring was conducted in the La Grande Complex before, during, and after development with emphasis on the reservoirs (Schetagne et al. 2005). Messier et al. (1986) focused on the lower reaches of the river near the bay and compared water quality between natural conditions (1978) and the first phase of development (1982–1984). One of the main differences identified by Messier et al. (1986) was a change in water temperature. Figure 5-6 shows a comparison of average water temperatures in the lower reaches of the river between LG1 and the river mouth under natural conditions and after the development of LG2 (Roche, 1985). The change in water temperature due to LG2 described by Messier et al. (1986) is apparent in this figure. With LG2 operating, river water temperatures are lower in summer by perhaps 3°C and higher in spring, fall, and winter (~1°C), compared to natural conditions.

Another change noted by Messier et al. (1986) was an increase of 40% in organic carbon content and a decease of 30% in silicic acid content. (Note that silicic acid (Si(OH)4) supplies the element silicon (Si) that the phytoplankton called diatoms require to produce their shells). The change in silicic acid was discussed in the context of primary production but considered *insignificant* because silicic acid was not at a limiting level in James Bay. These workers concluded that during the 1982–1984 period, the water quality of La Grande River had returned to values comparable to those previously observed, “despite a different flow regime, longer residence times in one or more reservoirs above LG2, increased turbulence between LG2 and the estuary, and erosion of late glacial clays”. They also did not anticipate future water quality changes because the water quality of the Eastmain and Caniapiscau Rivers was like that of the La Grande River before its regulation.

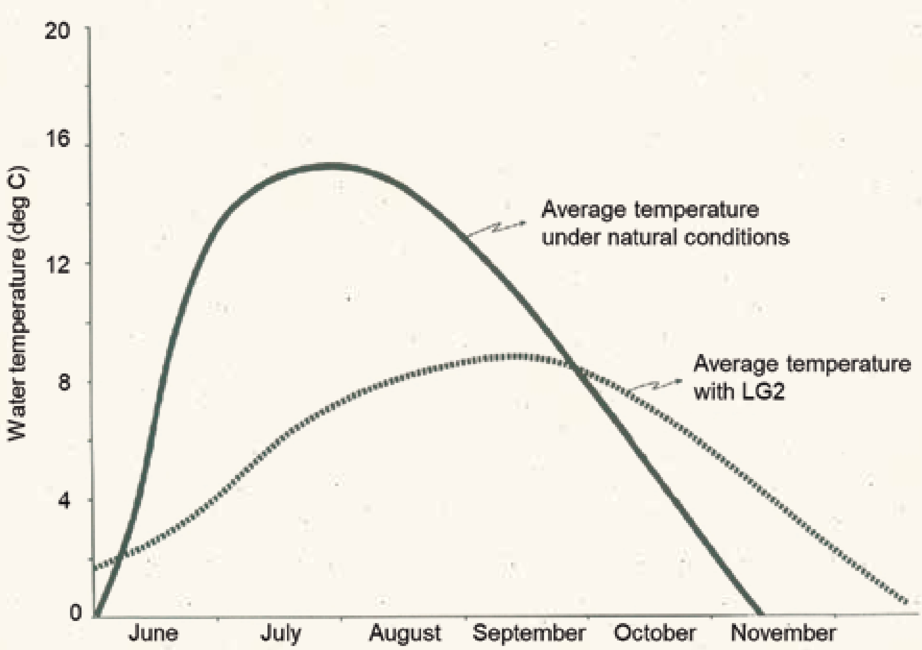


Figure 5-6. Average water temperatures during the open-water period in the lower reaches of the river between LG1 and the river mouth under natural conditions (solid line) and after LG2 reservoir development (dotted line). Source: Roche (1985).

Installation of dams and increased high flows downstream of dams are known to cause geomorphological changes such as riverbank and bed erosion and downstream sediment deposition. These types of changes occurred in the La Grande River. Previous geotechnical reports and scientific literature document several large riverbank collapses and erosion events under higher flows along the La Grande River. Approximately 3,500,000 m^3 of riverbank material was released during a bank undercutting/landslide event in 1987 (Lefebvre et al. 1991) and 1,500,000 m^3 in 1989 (Hydro-Québec and GENIVAR Groupe Conseil Inc., 2005). The 1987 event was described in detail by Lefebvre et al (1991). The bank material was estimated to consist of about 50% fine-grained sediments (silt and clay), and LG2 discharges were increased up to 5,000 $m^3 s^{-1}$ in the days following the slide to "flush the sediments downstream" (Lefebvre et al. 1991). It may be *assumed* these sediments reached the bay because there was no reservoir in place downstream of LG2 to slow the flows and interrupt the sediment transport.

The overall impact of these and other bank erosion events was that for more than a decade (1979–1991) the annual fluxes of sediment from the La Grande River were about four times higher than the natural levels (Table 5-5). According to Table 4 in Hydro-Québec and GENIVAR Groupe Conseil Inc. (2005), the average volume of sediment released into the river from bank erosion *each year* during the period 1979–1991 was 840,000 $m^3 yr^{-1}$ (Messier 2005) compared to an annual average of 202,000 $m^3 yr^{-1}$ during the pre-development period (1960–1978). Note that after LG1 installation in the 1990s, sediment released in the LG1 reservoir or upstream likely was trapped or partly trapped in the reservoir. This is well known as a long-term effect of reservoirs: they interrupt the natural pathways of sediment transport from land to the ocean (Syvitski et al. 2005; Vörösmarty et al. 2003).

Table 5-5. Average annual volumes of sediment from bank erosion (slumps and landslides) below the LG2 dam and downstream to the end of the well-defined main channel. Data source: Table 4 in Hydro-Québec and GENIVAR Groupe Conseil Inc. (2005).

PERIOD	VOLUME OF MATERIAL (M3)
1960–1978	202,000
1979–1991	840,000
1991–1993	319,144
1993–1995	140,037
1995–1997	158,779

The release and transfer of organic matter, including carbon from the watershed to the coastal environment during the development of the La Grande Complex, is less well known. In general, reservoir flooding leads to immediate, short-term changes in water quality including increased organic matter content in the water column, followed by more gradual and longer-lasting changes. The details of the changes depend on the character of the land that was flooded and the rate of decomposition of the associated organic matter, such as leaves from trees and shrubs, herbaceous plants, mosses, lichens, and humic material in forest soils. Dissolved organic carbon can be released and transported downstream and/or the oxidation of these materials within the reservoir can lead to a consumption of dissolved oxygen and release of dissolved carbon dioxide (inorganic carbon) and nutrients. Water quality also changes with the gradual dilution or replacement of water from the initial water bodies by the waters of the rivers diverted into the reservoir. The release of phosphorous and nitrogen from flooded lands often leads to transient increases in phytoplankton biomass and an upsurge in primary production in the years following flooding (Maavara et al. 2020; Maavara et al. 2017). However, nutrient concentrations tend to decline as reservoirs age, and this is what was observed in the La Grande Complex (Table 5-6). The total organic carbon concentration in La Grande River water increased from 6.4 mg L^{-1} in 1978 to 12.3 mg L^{-1} in 1979 but then decreased to 5 mg L^{-1} after 1980 (de Melo et al. 2022). Total phosphorous concentrations increased from 9 mg L^{-1} to 20 mg L^{-1} and are now at 8 mg L^{-1}. Only nitrogen concentrations appear to be slightly *higher* in the La Grande River water at the present time (0.19 mg L^{-1}) compared to 1978 conditions (0.15 mg L^{-1}). Slight increases in the concentrations of nitrate (one form of nitrogen) in La Grande River were also found before and after development. La Grande River water collected between LG1 and the river mouth had nitrate concentrations averaging 1.6 μmol L^{-1} before development (1.6–2.1; n=16) as compared to an average of 2.8 μmol L^{-1} in summer and 4.5 μmol L^{-1} in winter during 2016–2017 (Guzzi et al., in prep.).

Table 5-6. Comparison of water properties in La Grande River before, during, and after impoundment, and current estimates. Source: Table S5 in de Melo et al. (2022).

VARIABLE	BEFORE	DURING	AFTER	CURRENT*
	(1978)	*(1979)*	*(1980-2000)*	*(2018-2019)*
Discharge ($m^3 s^{-1}$)	1700	-	3400	3780
O_2 saturation (%)	105	98	96 ±3.1	95
pH	6.5	7.0	6.4 ±0.1	6.2
Conductivity (μS cm^{-1})	14	58	14.2 ±1.7	11
Total nitrogen (mg L^{-1})	0.15	0.18	0.16 ±0.02	0.19
Total phosphorous (μg L^{-1})	9	20	13 ±3.9	8
Total inorganic carbon (mg L^{-1})	1.1	1.1	1.6 ±0.2	1.4
Total organic carbon (mg L^{-1})	6.4	12.3	5.0 ±0.8	5.0

*Current: downstream of LG1 dam (G1300); Years after: 1980 to 1984, 1988, 1992, 1994, 1996, 2000.

An attempt was made in a previous study to estimate the total releases (fluxes) of organic carbon during the periods of reservoir flooding when higher concentrations were detected (Weissenberger et al. 2010).

The study used the limited available data together with models. These researchers estimated that, in total, 31.3 Tg of carbon (teragram; 1012 grams) was *released* as a result of the flooding of six reservoirs in the La Grande Complex. More than 80% of this carbon may have been *exported* out of the reservoir complex to downstream areas during the initial years after flooding, some as eroded soil and some as dissolved carbon released through degradation and leaching in the soils (Figure 5-7). This quantity of carbon (31.3 Tg) is about six times as much organic carbon as supplied annually by rivers into the entire Hudson Bay and James Bay systems at the present time (Capelle et al. 2020). Possible additional carbon releases from water level fluctuations (e.g., ±8 m in the LG1 Reservoir and ±7.7 m in the LG2 Reservoir) were not incorporated into the model (Weissenberger et al. 2010). As mentioned above, the releases of sediment and organic matter from the reservoirs was a temporary phenomenon during development: as the hydroelectric complex has aged, the trend has reversed, and the reservoirs are currently capturing and trapping particulate and dissolved carbon and nutrients (de Melo et al. 2022) as well as of mercury (Fink-Mercier et al. 2022) relative to the pre-dam conditions.

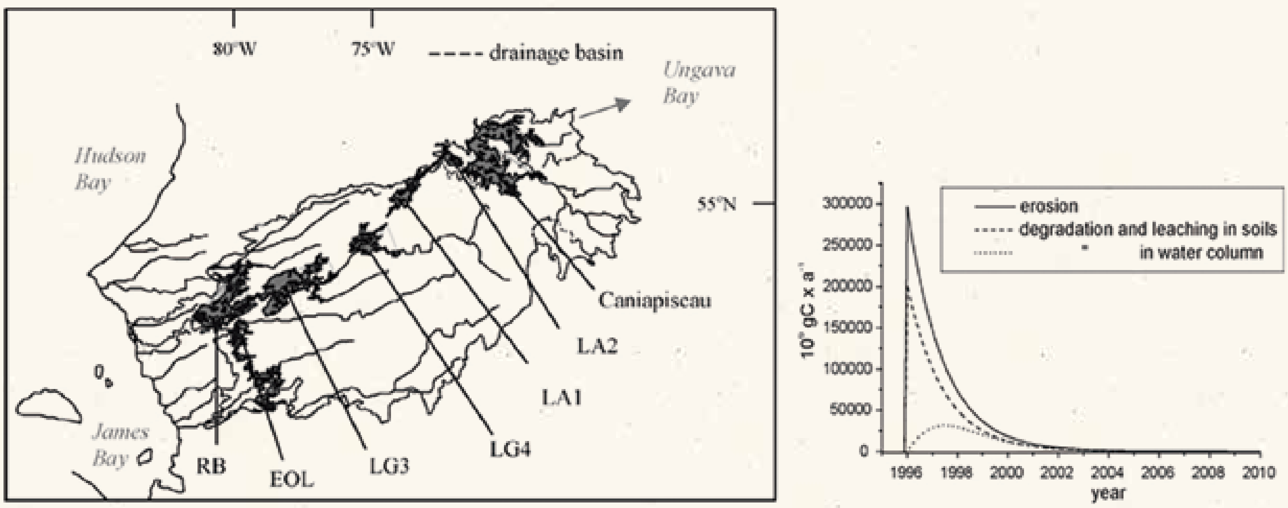


Table 1
Physical characteristics of the reservoirs of the La Grande complex[a].

Reservoir	Year of flooding	Surface area (km²)	Volume (km³)	Yearly outflow (m³/s)	Residence time (days)
Caniapiscau	1983	4275	53.79	795	738
LA2	1996	260	1.840	825	26
LA1	1993	1288	7.777	965	93
LG4	1986	765	19.53	1543	147
LG3	1982	2420	60.02	2064	337
R-B (LG2)	1978	2835	61.72	3374	211
EOL	1979	1040	20.80	878	275

[a] Data from Hydro-Québec (1992, 1998). Surface area and volume at maximum water level.

Figure 5-7. Modelled release of carbon in the years following flooding of the Laforge 2 reservoir in 1996 due to erosion of flooded soil, degradation-leaching of flooding soil, and degradation in the water column. Similar patterns of carbon release, scaled up according to the size of the reservoir, were modelled for the six other reservoirs described in the table and identified in the figure. Source: Weissenberger et al. (2010).

FLUXES FROM NATURAL FREE-FLOWING RIVERS

Having installed gauges to measure discharge and collected water samples, the CHCRP river team estimated how the *delivery* of nutrients and carbon to the coastal waters of eastern James Bay has changed (de Melo et al. 2022). With annual freshwater discharge from the La Grande River having approximately doubled since before development (3,780 vs. 1,700 $m^3 s^{-1}$), the river's *exports* (releases) of carbon and nutrients into the bay increased substantially (see Table 4 in de Melo et al. 2022). The La Grande River is now the largest exporter of nutrients and carbon to James Bay (Figure 5-8). La Grande River exports today are in the order of 512,000 t yr^{-1} (32% of the total) dissolved organic carbon, 21,296 t yr^{-1} (40%) total nitrogen, and 1,091 t yr^{-1} (26%) total phosphorous (de Melo et al. 2022). The large contribution of La Grande to total riverine nutrient and carbon export to James Bay is mainly driven by its large water discharge because the actual carbon and nutrient yields (exports in proportion to the size of the watershed area) are not particularly high. This is due in part to the presence of reservoirs, which tend to trap particles and some of the nutrients and carbon loads coming from the watershed. The ratio of nitrogen to phosphorous in La Grande River is high relative to that in the ambient coastal seawater (Guzzi et al. 2023).

It is important to note that the measurements of water quality in La Grande River obtained during the CHCRP do not address irregular or sporadic events that may lead to pulsed releases of materials. They also do not reflect processes occurring in the lower reaches of the river near Fort George Island and the river mouth, which are downstream of the river sampling sites. During the CHCRP, we typically measured low concentrations of suspended particulate matter (SPM) in the La Grande River, *upstream of Fort George*, compared to other regional rivers. For example, over five field campaigns between 2018 and 2019, the average SPM concentration in the La Grande upstream of Fort George was 2.2 mg L^{-1}, whereas the average concentration at sampled river mouths all across the region was more than 10 mg L^{-1} (de Melo et al. 2022). The low concentrations of SPM below LG1 and upstream of Fort George may be explained by the trapping of sediments in the reservoirs.

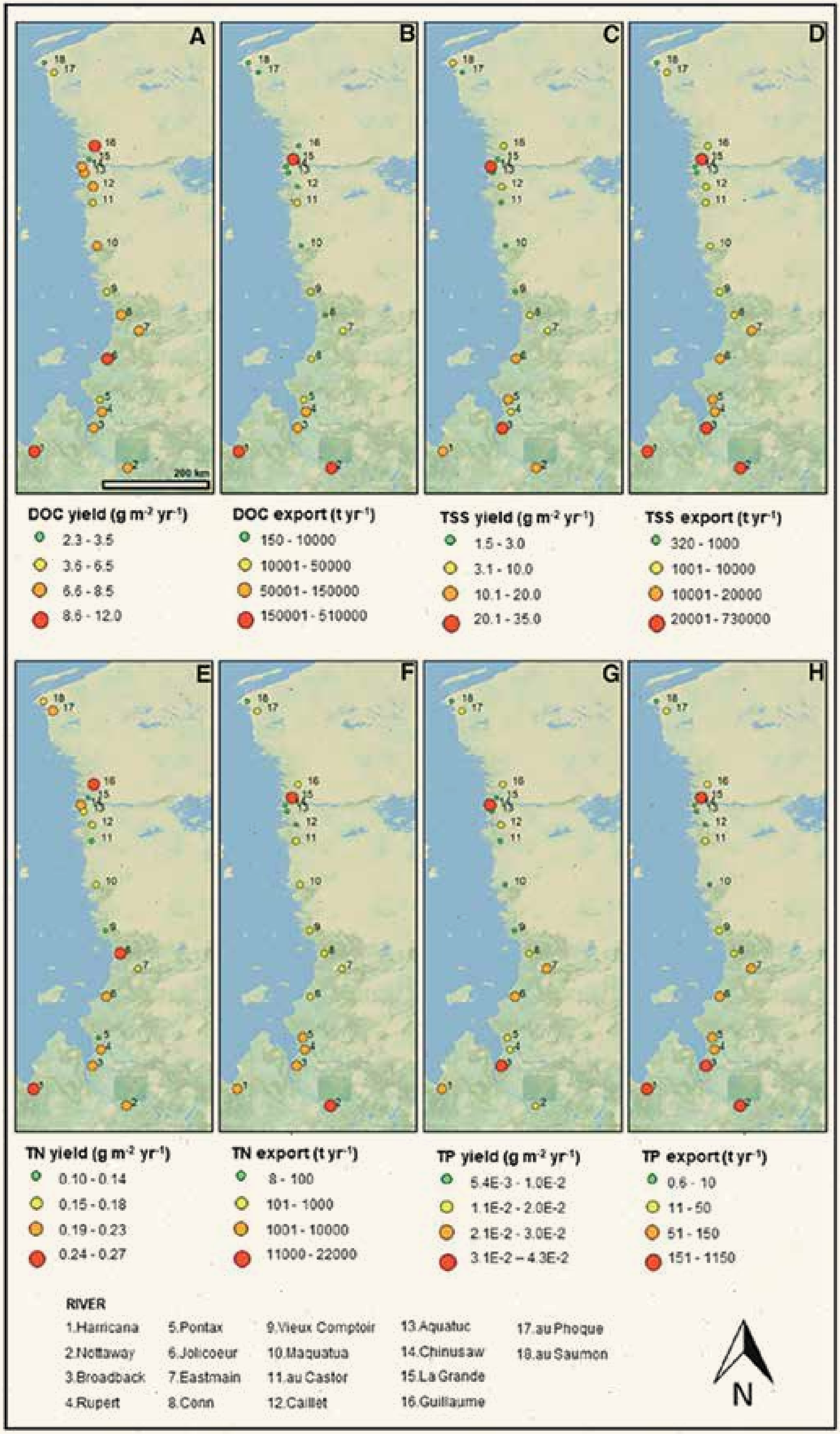


Figure 5-8. Annual exports and yields of carbon, sediment, and nutrients for rivers of east James Bay. Abbreviations are as follows: A, B dissolved organic carbon (DOC); C, D total suspended solids (TSS); E, F total nitrogen (TN); G, H total phosphorus (TP) of the 18 sampled rivers flowing into the Eastern James Bay. Note that the position of La Grande (15) has been shifted towards the bay to avoid overlap with labels. Sampling occurred at 53.7927° N, 78.8924° W. Source: de Melo et al. (2022),

La Grande River freshwater plume

SALINITY

As described in section 2, a river plume is a feature that forms where a river discharges its freshwater into the coastal marine environment. Freshwater is lighter (less dense) than seawater so the river water "floats" on the surface of the seawater until the forces of gravity and Coriolis and the energy of the tide and wind-driven mixing cause the two types of water to become mixed. In the summer, river water typically mixes with the ambient seawater quite quickly because of the wind. This means that surface water salinity increases from 0 (river water) to brackish levels (10–20) within a short distance of the river mouth.

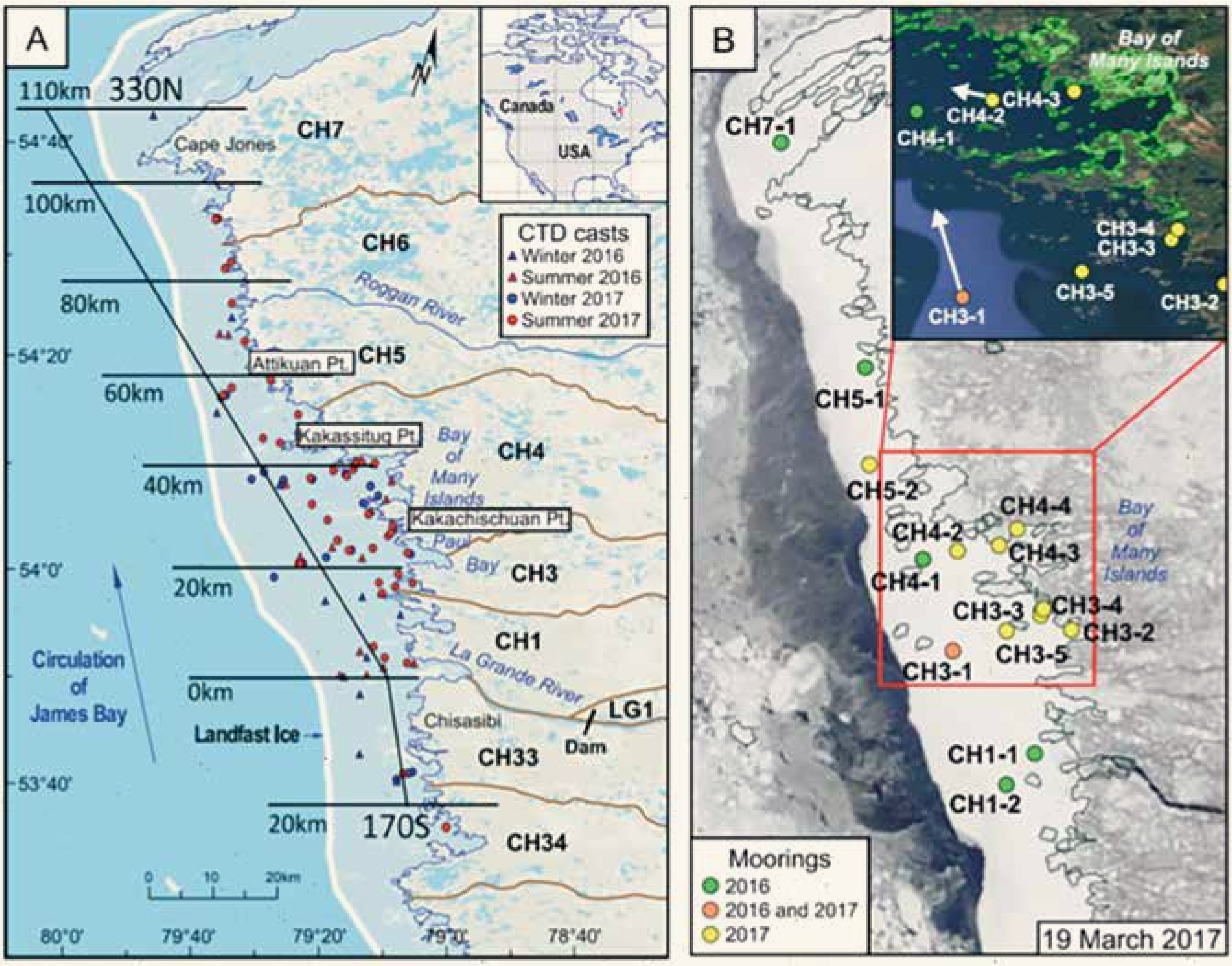
When a river enters a coastal environment covered by landfast ice, it forms a freshwater surface layer under the ice and spreads out over the underlying salty water forming an "under-ice river plume" or "under-ice plume". Most under-ice plumes are fresher and spread much further than plumes formed in open-water conditions (no ice) at equivalent river discharge (cf., Freeman 1982; Ingram 1981; Ingram and Larouche 1987b; Kasper and Weingartner 2015; Macdonald et al. 1995; Peck et al. 2022). These characteristics may be explained by a lack of direct wind mixing (under the ice) and a dampening of the tides by the ice.

Changes in the under-ice plume of the La Grande River were a focus of monitoring before, during, and after the early phases of development and were also studied during the CHCRP to obtain an updated picture of its size and distribution. As the winter discharge of the La Grande River increased, the size of the under-ice river plume increased and nearshore areas both north and south of the river mouth began to experience low salinity during winter. Ingram and Larouche (1987a) reported on the changes in the plume based on observations from February-March 1976, 1979, 1980, and 1984. The natural under-ice plume observed in winter 1976 (discharge 460 $m^3 s^{-1}$) was characterized by an area of about 200 km^2 with salinity <5, an area of 400 km^2 with salinity <10, an area of 800 km^2 with salinity <20, and an area of about 1,800 km^2 with salinity <25 (Table 5-7). When there was no runoff in February 1979 due to reservoir filling, the salinity was nearly constant at 25 from surface to bottom in the area immediately offshore of the river mouth (Freeman 1982). In March 1980, with discharge averaging 1,750 m^3 s1, the area with salinity <5 increased from 200 km^2 to 750 km^2 and all the other areas of reduced salinity also expanded. In winter 1984, with discharge increased to 3,000 $m^3 s^{-1}$, the area with salinity <5 increased further to 1,200 km^2, while the area with salinity <10 expanded to 1,650 km^2, the area with salinity <20 expanded to 2,300 km^2, and the area with salinity <25 was >4,300 km^2. What this means is that by winter 1984, some degree of dilution was felt as far away as Dead Duck Bay to the south and as far northwest as Hudson Bay (Roche 1985). In winter 1987, a further increase in the winter river discharge to ~3,700 $m^3 s^{-1}$ in winter 1987 was expected to cause the area with salinity <5 to exceed 1,200 km^2 but it did not (Messier et al. 1989).

Table 5-7. Table reproduced from Ingram and Larouche (1987) showing how the size of the under-ice river plume increased with increasing discharge. Surface areas in units of square kilometers (km^2) are given for areas with salinity less than 5 (A5), salinity less than 10 (A10), salinity less than 20 (A20), and salinity less than 25 (A25).

YEAR	DISCHARGE ($M^3 S^{-1}$)	A5	A10	A20	A25
1976	460	200	400	800	1800
1979	0	0	0	0	0
1980	1750	650	900	1300	2800
1984	3000	1200	1650	>2300	>4300

In collaboration with the Cree Nation of Chisasibi and as part of the CHCRP, a detailed study of the plume was carried out in the winters of 2016 and 2017, when La Grande discharge averaged 4,800 $m^3 s^{-1}$ (Peck et al. 2022). Salinity was measured using a conductivity-temperature-depth sensor (CTD) and was recorded continuously for the January-April periods using moorings deployed under the ice (Figure 5-9). Although the overall region of freshwater influence of the La Grande River was found to be very extensive reaching Cape Jones at the northeastern tip of James Bay, the very fresh core of the plume with salinity below 5–10 extended a similar distance north of the river mouth (~40 km) as during previous survey periods in 1984–1987. This means that although the *overall* river plume got larger, the very fresh unmixed portion of the plume with very low salinity (<5) that is harmful to eelgrass *did not*. The similarity in size of the plume core was surprising considering the ~30% higher winter discharge in 2016–2017 compared to the early survey periods. The stability of the size of the plume core relates to the coastal geometry and width of the landfast ice cover, under which the plume can spread with limited mixing. As can be seen in Figure 5-10, all major rivers along eastern James Bay that continue to flow during the winter form river plumes but nowhere near the size or scale of the La Grande River plume because of their low winter discharge.



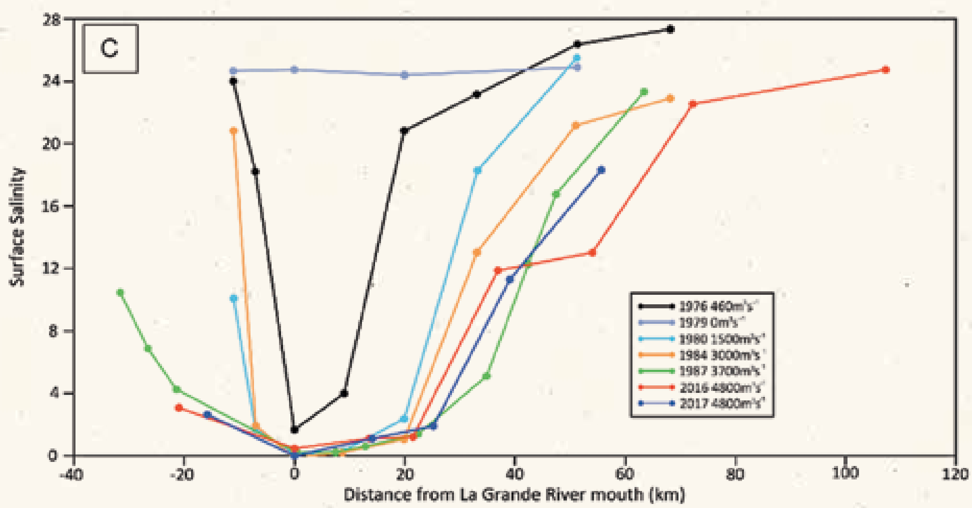


Figure 5-9. Map of CTD casts (panel A) and mooring locations (panel B) from a study of the winter plume of the La Grande River and a plot of surface salinity as a function of distance from La Grande River mouth during various years with different February discharges (panel C). Distance is measured from the LGR mouth along the bearings shown on the map in panel A. Source: Peck et al. (2022).

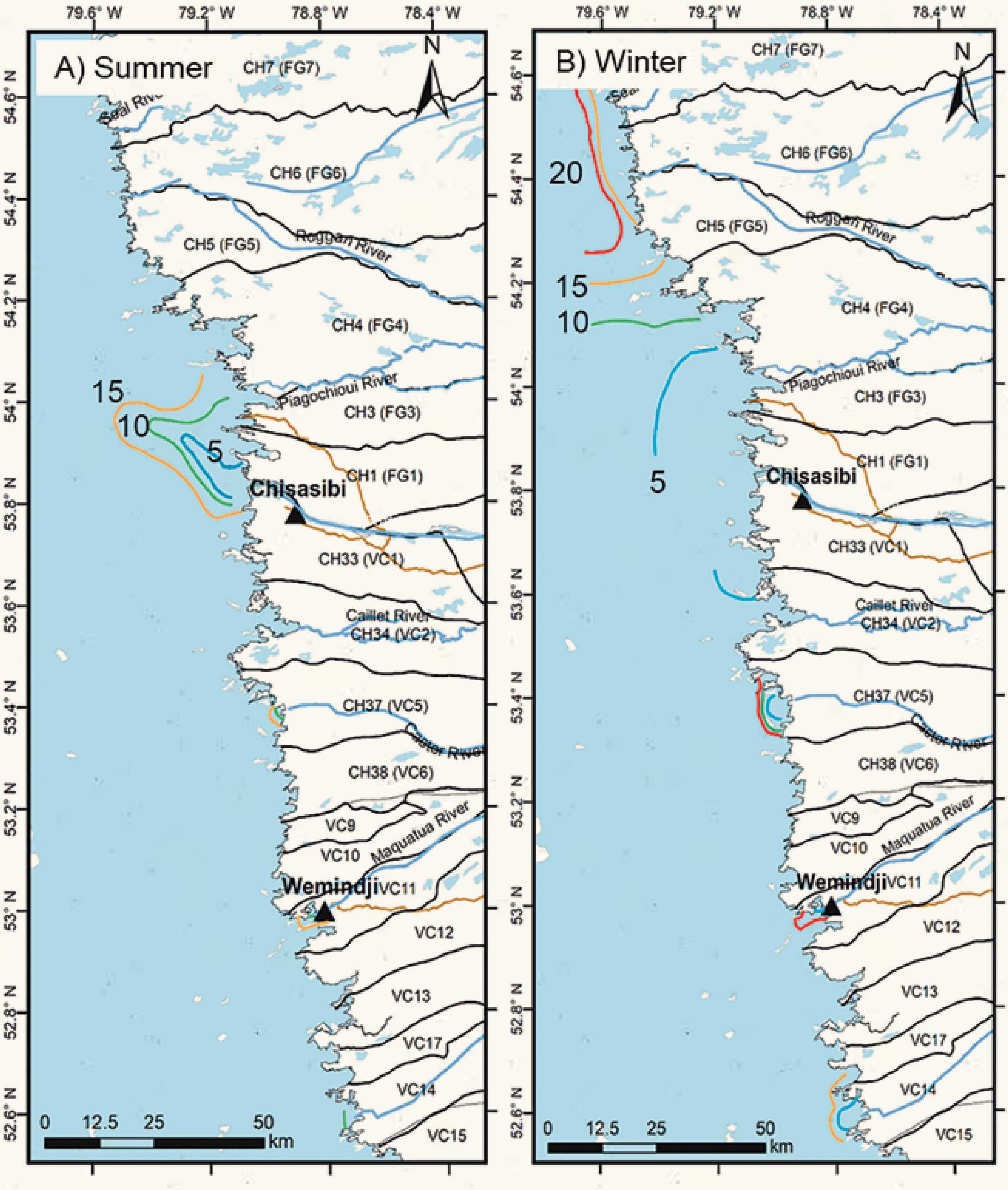


Figure 5-10. Surface salinity in the La Grande River plume and smaller plumes along the eastern James Bay coast. Panel A) shows summer (2018, 2019, and 2021) and panel B) shows winter (2018, 2019, and 2020). "

WATER TEMPERATURE

Surface water temperature measured during the CHCRP was variable along the coast during both summer and winter (Figure 5-11). Rivers bring in warmer water during summer, as evidenced by the highest temperature in river mouths and nearby sites, except for La Grande, which brings in colder water during the summer because the dams flush colder water from the deep portions of the reservoirs. During winter, the effect is the opposite, and relatively warm river water is delivered to the coast. Higher water temperatures in the winter plume of the La Grande reflect the higher freezing point of freshwater (near 0°C) as compared to seawater (as low as -1.5°C in eastern James Bay).

The Société d'énergie de la Baie James (1994) described how the ice conditions around the La Grande estuary differed between natural conditions and after the construction of LG2 and LG1. As summarized in a recent publication (Taha et al. 2019), before 1979, the estuary had a stable ice cover 6 months per year that the local communities used for snowmobiling. After the construction of LG2, an increase in flow rates and warm water temperatures from the LG2 reservoir reduced that period to three months with

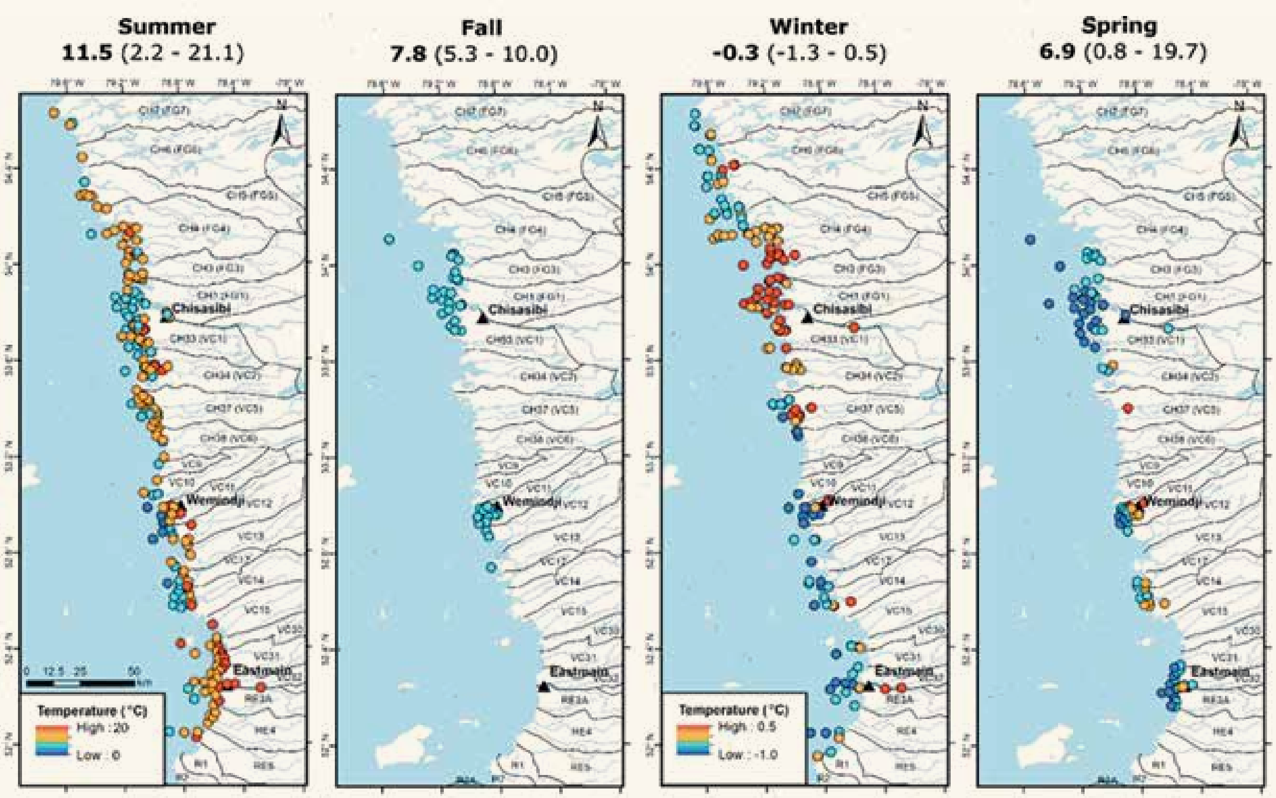


Figure 5-11. Surface water temperature along the eastern James Bay coast during summer (2018, 2019, and 2021), fall (2017 and 2018), winter (2018, 2019, and 2020), and spring (2018 and 2019). Note the unique legend for the winter plot, which allows visualization of the La Grande plume. Mean values and the range (in parenthesis) are indicated above the map. Data were obtained from CTD measurements. Source: Fink-Mercier et al. (2023).

frequent openings during warm spells, and the ice stability at the river mouth was further reduced after the construction of LG1. Outside the river mouth, the increased heat flux during winter alters the local ice breakup pattern such that an opening 5–8 km in radius forms at the river mouth while the coastal ice cover remains intact. Downstream advancement of the freezing front from the river toward or out into the estuary was a predicted effect of the partial diversion of the Rupert River toward the La Grande River during 2009–2012 (Messier 2005).

CURRENTS AND EROSION

One implication of the relatively constant size of the plume core, despite an increase in winter discharge, is that freshwater must be turned over more quickly within this area. Put simply, the under-ice currents within the plume core area are faster (Peck et al. 2022). Currents measured in the plume near the mouth of the La Grande (site CH1-1; Figure 5-9b) during winter 2016 were fast-flowing, with an average velocity of 16.7 cm s^{-1} in a north-northwesterly direction; they showed significant short-term variations corresponding to changes in river discharge as well as tidal stages (Figure 5-12). One example is the gradual increase in maximum plume velocities from the beginning of the record through to about Year Day (YD) 55 when peak flows exceeded 20 cm s^{-1}. This increasing trend spanning several weeks reached a maximum of 25 cm s^{-1} on YD 55 (February 24, 2016) and was coincident with increasing river discharge. Faster current speeds near the La Grande River mouth during winter will have several consequences. A faster current increases the volume of water flowing across surfaces. If the currents were to flow across eelgrass shoots, this would stimulate the diffusion of dissolved nutrients and increase nutrient availability (positive effect on eelgrass). The same would be true for all attached plants (macroalgae, *Rupia*, ice algae, etc.). In contrast, free-floating algae would be flushed out of the area at a higher rate. On the other hand, if faster currents flow over riverbanks or the seabed, they may promote erosion. In sheltered Manitounuk Sound, previous workers estimated that a current velocity of at least 20 cm s^{-1} at 100 cm above the bed was necessary for causing the transport of the native silty sediments found between 6 and 12 m water depths (Hequette et al. 1999). This velocity was exceeded in the plume during winter 2016; however, the threshold for sediment resuspension at that particular location depends on the sediment grain size and density (Miller et al. 1977). For example, during a controlled flood in the Eastmain estuary in 1984, resuspension of the modern estuarine mud was initiated at a critical erosion velocity of ~30 cm s^{-1}. This mud consisted of very liquid (80% water) material made of silts and clays in equal proportions with a median particle size of around 2 μm (Ingram et al. 1986).

Elevated SPM was measured in La Grande near Fort George Island relative to the concentrations upstream and appears to be associated with elevated discharge at LG1 (Figure 5-13). The SPM dataset for the northeast coast collected during the CHCRP suggests that concentrations in coastal waters are extremely variable both south of La Grande River and near the river mouth with very high values on some occasions both during ice-covered months (January) and the fall (September) (Figure 5-14). During summer, wave-driven resuspension is likely the cause of high SPM during and after storms especially in shallow muddy embayments. During the ice covered period, there are few processes that cause suspended sediment aside from river inflow and tidal currents. While the shoreline stability and erosion and deposition occurring near the La Grande River mouth are currently undergoing study from a geomorphological perspective, there is also a need to look closely at these processes in relation to variation in SPM within the La Grande River plume. Elevated SPM may be attributed to bank erosion near or downstream of Fort George Island, considering that high concentrations are generally not found upstream. Bank erosion in this area is well documented (Paquet et al. 2019). Sediment-laden ice in and along the La Grande River also has been reported by Cree and research teams during fieldwork and in previous reports. In winter 2016, instruments suspended below the ice at a location near the river mouth but west of the barrier islands (CH1-2 in Figure 5-9b) became heavily coated in a mixture of sediment and frazil ice (Figure 5-15), which suggests that suspended sediments were being transported with the winter plume of the La Grande River. However, the amount of sediment erosion and transport remains unquantified.

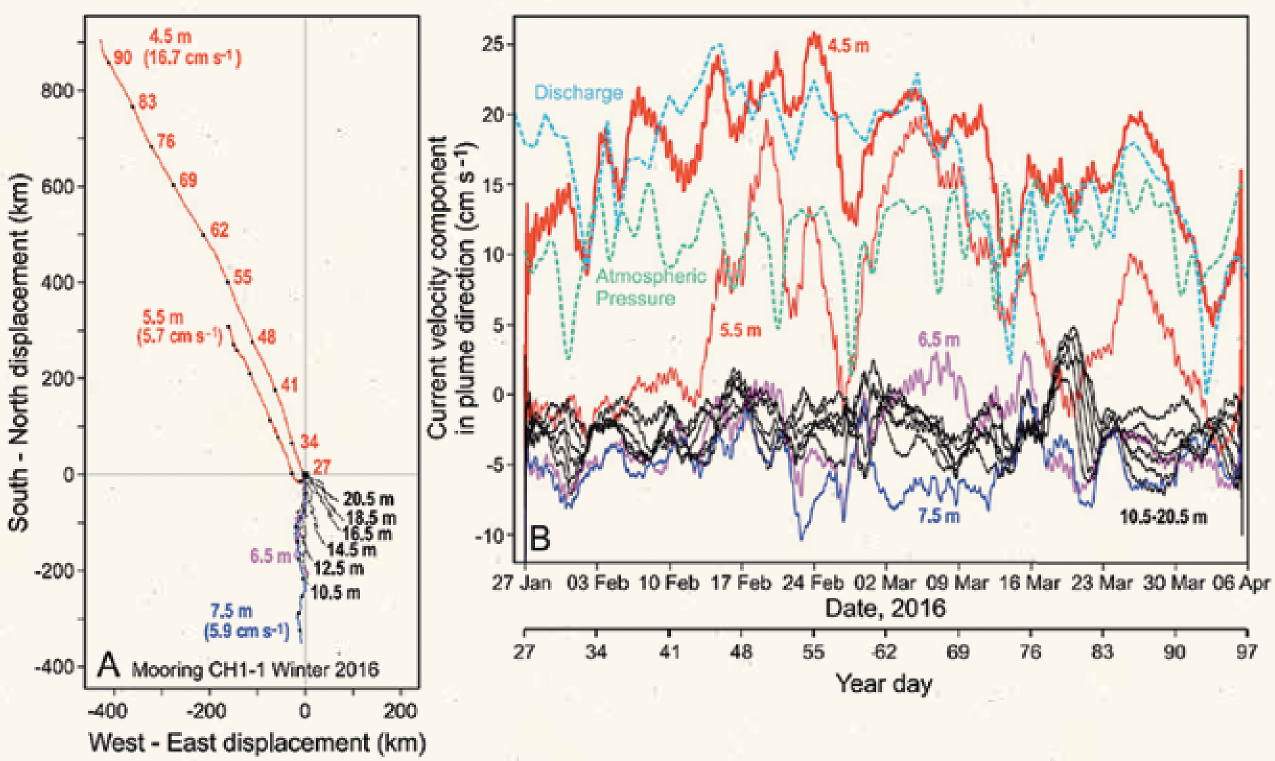


Figure 5-12. Progressive vector diagram of currents at CH1-1 during winter 2016. The length of the line shows the distance and direction a parcel of water at a particular depth (e.g., 4.5 m) would have travelled between Year Day 27 (27 Jan) and Year Day 97 (6 April). The lines are labeled with water depth and average current speed. The black-filled circles along the lines show Year Days (weekly intervals). Panel B) shows along-plume current velocities for various water depths. The blue dashed line shows normalized daily river discharge (courtesy Hydro-Québec), and the green dashed line shows atmospheric pressure as recorded at the Wemindji airport. Source: Peck et al. (2022).

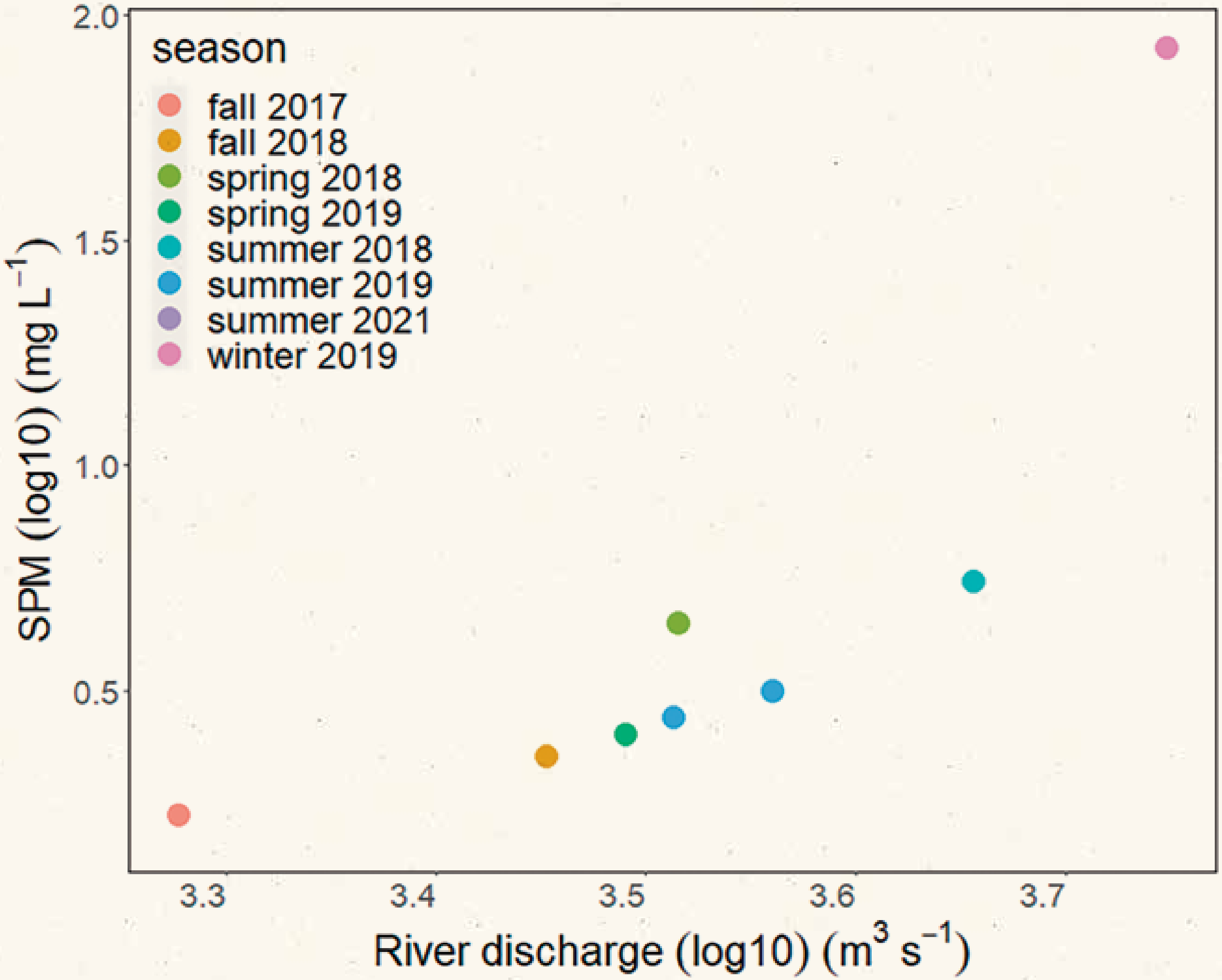


Figure 5-13. Positive relationship between river discharge and suspended particulate matter (SPM; both log10 transformed for better visualization) in La Grande River (near Fort George) measured during multiple seasons and years (dot colors). Our sampling captured an event with extremely high SPM concentrations in winter 2019 (84.5 mg L^{-1}), when river discharge was also higher.

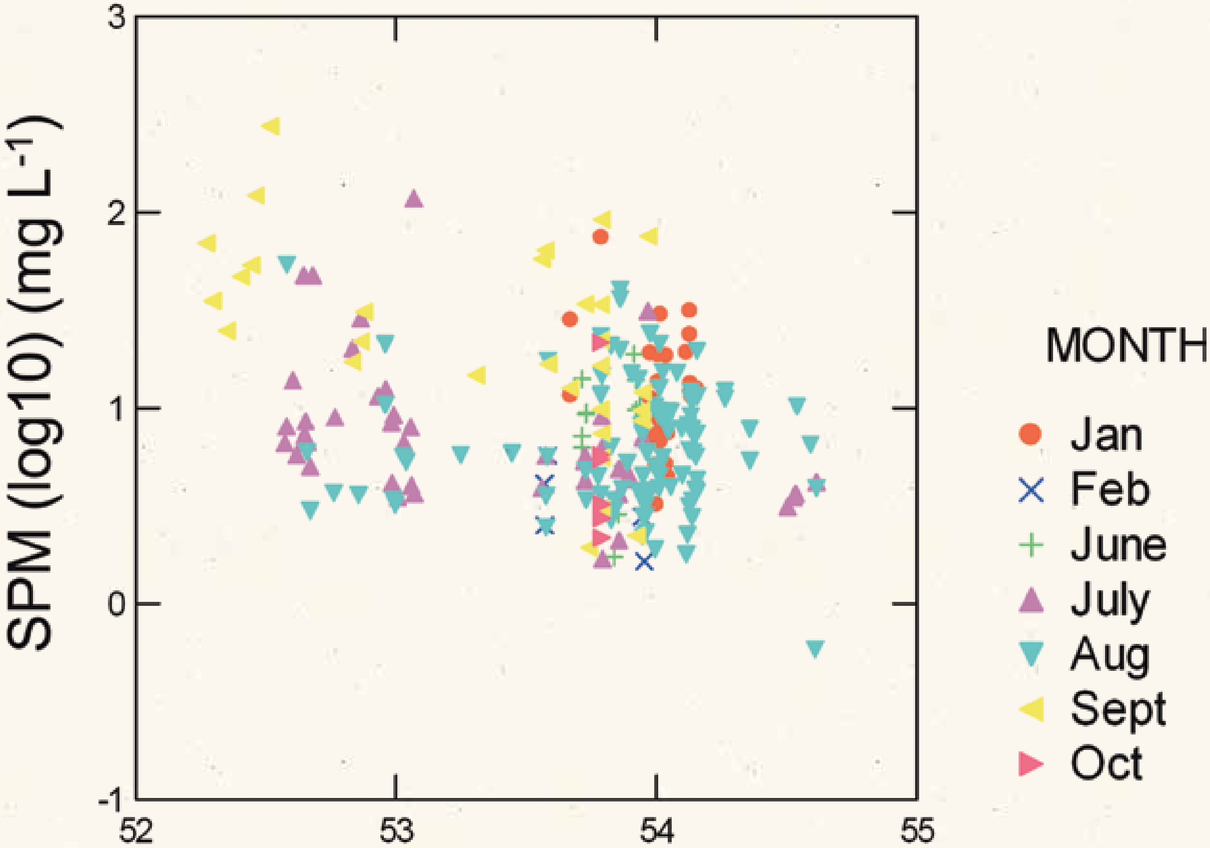


Figure 5-14. SPM concentrations measured in coastal waters, shown by latitude and by month.

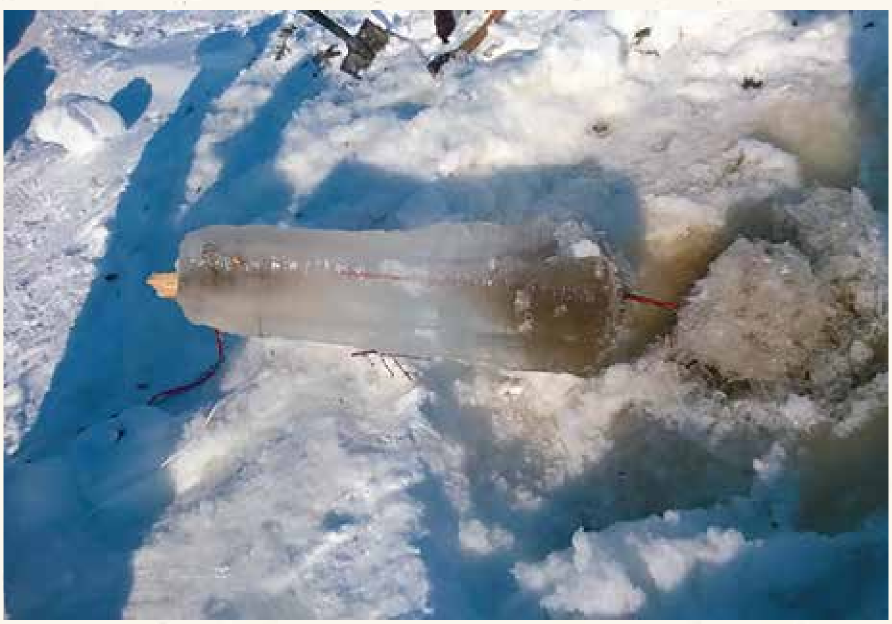


Figure 5-15. Photo of ice and sediment surrounding a set of tethered instruments, which were deployed on a mooring under the landfast ice during winter 2016 at location CH1-2 outside the river mouth.

Although the fate of fine-grained sediment transported into the bay is not known with certainty, we expect that during winter, particles would settle out under the ice in the frontal area of the plume where currents are slower and increasing salinity would promote flocculation (forming of larger particle aggregates). However, particle dynamics are influenced by changes in river inflow, tidal currents, waves, and weather events (storms). The fact that any relationship may be detected in the limited SPM vs. discharge dataset for the La Grande is surprising because it is well known that these relationships are nonlinear and dynamic with higher SPM being generated when flows are rising vs. descending. The strong density contrast between the fresh buoyant plume forming the surface layer and the underlying dense seawater means that particles could settle to the interface and then remain suspended at that layer.

A detailed study in Rupert Bay found that sediments delivered by the river settled out below the ice cover, and subsequently were returned to the water column the following spring (d'Anglejan 1980). During a controlled flood in the Eastmain River estuary in 1984, rising flows induced high current velocities (65 cm s^{-1}) that resulted in sediment resuspension and SPM values about 80 mg L^{-1} higher than ambient SPM concentrations. It was estimated that this one high-flow even transported 60,000 tons of material from the upper to the lower estuary over a four-day period, which was equivalent to two years of the river's average annual sediment discharge, or 25% of all the sediment deposited in the estuary over a four-year period.

NUTRIENTS

Nutrient concentrations measured along the eastern coast of James Bay during the CHCRP were highly seasonal, with the highest concentrations found during winter. During this season, average concentrations of nitrate+nitrite were 3.25 µmol L^{-1} (Figure 5-16), while average concentrations of silicate and phosphate were 29.0 µmol L^{-1} and 0.38 µmol L^{-1}, respectively (not shown). During the summer, nutrient concentrations were low. Nitrate+nitrite decreased to 0.30 µmol L^{-1} on average and very near zero in many areas. Average summertime concentrations of silicate and phosphate were 14.9 µmol L^{-1} and 0.18 µmol L^{-1}, respectively. These summer concentrations are in the lower range of nitrate+nitrite (1.22–2.65 µmol L^{-1}), silicate (3.82–4.88 µmol L^{-1}), and phosphate (0.69–1.05 µmol L^{-1}) measured in the greater Hudson Bay region (Ferland et al. 2011). Historical data for eastern James Bay are too limited to determine if these average concentrations have changed. In summer and spring, concentrations of nitrate+nitrite were highest near the La Grande River mouth showing that this river supplied higher concentrations compared to surrounding rivers. During the winters of 2016–2017, nitrate concentrations decreased with increasing salinity in the La Grande plume and the vast majority of the nitrate inventory was derived from river water (Guzzi 2022). Under natural conditions, with the highest flows during spring, higher nitrate concentrations would have extended over a larger area around the river mouth during spring.

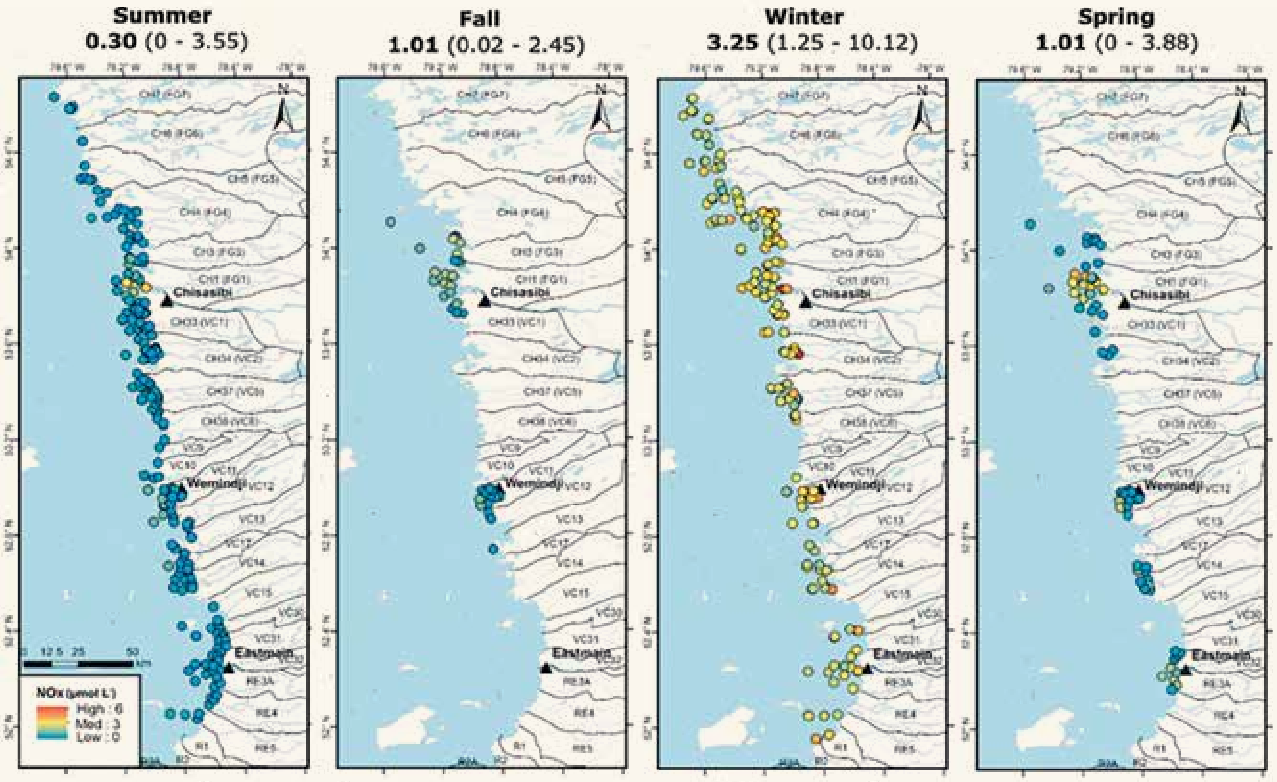


Figure 5-16. Surface nitrogen (nitrate+nitrite) concentrations (µmol L^{-1}) along the eastern James Bay coast during summer (2018, 2019, and 2021), fall (2017 and 2018), winter (2018, 201,9 and 2020), and spring (2018 and 2019). Average values (bold) and the range (in parenthesis) are indicated above the map. Source: Fink-Mercier et al. (2023).

Eastmain River estuary

Diversion of the Eastmain River in 1980 brought about increased salinity and tidal flow in the lower 10–15 km of the river, an increase in salinity near the river mouth (Lepage and Ingram 1986), and alterations in the phytoplankton community (Ingram et al. 1985). Phytoplankton (seston) increased in the lower reaches of the river and the enclosed estuary area because the lower flows lead to increased stability of the water column. Outside the enclosed estuary, the river plume extending along the coast was reduced by about 50% (Figure 5-17; (Messier et al. 1989), with much higher salinities and weakened stratification occurring within 6–7 km of the Eastmain River mouth (Ingram et al. 1985; Lepage and Ingram 1986). In this coastal area, the lower flows and lower nutrient fluxes after diversion (discussed above) presumably have led to lower phytoplankton production.

Sedimentation in the estuary also changed after the river diversion (d'Anglejan 1982; d'Anglejan and Basmadjian 1987). Prior to diversion, the seabed in the estuary comprised Tyrrell Sea clays with no modern sediment deposits (d'Anglejan 1982). Approximately 1 x 10^6 tons yr^{-1} of suspended sediment was exported to the bay (d'Anglejan 1982; Ingram et al. 1986). After the diversion, the export of suspended sediments from the Eastmain River to James Bay decreased to about 3 x 10^4 tons yr^{-}

[1]. However, during the 1980–1986 period, approximately 80% of the bottom across the estuary accumulated a 2–5 cm thick layer of loose (unconsolidated) fine mud with a median grain size of 2 µm or 0.002 mm; (Messier et al. 1986). The deposits formed a thin layer over the compact, massive Tyrrell clays. During wind events, the lower reaches of the river tend to be more turbid than James Bay in part due to the resuspension of the loose bottom sediments.

Data collection during the CHCRP showed that water quality in the Eastmain River was changed by the low flows after diversion. Specifically, the Eastmain River shows *increases* in the *concentrations* of nitrogen, phosphorous, and organic carbon (Table 5-8), but *decreases* in the *fluxes* of nutrients and carbon from the river to the bay because of the large reduction in discharge. Dissolved organic carbon, total nitrogen, and total phosphorous exports from the Eastmain-Opinaca River to the bay have all decreased by at least five-fold (de Melo et al. 2022).

The residual discharge of the Eastmain River also is characterized by higher concentrations of CDOM than before the development (Messier et al. 1986). The absorption coefficient at 440 nm, a proxy for water colour due to presence of CDOM, is presently, on average, about 10.3 m-1 in the Eastmain River, which approaches the values in small nearby undeveloped rivers, the Jolicoeur (12.4 m-1) and the Conn (14.5 m-1) (de Melo et al. 2022).

As noted above for La Grande River, the recent water quality measurements for the Eastmain River do not address occasional events which may lead to pulsed releases of materials. These events may include forest fires, snowmelt in spring, and intense rain events (de Melo et al. 2022). The high-frequency sampling necessary to detect these kinds of variations in water quality was not achieved during the CHCRP. However, a series of satellite images illustrates how intense forest fires caused turbid water in the Eastmain River in 2013 (Figure 5-18).

Table 5-8. Comparison of water conditions in Eastmain River (downstream to the confluence with Opinaca river) before, during and after impoundment, and current estimates. Source: Table S6 in de Melo et al. (2022)

VARIABLE	BEFORE	BEFORE	DURING	AFTER	CURRENT*
	(1978)	*(1979)*	*(1980)*	*(1981–1998)*	*(2018–2019)*
Discharge ($m^3 s^{-1}$)	908	-	-	-	63
O2 saturation (%)	100	99	97	88	97
pH	6.3	6.2	6.7	6.8 ± 0.1	6.1
Conductivity (µS cm-1)	13	13	22	31.7 ± 3.5	19
Total nitrogen (mg L^{-1})	0.17	0.12	0.24	0.32 ± 0.05	0.27
Total phosphorus (µg L^{-1})	29	7	23	38 ± 4.5	46
Total inorganic carbon (mg L^{-1})	1.0	0.4	1.5	1.9 ± 0.3	1.5
Total organic carbon (mg L^{-1})	8.0	9.3	10.2	12.9 ±1.4	13.0

*Current: downstream dam, from HQ report – station Eastmain-Opinaca (EA300); After: 1980 to 1984, 1988, 1992, 1998.

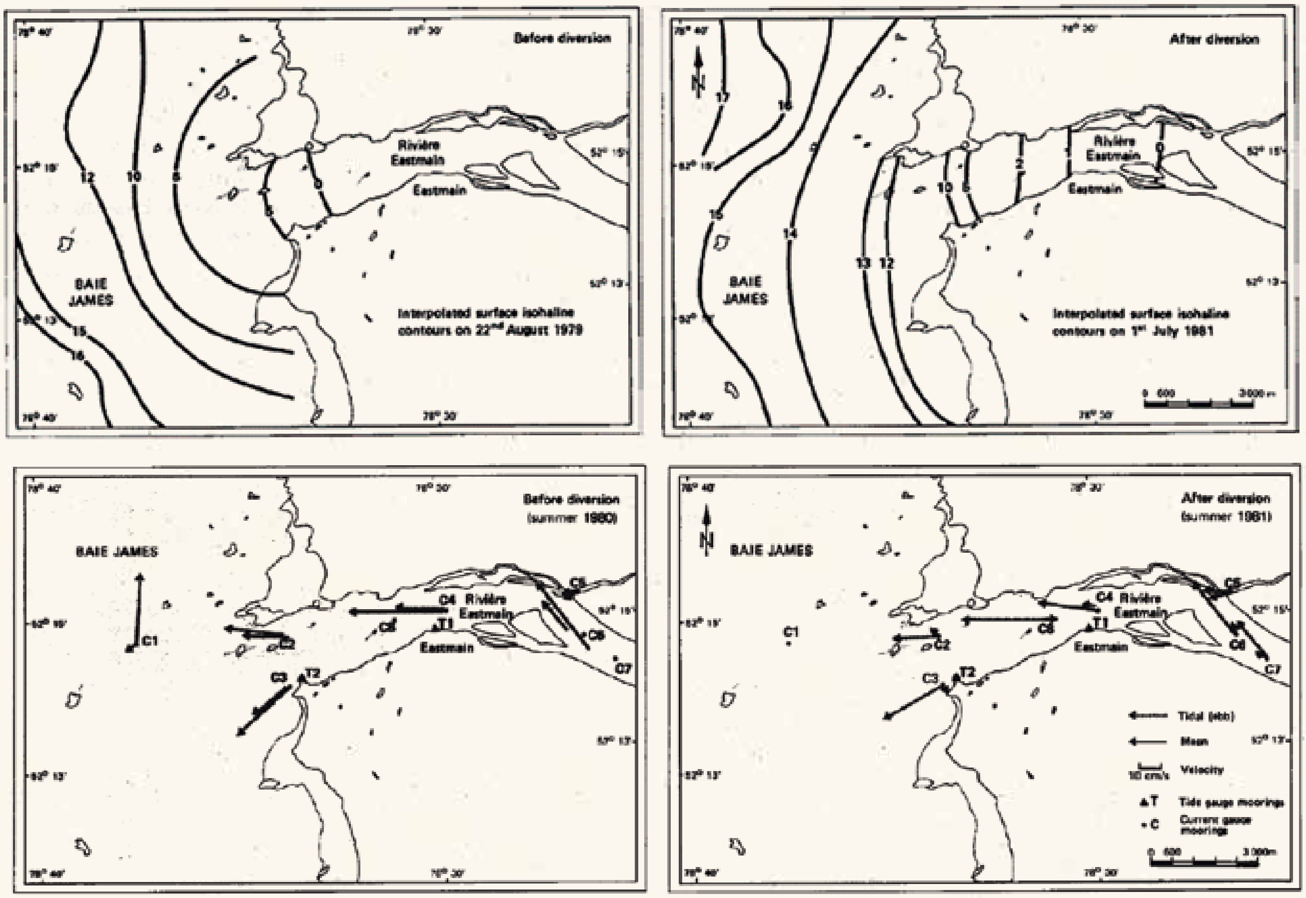


Figure 5-17. Surface salinity contours (upper panel) and mean and tidal currents (lower panel) during high tide before and after diversion of the Eastmain River. Source: Messier et al. (1986).

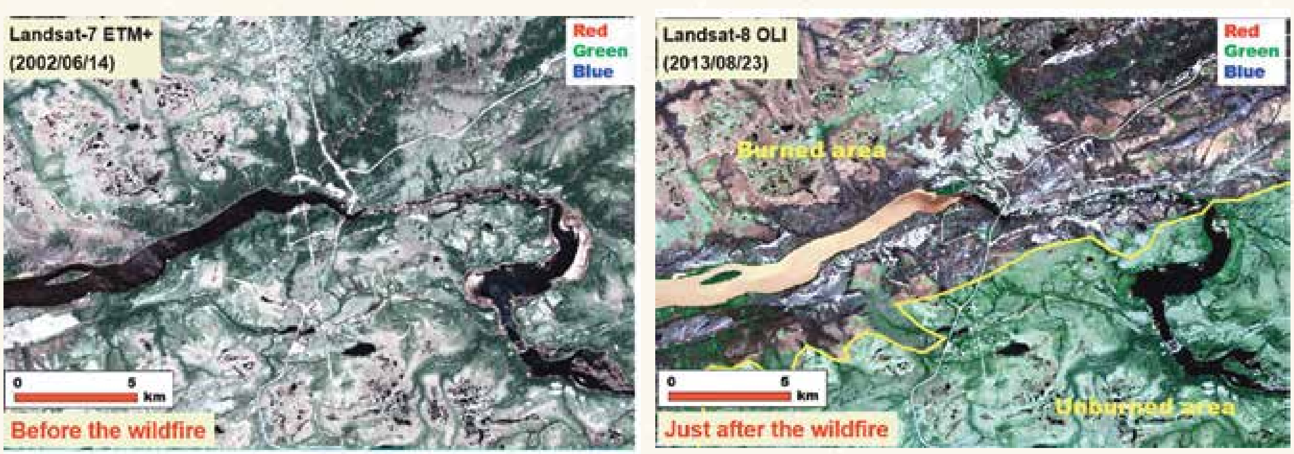


Figure 5-18. Satellite images showing turbid waters in the Eastmain River after the 2013 fire. Source: Leblon et al. (2022).

ICE BREAKUP AND EXTREME CLIMATE EVENTS

The greater Hudson Bay marine region appears sensitive to climate warming with rising air temperatures being linked to significant observed changes in the sea ice including later freeze-up and earlier breakup (Gagnon and Gough 2005a; Gagnon and Gough 2005b; Gough and Wolfe 2001; Kowal et al. 2017). Specific to James Bay are trends of earlier fast ice breakup dates (Galbraith and Larouche 2011; Taha et al. 2019) and warming of sea surface temperatures (Galbraith and Larouche 2011). Several climate change effects on the coastal waters of Eeyou Istchee may be seen in the late 1990s, which add to the regional picture of change in ice breakup dates in James Bay described in previous works (Galbraith and Larouche 2011; Gupta et al. 2022; Taha et al. 2019). There were some very anomalous conditions in winter and spring 1998, which appears to have been the beginning of a regime shift because, since that time, similar exceptional conditions have occurred repeatedly. During the winter months of 1998, a major El Niño affected central Canada bringing warm temperatures and extreme weather events. In southern Quebec, a massive ice storm (and one of the largest natural disasters in Canadian history) occurred between 4 and 10 January 1998.

Following the relatively warm winter was a warm spring, and the sea ice broke up exceptionally early both in northeast James Bay and southern Hudson Bay. In northeast James Bay, the ice breakup occurred on around May 15, 1998, nearly a month earlier than usual (Figure 5-19). Ice concentrations throughout James Bay decreased rapidly during the month of May leaving lots of open water area by the first week of June (Figure 5-20). With low ice concentrations, waves were able to build up when a storm developed on the first day of June. The early open water and this early spring storm made it possible for 2 m waves to develop in northeast James Bay for a brief period in early June 1998 (Figure 5-21). Landsat satellite imagery from 1–2 June 1998, shows fine-grained sediments being transported northward from the river mouth following the storm (Figure 5-22).

A second consequence of the early ice breakup in May 1998 was that surface water temperatures reached unprecedented warm temperatures in June of that year (Figure 5-23). Throughout the 1980s and early 1990s, the average water temperature in northeast James Bay in June was generally between 0°C and -1.5°C (near the freezing point for the water) because there was such a large concentration of ice. In June 1998, with the sun warming the waters after the ice retreated, the coastal water temperature averaged more than +1.5°C. The warm water temperature in June 1998 appears to have marked the start of a new regime in which similar warm June water temperatures recur every few years.

BOTTOM SEDIMENT PROPERTIES AND HARDENING

Grain size analysis of surface sediments along the eastern James Bay coast analyzed as part of the CHCRP showed that the sediments associated with eelgrass beds varied from clayey mud to sand; however, most samples contained some fine-grained material (mud). Slightly gravelly sandy mud, slightly gravelly muddy sand, and muddy sandy gravel were found most commonly (Figure 5-24). Coarse silt (31–

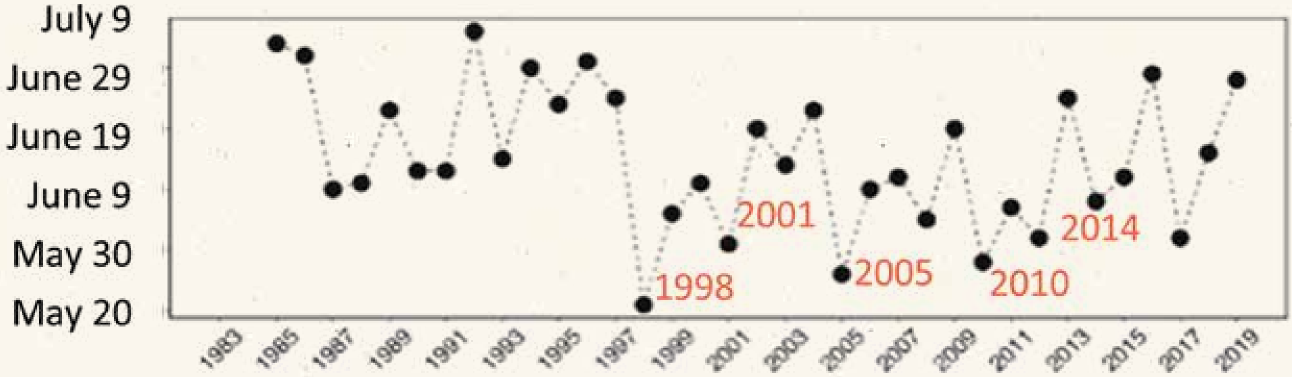


Figure 5-19. Date of sea-ice breakup in northeast James Bay. Source: Leblanc et al. (2022).

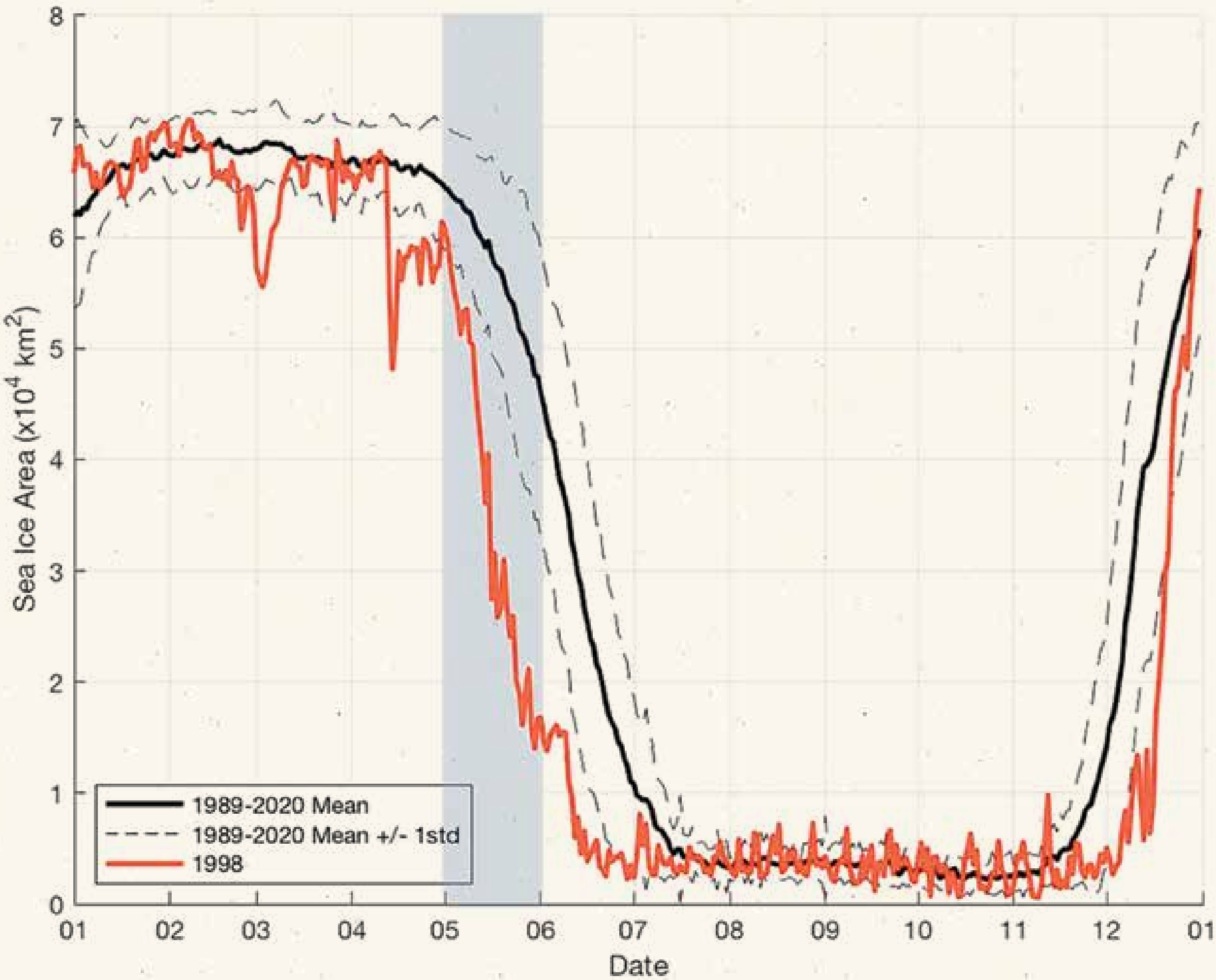


Figure 5-20. James Bay sea-ice area in 1998 compared to long-term average, derived from satellite data. Courtesy: D. Babb.

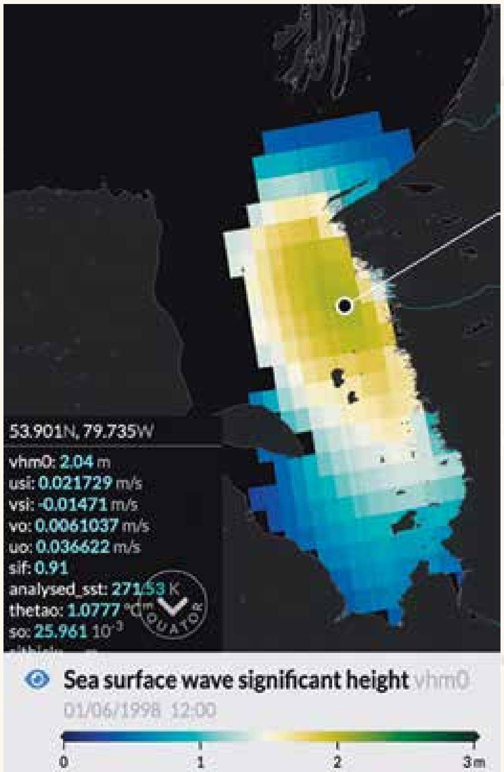


Figure 5-21. Waves in northeast James Bay, simulated by Wavery for the storm event on 1–2 June 1998. Courtesy: J. Ehn.

Figure 5-22. Landsat satellite image of northward transport of fine sediments in the plume of the La Grande River following a storm-driven erosion event (1–2 June 1998). Courtesy: J. Ehn.

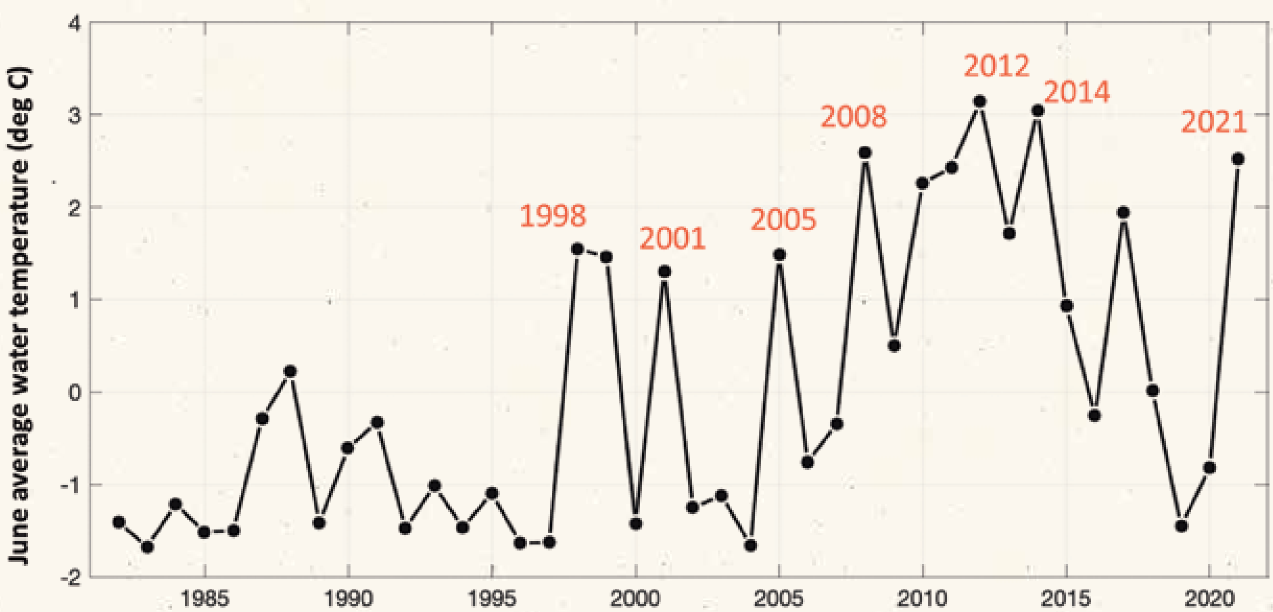


FIgure 5-23. Sea surface temperatures in northeast James Bay in June. Source: Leblanc et al. (2022).

63 μm) was the dominant grain size class, while mean grain size varied between 1.67 μm (clay) and 59.73 mm (very coarse gravel). The mean percentage of mud across all samples was 52% (Caron et al. In prep).

Sediment cores up to 58 cm in length were collected across six Chisasibi traplines between 2017 and 2021 (Figure 5-25). To assess whether erosion had occurred, the sediment cores were analyzed for cesium (137Cs), which is an artificial radionuclide tracer expected to BE present in coastal sediments deposited after ~1954, when this material was first introduced into the environment by atmospheric nuclear bomb testing. Downcore profiles in the sediment cores show that 137Cs is present in the upper 5–40 cm in many cores, as expected for sites of modern sediment accumulation (Figure 5-26). However, other sediments lack 137Cs near the surface, and a few lack 137Cs over their entire length, which may be explained by the intensive erosion of modern sediments. Considering these results and porosity profiles that indicated unusual compacted material near the surfaces of several cores, we conclude that in some cases, soft modern sediments have been eroded, exposing what are most likely ancient Tyrrell Sea clays (cf., discussion in (d'Anglejan 1982; d'Anglejan and Basmadjian 1987). These eroded areas are likely to be perceived as harder sediment.

WATER COLOUR AND CLARITY

Shallow waters along the coast of Eeyou Istchee are experiencing varying amounts of suspended sediments and coloured dissolved organic matter (CDOM) that can limit light from reaching the bottom of the water column. While suspended sediment causes the water to become more turbid and murkier, the effect of CDOM is the yellowing/browning (or darkening) of the water.

INCREASED WATER COLOUR (LARGE-SCALE)

CHCRP results show that the color of the coastal water has changed at the scale of the whole of eastern James Bay and over periods of decades (Figure 5-27). There has been a large-scale increase in remotely sensed CDOM (*ag*440 nm) concentrations in the region since 1998, and particularly since 2010 and in the month of June. Satellite images recorded over the last decades show an overall increase in CDOM, darkening the waters in the region. We found that the interannual variability in CDOM is linked with interannual variability in river discharge (Figure 5-28), not just in the territory but also in southwest James Bay. For example, in 2012–2013, an abrupt increase in river discharge in southwest James Bay corresponds to an abrupt increase in CDOM in eastern James Bay up to southern Chisasibi traplines. The influence of the fire that occurred in the Eastmain and Rupert River watersheds in summer 2013 on CDOM cannot be separated from the high discharge. Future work is needed to suggest an underlying mechanism. We can nonetheless assume these bay-wide effects are linked to more large-scale phenomena associated with hemispheric climate variability.

Figure 5-24. Ternary diagram showing the texture of the surface sediment along the eastern James Bay coast. Green filled dots identify the samples where eelgrass was present during the sampling while black dots identify samples without eelgrass (or no information available). Source: Neumeier et al. (in prep.).

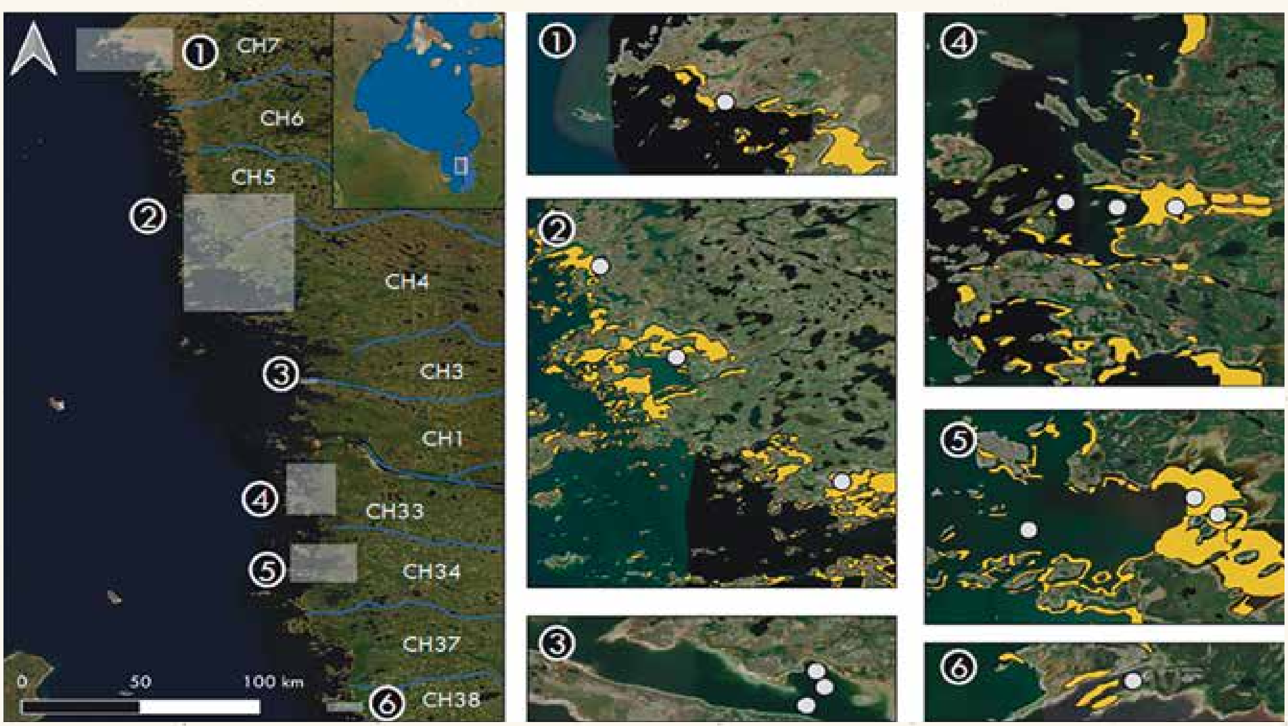


Figure 5-25. Map showing locations of sediment core collection from 2017 to 2021. Yellow polygons indicate mapped eelgrass extent (Hydro-Québec 1996).

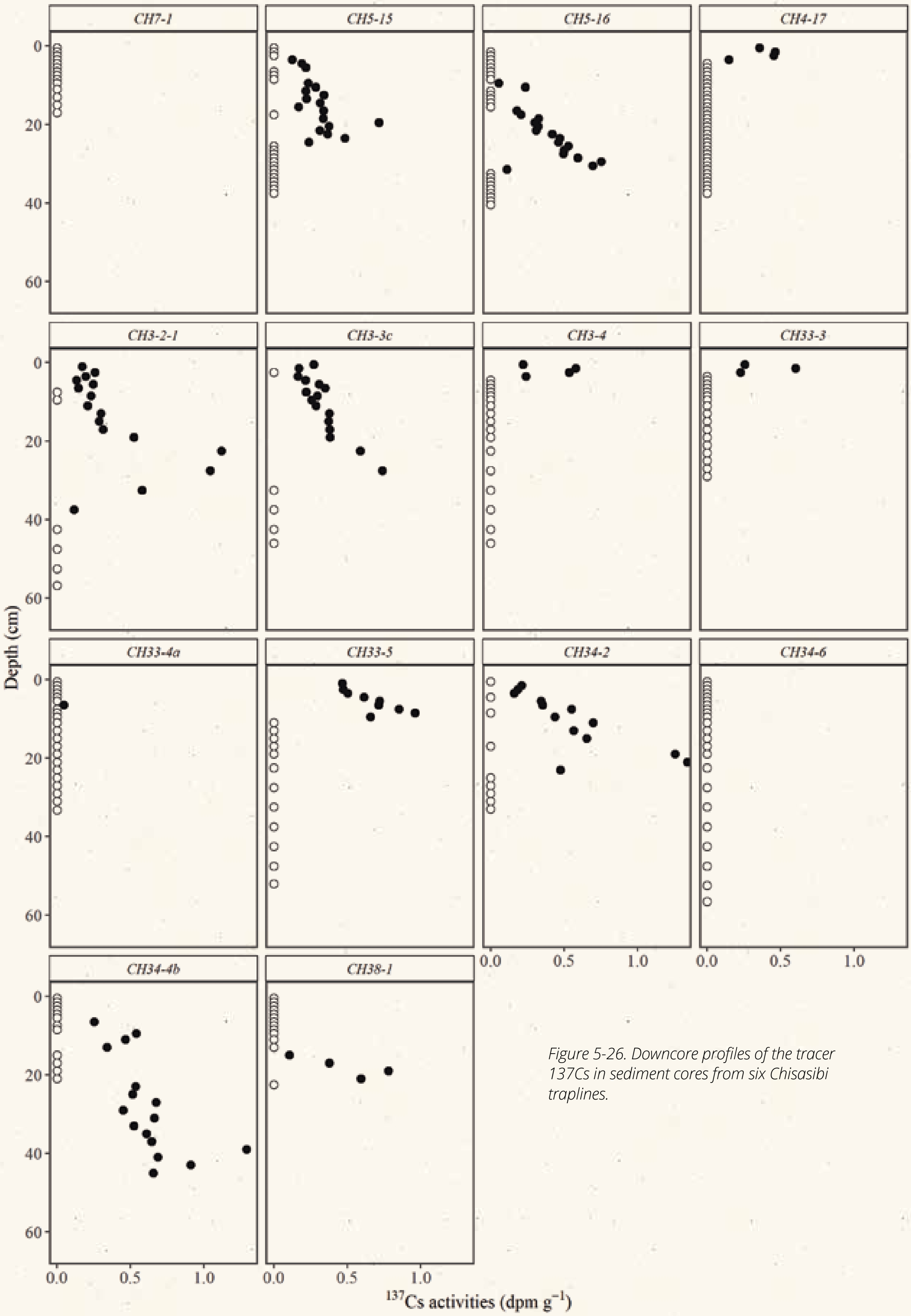


Figure 5-26. Downcore profiles of the tracer 137Cs in sediment cores from six Chisasibi traplines.

REDUCED WATER CLARITY DUE TO SEDIMENT RESUSPENSION

Murky (unclear) waters in the form of sediment plumes are visible from space using satellites in offshore waters and locally highly turbid areas near the coast (Figure 5-29). The high concentrations of suspended sediments can vary from bay to bay and throughout the season. In offshore waters, there are no clear time trends detectable from satellite data. However, changes in suspended sediment in shallow bays when it is windy are likely related to the local dynamics of losing eelgrass along the coast, with possibly some impact also of an increased ice-free season. High-resolution satellite image analysis and/or in situ observations are required to assess trends in those areas. CHCRP researchers are in the process of examining relationships between turbidity and wind exposure or "fetch", which is the distance over which wind can travel across open water and thus dependent on coastline configuration and winds. Qualitatively, when we compare historical and recent Secchi depth observations (Figure 5-30), poor water clarity appears to be more prevalent along the coast during the recent period. Secchi depth is a measure of the transparency of seawater obtained by lowering a white and black 'Secchi disk' into the water until it can no longer be observed (Morris 1992).

Conclusions about environmental factors affecting eelgrass

EELGRASS DECLINES

Based on all the available evidence, we conclude that eelgrass declined during the 1980s and early 1990s in some Chisasibi traplines due to the development of the La Grande River (LG1, LG2, etc). Coastal Cree land users reported seeing changes near Chisasibi in the late 1980s. The scientific evidence also collectively suggests that the condition of some of the monitored eelgrass beds near Chisasibi was decreasing between 1982 and 1995. Some eelgrass beds were shrinking, some were becoming discontinuous or fragmented, some were losing biomass in shallow areas and others in deeper areas, some areas were experiencing root rot, and some places were losing areas of high eelgrass cover. Environmental factors that may have contributed to the eelgrass declines near Chisasibi include disruptions of La Grande River flow, freshening of coastal waters, and releases of soil and sediment from reservoir flooding and riverbank erosion. During this early period (1980s–1990s), eelgrass was thriving at other locations along the coast except for an area immediately south of the Eastmain River, where Cree noted some decrease in eelgrass following the Eastmain River diversion.

Between 1996 and 1999, the condition of some eelgrass beds near Chisasibi worsened abruptly. Near Chisasibi, several environmental changes that may have affected eelgrass followed one another in quick succession between 1994 and 1998 (the LG1 development, an increase in La Grande River winter flows to 5,000 $m^3 s^{-1}$, a climate-induced minimum in natural river discharge, an exceptionally early sea-ice breakup, and anomalously warm June water temperatures). The relative importance of the

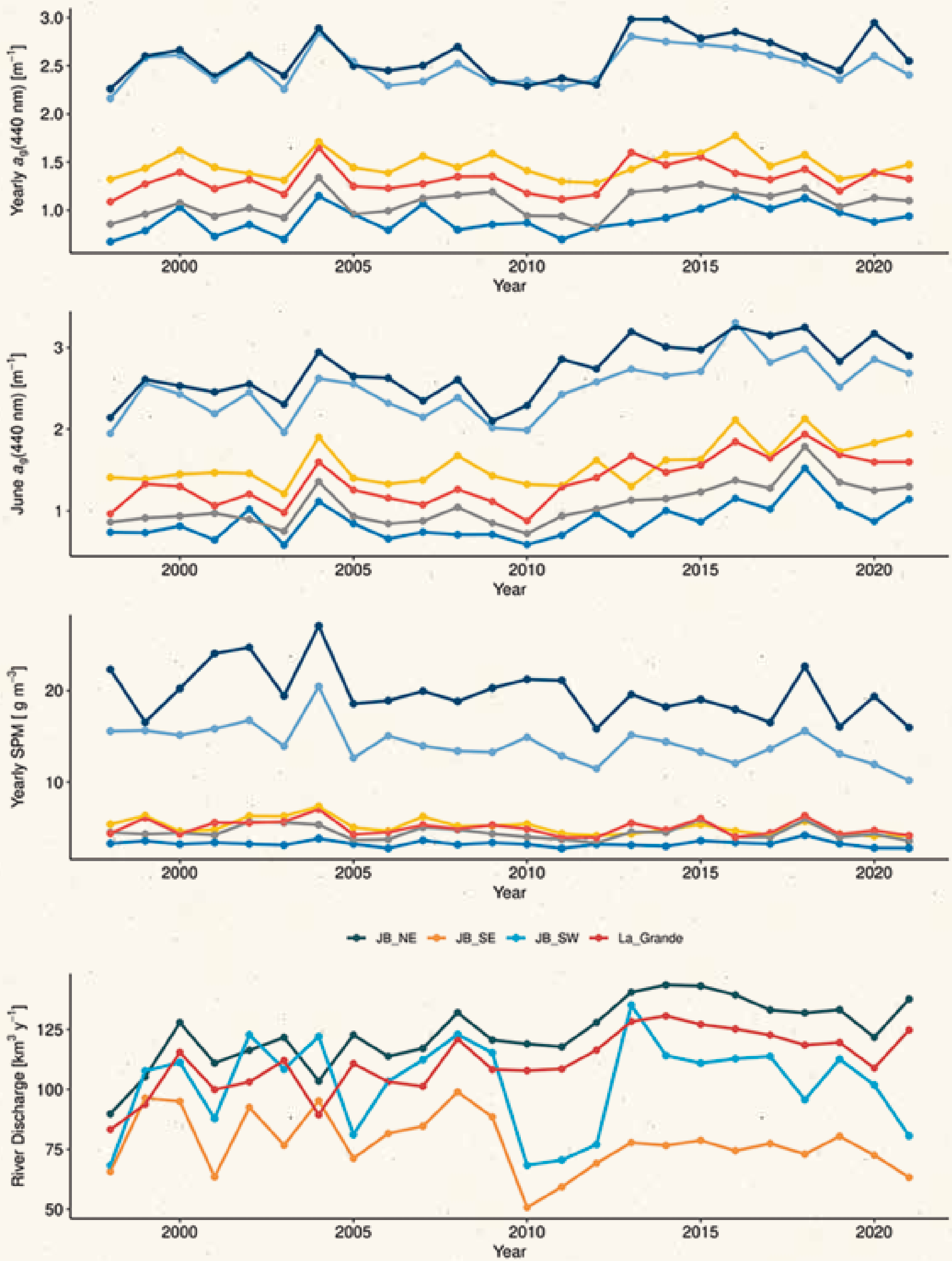


Figure 5-27. Time series of the variation in ag (440 nm) (top), CSPM (middle), and annual river discharge (bottom) in northeastern JB (Waskaganish and Eastmain), southeastern JB (Wemindji and Chisasibi), and La Grande area (traplines CH1, CH33 and CH3 or La Grande river only in the case of discharge) from 1998 to 2021. ag(440 nm) CSPM was computed using MODIS-Aqua and SeaWiFS MLAC data. Discharge data was computed using La Grande gauged station (data provided by Hydro-Québec through the River Team of the CHCRP) and ERA5 dataset (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era) for the other rivers.

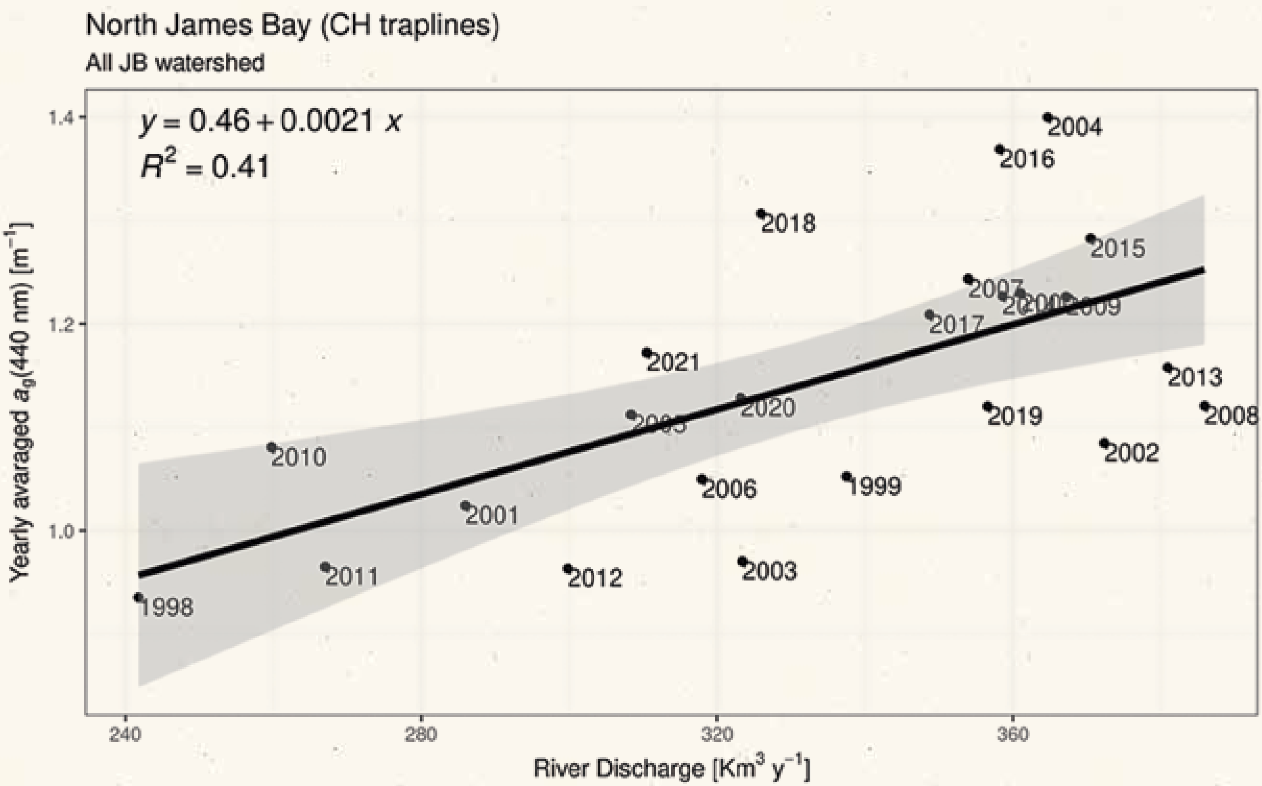


Figure 5-28. Relationships between averaged CDOM from May to October in northeastern James Bay (CH traplines) and cumulative discharge in the whole of James Bay.

various factors cannot be determined in the absence of annual eelgrass biomass monitoring data and measurements of the properties of the coastal waters (cf., Leblanc et al. 2022). However, eelgrass cover also decreased sharply at eelgrass beds near Wemindji and Eastmain between 1996 and 1999. Thus, the late 1990s onset of extreme and recurring climate events in the coastal marine environment of eastern James Bay, including very early ice breakup and strong warming of coastal waters in spring, is believed to have *accelerated* the eelgrass decline that had begun already in Chisasibi and *extended* the decline along the coast. An analysis of historical monitoring data (1982–2009) and new data from 2019 revealed that both high discharge from the La Grande River *and* warmer spring water temperatures negatively affected eelgrass biomass at some eelgrass beds near Chisasibi (Leblanc et al. 2022). The eelgrass declines in the late 1990s were massive and included decreases in the size (height), shoot density and biomass of the eelgrass, *and* decreases in the area covered by eelgrass beds. Large beds and meadows became very scarce or disappeared entirely. Beds became thin and sparse; eelgrass shoots got shorter averaging less than 1 m in height and rarely if ever reaching the ~2–2.5 m documented during the 1970s and '80s. Eelgrass beds came to be located primarily in shallow water depths (<1 m). Only in a few places did they still lie along the surface at low tide, calming the waters.

SIGNIFICANCE OF ALTERED ICE REGIME AND WARMING

The ice regime is significant for eelgrass growth in eastern James Bay, and we suspect that the shift to very early ice breakup in some years, which started in 1998, has major consequences on eelgrass, including some negative effects. It may seem counter-intuitive that early ice off would be detrimental to eelgrass growth (cf., Krause-Jensen et al. 2020; Olesen et al. 2015). When snow and thick sea ice persist into late June, preventing sunlight from reaching the underlying water column, it delays the start of the growing season (Lalumière et al. 1994; Leblanc et al. 2022). The negative effects of early ice off may come about because of increased nearshore seabed erosion by ice scouring and near-bottom currents (cf., Hequette et al. 1999). The resuspended sediments would generate turbid waters, reducing light availability underwater and holding back early-season eelgrass growth. In Greenland and Alaska, where eelgrass has been studied in winter, it was found that eelgrass may remain alive throughout winter under the ice (McRoy 1969; Olesen et al. 2015). The CHCRP observations of rhizomes collected in summer show that eelgrass in eastern James Bay *also* remains alive and slowly grows under the ice. Furthermore,

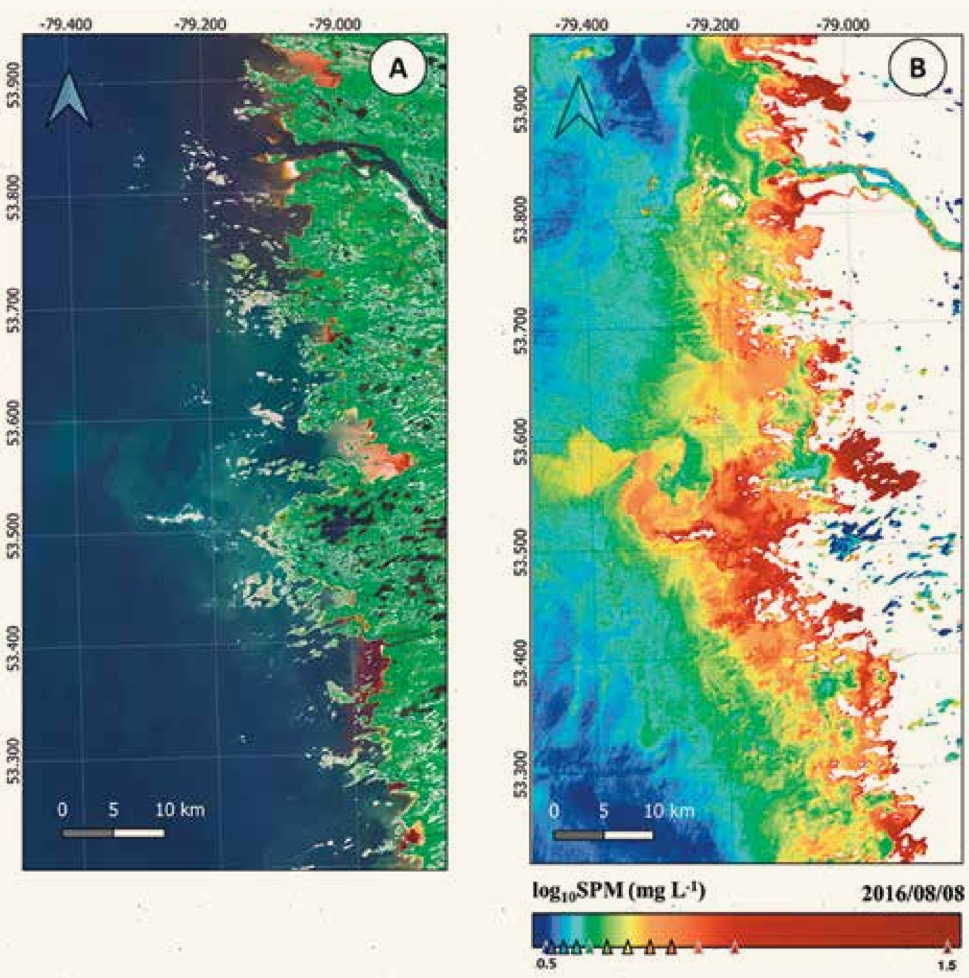


Figure 5-29. True color composite and SPM concentration as observed by MSI on 8 August, 2016. Courtesy: S. Bélanger.

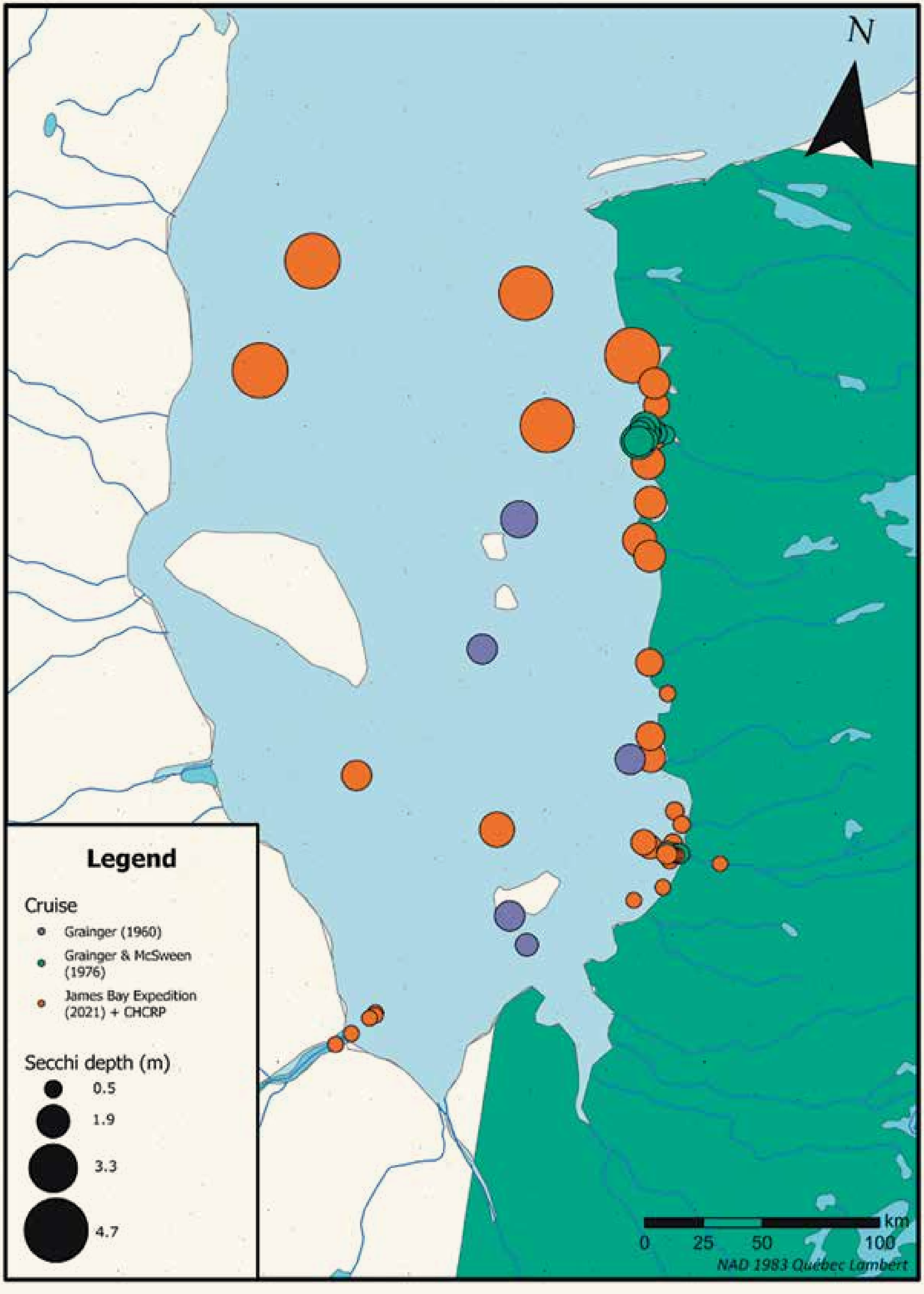


Figure 5-30. Secchi depths in eastern James Bay in the 1960s and recent years. Courtesy: M. Gosselin.

how well they grow during winter is a good predictor of *how well* they grow in summer. Eelgrass growth rates measured in eastern James Bay in late June–early July 2021 of >3% per day were high compared to typical eelgrass growth rates of 1%–2% per day in both Atlantic and Pacific subspecies (cf., Figure 5-31) (Ruesink et al. 2018). However, the number of days with high light availability (necessary for high growth rates to be sustained) was severely limited over the growing season. All the photosynthetic active radiation (PAR) records collected from the coastal habitat to date show that light availability underwater becomes poor for extended periods in late July and/or August. The reasons are not completely understood but one factor may be the large-scale browning of the bay's waters and a second likely factor is storm-driven resuspension of sediments that are no longer being stabilized by dense eelgrass beds. Considering that eelgrass shoots do not reach the great (2 m) lengths in August that they once did, they generally *do not* lie along the surface of the water during low tide, getting maximum light exposure. This leaves them vulnerable to the negative effects of poor water clarity (poor growth, no ability to build up energy reserves). The eelgrass beds generally occur in shallower water (0.5–1.5 m) than they did before when they extended between depths of 0.5–4 m or so (Lalumière et al. 1994). There is likely an upper limit to where dense perennial eelgrass beds can occur because of too frequent disturbance by ice and waves. If ice grows thick enough to freeze onto the seabed, then it would disturb the sediments and eelgrass roots repeatedly as it moves up and down with each tidal cycle. The landfast ice averages about 1 m by the end of winter and the tidal range is typically 1–1.5 m (Gupta et al. 2022; Peck et al. 2022). The lower depth limit of eelgrass growth depends on water clarity and eelgrass length, which are interdependent. We speculate that early ice off that leads to poorer underwater light availability might set off cascading effects wherein shoots grow less effectively in June, remain too short to reach the water's surface at low tide in July and August so get no opportunity to experience maximum light conditions, and ultimately store fewer carbon reserves to help them survive the low light conditions that occur in fall and winter. During the growing season, it is critical that eelgrass shoots not only grow taller but also store energy in the roots (rhizomes), so the eelgrass can live on the stored energy (carbohydrate reserves) until the ice breaks up the following spring.

A second possible way that early ice off may negatively affect eelgrass is indirectly by causing unusual extreme warming of the coastal waters and so-called 'marine heat waves'. Benthic ecosystems tend to respond to marine heat waves at the community level, with different species responding differently, some benefitting while others are negatively affected (Pansch et al. 2018). Warming of coastal waters in late winter–early spring recently was discovered to be very harmful to eelgrass, causing it to burst into flower prematurely, using up energy reserves and causing mortality later on in the growing season (Sawall et al. 2021).

FACTORS HOLDING BACK EELGRASS RECOVERY

Several factors are holding back eelgrass recovery. First, with the massive declines in eelgrass, especially the loss of large dense eelgrass beds and meadows, the positive effects of eelgrass on the surrounding environment have been lost (Figure 5-32). Waters are not being calmed by the large eelgrass beds and waves will stir up sediments off the bottom more often, which makes the waters turbid. With the ice disappearing weeks earlier in the spring, there would be a longer period during which waves can form and cause the turbid waters. This includes the springtime, when eelgrass shoots are small and do not reach the water's surface to get full exposure to sunlight, even at low tide.

Eelgrass cannot grow, spread, or overwinter as successfully when turbid waters cause there to be insufficient light during the growing season. Nearshore waters that *do not have eelgrass* naturally are prone to being turbid whenever there are waves because the bottom is muddy and fine sediments are constantly being brought up by isostatic rebound into the water depths affected by waves. With some of the highest rates of isostatic rebound in the world (Pendea et al. 2010; Sella et al. 2007), sediment resuspension likely prevails in the shallow muddy embayments of eastern James Bay *except* where big dense eelgrass beds counteract the waves. Isostatic rebound and ice scouring have been considered important processes affecting eelgrass condition and distribution (Lalumière et al. 1991). CHCRP researchers do not believe that isostatic rebound can be blamed for *causing* the general declines in eelgrass because there should be no *net effect* of rebound and shallowing on eelgrass habitat: all else being equal, uplift *creates* new potential eelgrass habitat at the same rate that it takes it away. The rate of change in water depth is slow and gradual and healthy eelgrass beds are expected to shift into deeper, adjacent areas as other areas become too shallow. Isolated eelgrass beds growing in shallow places might individually disappear due to isostatic rebound but new beds should appear as other areas become less deep and eelgrass seedlings take root and thrive. Isostatic rebound also is not a viable explanation for eelgrass beds that are shrinking from all sides, nor for beds that are becoming thin, discontinuous, or fragmented. However, isostatic rebound likely makes eelgrass recovery after losses more difficult by exacerbating the sediment resuspension-turbid water problem (continually supplying fine-grained sediments into water depths affected by waves). A longer ice-free season means a longer period each year when the waters will be affected by waves. Early breakup means that sediment resuspension may begin earlier each spring/summer before eelgrass has had a chance to grow long and approach the surface of the water.

In addition to the lack of light due to sediment resuspension where eelgrass was lost, there has been an overall browning of the bay's waters, especially in June, that further reduces the light availability. Water colour and suspended sediment can interact in the water to scatter and absorb the light and lead to low availability and poor eelgrass growth.

Finally, in the La Grande plume, high flows continue to hinder eelgrass recovery. It is well known that low salinity prevents or negatively affects eelgrass growth. The area influenced by low salinity (below 5–10) during winter has been delineated. Less well known is whether episodes of high turbidity occur during the growing season when sediments that were eroded during periods of high flow get resuspended by wind-driven waves and what area may be affected if this kind of sediment transport occurs.

We *do not* consider altered nutrient fluxes from the watershed to be a significant factor holding back eelgrass recovery at the present time. The significance of the annual and seasonal shifts in nutrient delivery must be assessed in terms of the nutrient demands of eelgrass and other plants and whether these demands are met without the nutrients delivered by the rivers. Nutrient distributions in the Eeyou coastal waters were studied as part of the CHCRP. These data showed that nitrogen is an element *potentially limiting* plant growth in the Eeyou coastal waters, which is also the case throughout Hudson Bay (Ferland et al. 2011; Gosselin et al. 1990; Sibert et al. 2011; Tremblay et al. 2019). But eelgrass can access nitrogen from the sediments. Phosphorus in the form of phosphate was generally in good supply relative to the needs of eelgrass and phytoplankton (algae). The only exception was during winter months in the very low-salinity (<5), core plume area near the La Grande river mouth, where phosphorus concentrations were near zero (Guzzi et al. 2023). With nitrogen *potentially limiting* plant growth in the Eeyou coastal waters, the increased *annual* nitrogen fluxes from the river would tend to promote plant productivity in northeast James Bay except for the fact that much of the flux occurs during the winter

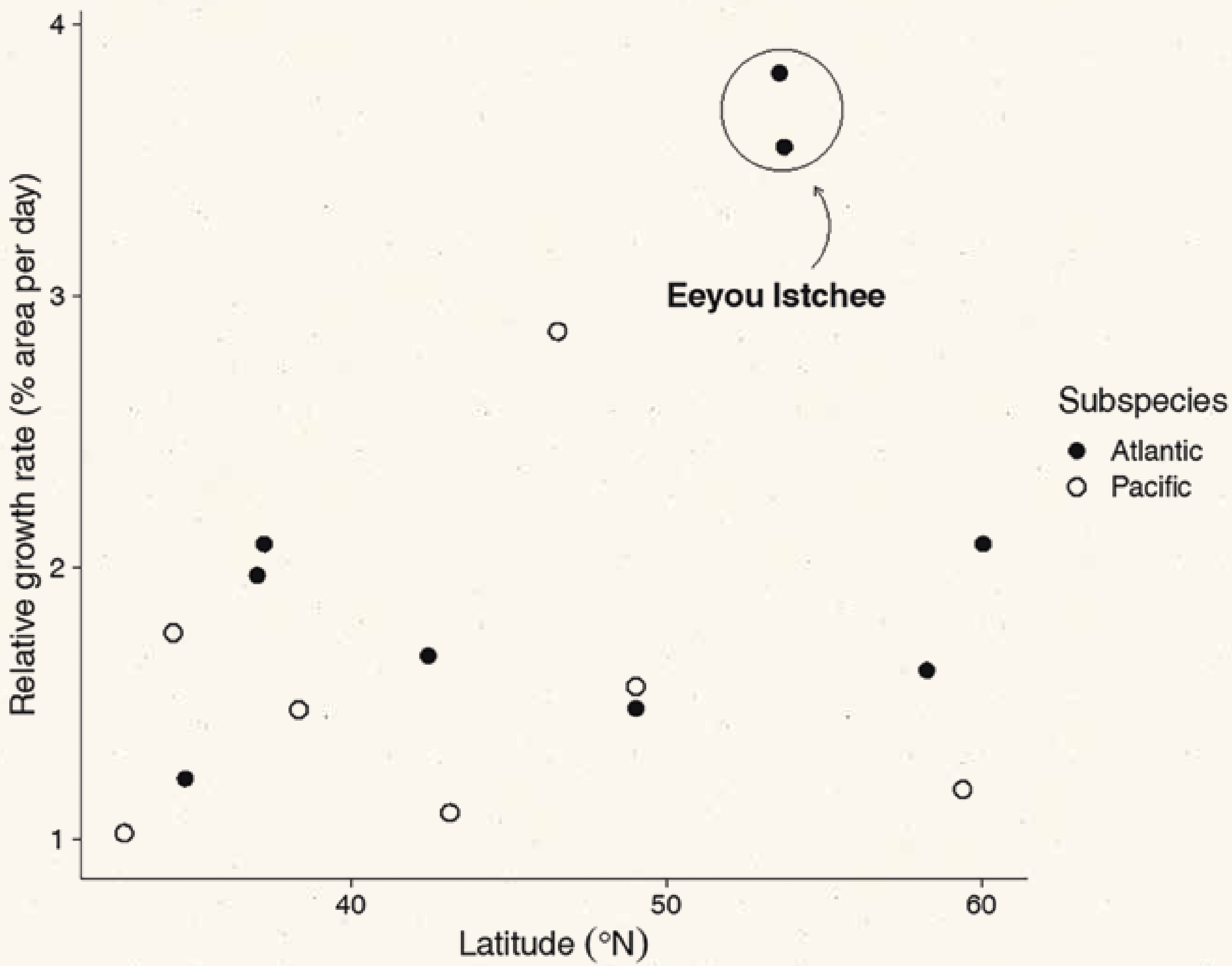


Figure 5-31. Relative growth rates (% per day) measured in this experiment in the context of global Zostera marina L. growth rates as reported in Ruesink et al. (2018). Source: Davis et al. (in prep.).

months. Increased plant productivity stimulated by the larger nitrogen exports of the La Grande most likely occurs somewhere downstream (e.g., Hudson Bay) rather than northeast James Bay (i.e., whatever region benefits from the imported nutrients, when the growing season arrives).

A further consideration in assessing the impacts of altered riverine nutrient fluxes is the evidence generated from the nutrient experiments that eelgrass satisfy their nutrient needs during the growing season by taking up nutrients from the sediments. Collectively, we conclude that the altered exports of nutrients from the La Grande and Eastmain River systems would tend to reduce nitrogen availability and hence plant productivity in southern James Bay but have a minor impact on the productivity of eelgrass or phytoplankton during the growing season in northern James Bay. It should be noted also that ice algae, which can be important producers during the season of sea-ice cover and could have their productivity stimulated by larger nutrient fluxes in winter, were not observed to be abundant in the core area of the under-ice plume, which may be explained by the large fraction of freshwater in the surface waters and ice (Gosselin et al. 1985; Gosselin et al. 1990). Ice-algal biomass was observed in the ice bottom in the far-field portions of the plume, but no historical data were identified that would allow evaluation of a change in distribution or biomass.

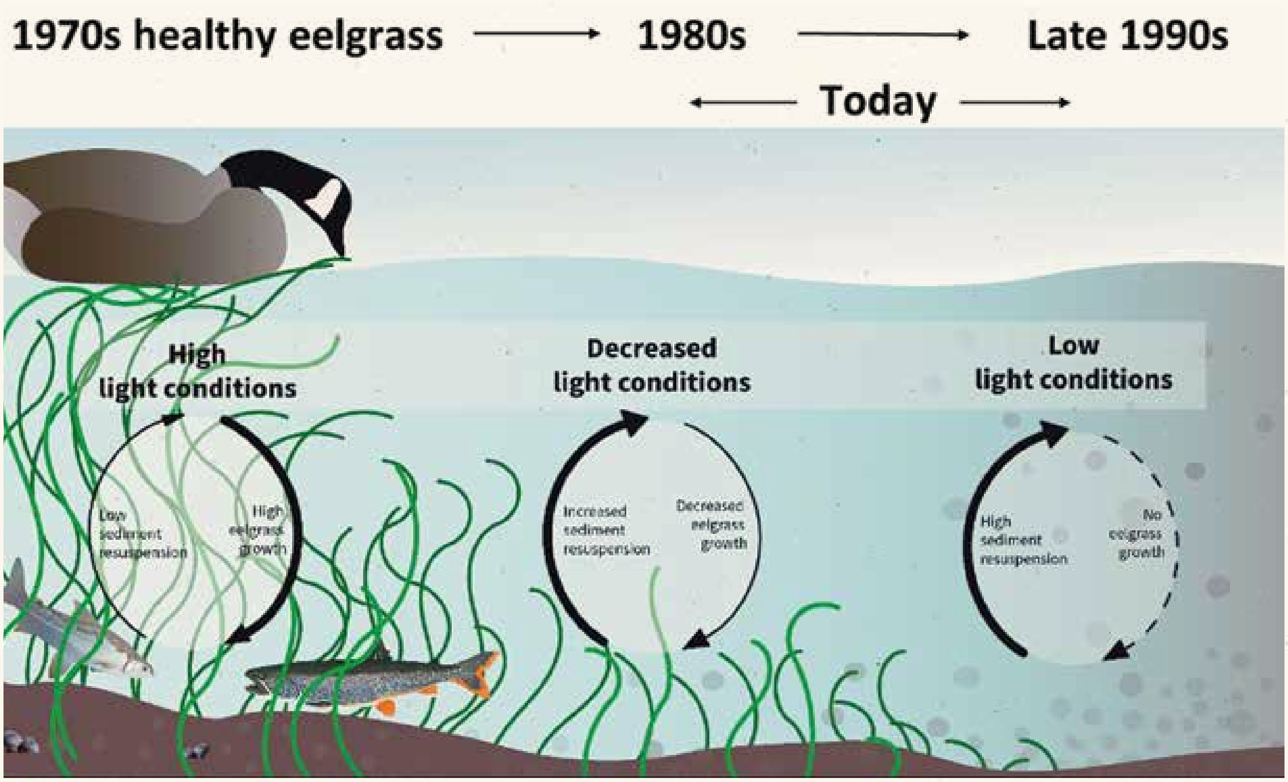


Figure 5-32. Illustration of the effects of eelgrass decline on sediments and water turbidity and the consequences for light availability and hence eelgrass growth.

Impact of eelgrass on waterfowl presence and Cree hunting

As mentioned in the Introduction to this report, Cree land users have reported a lower number of short-necked geese and other bird species that migrate along the east coast of James Bay. They also describe reduced hunting success in spring and more importantly in fall. Changes in goose numbers reported by Cree land users along the James Bay east coast do not reflect trends in overall population size. The Atlantic population of short-necks is monitored each spring by the Canadian Wildlife Service by surveying the same transects across the Ungava Peninsula using fix-winged aircraft. The population declined between 1993 and 1995, which triggered the implementation of hunting restrictions in the south (seasons were closed) that allowed the Atlantic population to recover (Figure 6-1). The population was stable between 2002 and 2018, when a lower number of pairs was recorded, due, in part, to a very late spring in northern Quebec, which resulted in a complete breeding failure in 2018. Hunting restrictions including shortened seasons and reduced bag limits were imposed in the U.S. starting in 2019 and in southern Quebec in 2020. After two years with no survey due to the COVID-19 pandemic, the 2022 survey showed that the population was near the long-term average. Wildlife agencies are considering the possibility of relaxing the hunting regulations in the coming years.

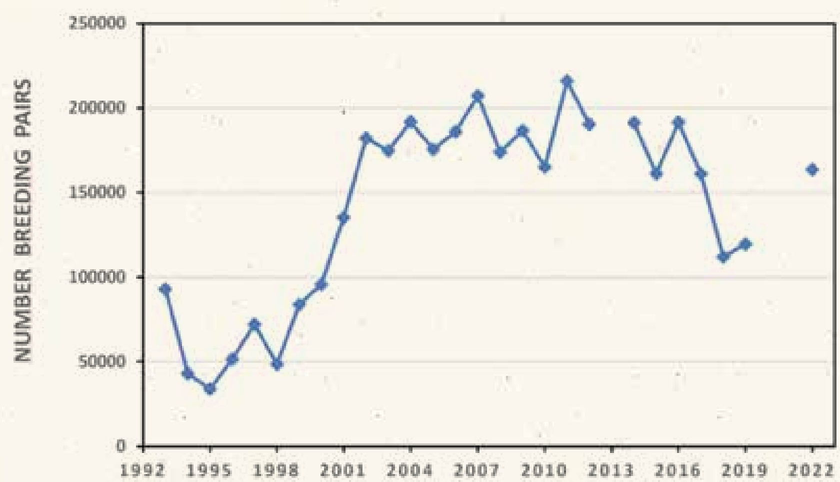


Figure 6-1. Number of breeding pairs of short-necked Canada Geese surveyed in spring across the Ungava Peninsula (U.S. Fish and Wildlife Service 2022). No survey was conducted in 2013, 2020, and 2021.

Cree land users along the northern sector of the coast also see fewer Atlantic Brant than they did in the 1970s when thousands of birds fed extensively on the abundant eelgrass (cf., Table 6-1). The Atlantic Brant population was subject to a significant decline in the early 1930s following a widespread and drastic decline of eelgrass along the Atlantic coast (Cottam *et al.* 1944). Prior to the eelgrass decline, Atlantic Brant used to commonly migrate through the Maritime provinces of Canada during the fall and spring. Since the 1940s, however, a greater proportion of the Atlantic Brant population takes a more direct path between their breeding and wintering grounds, flying directly to eastern James Bay (Quebec, Canada) and fewer individuals pass through the Maritimes (Erskine 1988; Castelli *et al.* 2010). The Atlantic Brant population in eastern Canada has been decreasing since 2000 but has remained stable over the last five years, with an estimated population size of about 106,000 (75,000–138,000) in 2019 (CWSWC 2022). While the population is stable, Cree hunters have noticed a sharp decline in Atlantic Brant presence along the east James Bay coast over the past decades (CRA 2008).

HISTORICAL REVIEW OF EELGRASS-GOOSE RELATIONSHIP AND HUNTING

Because the overall population trend could not explain the reduced number of geese reported by Cree land users, CHCRP researchers reviewed the information available about Canada Geese and eelgrass in eastern James Bay in addition to conducting new observations. For coastal Cree community members, interest and knowledge of eelgrass ecology is founded in the understanding that there is a close relationship between goose presence and eelgrass. This is the knowledge of the Cree hunters familiar with the coast and possessing long-term continuous knowledge of its environmental conditions. As described by Ettinger and Lavoie (1995), “*eelgrass is seen as a critical source of food for brants and geese*”.

In the early and mid-1970s, observers remarked on the strong subsistence harvest of waterfowl especially Canada Geese in Fort George and how the sheer numbers (>140,000) that seasonally passed through Fort George lands, including lands near the coastal settlement, provided access to particularly productive resources. Feit (1978) considered that the abundance of geese limited conflict between intensive wage labour and subsistence harvesting; Cree were adapting work schedules to the seasonal migrations and thus achieving most of the subsistence harvest yields taken by full-time hunters (Feit 1978). Traditionally, for decades leading up to the beginning of the La Grande development, the spring waterfowl hunting was considered the most important activity of the year. It took place at a time of scarcity—at the end of winter—and storage/freezer capacity was an important practical limitation. In September and October, the important fall goose hunt occurred. This hunt became increasingly important during the 1970s. In the Cree hunting surveys of the 1970s (Native Harvesting Research Reports (NHR); 1972–1979), it was estimated that about 55.5% of the goose harvest (>29,000 Canada Geese every year) was completed in the fall (NHRC 1982).

Goose hunting in the spring and fall was the most regularly occurring activity for the past five or six decades leading up to the La Grande development. Accessibility of the resource along the coast was key for coastal Cree communities because there were no roads leading inland. Hunting was necessarily limited to a few key coastal sites and great care was taken to maintain those sites for continued good hunting into the future. Feit (1978) notes: "*Describing their harvesting practices, the hunters indicated that for these resources a strict regulation of harvesting activities was practiced, not to limit the harvest, but to maximize it in the long run by not shortening the period of waterfowl would stay in the area, nor scaring them away from areas where they could be easily hunted. The structure of decision-making in waterfowl hunting is critical because it indicated that the intensity with which this activity is practiced does not depend on the harvests of other resources*."

The importance of managing the goose hunt and the significance of eelgrass in that management came across in interviews conducted for the CHCRP. Land users described that historically the eelgrass-goose relationship allowed for this critical good management of the goose hunt. Because of a close relationship between eelgrass and geese, short-neck behaviour in fall (before hydro development) was quite predictable—the geese would feed on eelgrass growing in shallow water in the coastal bays during low tide and calm water, and then fly to the offshore islands in the bay, often early in the morning, to feed on ripened berries. The goose boss, a senior hunter who supervises the hunt, could make informed decisions about where and when hunters should be located to wait for geese. Typically, all hunters on a territory on a given day were expected to use one and the same spot, allowing all other spots to "rest." Geese were extremely important for the coastal Cree way of life, reportedly representing as much as one-quarter of all annual subsistence production in some communities (Scott 2011). A large harvest survey conducted by the Cree government during 1972–1979 similarly showed that waterfowl contributed to 43.6% of the total wild food harvest including more than 29,000 Canada Geese. This magnitude of harvest along the coast is simply not possible in recent decades. As Wemindji Cree community member J. Blackned said in 2011: "*In 1984, got 50 a day, now you get ten and return home because you know you won't get any more*" (Peloquin and Berkes 2009). With the arrival of transportation infrastructure for the La Grande development, there have been geographical shifts in hunting (some hunters using areas inland or further south). The economics of the goose hunt also have changed; the demographics of communities have changed; schools no longer have fall 'goose breaks' that helped maintain the family cultural traditions around the goose hunt. In view of the profound evolution of goose hunting in the territory and the continued importance of the hunt, it would be interesting in future work to explore questions such as how hunting practices and returns along the coast and how the role of the 'goose boss' have evolved over time.

GOOSE SURVEYS AND OTHER SCIENTIFIC OBSERVATIONS

Scientific observations of Canada Geese's presence along the eastern James Bay coast are very limited. Migratory waterfowl surveys have been conducted along the coast of eastern James Bay only a few times, including in the 1970s, early 1990s, early 2000s, and 2018–2019 for the CHCRP (Figure 6-2). Most surveys covered only the northern or southern portion of the coast. No studies comparable to the harvest survey conducted by the Cree government during 1972–1979 have been completed during recent decades.

During the 1970s, subarctic-breeding Canada Geese made extensive use of eelgrass as documented in Cree Knowledge studies (Ettinger and Lajoie 1995). The first systematic waterfowl surveys in eastern James Bay were conducted in the spring and fall of 1972 by Canadian Wildlife Service biologist, Steven Curtis (Figure 6-2). In the fall of 1972, large-scale aerial surveys were conducted. The surveys were conducted with a transect width of 3.2 km (i.e., 1.6 km on either side of the aircraft), which was considered sufficient for complete coverage of much of the coast. The surveys extended in various segments (lengths 5 to 114 km) during the months of September and October (Table 6-1). They extended overall from Attawapiskat along the western coast of James Bay to Cape Jones on the northeast coast and included Charlton Island. The most abundant geese during the surveys along the eastern coast were Canada Geese (*B.c. interior*, short-necked geese) followed by Snow Geese (*Anser caerulescens*) (Table 6-1). Indeed, almost 11,000 geese were counted in Dead Duck Bay alone in late September, 1972. Biologist S. Curtis noted that "*the geese in Dead Duck Bay were apparently feeding on rather extensive beds of eelgrass, Zostera marina, and showed unusual reluctance to take flight at the approach of the aircraft*".

Less is known about the link between eelgrass and geese in the spring. Cree land users describe how, before the decline, the geese would feed on eelgrass in spring in the areas of open water (faster currents). Chisasibi land users noted, following the eelgrass decline in summer 1999, that "*Some geese were feeding on ice floes on eelgrass in the past; last spring, there was no such behavior*." (Lemieux et al. 2000).

Table 6-1. Results from aerial surveys completed at 400–500 ft during a) September 19–22, 1972, and b) October 4–10, 1972. The transect width for the surveys was 3.2 km (1.6 km on either side of the aircraft), which was sufficient for complete coverage of much of the coast. Miles were converted into kilometers. Species identified as B. c. hutchinisi (in report) is now classified as B. hutchinsii (Cackling Goose). Source: Curtis (1973).

LOCATION	KMS	B.C. INTERIOR (NISK) SHORT-NECKED GEESE	B. HUTCHINSII CACKLING GEESE	AT-LANTIC BRANT	SNOW GEESE
September 19-22, 1972					
Rupert to Jolicoeur (Jack) River	85	1,283	242		9,783
Jolicoeur (Jack) River to East-main	19	103			47
Eastmain to Vieux-Comptoir (Old-Factory)	48	2,575			1,156
Vieux-Comptoir (Old-Factory) to Wemindji	56	5,224	599		2,808
Wemindji to Castor River	71	9,686	403		359
Castor River to Dead Duck	29	6,780	100		700
Dead Duck Bay	5	11,482	20	425	0
Dead Duck Bay to Fort George	26	2,520			759
Fort George to Roggan River	105	7,604	8	90	2,215
Roggan River to Cape Jones	32	9,390		100	15,146
Stratton Islands and Charlton Island	64	975			8
Total	540	57,622	1,372	615	32,981
October 4-10, 1972					
Fort George to Castor River	60	8,732		1,900	
Castor River to Wemindji	71	4,153			
Wemindji to Vieux-Comptoir (Old-Factory)	35	11,176		125	125
Vieux-Comptoir (Old-Factory) to Eastmain	56	2,237			384
Eastmain to Ruppert	114	795	6		6,687
Stratton Islands and Charlton	64	522		212	
Total	400	27,615	6	2,237	7,196

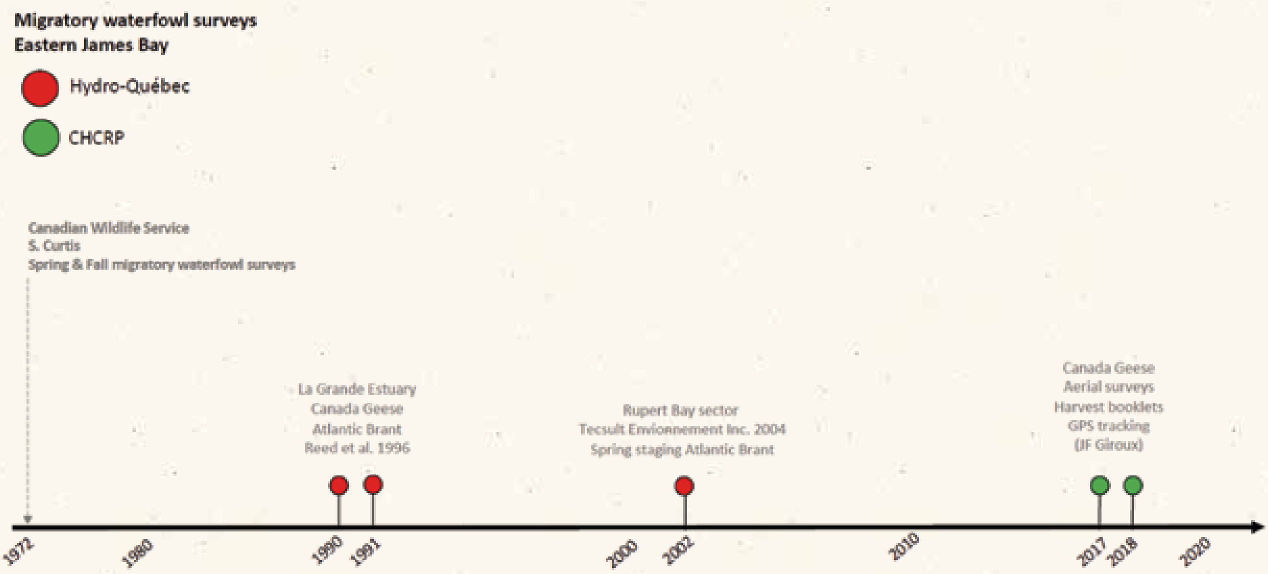


Figure 6-2. Timeline and description of goose studies along the Eeyou Istchee coast.

Subarctic-breeding Canada Geese and Atlantic Brant were surveyed in the early 1990s near Chisasibi (CH05, CH04, CH33, and CH34) (Reed et al. 1996). The study did not find evidence of Canada Geese using the eelgrass meadows. This conclusion was based on aerial surveys conducted in July/August 1990, behavioural observations in three locations (only one having dense eelgrass), and diet analyses completed by the authors. Spring Canada Geese' diets were determined from 150 digestive tracts from geese harvested in five different hunting territories spread along the coast in May 1990. Fall Canada Geese' diets were determined from 14 digestive tracts from geese harvested in one hunting territory (Bay of Many Islands). During stopovers for both spring and fall migrations, Canada Geese were observed mainly using salt marshes and heath. Atlantic Brant relied nearly entirely on eelgrass.

In the mid- to late-1990s, Cree hunters observed many changes taking place along the coast. These changes included a decline in eelgrass health, an increased human disturbance along the coast, changing terrestrial habitat due to climate change and isostatic rebound, the arrival of new species and an increase of others that could prey upon or compete with geese, and changes in migration patterns associated with increased availability of food on the southern staging areas because of agriculture (Idrobo et al. 2023).

After 1992, there were no follow-up surveys of Canada Geese along the coast, although there were a few surveys of Atlantic Brant. Aerial surveys undertaken in the spring of 1995 (June 2, 7, and 8) between Cape Jones and Castor River found approximately 12,000 Atlantic Brant, with the highest concentrations

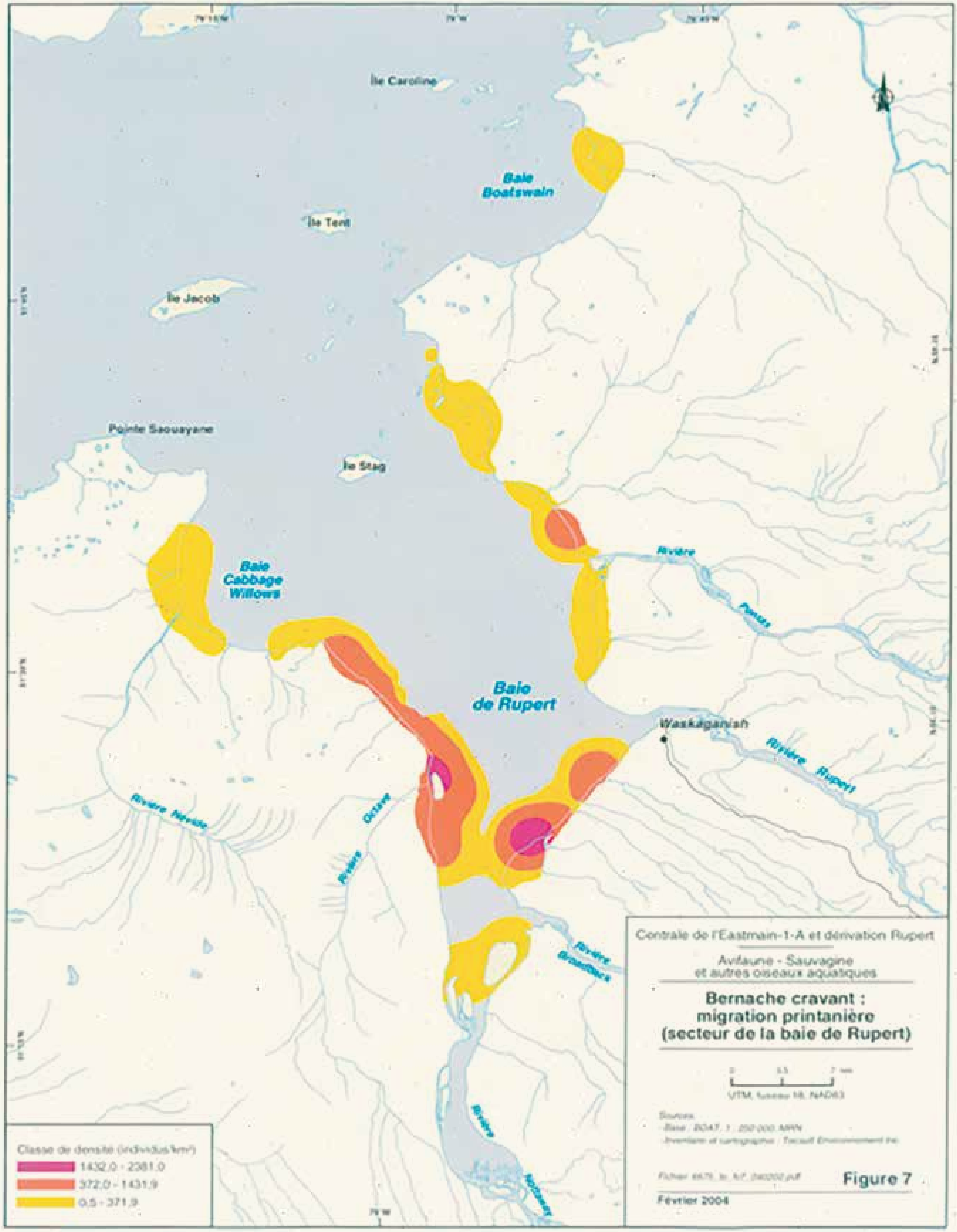


Figure 6-3. Atlantic Brant: spring migration (based on aerial surveys May 6, 12, and 16, 2002; Rupert Bay). Colour gradient from dark to light indicates Brant abundance from high to low. Source: Tecsult Environnement Inc. (2004).

observed in the Bay of Many Islands, Dead Duck Bay, and Kakachischuan Point (Reed et al. 1996). The authors noted that the presence of Atlantic Brant was strongly linked to the presence of eelgrass beds along the north coast.

In the early 1990s, high concentrations of Atlantic Brant south of James Bay in Rupert Bay were rare. However, in the 2000s, the number of Atlantic Brant in southern James Bay strongly increased (Tecsult Environnement Inc. 2004). Spring-staging Atlantic Brant numbers in Rupert Bay increased nearly 12 times from 1972–1974 (maximum counts 2,359) to 2002 (maximum counts 49,729) (Figure 6-3), although the population did not increase significantly during the 1990s (Tecsult Environnement Inc. 2004). The high number of Atlantic Brant observed in Rupert Bay in 2002 was thought to be linked to two events that happened at the same time: the late spring thaw and the decline of eelgrass beds in the preceding couple of years. These two events may have caused Atlantic Brants to spend more time in Rupert Bay in the spring before migrating directly to their breeding region farther north. It is thought that the temporal pattern of migration events for Atlantic Brant varies between years with a longer duration of staging in James Bay during cold springs like 2002 (Castelli et al. 2010).

From 2004 to 2008, the Cree Regional Authority (CRA), the Cree Trappers Association (CTA), Environment Canada (formerly known as Environment and Climate Change Canada), and the Canadian Wildlife Service worked together to learn more about the state of migratory bird harvest in Eeyou Istchee. One of the project's goals was to compare 2005–2006 harvest estimates to 1972–1979 harvest estimates. To do so, over 100 households in each of the three communities (Waskaganish, Wemindji, and Mistassini) were interviewed in 2005 and 2006. The report presented evidence of a decrease in Canada Goose harvest in Waskaganish and Wemindji but an increase in Mistassini when comparing the two periods (Table 6-2).

Table 6-2. Comparison between estimated 2006 harvest and 1972–79 harvest study of migratory waterfowl in Eeyou Istchee. Source: CRA(2008).

SPECIES	2005 ESTIMATED HARVEST	2006 ESTIMATED HARVEST	AVERAGE	1972–1979	DIFFER-ENCE	% CHANGE
Waskaganish						
Canada Goose	3823	7034	5429	7509	-2080	84
Snow Goose	346	2001	1174	9734	-8560	478
Brant	0	38	19	126	-107	-
Ducks	2465	2877	2671	3322	-651	17
Loons	0	5	3	25	-22	-
Wemindji						
Canada Goose	4024	3267	3646	9069	-5423	-18

SPECIES	2005 ESTIMATED HARVEST	2006 ESTIMATED HARVEST	AVERAGE	1972–1979	DIFFER-ENCE	% CHANGE
Snow Goose	33	16	25	1262	-1237	-55
Brant	148	56	102	1892	-1790	-62
Ducks	1163	1043	1103	4390	-3287	-10
Loons	16	26	21	742	-721	62
Mistissini						
Canada Goose	-	11355	-	4458	6897	155
Snow Goose	-	100	-	102	-2	-2
Brant	-	9	-	25	-16	-56
Ducks	-	11672	-	17250	-5578	-32
Loons	-	423	-	743	-320	-43
Eeyou Istchee (estimation)						
Canada Goose	-	49960	-	63136	-13176	-21
Snow Goose	-	4890	-	20639	-15749	-76
Brant	-	240	-	6424	-6184	-96
Ducks	-	35970	-	47716	-11746	-25
Loons	-	1050	-	3577	-2527	-71

In 2018, observations suggested limited use of eelgrass by subarctic-breeding and temperate-breeding Canada Geese. Canada Geese observed during four aerial surveys (both spring and fall) were found to mostly prefer salt marshes (Morais et al., in prep). A study of band returns found that Cree hunters harvested more molt migratory temperate-breeding geese (long-necks) and fewer short-necks between 2000 and 2020, indicating that fewer short-necks were present along the coast during the autumn migration (Giroux et al. 2022). When combining all sources of information, including Cree Knowledge (Idrobo et al. 2023; Consortium Waska-GENIVAR 2011; CRA 2008; Ettinger and Lajoie 1995), aerial surveys (Sorais et al., in prep.; Reed et al. 1996), GPS tracking of temperate-breeding molt migrants (Sorais et al. 2023), and testimonials (FOPO 2008), we concluded that there are fewer short-necks present along the coast during the fall migration, and those that do fly along the coast are often at high altitude, passing quickly, and making limited use of the eelgrass beds.

In contrast to the situation 40–50 years ago, the research conducted during the CHCRP suggests that the current condition of eelgrass in eastern James Bay is likely not profitable for Canada Geese (Figure 6-4).

The decrease in the number and size of eelgrass beds, lower shoot density, and shorter shoot length all contribute to the lower profitability of the eelgrass as a food source. Canada Geese are generalists and can feed on many alternative plant types found in salt marshes, tidal flats, freshwater wetlands, and berries on the tundra.

With geese being very sensitive to human disturbance, there also are reinforcing feedback between the low abundance of geese on eelgrass, low predictability of goose movements for hunting, and increased human disturbances, which further reduce hunting success. It is also possible that the presence of molt migrant temperate breeding geese (i.e., long-necked geese) may influence the distribution of subarctic-breeding geese (short-necked geese) during the fall migration. Thus, the decline in eelgrass and the current poor condition of the eelgrass beds impact Cree land users with a decline in hunting success, erosion of traditional knowledge and associated institutions, and food security.

In a previous study, Wemindji land user F. Stewart was reported as saying: "*It's been getting worse every year, bad goose hunt last two years; I did not catch any goose this spring (2006). Many others also did not catch any. It used to be 100 in a season*." (Peloquin and Berkes, 2009). Many Cree land users highlight the eelgrass decline as a central factor affecting waterfowl abundance:

When I started hunting in the 1950s I always saw waterfowl in the bay and we always saw that the habitat was healthy. We knew something was going on when eelgrass stopped growing. Not having eelgrass is affecting the waterfowl. The birds that used to eat eelgrass are not around anymore. Today the birds that come to the bay aren't even native (i.e., long-necks) and the birds that ate eelgrass don't come to the bay anymore. Geese are flying inland because they know there's no eelgrass here anymore" (CH7, Freddie Scipio, 2019).

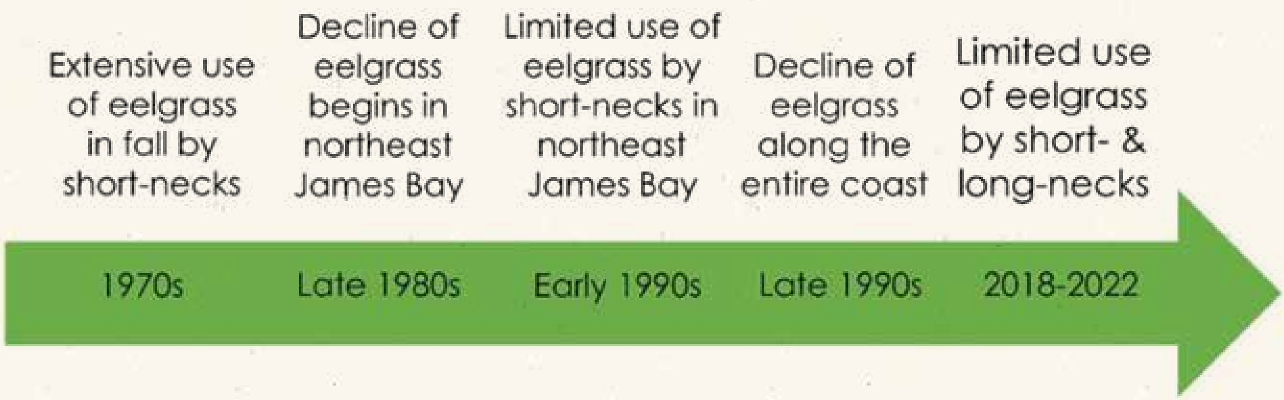


Figure 6-4. Historical review of the relationship between Canada Geese and eelgrass along the east coast of James Bay.

ADDITIONAL FACTORS AFFECTING GOOSE PRESENCE

While placing the eelgrass decline as central to the low presence of geese, land users also recognize that eelgrass is just one of many elements that make up waterfowl habitat (Figure 6-5). The interaction of the eelgrass decline with other factors in the coastal habitat has resulted in profound changes in the daily movements of geese. The berries (*Empetrum* sp. and *Vaccinium* sp.) from the tundra and the sedges [e.g., marsh arrowgrass (*Triglochin palustris*), scaly sedge (*Carex paleacea*) and needle spikerush (*Hippuris tetraphylla*)] and other plants from the high salt marshes have also been declining. While isostatic rebound has always been there in the background causing changes along the coast (lifting the land and making it drier), several summers that are "warmer than normal" have strongly affected the production of berries and resulted in faster vegetation growth (longer growing season). These changes are part of the well-documented 'greening of the Arctic' that leads to an evolution of tundra to forested areas because of the northward movement of the tree line. As part of the CHCRP, researchers showed an increase in forested land classes between 1985 and 2019 in the territory (Olatunji 2022). These recent habitat changes represent an additional factor contributing to the changes in the presence of the geese.

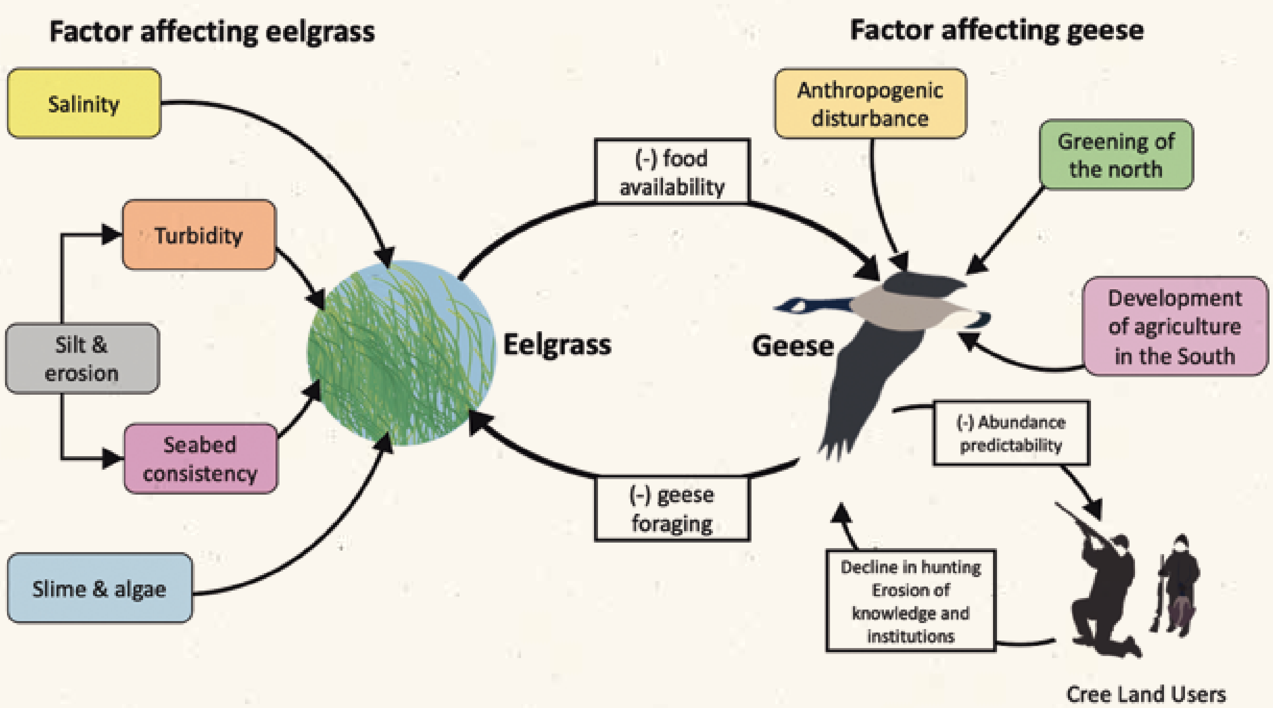


Figure 6-5. Summary of the main environmental factors affecting the state of eelgrass and the impacts on geese and Cree land use. Source: Idrobo et al. (in prep).

Less eelgrass and fewer berries have resulted in a break in the daily movements of geese while staging in James Bay during the fall migration (Figure 6-6). Before the decline of eelgrass and berries, geese spent the high tide feeding on berry bushes inland or on the islands near the shore. Once the tide receded, geese flew to the bay to feed on eelgrass. Cree land users used to take advantage of this daily cycle to scare geese away in the mornings as the tide was receding and wait for them to come back during the high tide to harvest them. Geese became unpredictable as eelgrass and berries declined. Few geese land to eat the little food available, while the rest of the geese fly too high to be hunted or simply avoid migrating through the bay.

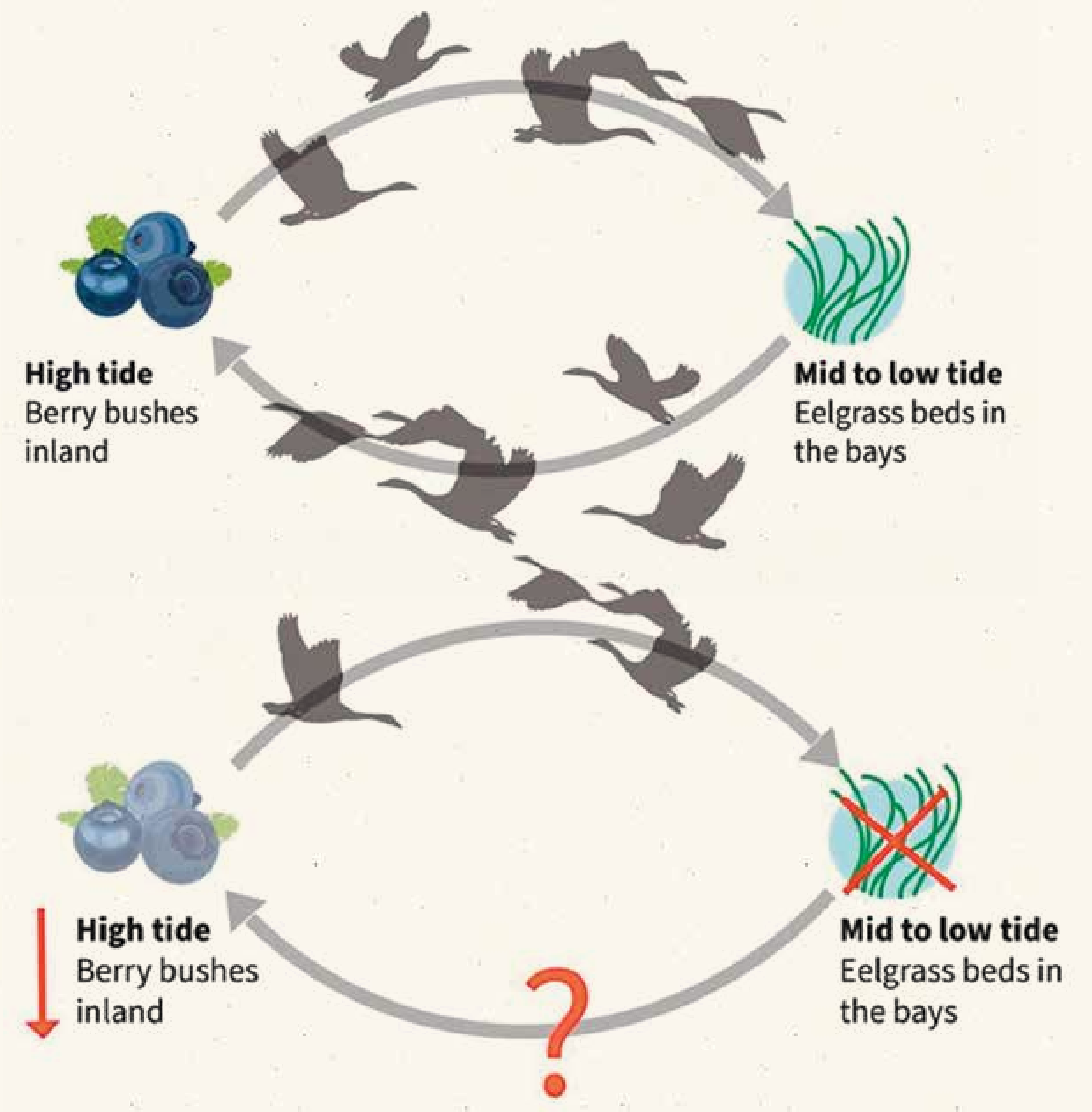


Figure 6-6. Changes to daily feeding behaviour and movement of short-neck geese. Top panel shows historical pattern with geese feeding on eelgrass beds in the bay during mid to low tide. Bottom panel shows how goose distribution is unpredictable due to declines in eelgrass and climate-related changes in berry bushes and other features or the local terrestrial habitat. Source: Idrobo et al. (in prep).

During interviews conducted for the CHCRP, Cree reported human disturbances to the goose habitat associated with the profound social and economic changes brought about by hydro development in the region. As Air Creebec began operations in 1982 (Air Creebec 2007), airports were built in each community and flying paths were established along the coast. Around 1986, the helicopter service known as airlift began to operate to facilitate the travel of families to and from the hunting camps. Additionally, around the same time, hunting and travelling on the land became mechanized, increasing noise levels in the bay:

"Before mechanization hunters moved carefully and silently through the land. They travelled by boat, walked on land and worked together. After mechanization, we used snowmobiles and ATVs to move through the land. The birds see us. They are smart and avoid us[...]. The helicopter that brings land users to their traplines makes noise in all communities along the coast when the geese are migrating. That must disturb the geese. Maybe that's why the short neck geese fly high" (VC 14, Henry Steward, 2022).

Ettinger et al. (1995) reported that for most Wemindji hunters, the main impacts on local waterfowl populations were those related to human activities, not eelgrass, which had not yet declined in the Wemindji area in the mid-1990s. Improper hunting techniques like shooting on days without wind were identified as an important factor that reduced the quality of hunting.

Cree land users also report changes to local ecosystems and the arrival of new species to the coast that are negatively affecting geese and their staging habitat. These changes can be attributed to the greening of northern ecosystems phenomenon (Berner et al. 2020). Shrubs now cover former geese feeding grounds: "*The main change we have experienced is that the areas where geese used to feed are now overgrown with willows and alder*" (VC12, Sinclair Mistacheesick, 2022). This has meant an increased abundance of moose and their predators in the area. Likewise, Cree also report more bald and golden eagles and sandhill cranes, which can prey upon and disturb the geese. Some Cree explain that geese might be changing their flying paths and behaviour partially in response to the presence of these predators in the area. Long-necked geese (molt migrant temperate-breeding Canada Geese) are also considered a new arrival to the area. Long-necked geese are noticeably larger on average (Sorais et al. 2023). Recent research showed that concurrent with the decrease in short-necks along the coast there has been an increase in the number of long-necked geese, which may lead to increased competition with subarctic-breeding Canada Geese (Sorais et al. 2023). Lastly, for some Cree, the development of agriculture in the south has created new food sources for geese that have affected their migration patterns. Changes at the local and continental scales and the interaction among the aforementioned factors not only affect the abundance of geese during their fall staging period in the bay but also their behaviour in ways that make them harder to predict or make them inaccessible to hunters.

Although it is impossible to rank the importance of each factor, the profound changes in goose presence and movements directly impact Cree hunting (Figure 6-7). The tracking of geese as part of the CHCRP contributed to a better understanding of the links between the breeding, staging, and wintering areas of the birds harvested by Cree hunters. These have been depicted in several videos that are available on the Niskamoon YouTube channel in Cree and English languages: https://youtube.com/channel/UC6SL4sH-VdGrAgMoEe77_CQ. However, there remain significant data gaps, including where nesting is taking place for the short-necks that are presently harvested along the coast.

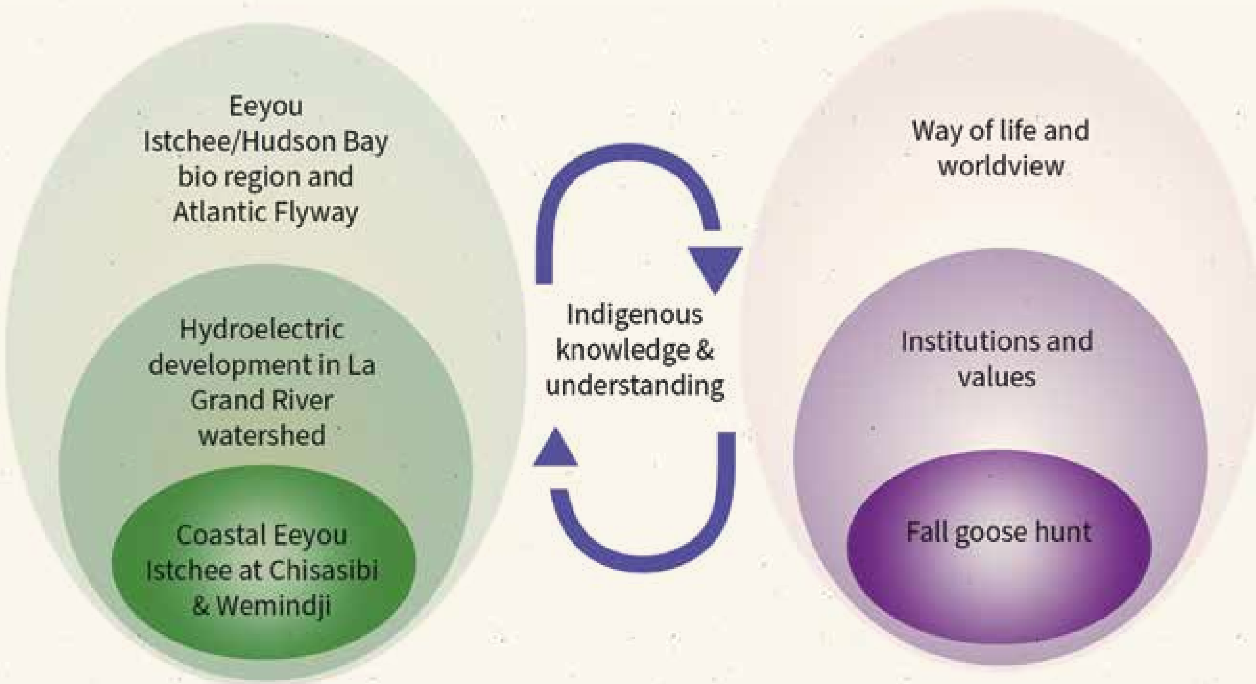


Figure 6-7. Interactions among changes in the coastal habitat of Eeyou Istchee, the tradition of the fall goose hunt, and Cree institutions, values, and way of life. Source: Idrobo et al. (in prep).

Closing remarks and future perspectives

Forty years ago, when considering the proposed development of La Grande River, Chisasibi hunter Joshua Lameboy (father of Steering Committee member John Lameboy) predicted that the eelgrass would disappear “*when the discharge of freshwater goes to the Bay from La Grande*”. As mentioned in the introduction of this report, in Chisasibi, the Cree term for healthy eelgrass (*aayoshtinuukticj*) encapsulates the eelgrass *and* its central role in coastal ecosystems: the way that large dense meadows settle and calm the water and provide unique habitat. It goes without saying that the large dense eelgrass meadows attracted short-necked geese in great numbers, which supported the tradition of the fall goose hunt. Unfortunately, Chisasibi Cree hunters have seen the healthy eelgrass (*aayoshtinuukticj*) disappear as Joshua Lameboy predicted. The ones we heard from during the CHCRP expressed no doubt that the development *started* the eelgrass declines in their area and many believe that “*still today, La Grande has more effect on the north side of the river than climate change*”. The conclusions of this report do not contradict this statement.

The project focused on two main questions:

- *What are the main factors affecting the current state of eelgrass along the eastern coast of James Bay?; and*
- *What is the impact of the current state of eelgrass on waterfowl presence and consequently Cree hunting activities?*

To answer these two questions, we used information shared with us during interviews and workshops and various scientific data collected along the coast. There is not just one ‘factor’ that explains the poor condition of eelgrass along the eastern James Bay coast today, nor the limited numbers of geese that stop in the fall. In the midst of this project, it became obvious to us that the history of eelgrass declines influences the state of eelgrass today, leading us to consider climate and La Grande development, over many decades (Figure 7-1). When considering both Cree and science perspectives, the report clearly shows that *both* high flows from La Grande *and* climate change negatively affect eelgrass biomass in the Chisasibi region. In the southern part of the coast, climate change and lingering effects of the massive decline in eelgrass in the 1990s continue to hold back eelgrass recovery.

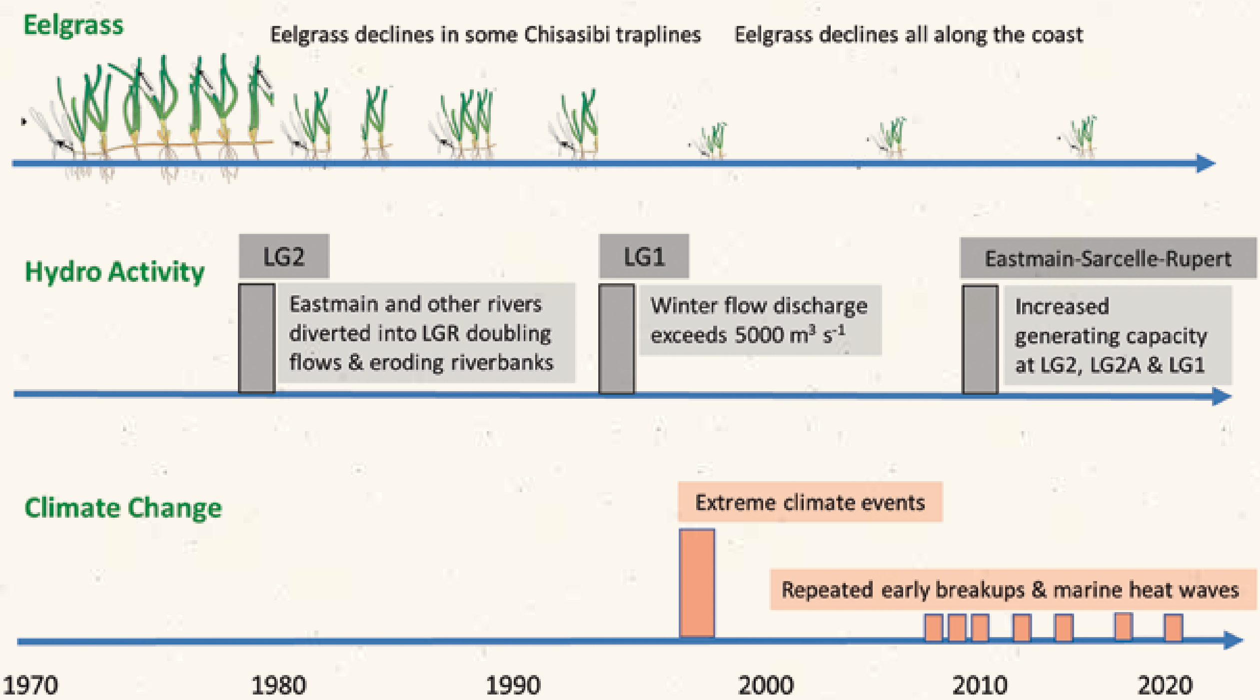


Figure 7-1. Timeline of eelgrass declines and environmental changes in the Eeyou coastal habitat.

WE SUMMARIZE THE *KEY FINDINGS* AS FOLLOWS:

- *The current state of eelgrass along the eastern coast of James Bay is partly a consequence of the massive eelgrass decline that occurred in the past, which decimated the large, dense eelgrass beds and meadows, disrupting the feedbacks that keep the water clear in meadows. The research showed that the light available underwater for eelgrass during the growing season is insufficient for some eelgrass meadows, which limits the height and density of the eelgrass beds and may reduce winter survival.*
    - *Eelgrass recovery is likely further impeded by large-scale stressors including the browning of James Bay waters and exceptional ice breakup dates and warm water temperatures.*
    - *In the La Grande River sector of the coast (CH34 to CH5), a third stressor on the eelgrass is the modified high river flows.*
- *The current poor state of eelgrass reduces the number of geese making use of the coastal habitat at least during fall migrations, and makes the distribution of the geese unpredictable, thus impacting Cree hunting activities and associated cultural and socio-economic aspects of Cree society. Additional factors, both local and global, also impact waterfowl presence including changes to waterfowl feeding habits and hunting, and changes in habitat and wildlife due to climate change.*

> *It is important to note that* if *the coastal habitat can be improved and eelgrass recovers, there is a greater chance of short-necked geese coming back, but it* cannot *be said with any certainty when or if the geese will come back.*

After spending two summers surveying eelgrass and geese with Cree land users along the eastern coast of James Bay in the 1970s, Canadian Wildlife Service biologists remarked:

"Eelgrass beds are very important feeding areas for the Canada Goose and the Atlantic Brant. Other waterfowl also feed in the eelgrass beds where epiphytic organisms and a great number of invertebrates thrive. Eelgrass communities are very productive and form an important base for major food chains in the James Bay marine ecosystem. They stabilize sediments and provide shelter and feeding areas for fish and other forms of marine life. Eelgrass communities are vitally important to waterfowl and their destruction along the James Bay coast would be a major ecological disaster." (Curtis and Allen, 1976).

This report synthesizes all the information that has come to the attention of the CHCRP researchers from Cree land users, published reports and unpublished datasets, as well as new data collected under the Niskamoon mandate. Collectively, the information paints a picture of a *near* ecological disaster, with major declines in eelgrass and geese that have impacted Cree hunting. However, there are still some eelgrass beds, there are still some geese taken by Cree hunters each fall, and there is much knowledge and many ideas amongst Cree land users and leaders about steps to take to improve and protect the traditional hunting territories.

In addition to the physical effects of hydroelectric development followed by climate change, there were social consequences that are beyond the scope of this report. Chisasibi was strongly impacted by the La Grande development. As noted by previous workers (cf., Tanner 1999), it is not always easy to distinguish between social and environmental changes. Tanner (1999) explains that:

"Whether a physical effect is considered to be positive, negative, or neutral depends in part on the value attached by the members of a particular social group to the physical environment that is likely to be affected. Thus, a physical effect acquires a social dimension in the way it is understood and evaluated by a group. The Cree's view of the likely physical effects of development derives, in part, from their own culturally framed knowledge of the physical environment, knowledge gained through long-term empirical observation."

Tanner (1999) goes on to argue that a way to address this challenge of social and physical impacts being inseparable is to consider Cree Knowledge of physical impacts in parallel to Western scientific knowledge, the former being based on "*intimate and highly practical experience of the environment on which the survival of the Cree depends*".

This research was able to contribute to a comprehensive understanding of recent environmental changes in eastern James Bay because the project considered Cree and scientific perspectives to gain insights into how and why coastal ecosystems have changed. Although unanswered questions remain, particularly about what could facilitate eelgrass recovery and a return to productive fall goose hunts, much progress was made in documenting the properties of the coastal habitat and the variability of its conditions in time and space as well as properties of the eelgrass and the geese. Progress was also made in developing a foundation for monitoring and further study.

Because eelgrass in eastern James Bay has persisted through major environmental changes in the past, perhaps it can recover, but much depends on *both* how the climate varies in the coming years *and* future coastal management. Eelgrass has declined and recovered in other places. From these examples, we know that to protect these ecosystems, it is important to conduct coastal monitoring over the long term and to consider ecosystem health in environmental impact assessments and decisions about infrastructure development. The coastal habitat of Eeyou Istchee is large and complex. Some eelgrass beds may be more impacted by coastal development and others by climate change, and in places, these stressors may interact. Although some impacts associated with climate change can be neither controlled nor avoided, *there is* potential to predict, manage, and mitigate the potential effects of hydroelectric and other regional development as they impact coastal ecosystems. Because Canada Geese are opportunistic and change their behavior, it is difficult to predict how they will adapt to future changes at the local and continental scales. Nevertheless, the creation of waterfowl habitats including ponds and small no-hunting zones that attract geese, and the implementation of measures to reduce disturbance may improve the hunting success of geese and other species. *In view of the importance of healthy coastal ecosystems for fish and wildlife, Cree way of life, and global processes, understanding and protecting the eelgrass ecosystems is important for the long term. We expect the results will contribute to future Cree-led monitoring and management.*

In view of the importance of healthy coastal ecosystems for fish and wildlife, Cree way of life, and global processes, understanding and protecting the eelgrass ecosystems is important for the long term. It is our expectation that this report will help support future Cree-led monitoring and management. Based on our findings and discussions with Cree community members, we make the following recommendations:

The eelgrass beds are changing, as is the whole coastal ecosystem of the Bay, and even if they do not return to their past condition, these beds will remain very important ecologically. Monitoring the distribution and density of eelgrass meadows is complex and challenging, but vitally important from an ecological standpoint. A suitable monitoring strategy needs to include the following points:

- *Maximize community interest and involvement with local and regional governments and Hydro-Québec support,*

- *Employ several sampling techniques as developed in the CHCRP,*
- *Address knowledge gaps identified over the course of the CHCRP such as the influence of the high winter flows of the La Grande River on eelgrass and the influence on light-sediment resuspension on eelgrass,*
- *Assess eelgrass abundance and conditions annually to quantify spatio-temporal trends,*
- *Assess eelgrass health in areas not surveyed by researchers during the CHCRP especially north of the La Grande River.*

Monitoring the abundance and distribution of migratory waterfowl should include the following points:

- *Maximize community involvement while minimizing impacts on traditional hunting activities,*
- *Assess the changes of goose populations and track harvest success by collecting Canada Geese harvest booklets, determining the proportion of the two subspecies in the harvest (long- and short-necked geese), developing a protocol for the return of goose bands, and promoting the use of CTA's harvest phone app,*
- *Assess how the Cree waterfowl harvest has changed by compiling information on where goose camps operate, and how hunting activities are coordinated,*
- *Address knowledge gaps about the breeding grounds of the short necks hunted in fall along the coast,*
- *Assess the success of different habitat enhancement measures during the fall goose hunt by working closely with land users,*
- *Continue to assess the relationship between geese and coastal habitats, including eelgrass, by building on knowledge already compiled during the first phase.*

Discussions should continue on the feasibility and desirability of site-specific measures to restore eelgrass meadows in selected areas. An eelgrass restoration expert should be called on for advice about feasibility, and requirements for monitoring and evaluation in such an initiative.

Future development activities in the territory should recognize the vulnerability of eelgrass to sediment releases and sediment disturbance that affect water clarity in the coastal environment and if feasible include strategies to minimize and monitor these potential impacts.

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APPENDIX A

Summary of Cree Café, Chisasibi, September 2022

In September 2022, a research symposium was held over two days in Chisasibi with participation of land users from the other coastal communities. A workshop was arranged on the morning of the third day to promote discussion among land users and researchers about next steps and the way ahead. Discussions encompassed future research and monitoring, as well as identifying knowledge gaps. Participants included community members who had participated in the symposium or heard it on the radio, as well as new participants. Below is a summary of the concepts and suggestions put forward by land users during the workshop.

EELGRASS

- *Monitor eelgrass*
- *Locate healthy eelgrass beds*
- *Research sediments (sources, amount of seabed hardness)*
- *Eelgrass restoration*
- *Biodiversity in eelgrass habitats (fish and birds that rely on healthy eelgrass)*

GEESE

- *Monitor Canada geese (using different methods)*
- *Locate short-neck geese breeding areas*
- *Better understand Brant migration*
- *Canada geese habitat restoration (berries, salt marshes plant and other plants, turn)*
- *Canada geese habitat enhancement (turn the soil over, expose roots, control burning, reduce grass accumulation, fresh grass)*
- *Canada geese habitat conservation*
- *Delineate no hunting zones*
- *Develop new hunting regulations*

- *Include land users/tallymen in data collection/monitoring*
- *Improved hunting management*
- *Create bird sanctuaries based on Cree knowledge*
- *Better noise management during the spring and fall geese migrations*
- *Hunting course for youth (bird migration and how the weather affects their flight patterns, knowledge of other birds)*

RESEARCH PROCESS (COMMUNICATION AND COMMUNITY ENGAGEMENT)

- *Validation of TEK from elders*
- *Train community members to collect data*
- *Increase the presence of land users on traplines*
- *Increase presence of researchers in communities*
- *Increase discussion between researchers and land users/tallymen during research*
- *Share research progress/outcomes with other local/regional entities (CTA, Eeyou Marine Region Wildlife Board, CERRI)*
- *Collaboration between other local/regional entities*
- *Cree-led conferences to aggregate knowledge in different communities*

OTHER

- *Monitor water circulation*
- *Need for better communication between tallyman, goose boss, and hunters*
- *Research fish health*
- *Monitor climate*
- *Monitor rivers*
- *Research the changes of other birds (loons, terns, and guillemots)*
- *Research water quality (pollution from mining)*

Glossary of Terms

Abiotic (factors): Non-biological (e.g. salinity, light, temperature, wind patterns, tides, currents and precipitation). As opposed to *biotic*.1

Aboveground biomass: The mass (weight) of the portion of the plant above the ground, so not including the roots or rhizomes. Usually the material is collected and dried gently in an oven.

Algorithm: A precise set of calculations that leads to the solution of a mathematical problem.2

Algae: Any of a large group of mostly aquatic organisms which can carry on photosynthesis, but lack true roots, stems or leaves; they range from microscopic single cells to very large multicellular organisms. They live or occur only in the presence of oxygen.2,3

Ammonium (NH4+): A nitrogen-containing form of nutrient used for growth by algae and seagrasses.4

Anaerobic: A descriptive term for a process, such as fermentation, that can proceed only in the absence of oxygen, or a living being that can survive only in the absence of oxygen.3

Anomaly: Difference between observed conditions relative to average conditions. Often used to report the difference between present conditions of climate (e.g. air temperature in 2021) relative to the average conditions of climate in a specified period of time (e.g. mean air temperature from 1970 to 2021).2

Anoxic: Without oxygen.3

Anthropogenic: Derived from or associated with human activity.3

Algal bloom: The sudden rapid growth or accumulation of algae in an aquatic ecosystem. It can occur naturally in spring or summer when algae growth exceeds predation by aquatic herbivores or can be the result of nutrient enrichment of waters due to pollution. Algal blooms are characteristic of eutrophication (excessive nutrients in the water) and can cause lack of oxygen and death of animal life .3

Bacteria: Very small organisms, which can only be seen through a microscope. They are the simplest living microorganisms, but they are responsible for important functions in the planet such as the degradation of the organic matter and regeneration of nutrients.2

Backscatter sensor: Sensor determining turbidity by measuring the reflection of an infrared light by suspended particles in the water2,4

Baseline: The existing physical, chemical, biological and human conditions of the environment prior to the start of an activity.1

Bathymetry: The science of measuring the depths of oceans and other bodies of water.2

Biodiversity: A description of the variety, abundance, and distribution of living organisms within a defined ecosystem or habitat.3

Biogeochemical cycles: The processes and pathways by which a chemical substance (e.g. carbon, nitrogen) circulates from the nonliving components (abiotic – soil, air, water) of Earth to the living (biotic – vegetation and animals) components and back.2

Biotic (factors): Belonging to, or caused by, living organisms (e.g. grazing). As opposed to abiotic.1

Carbon sink or source: A carbon sink is anything that absorbs more carbon from the atmosphere than it releases – for example, plants, the ocean and soil. In contrast, a carbon source is anything that releases more carbon into the atmosphere than it absorbs – for example, the burning of fossil fuels, decaying organic matter, or volcanic eruptions.5

Chlorophyll: A group of green plant pigments that captures light to be used in photosynthesis. These pigments give plants their green color by absorbing red and blue-violet lights and reflecting green light.2

Chlorophyll a: A blue-green chlorophyll found in all higher plants and in algae. This pigment is used as a measure of algal biomass.2

Clay: Mineral particle with a dimension smaller than 0.002 mm (or 0.004 mm), smaller than silt and sand. The particles are so small that one cannot feel the grain roughness.

Colored dissolved organic matter (CDOM): Colored matter in water, which is so small as to pass through a filter (usually 0.2 µm or 0.45 µm pore size). It is the coloured fraction of dissolved organic carbon (DOC). CDOM occurs naturally in aquatic environments primarily as a result of rainwaters draining soils containing decaying terrestrial vegetation that is rich in tannins, which gives a brownish or yellowish color to the waters. This decaying vegetation colors rainwater just like tea leaves color water in a teacup. Due to its darker colour, CDOM absorbs light and diminishes the remaining light penetrating down through the water column.4

Community (biological community): A group of interdependent organisms inhabiting the same region and interacting with each other.3

CTD (Conductivity-Temperature-Depth device): Instrument used to measure water salinity and temperature. It is typically lowered down through the water column from top to bottom providing a vertical profile of salinity and temperature showing how these properties change with depth.2

Current velocity profiler (ADCP; Acoustic Doppler current profiler): Instrument using sound to measure the water currents (speed and direction) throughout the water column.2

Shoot density: A count of the number of shoots found within a specific surface area (like one square metre) of the seabed.

Discharge: See *River discharge*.

Discharge peak: Maximum river discharge during the year. For subarctic rivers, it usually happens in spring due to snowmelt and is called the 'spring freshet'.2

Disease: A disorder of structure or function in an organism that produces specific signs that are not caused by physical injury alone.1

Distribution: The geographic occurrence or range of an organism.3

Disturbance: A temporary change in average environmental conditions that causes a pronounced change in ecosystem structure. Disturbances may be natural (e.g. caused by a major storm) or anthropogenic.3

Dissolved organic carbon (DOC): Product of the decomposition of dead plants and animals. It may or may not have any colour and is considered dissolved because it is able to pass through a very fine filter (usually pore size of 0.2 µm or 0.7 µm). It can originate in terrestrial systems and be transported to water bodies or can be produced and released by aquatic plants and animals.6

Drivers (such as environmental drivers): Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

Ecology: The scientific study of the relationship between plants, animals, and their environment.3

Ecosystem: An ecological community interacting with its environment, functioning as a unit.3

Eelgrass: The temperate seagrass *Zostera marina,* which is the dominant seagrass from Canada to the Carolinas, in northern latitudes on the Eastern Atlantic coast of Europe and the Pacific ocean.3

Ecosystem service: The benefits provided by the ecosystem (e.g. seagrass beds) to humans such as water and air purification, food, control of diseases, etc.1

Epiphytes: Organisms that live on the surface of plants, seagrass, and seaweeds, and use it as a support to grow.3

Erosion: Natural processes that remove or wear away materials (soil and rocks) at the Earth's surface. The principal agents are gravity, running water, near-shore waves, ice (e.g. glaciers or sea ice), and wind.3

Estuary: A partially enclosed coastal body of water, having an open connection with the ocean, where freshwater from inland streams and rivers is mixed with saltwater from the sea.3

Experiment: In an experiment, the experimenter deliberately manipulates one or more variables (factors) in order to determine the effect of this manipulation on the other variables (or variables).

Export Yield (or yield): Represents the riverine export or flux (of water, nutrients, suspended particulate sediments) per unit of watershed area. To calculate it, the total export or flux of material from the river is divided by the size of the watershed.6

Feedback mechanism: A loop system in which the system reacts to a change, either by reinforcing the change in a positive feedback loop (also called vicious cycle when the outcome is negative), or counteracting the change to return a system to its original state.

Fertilizer: An organic or synthetic material added to the soil or water, to increase the nutrients available for plant growth.

Forage: The act of looking or searching for food.3

Free-flow rivers: As applied to any river or section of a river in a natural condition without impoundment, diversion, straightening, riprapping, or other modification of the waterway. It allows free movement of migratory fishes.6

Gene pool: The collective genetic information contained within a population of sexually reproducing organisms.3

Genetic diversity: The variety of genetic material within a single species of organism that permit the organism to adapt to changes in the environment.3

Global warming: An increase in the average temperature in the Earth's atmosphere, believed by most scientists to be the result of an enhancement of the greenhouse effect caused by air pollution.3

Goose population: Group of individuals of the same species or subspecies that share the same breeding and wintering ranges and use the same migration routes. Each population has its own fecundity and mortality rates that affect population size. Goose biologists manage each population separately.

Grab sampler: An instrument to sample sediment in water environments. Different models exist (e.g., Van Veen grab sampler, Ponar grab sampler), which often have clamshell buckets that grab a sediment sample from the sea floor.

Herbivore: An animal that feeds primarily on plants.3

Hydrologic cycle: The continuous movement of water in its different states (solid, liquid, gas) on, above and below the surface of the Earth (e.g. from ocean, to the atmosphere, to the land, and back to the ocean).2

Hydrologic projection: Uses meteorological observations from the past and present to be able to estimate the future situation or trend of the water flow in a river.

Hydrology: The study of the movement, distribution, and management of water on Earth including the water cycle and water resources.2

Hydrometric station: Monitoring stations where water quantity and quality data (e.g. river discharge) are collected and recorded.6

Hypothesis: A tentative explanation for an observation, phenomenon or scientific problem that can be tested by further investigation.3

Inorganic matter: Compound that isn't organic, usually it doesn't contain carbon and can be found in non-living things.2

Invertebrates (benthic): Small animals that live in seagrass meadows. Some live in the sediments, while others on the seagrass leaves.

Intertidal: The area between the high-water line and the low-water line during spring (large) tides. This term is used commonly by geologist; see also *Littoral*.3

Land cover (or land use): Data on how much of a specific region has its land covered by forests, water, wetlands, roads, agriculture, and other vegetation types. It is usually determined for large regions by using satellite images.6

Landsat imagery: Imagery of the Earth's surface acquired from a satellite that is part of the Landsat program of the NASA.2

Littoral: The region or zone along the coast, which is intermittently influenced by salt water. It comprises mainly the area between the limits of low tide and high tide, but it also includes higher zones that are regularly wetted by the swash and the spray of waves. This term is used commonly by biologists; see also *Intertidal*.3

Material concentration: Amount of a substance in a defined volume (e.g. the amount of dissolved carbon in one liter of water).

Meadow (or bed): A tract of land where grass or grass-like vegetation is the dominant form of plant life.3 Seagrass meadows are also called seagrass beds.

Mean annual discharge: The average discharge of a river or stream for an individual year (365 days). The average is sometimes calculated over several years. It is expressed typically in cubic metres per second.

Modeling (empirical modeling, computer modeling based on empirical observations): Representing a complex system using observations, mathematics and computer science. The term "empirical work" can be defined as the gathering and analysis of a phenomenon observed in the real world. We can then look at the relationships between observations, build mathematical formulas and expand our knowledge to places where we don't have all the information about the studied phenomenon. For example, we can gather data on watershed size and annual river discharge and then use the relationship between these variables to build a model that will estimate the annual river discharge of other rivers in the same region that couldn't be studied and for which we only know the watershed size. 2,7

Mooring: Oceanographic instruments attached to an anchor for a determined time period (one week to over one year) in order to record water properties at regular time-steps (for example recording of salinity or currents every 15 minutes). Moorings can be vertical structures with anchor-line-buoy, to which instruments are attached, they can be a tripod or platform resting on the seabed, or they can have other shapes. 2

Molt migration: Migration made by yearlings (1-year old), sub-adults, and adults of many species of waterfowl, including Canada geese, that have encountered a nesting failure. The bird's molting sites are in the north and the pre-molt migration is done in late spring.

Nitrate and nitrite (NO3 + NO2): Nitrogen forms that are essential nutrients for the growth of algae and seagrasses.8

Nutrient (for plants): Essential elements for the growth and the reproduction of plants. Phosphate, nitrite, nitrate and ammonium are nutrients for plants. Plants take nutrients from sediments and the water.

Organic matter: Compound that contains carbon-hydrogen bonds and is derived from living matter.2

Pelagic: In the water column of the open sea not directly influenced by the coastal zone; the open water above the sea floor.3

Phenotype: The observable physical or biochemical characteristics of an organism, as determined by both genetic makeup and environmental influences.3

Phenotypic plasticity: The ability to alter one's growth form to suit current conditions; the ability of a genotype to change its phenotype in response to changes in the environment.3

Phosphate (PO4): A naturally occurring form of phosphorus, which is an essential nutrient for the growth of algae and seagrasses.8

Photosynthesis: The process in which green plants and certain other organisms utilize the energy of sunlight to manufacture carbohydrates from carbon dioxide and water in the presence of chlorophyll, usually producing oxygen as a by-product. Photosynthesis produces energy for the organisms to live, grow and reproduce 3

Photosynthetically available radiation (PAR): Light between wavelengths 400 nm (violet) and 700 nm (red) that is used by plants in photosynthesis.4

Physical stresses: Abiotic (heat, water loss, wave impacts) as opposed to biotic (competition, predation) stresses.3

Physico-chemical variables: Related to physics and chemistry characteristics. Temperature and salinity are physical variables of the water, while nutrient concentration is a chemical variable of the water.

Phytoplankton: Single-celled microalgae that are found suspended in the water column and provide that first step in most marine food chain.3

Plankton: The collection of small or microscopic organisms, including algae and protozoans, that float or drift in great numbers of fresh or saltwater, especially at the or near the surface, and serve as food for fish and other larger organisms.3

Population: A group of organisms of the same species living in a given area.3

Pre-dam conditions: The state of the environment in the past before the construction of dams and reservoirs.

Primary producer: An organism that is at the base of the food chain in an ecosystem; usually a green plant or algae.2

Quadrat: Small rectangular plot used for close study of the distribution of plants or animals in an area. We use this term when referring to PVC frames, which were used to determine the shoot density of a given area (e.g. 0.25 m2).3

Remote sensing: The gathering and analysis of data obtain from a remote station, notably from satellite or aerial photography.2

Rhizome: A horizontal, usually underground stem that often sends out roots and shoots from its nodes.3

Regulated river: River that has its natural flow affected by dams, weirs, canalization, or other human intervention.

River discharge (or streamflow): The volume of water, which flows through a river section per unit of time (e.g. cubic metres per second). When no particular location is specified, river discharge is the volume of water per time unit which flows at the river mouth into the sea.2

River diversion: Permanent or temporary removal of water from its natural course by transferring from one watershed to another by using dams, dikes, and levees.6

River export: Quantification of a given material transported by a river to another system such as the coastal ocean.

River plume: A mass of freshwater or brackish water floating on sea water and originating from the river waters discharged into the sea. The extend of a river plume depends notably on the amount of freshwater delivered to the coast, obstacles limiting the plume propagation (e.g. islands), and mixing processes.9

Roots: The usually underground portion of a plant that lacks buds, leaves, or nodes and serves as support, draws minerals and water from the surrounding soil, and sometimes stores food.3

Runoff: Occurs when there is more water than land can absorb. The excess liquid flows across the surface of the land and into lower elevation reliefs such as streams and valleys.2

Salinity: A measurement of the amount of salt that is dissolved in sea water. It is defined either on the *practical salinity scale* without units (indicated sometimes by *psu*) or as the newer *absolute salinity* in g/kg 3

Sample: A small portion of something that preserves the same characteristics of a larger group. Water samples are a small portion of the water (e.g. 1 liter) present at a specific location and is taken because we cannot study the total volume of water present at this location.

Sand: Mineral particle with a size between 0.063 and 2 mm (bigger than clay and silt), forming a major constituent of beaches, riverbeds, the seabed, and deserts.

Secchi disk: A white and black disk used to measure the transparency of seawater by lowering the disk into water until it can no longer be observed.2

Sediment: Generally inorganic particles that get deposited on the seabed, river beds, lake bottoms and the ground. Sediment can also contain a fraction of organic particles. An important characteristic of sediment is the size of the individual particles (also called grain size). On the seabed the grain size ranges generally from fine clay to coarse gravel.3

Silt: Mineral particle with a size between 0.002 (or 0.004) and 0.063 mm, bigger than clay but small than sand.

Spatial resolution: The spatial precision of measurements or observations. The term can be used for the distance between sampling stations (an area with a higher spatial resolution has a greater number of stations) or the pixel size of remote sensing images (high-resolution images have smaller pixels than low-resolution images, but more pixels per unit of surface).

Sheath: In plants, the protective covering at the base of the blade or stalk that covers the stem; an enveloping structure or covering enclosing an animal, plant organ or plant.3

Shoot: One of two primary sections of a plant; the other is the root. The shoot refers to what is generally the upper portion of a plant, and consists of stems, leaves, flowers, and fruits.3

Sampling Site: Location in the space where a sample was collected or an observation was done. Usually we use GPS coordinates to register a sampling location.

Stress/stressor: A perturbation applied to a system (a) which is foreign to that system or (b) is natural to that system but applied at an excessive level. In marine ecosystems, stressors are often anthropogenic, resulting from coastal development (e.g. excess nutrients/contaminants like nitrogen and phosphorus, overfishing, invasive species, increased temperature, etc.). Extreme values in temperature, precipitation, river discharge, or waves are natural stressor in marine environments. When multiple stressors occur, they can interact and intensify, altering predictability within that system, and therefore resulting in difficulty for restoration and management strategies.3

Sublittoral: The subtidal zone below the low tide line; permanently immersed. The sublittoral zone extends to the edge of the continental shelf.3

Suspended particulate matter (SPM): Particles of size greater than 0.7 µm, which are suspended in the water column and cannot dissolve in water. SPM can be composed notably of fine inorganic sediments (clay, silt, and fine sand) and living or dead small organisms. SPM concentration is measured by filtration of a water sample. SPM makes the water more turbid or murky, and it diminishes light as it penetrates water.2

Tolerance: The power or capacity of an organism to survive unfavorable environmental conditions.3

Total Nitrogen (TN): Sum of different forms of the chemical element nitrogen in the water that can be used by plants, including nitrate, nitrite, and ammonia, but not the gas dinitrogen (N2). It can also be supplemented by runoff of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent.

Total Phosphorus (TP): Sum of different forms of the chemical element phosphorus in the water. Natural sources are soil, dissolving rocks, and from the biomass of plants and animals. It can also be supplemented by runoff of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent.

Tunicates: Sea squirts; a type of filter-feeding organisms that are common fouling organisms. Larvae show characteristic chordate features also found in the embryos of vertebrates.3

Turbidity: A cloudiness or haziness of water caused by suspended particles, especially clay and silt, which are stirred up (resuspended) locally or advected from a distant source.3

Water column: The water mass lying above the seafloor; the open water where planktonic and nektonic (swimming organisms) organisms live.3

Watershed (or drainage basin or catchment area): Any area of land where precipitation and snowmelt are collected and drained off into a common outlet, such as into a river or a lake. Usually they are bounded by hills, valleys, or mountains.2

Watershed properties: Characteristics of a given watershed, like size, elevation and land cover.

Wetlands: Ecosystem that is flooded by water, either permanently or seasonally. Land consisting of marshes or swamps.2,91

Wrack: Floating plant material (often containing seeds) that is carried away by winds and currents onto shorelines.3

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APPENDIX C

History of eelgrass mapping in eastern James Bay

Draft manuscript prepared by: Melanie-Louise Leblanc, University of British Columbia

Eelgrass (*Zostera marina*) mapping in eastern James Bay, Québec, Canada from 1974 to 2014

Coastal Habitat Comprehensive Research Project

March 2022_*Draft*

Coastal Habitat Comprehensive Research Project

Introduction

From 1974 through 2014, eelgrass beds were mapped throughout James Bay. The document contains information about the various maps created over the years, as well as who created them, and the methods used to create them. In 1974 and 1991, the entire eastern coastline was mapped. In 1982 and 1996, the northern sector of the coast (from Cape Jones to Castor River) was mapped. In 2011 and 2014, a few eelgrass beds north of Castor River were mapped. Table 1 summarizes the information. The place names presented in the document are the ones used by the authors.

Table 1 Summary of methods for mapping the distribution of eelgrass beds along the northeast coast of James Bay from 1976 to 2014.

	1975	1982	1986-1987*	1991-1992 A*	1991-1992 B*	1995-1996*	2011	2014
Mapping method	Data were gathered in August 1974 in the area north of Old Factory and August 1975 for the area south of Old Factory, mainly by means of helicopter surveys flown at low tide when the eelgrass beds are most visible.	Interpretation of 1:31 680 aerial photos black and white photos Topographic maps at a scale of 1:50, 000.	Interpretation of 1:10, 000 color aerial photos taken at low tide most of the time in August and September 1986. Topographic maps at a scale of 1:50, 000.	Color aerial photos at a scale of 1:10, 000 taken in 1986. Topographic maps at a scale of 1:50 000. Eelgrass distribution map of 1986-1987 at 1:125 000.	Color aerial photos at a scale of 1:10, 000 taken in 1986. Topographic maps at a scale of 1:50 000.	Interpretation of 1:10,000 scale color aerial photos taken at low tide in August 1995. Topographic maps at a scale of 1:50 000 enlarged to 1:10 000 on which the on which the results of the photointerpretati on were plotted	Interpretation of 1:10,000 scale color aerial photos taken at low tide in July 2011.	Interpretation of 1:10,000 scale color aerial photos taken at low tide in August 2014.
Ground truthing	Information provided by local James Bay Cree, familiar with eelgrass distribution, augmented the data base.	Validation August 1982. Stop checks during aerial surveys – near the La Grande River	Helicopter flights at low speed and low altitude Duration: 6 days in early August 1987 regardless of tidal phase Verification dives Validation does not cover the entire photointerpreted area	Helicopter flights at low speed and low altitude Flights always carried out at low tide Eight days (25 07 01 08 in 1991) Verification dives Validation of two coastal segments	Helicopter flights at low speed and low altitude Flights always carried out at low tide	Low speed, low altitude helicopter flights combined with higher altitude flights Flights always carried out at low tide Three weeks (29/07/1996 to 16/08/1996) Verification dives Complete validation of the entire photointerpreted territory (Figure 3)	No ground truthing	No ground truthing

Table 1 *Continued* Summary of methods for mapping the distribution of eelgrass beds along the northeast coast of James Bay from 1976 to 2019 (* from 197 to 1992 from Lalumière et al., 1996).

	1975	1982	1986-1987*	1991-1992A*	1991-1992B*	1995-1996*	2011	2014
Eelgrass classification	Four classes: 1-10%; 11-40%; 41-70% and > 70%	Four classes: 1-10%; 11-40%; 41-70% and > 70%	The assessment of eelgrass cover includes two classes: high density (continuous eelgrass cover or discontinuous cover where the plant cover is >50%) and low density (loose or patchy cover and where the proportion of bare areas exceeds 50%)				Dense and continuous eelgrass beds	
Spatial extent	Entire coastline	Northeast territory	Northeast territory	Northeast territory	Southern territory	Northeast territory	Few estuaries	Few estuaries
Mapped produced	1:125 000 km	1:50 000 km	1:125 000 km (the eelgrass distribution is also available as working papers at the following scales: 1:10 000 and 1:50 000)			1:125 000 km	1:2 km	1:2 km

Eelgrass distribution 1975

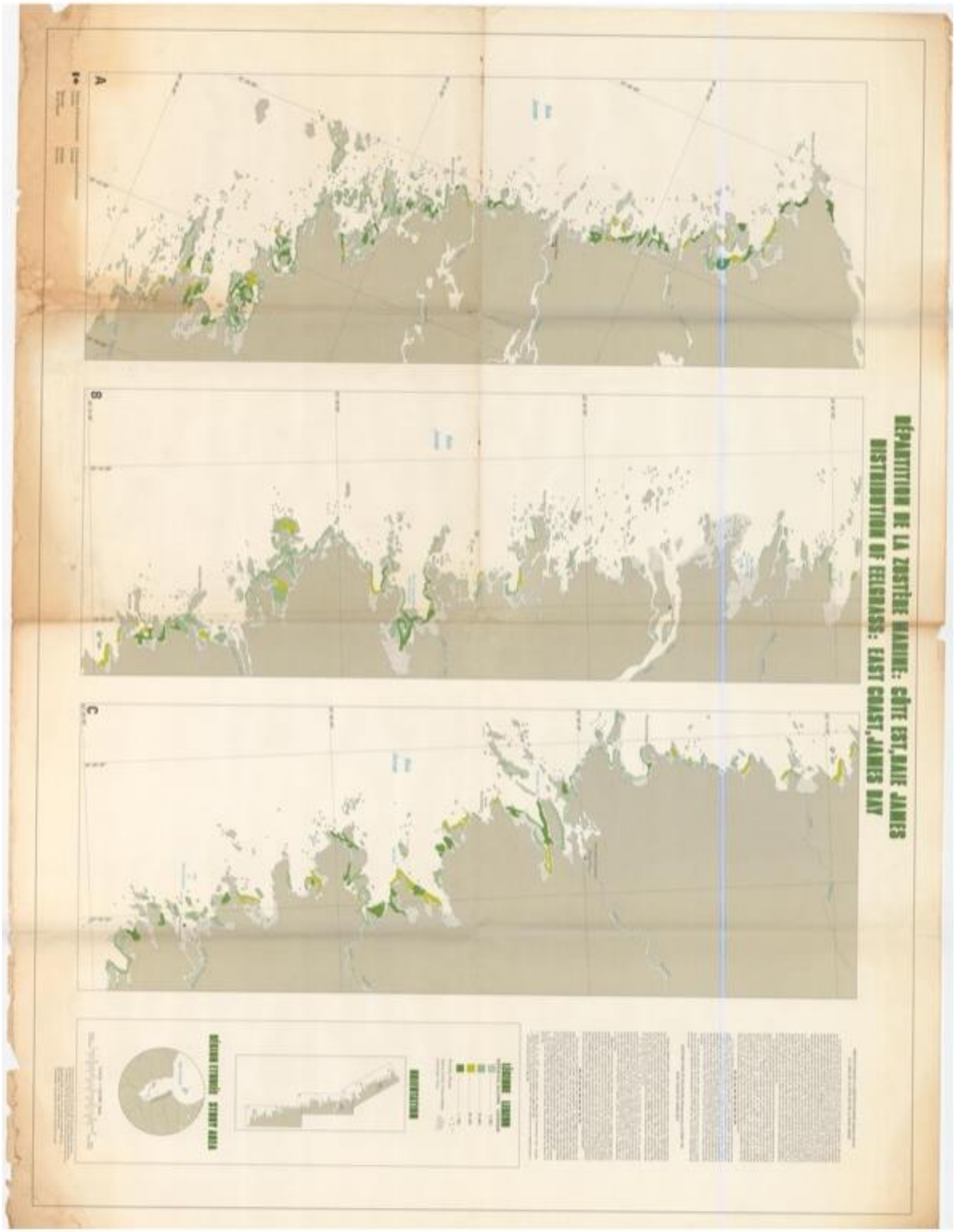
Reference: Curtis, S.C. 1974-1975. Distribution of eelgrass: east coast, James Bay. Map at a scale of 1:125, 000. Canadian Wildlife Service, Ottawa, ON.

<u>Methods (summary in Table 1)</u>:

The map was produced by Steven Curtis, biologist for the Canadian Wildlife Service (CWS). Methods on map reads "*Data were gathered in August 1974 in the area north of Nouveau-Comptoir and August, 1975 for the area south of Nouveau-Comptoir, mainly by means of helicopter surveys flown at low at low tide when eelgrass beds were most visible*." During his fieldwork, the author used medium-scale black-and-white aerial photographs and 1:50 000 topographic maps to make a direct transfer of the beds observed. There was no preliminary photo interpretation. During the helicopter flights, frequent stops were made for ground checks. Eelgrass distribution on the map is presented in four cover classes 1 (1-10%), 2 (11-40%), 3 (41-70%) and 4 (>70%).

- Eelgrass distribution and author's comments (see map below):
  - All major beds are said to be included. No major beds were detected south of Old-Factory.
  - Eelgrass at depths greater than two meters at low tide may have been missed.
  - According to Curtis, eelgrass beds with cover ranging between 11 to 40% were more frequent. Dense eelgrass beds (70 to 100%) were found in a few bays such as the Kakassituq Point area, Dead Duck Bay and Comb Islands.
  - By Curtis' own account, the map produced in 1974-75 is not rigorously accurate, but it does approximate the location of major concentrations of marine eelgrass along the eastern coast of James Bay. In fact, the map deliberately schematizes the outline of the coast and islands rather than faithfully reproducing the shoreline division (Lalumière et al., 1987). This map is not indented to depict every location where eelgrass exists, however, all major beds have been included.

C-6


RÉPARTITION DE LA ZOSTÈRE MARINE: CÔTE EST, BAIE JAMES
DISTRIBUTION OF EELGRASS: EAST COAST, JAMES BAY

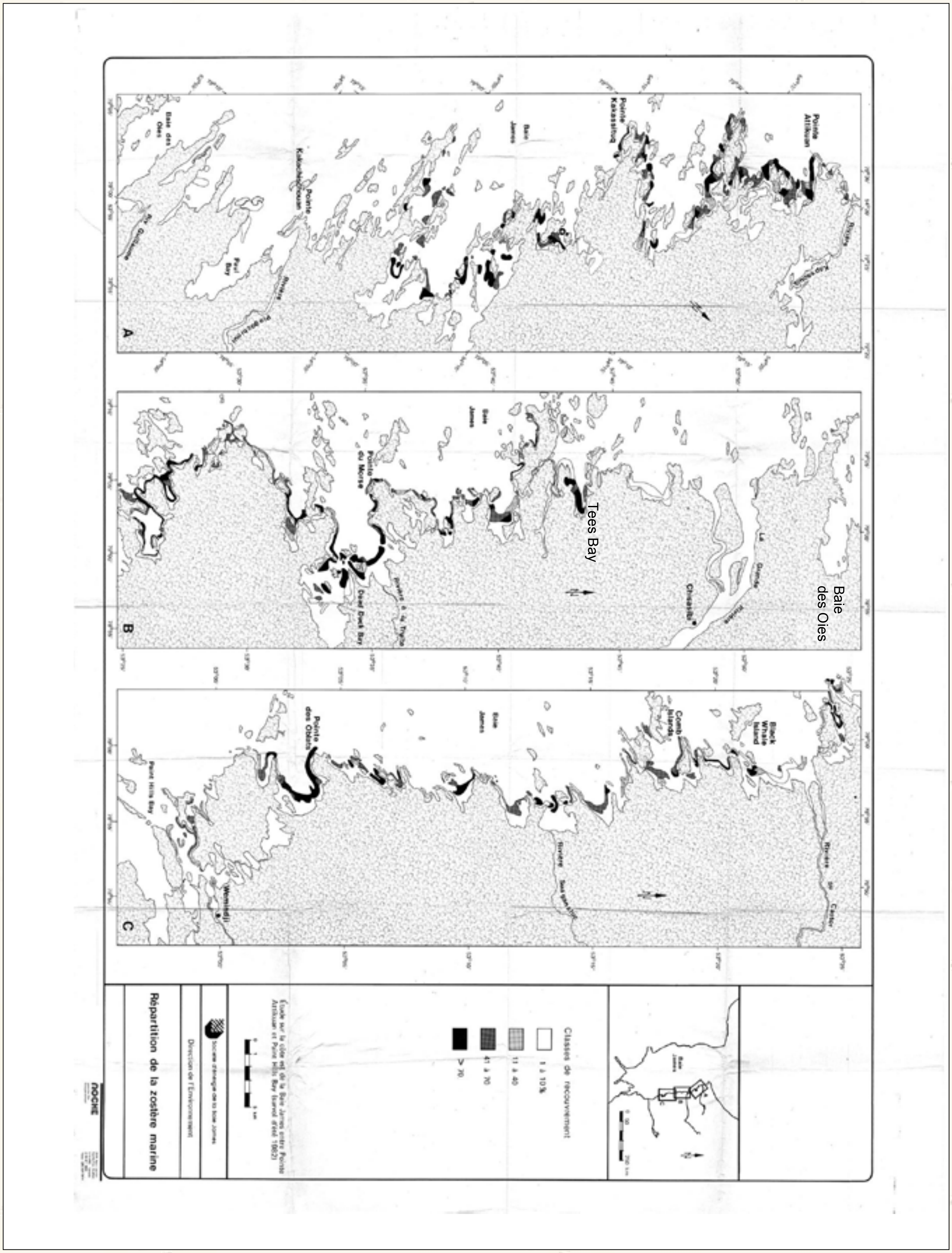
Eelgrass distribution 1982

Reference: Roche Ltée, 1982. Études océanographiques de la côte est de la baie James. Tome III. La végétation littorale. Rapport pour le compte de la Société d'énergie de la baie James. 104 p. et annexes.

Methods (summary in Table 1):

In 1982, the Société d'énergie de la Baie James commissioned Roche Ltd. to update a portion of the map produced by Curtis (1974-75). Aerial photographs, in black and white, at a scale of 1:31 680 were used to make direct transfers of the beds observed. There was no preliminary photo interpretation. The aerial photographs used were from 1959, taken in early July, August, and September (Lalumière, 1987). The cover classes were the same as those used by Steven Curtis. Validation work took place in August 1982 from the mouth of the Kapsaouis River in the north to Nouveau-Comptoir in the south. The entire coastline was flown, but the islands were excluded from the inventory (Lalumière et al., 1987).

- Eelgrass distribution and author's comments (see map below):
  - Eelgrass was particularly visible at low tide and easily observable down to two meters depth.
  - The areas of greatest abundance of eelgrass are between Attikuan Point and Kakassituq Point, as well as in the Dead Duck Bay area and at Oblate Point. In these areas at low tide, eelgrass generally covers more than 70% of any muddy bottom less than two meters deep.
  - Seen from the air, dense eelgrass beds are dark green; medium to low density eelgrass beds appeared greenish-gray because the eelgrass is shorter than the water depth. The mouth of La Grande Rivière is completely devoid of eelgrass as far north as Bay des Oies and as far south as Tees Bay.
  - No significant change in distribution between 1974 to 1982. Eelgrass beds found in the same locations. The areas of very high cover remained the same in 1982 as in 1974.


A
B
C
Tees Bay
Baie
des Oies
Pointe
du Morse
Pointe
des Ouais
Baie
James
Répartition de la zostère marine
Classes de recouvrement
1 à 10 %
11 à 40
41 à 70
> 70

Eelgrass distribution 1986-1987

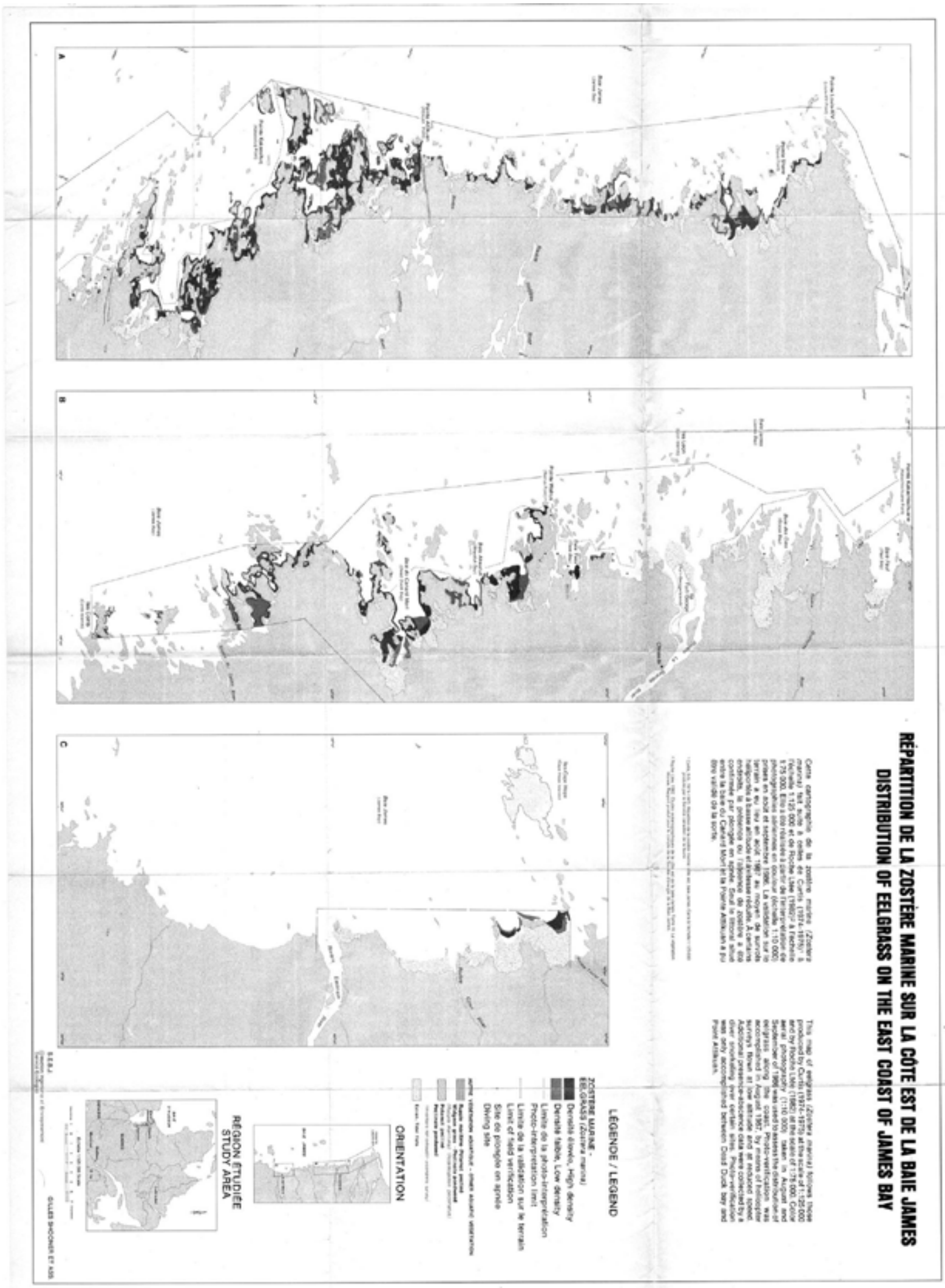
Reference: Lalumière, R. (1987). Répartition de la zostère marine (*Zostera marina*) sur la Rapport de Gilles Shooner et Associés à la Direction Ingénierie et Environnement de la SEBJ. Québec. 30 p. + annexes.

Methods (summary in Table 1):

The map reads "*This map of eelgrass follows those produced by Curtis (1974-75) at the scale of 1:125 000 and by Roche Ltée (1982) at the scale of 1:75 000. Color aerial photography (1:10 000) taken in August and September of 1986 was used to assess the distribution of eelgrass along the coast. Photo-verification was accomplished in August 1987, by means of helicopter surveys flown at low altitude and at reduced speed. The surveys were conducted at low and high tides (Lalumière et al., 1991). Additional presence-absence data were collected by diver snorkeling over certain sites. Photo-verification was only accomplished between Dead Duck bay and Point Attikuan*." Initially, the authors employed the same four classes as Curtis (1974-75) and Roche Ltée (1982). However, they felt that the classification was far too subjective. As a result, the authors used two categories of conservation: high density (above 50%) and low density (below 50%). Ground permitted to detect meadows of *Ruppia maritima* and sago pondweed (*Stuckenia pectinata*) that were identified as eelgrass by Curtis (1974-75) and Roche Ltéé (1982).

- Eelgrass distribution and author's comments (see map below):
    - Similar eelgrass distribution to the Curtis 1974-75 map but extent of eelgrass meadows differs (most likely due to ground truthing surveys in 1987).

C-10


RÉPARTITION DE LA ZOSTÈRE MARINE SUR LA CÔTE EST DE LA BAIE JAMES
DISTRIBUTION OF EELGRASS ON THE EAST COAST OF JAMES BAY
Cette cartographie de la zostère marine (Zostera marina) fait suite à celles de Curtis (1974-1975)[1] à l'échelle 1:125 000 et de Roche Ltée (1982)[2] à l'échelle 1:75 000. Elle a été réalisée à partir de l'interprétation de photographies aériennes en couleur (échelle 1:10 000) prises en août et septembre 1986. La validation sur le terrain a eu lieu en août 1987 au moyen de survols héliportés à basse altitude et à vitesse réduite. À certains endroits, la présence ou l'absence de zostère a été confirmée par plongée en apnée. Seul le littoral situé entre la baie du Canard Mort et la Pointe Attikuan a pu être validé de la sorte.
This map of eelgrass (Zostera marina) follows those produced by Curtis (1974-1975) at the scale of 1:125 000 and by Roche Ltée (1982) at the scale of 1:75 000. Color aerial photography (1:10 000) taken in August and September of 1986 was used to assess the distribution of eelgrass along the coast. Photo-verification was accomplished in August 1987, by means of helicopter surveys flown at low altitude and at reduced speed. Additional presence-abscence data were collected by a diver snorkeling over certain sites. Photo-verification was only accomplished between Dead Duck bay and Point Attikuan.
LÉGENDE / LEGEND
ZOSTÈRE MARINE -
EELGRASS (Zostera marina)
Densité élevée, High density
Densité faible, Low density
Limite de la photo-interprétation
Photo-interpretation limit
Limite de la validation sur le terrain
Limit of field verification
Site de plongée en apnée
Diving site
ORIENTATION
RÉGION ÉTUDIÉE
STUDY AREA
A
B
C
GILLES SHOONER ET ASS.

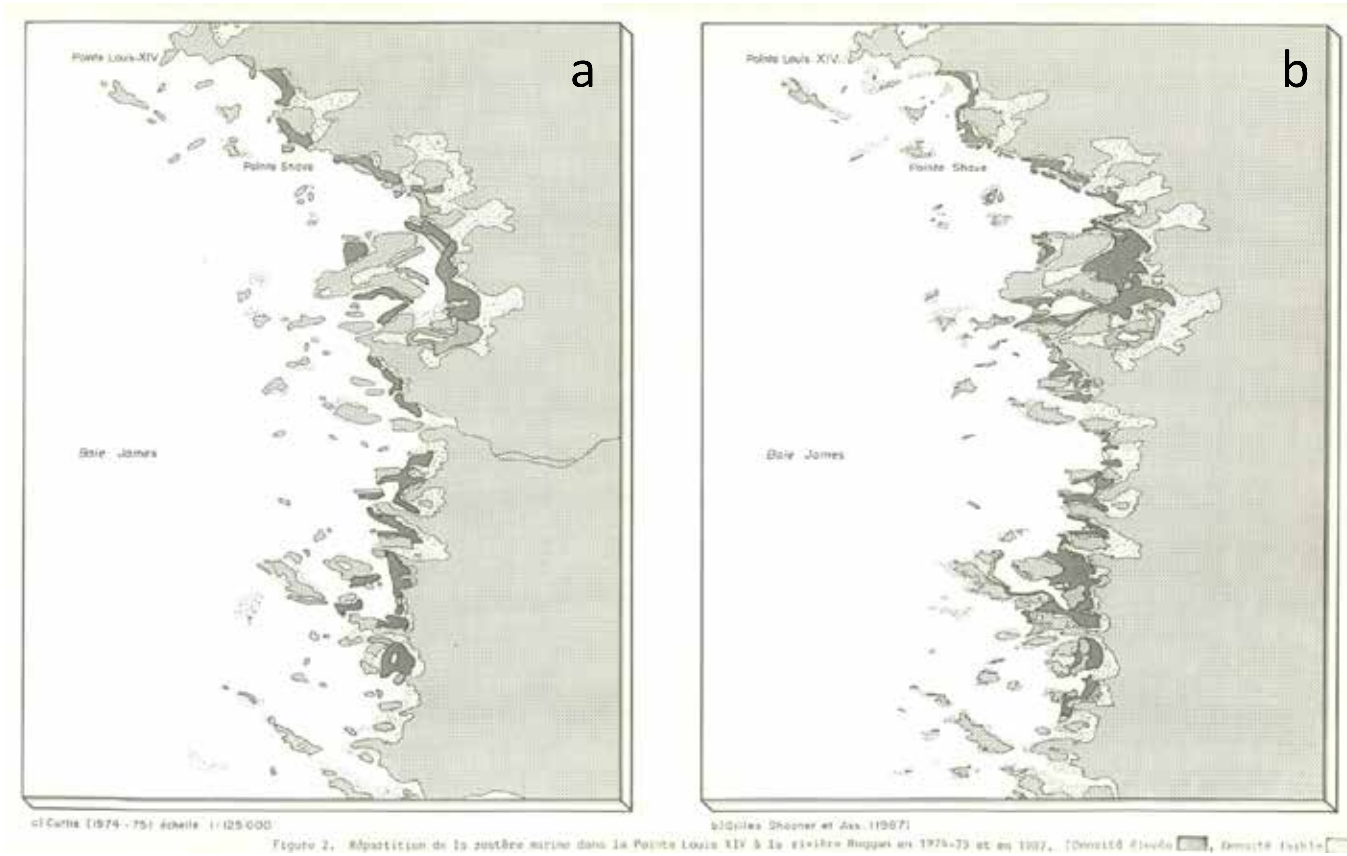
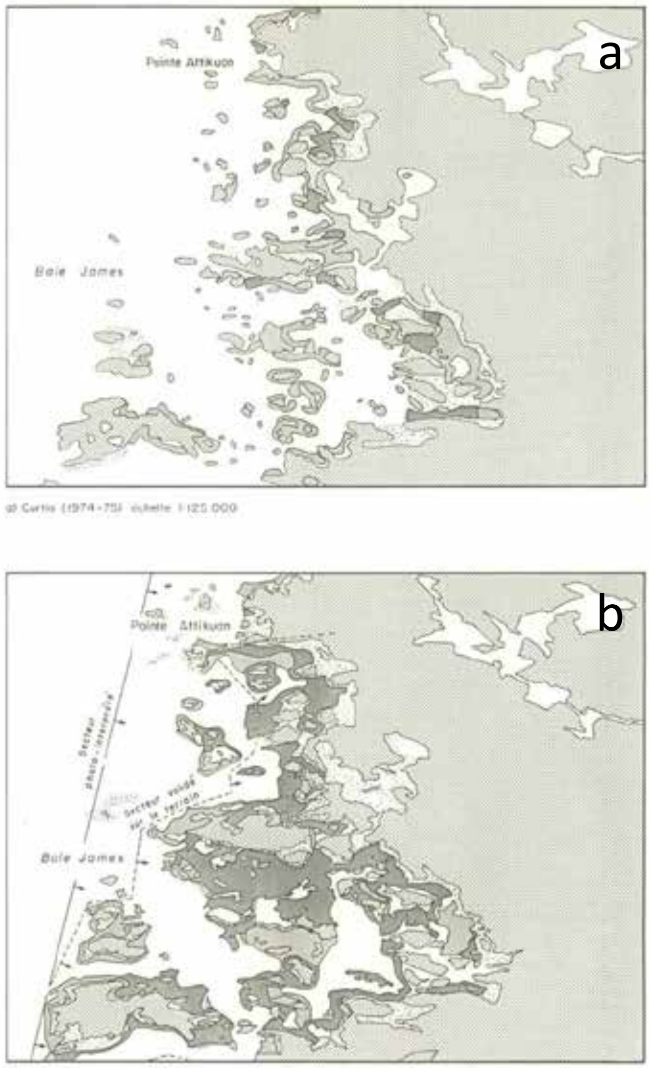


Figure 1. Eelgrass distribution from Pointe Louis XIV to Roggan River in a) 1974-75 and b) 1987. Dark gray representing dense meadows (above 50%) and light gray representing low density meadows (below 50%).



a) Curtis (1974-75) échelle 1:125 000

b) Gilles Shooner et Ass. (1987)

Figure 3. Répartition de la zostère marine de la Pointe Attikuan à la Pointe Kakassituq en 1974-75 et en 1987.
(Densité élevée ▭ , Densité faible ▭)

Figure 2. Eelgrass distribution from Pointe Attikuan to Pointe Kakassituq in a) 1974-75 and b) 1987. Dark gray representing dense meadows (above 50%) and light gray representing low density meadows (below 50%).

C-13

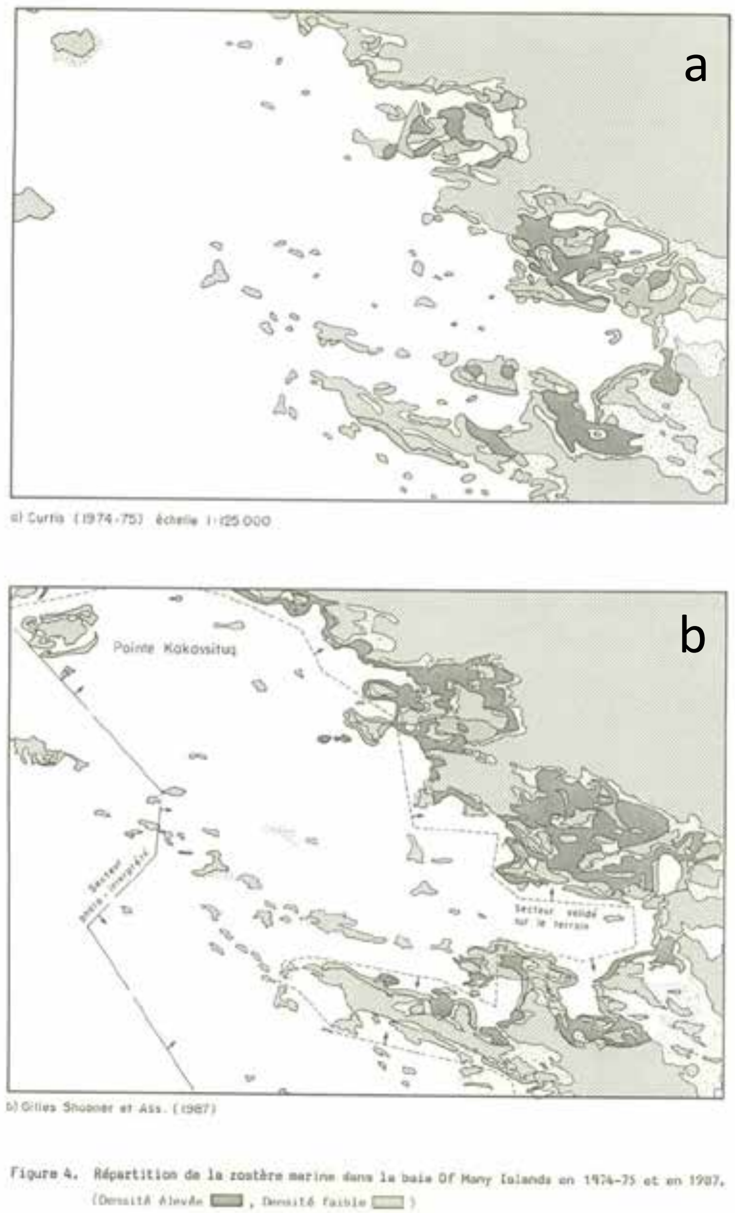


Figure 3. Eelgrass distribution in Bay of Many Islands in a) 1974-75 and b) 1987. Dark gray representing dense meadows (above 50%) and light gray representing low density meadows (below 50%).

C-14

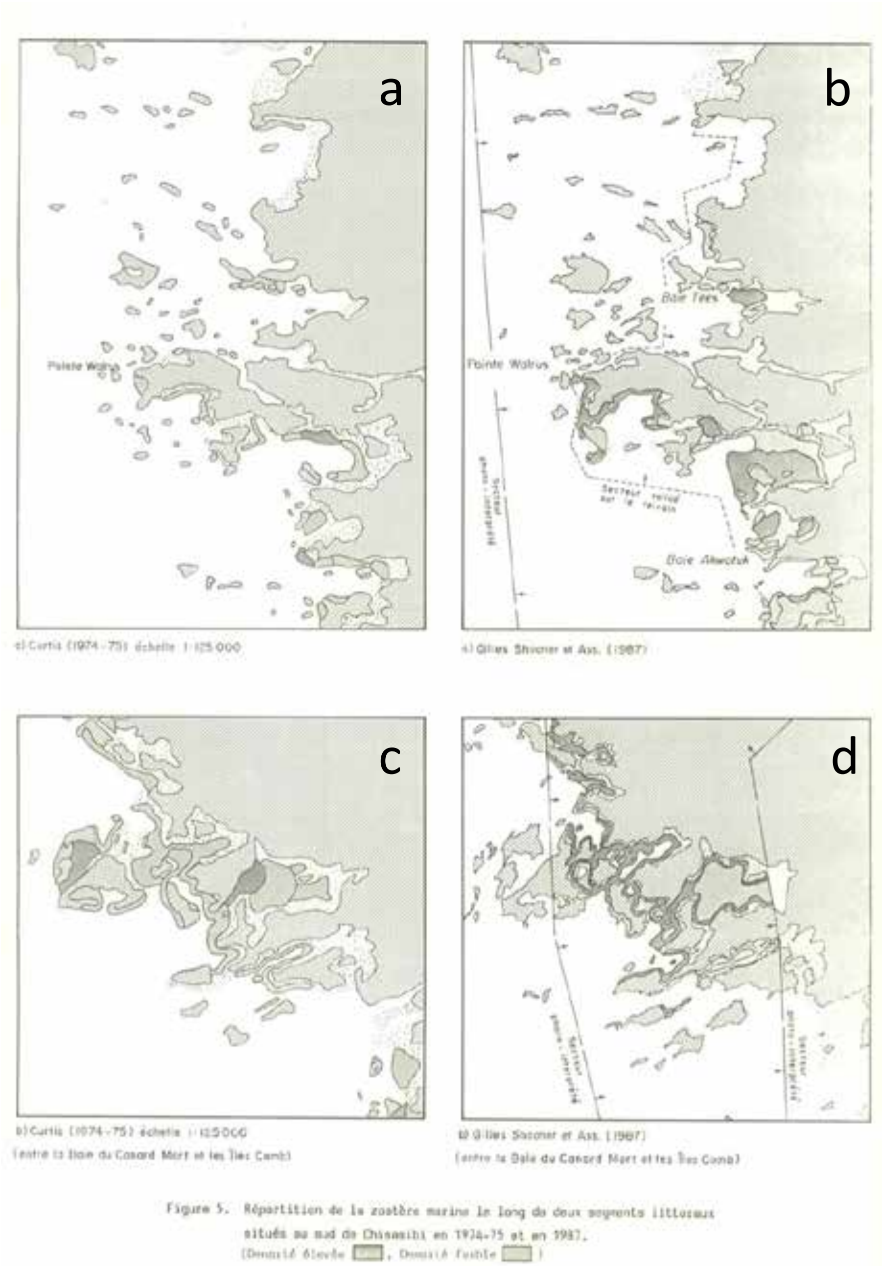


Figure 4. Eelgrass distribution in Tees Bay in a) 1974-75 and b) 1987, and near Comb Island in d) 1974-75 and e) 1987. Dark gray representing dense meadows (above 50%) and light gray representing low density meadows (below 50%).

C-15

Eelgrass distribution 1991 - A

Reference: Lalumière, R, Belzile, L, & Lemieux, C. (1991). Étude de la zostère marine le long de la côte nord-est de la baie James (été 1991). Rapport de Gilles Shooner et Associés à la Direction Ingénierie et Environnement de la SEBJ. Québec. 31 p. + annexes.

Methods (summary in Table 1):

Field work was conducted from July 25 to August 1, 1991. Three documents were used to support the field work: a map produced in 1987 (scale 1:125 000), aerial color photographs (scale of 1:10 000) taken in the summer of 1986 and the topographic maps (scale of 1:50 000). Low-level, slow-moving helicopter flights allowed observers to plot the distribution of eelgrass beds directly on the 1:50 000 topographic maps. In several locations, the presence or absence of eelgrass was confirmed by diving. The helicopter surveys were only conducted at low tide. As in 1987, the density of the meadows was noted according to two classes, high and low density. The first class (dense eelgrass) corresponds to a continuous cover of eelgrass or to a discontinuous cover where the coverage of the eelgrass is greater than 50 %. The second class (low density eelgrass) corresponds to patchy coverage where the proportion of bare areas exceeds 50%. The northern and southern sectors were completely overflown, including the offshore islands. The 1991 map shows the boundary of the eelgrass distribution established by photo-interpretation and the boundary of the area where eelgrass has been validated in the field. The eelgrass distribution map in 1991 is considered to be more accurate than the 1987 map for the following reasons: 1- better observation conditions in 1991, 2- helicopter surveys and ground truthing were always conducted at low tide. Mapping results of 1991 showed that in certain shallow areas there are noticeable changes compared to the 1987 distribution. These changes were attributed to isostatic rebound and ice scouring.

- Eelgrass distribution and author's comments (see map below):

  Northern sector:

  - The main concentrations of eelgrass are present in the same locations and in equivalent densities between 1987 and 1991.
  - The limit of the meadows in the subtidal zone differs in several places from one year to another. Authors mention that this is due to the difficulty of locating it

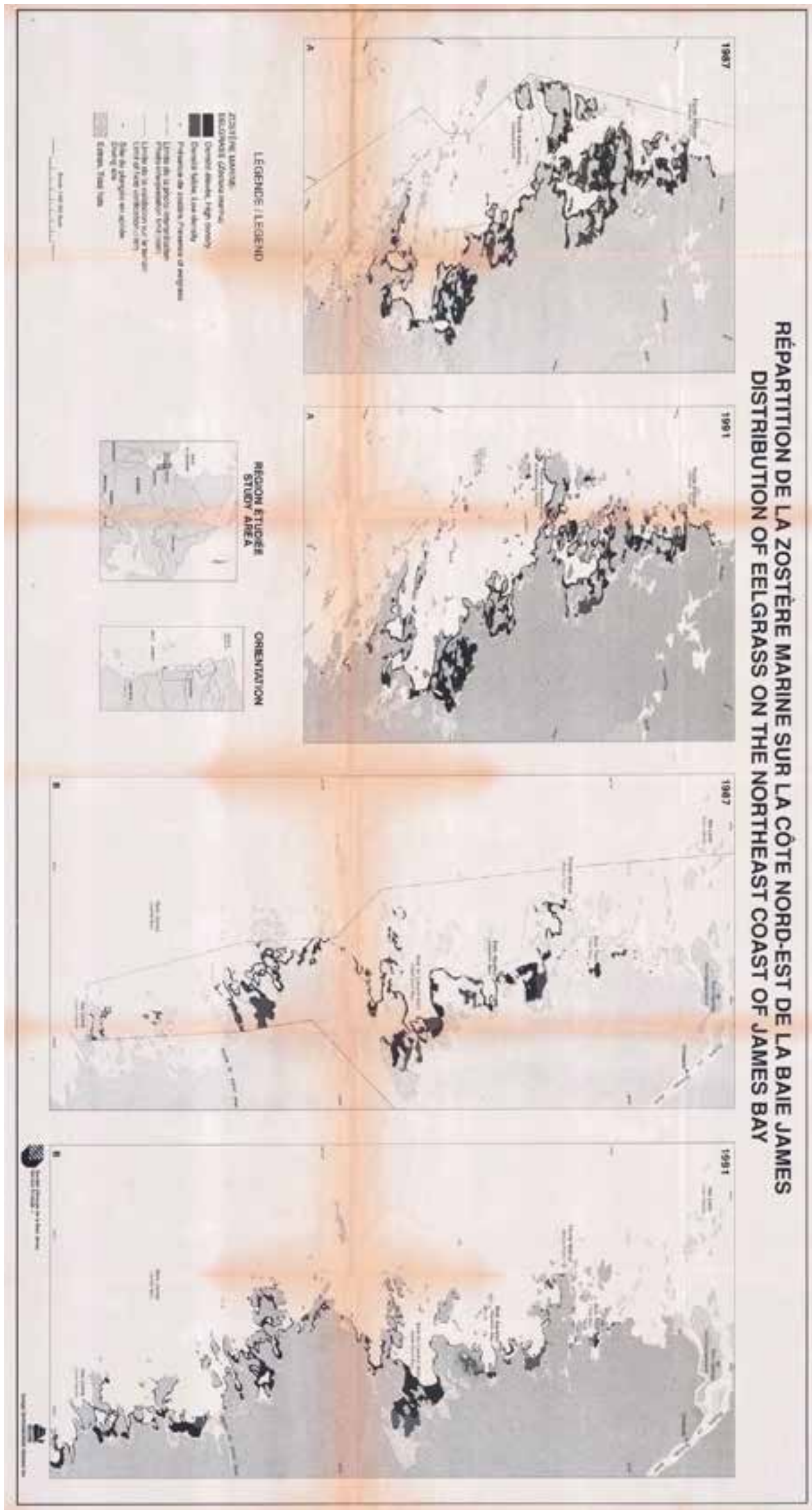
well during aerial surveys, and even during diving, when the water depth increases.

- The authors stated that the general distribution of eelgrass beds in this sector seemed stable between 1987 to 1991.

Southern sector:

- Important changes between 1987 to 1991 were observed at Tees bay, Akwatuk bay and Dead Duck Bay. Authors state that these differences are due to turbid water and high waves action during the helicopter surveys and photo-interpretation in 1987. According to the authors, these conditions could have led to overestimate the distribution of the eelgrass beds in 1987.
- The authors note the presence of eelgrass near the Castor River mouth, where winter salinity drops down to 5.
- The loss of eelgrass near the meadows edge is attributed to isostatic rebound and ice scouring.

C-18


RÉPARTITION DE LA ZOSTÈRE MARINE SUR LA CÔTE NORD-EST DE LA BAIE JAMES
DISTRIBUTION OF EELGRASS ON THE NORTHEAST COAST OF JAMES BAY
1987
1991
1987
1991
A
A
B
B
LÉGENDE / LEGEND
RÉGION ÉTUDIÉE
STUDY AREA
ORIENTATION

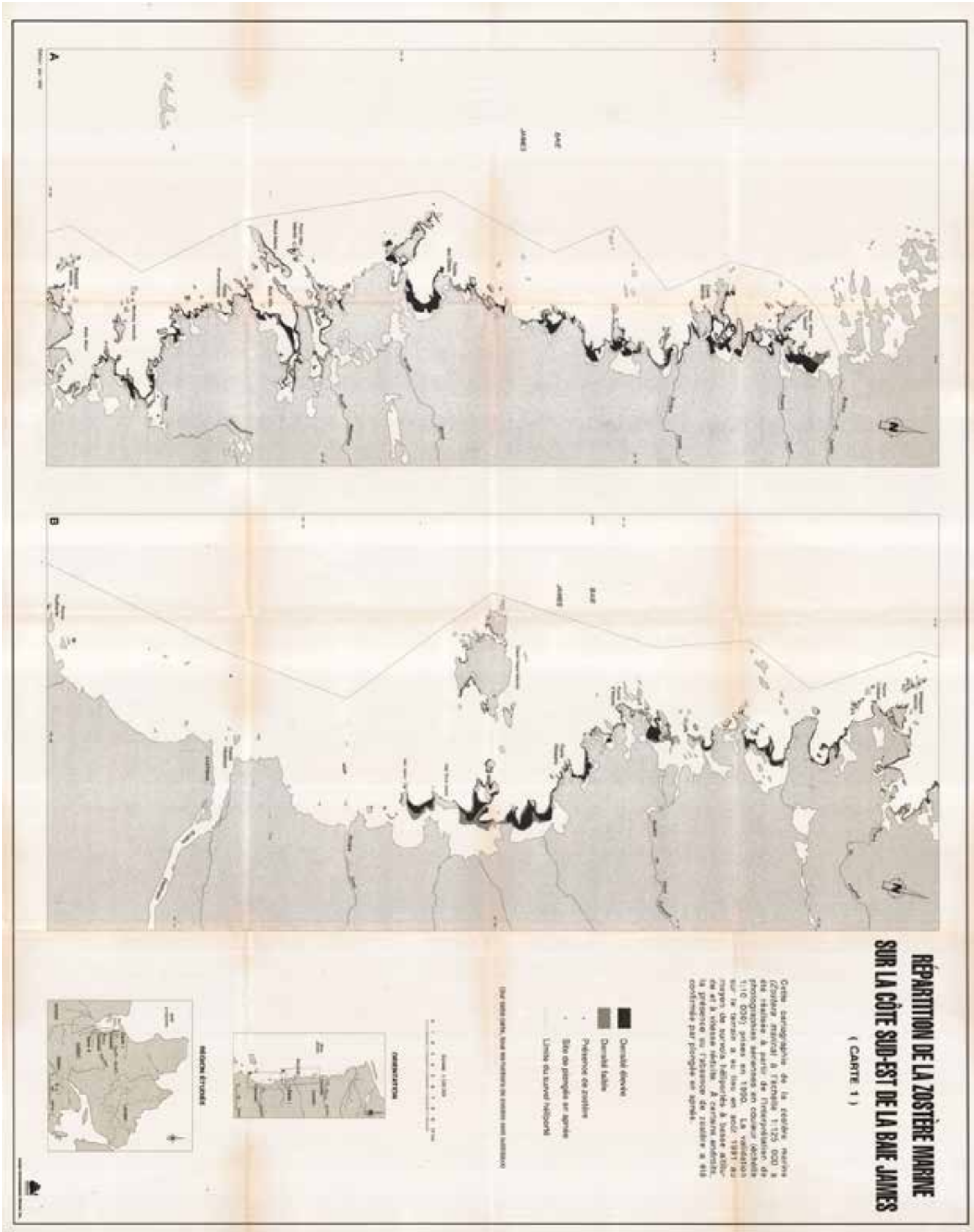
Eelgrass distribution 1991 – B

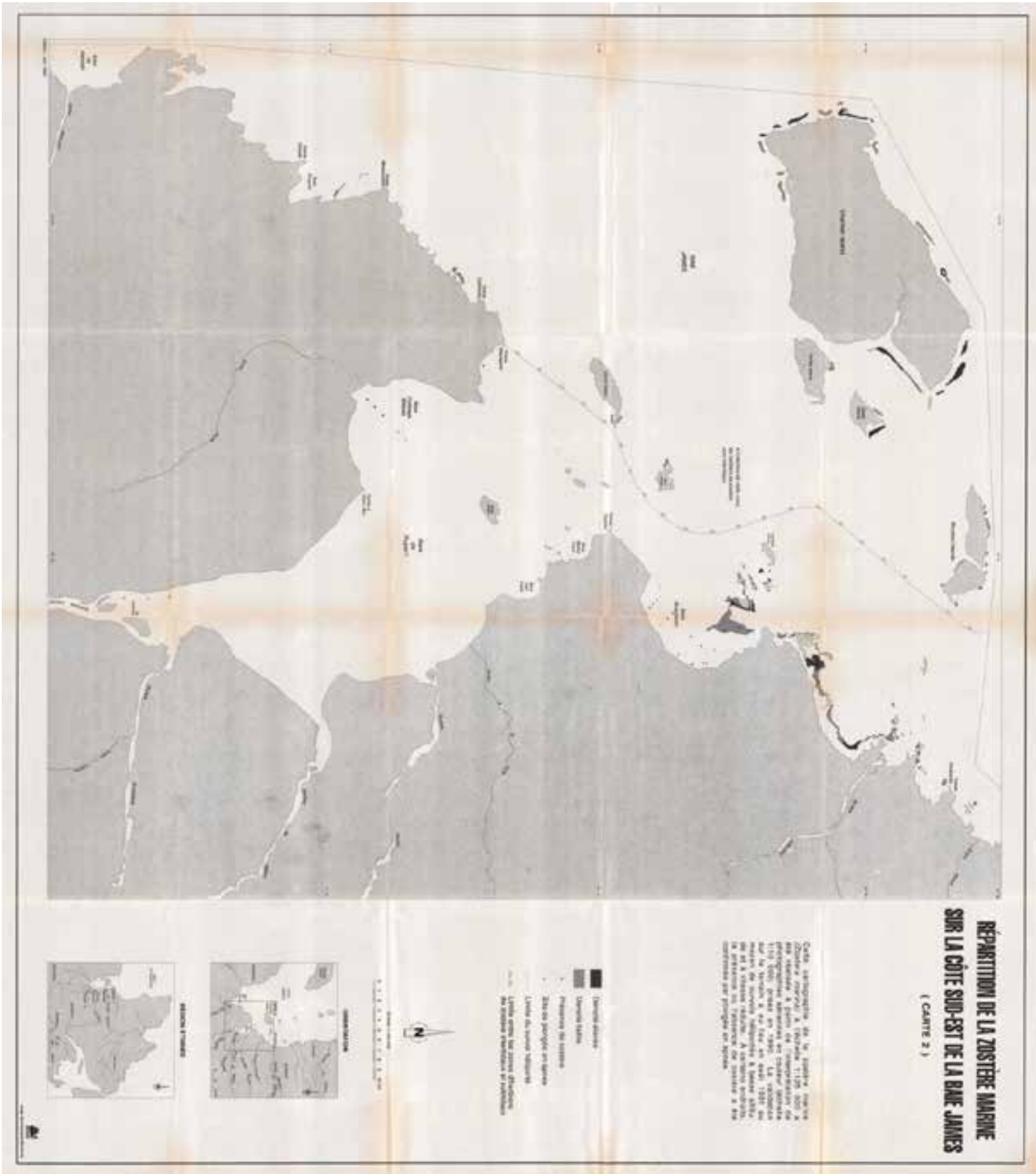
Reference: Groupe Environnement Littoral. (1992). Complexe NBR. La zostère marine. Rapport présenté à Hydro-Québec, Vice-présidence Environnement. Montréal, Québec, Groupe Environnement Littoral, 9 p., 1 figure et 2 pl.

Methods (summary in Table 1):

Field work was conducted from August 5-23, 1991. Two documents were used to support the fieldwork: 1) 1:10 000 color aerial photographs taken in the summer of 1990 and 2) 1:50 000 topographic maps. Low altitude, slow speed helicopter flights allowed observers to plot the distribution of eelgrass beds directly on the topographic maps. It is important to note that the helicopter flights were conducted only at low tide in order to better delineate the eelgrass beds, particularly in the subtidal zone. In several places, the presence or absence of eelgrass was confirmed by diving. About sixty control points were carried out in this way. The presence of eelgrass beds on the top of the beach was used in several places as a clue for the verification dives. As in 1987, the density of the meadows was noted according to two classes, high and low density. The first class (dense eelgrass) corresponds to a continuous cover of eelgrass or to a discontinuous cover where the coverage of the eelgrass is greater than 50 %. The second class (low density eelgrass) corresponds to patchy coverage where the proportion of bare areas exceeds 50%. The entire mapped area was completely overflown, including the offshore islands. (Charlton, Danby, Carey, Strutton, Cape Hope, Walrus and Paint Hills as well as a few unnamed small islands). The map shows the distribution of eelgrass at a scale of 1:125 000.

- Eelgrass distribution and author's comments (see map below):
    - To the south, the last extensive eelgrass beds are located in the upper part of Boatswain Bay. South of Boatswain Bay, the species forms more or less discontinuous linear bands in the intertidal zone colonizing the troughs where there is still water at low tide.
    - Eelgrass is completely absent from Rupert Bay.


RÉPARTITION DE LA ZOSTÈRE MARINE
SUR LA CÔTE SUD-EST DE LA BAIE JAMES
(CARTE 1)
Densité élevée
Densité faible
Présence de zostère
Site de plongée en apnée
Limite du survol héliporté
BAIE
JAMES
A
B


RÉPARTITION DE LA ZOSTÈRE MARINE
SUR LA CÔTE SUD-EST DE LA BAIE JAMES
(CARTE 2)

C-21

Eelgrass distribution 1995-96

Reference: Lalumière, R., Lemieux, C. et L. Belzile. (1996). Répartition de la zostère marine (*Zostera marina*) sur la côte nord-est de la baie James – Éte 1996. Rapport du Groupe-conseil Génivar présenté au Service écologie, Direction Ingénierie et Environnement, Société d'énergie de la Baie James. 44 p. et 4 annexes.

Methods (summary in Table 1):

The 1996 eelgrass distribution map is based on the interpretation of 1:10 000 color aerial photographs taken at low tide in August 1995. The area covered is the same as in 1986-1987. The results of the photo-interpretation were transferred to 1:10 000 enlargements of 1:50 000 topographic maps, which were used for field validation. The field validation took place from 29 July to 16 August 1996 by the same observers who had carried out the 1991 field work. The helicopter overflights were conducted at low tide to optimize visual detection of the beds. Validation included both low-speed, low-altitude overflights and high-altitude (~ 500-750 m) overflights, the latter allowing for easier location of the lower limit of the meadows. As in 1986-1987 and 1991-1992, numerous verification dives were carried out and the assessment of meadow cover was also done in two classes (high density and low density). The first class (dense eelgrass) corresponds to a continuous cover of eelgrass or to a discontinuous cover where the coverage of the eelgrass is greater than 50 %. The second class (low density eelgrass) corresponds to patchy coverage where the proportion of bare areas exceeds 50%. The entire area covered by the photo-interpretation was validated in the field.

- Eelgrass distribution and author's comments (see map below):

Northern sector:

- In general, the high density eelgrass beds indicate a clear spatio-temporal stability during the period 1986-1995.
- In some places, it is evident that these boundaries have moved offshore and that in shallow water the high cover has decreased.
- The authors state that maps produced in 1987 and 1996 cannot be compared given the methodological differences.

C-22

North-center sector:

- In 1991, the lower limits of the meadows are generally further offshore than in 1996 and reflect the difficulty of locating them on a topographic map.
- In several locations in the bay in the deeper end, eelgrass has either disappeared over variable areas or its cover has decreased from high to low density.
- In the northern part of the Bay of Many Islands, the eelgrass cover has decreased in shallow water from high to low density.
- On the periphery of some islands, the cover has also decreased in some places.

Center sector:

- This is the area of the northeast coast of James Bay that is most devoid of eelgrass. The distribution of eelgrass beds in 1996 is comparable to previous years. Good observation conditions in the summer of 1996 allowed the detection of some eelgrass beds in Paul Bay that had not been detected before. This is not a new colonization, but probably eelgrass beds that were missed in previous surveys.

Southern center sector:

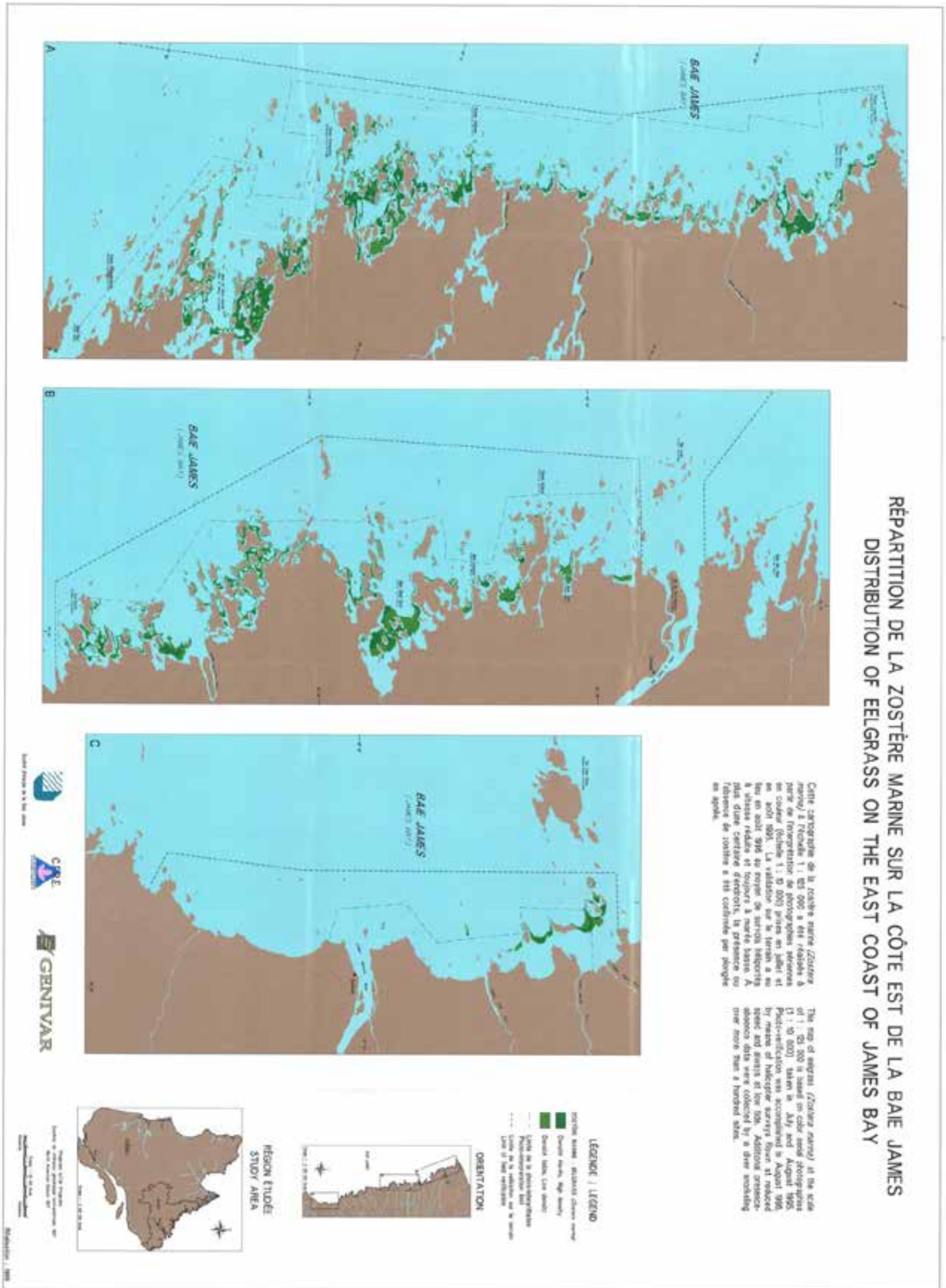
- In 1996, the presence of a low density eelgrass bed in the first large bay south of the mouth of La Grande River was detected. The authors state that the presence of eelgrass so close to the mouth of La Grande River shows its ability to tolerate high variations in salinity as well as very low salinities, especially in winter under the ice.
- Eelgrass cover has decreased in shallow water in Aquatuc and Dead Duck bays.
- Where eelgrass occurs in linear beds along the coast, their widths are generally narrower in 1996 than in 1991-1992. In some locations linear eelgrass beds have disappeared such as between Aquatuc and Dead Duck bays.
- Eelgrass cover has increases in the bay north of Aquatuc Bay.

Southern sector:

- South of Dead Duck Bay, the cover has decreased in shallow areas.

Eastmain sector:

- The authors state that this area is of particular interest because the July 1980 cutoff of the Eastmain River significantly reduced its flow from an average of 980 m^3/s to 90 m^3/s. As a result, the area of the freshwater plume in winter decreased from 305 km^2 to about 75 km^2. It was therefore interesting to verify whether eelgrass had succeeded in colonizing the estuary of this river to some extent, especially since a study by the Cree Regional Authority (1994), based on Cree observations and traditional knowledge, showed the presence of eelgrass beds in the estuary. During the photointerpretation, some eelgrass beds were indeed visible in the river estuary; these and those identified by the Crees were the subject of a specific field validation and multiple dives were conducted.
- Eelgrass was absent from the Eastmain estuary in 1996 and that the eelgrass beds seen in the aerial photographs were in fact green algae colonies.
- By comparing the 1987 and 1996 distributions, it is possible to see that some eelgrass beds have moved offshore, and in particular, the one located immediately north of the mouth of the Conn River (site 14).


RÉPARTITION DE LA ZOSTÈRE MARINE SUR LA CÔTE EST DE LA BAIE JAMES
DISTRIBUTION OF EELGRASS ON THE EAST COAST OF JAMES BAY
A
B
C
BAIE JAMES
LÉGENDE / LEGEND
ORIENTATION
RÉGION ÉTUDIÉE
STUDY AREA
GENIVAR

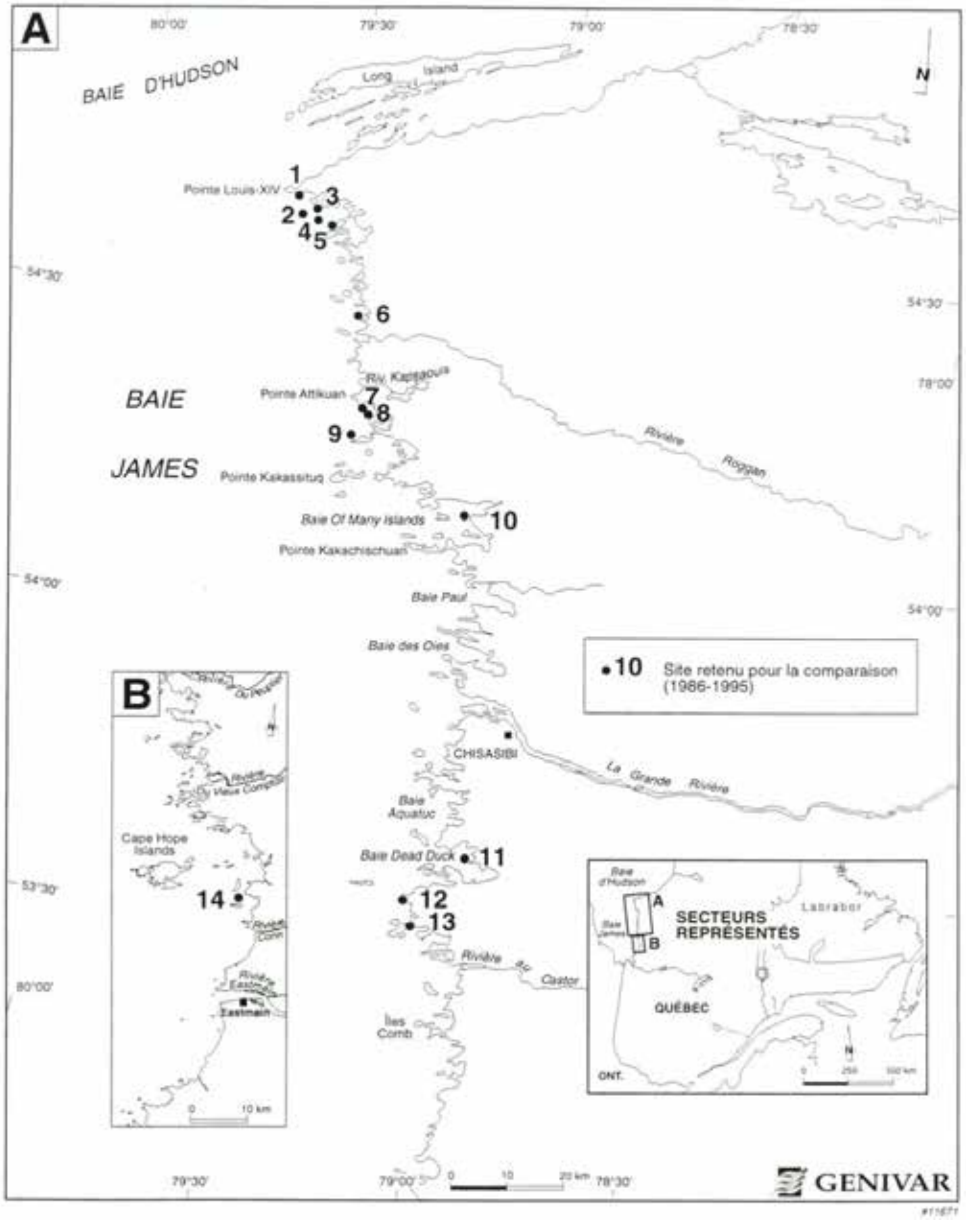


Figure 5. Location of sites selected to compare the distribution of dense eelgrass beds and low density eelgrass beds in 1986 and 1995 using color aerial photos at a scale of 1 :1 0,000 (see **Figures 6** to **17** below). Dense eelgrass corresponds to a continuous cover of eelgrass or to a discontinuous cover where the coverage of the eelgrass is greater than 50 % and low density eelgrass corresponds to patchy coverage where the proportion of bare areas exceeds 50%.

C-26

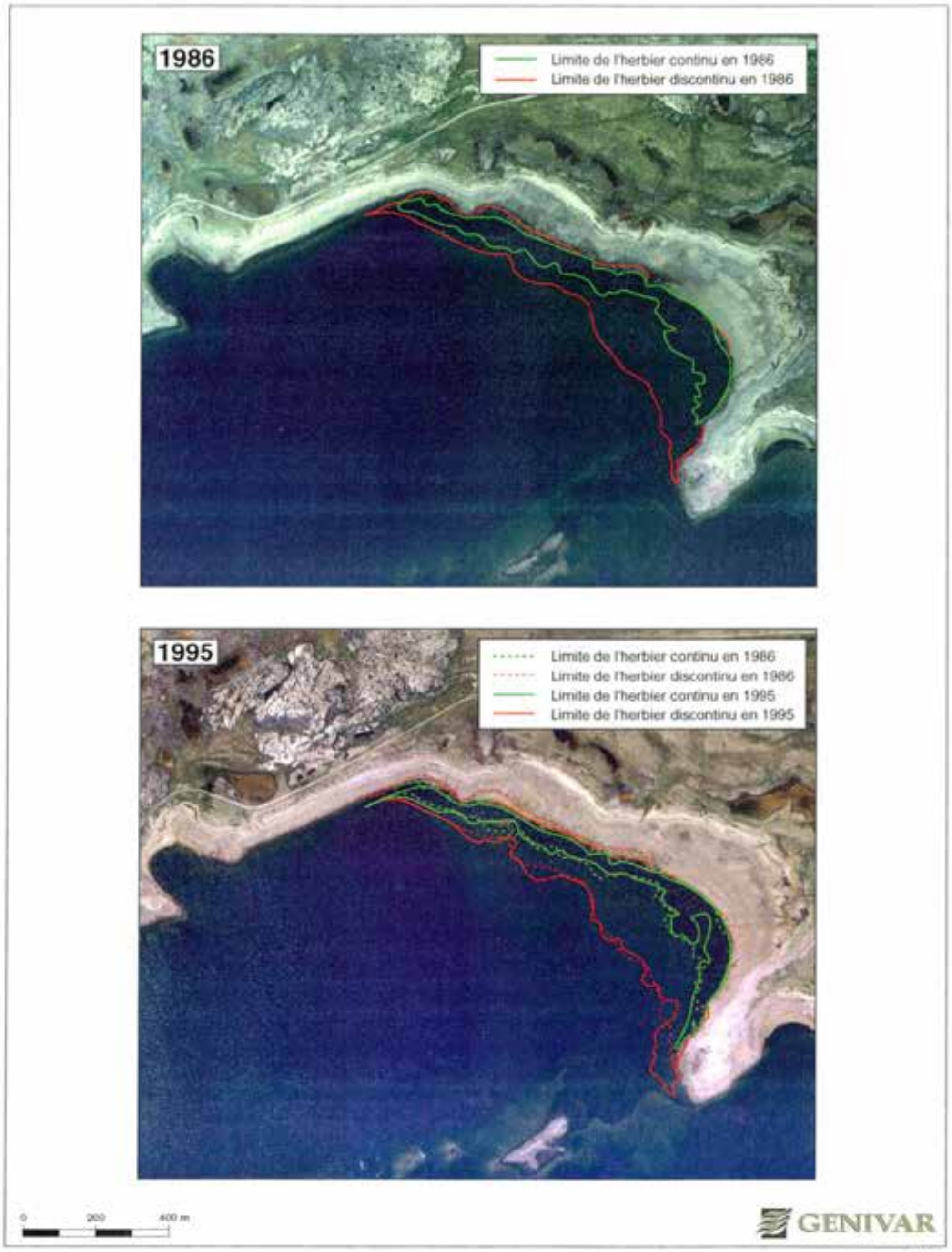


FIGURE 5. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 1.

Figure 6. Dense and low eelgrass meadows in site 1 (trapline CH07) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-27

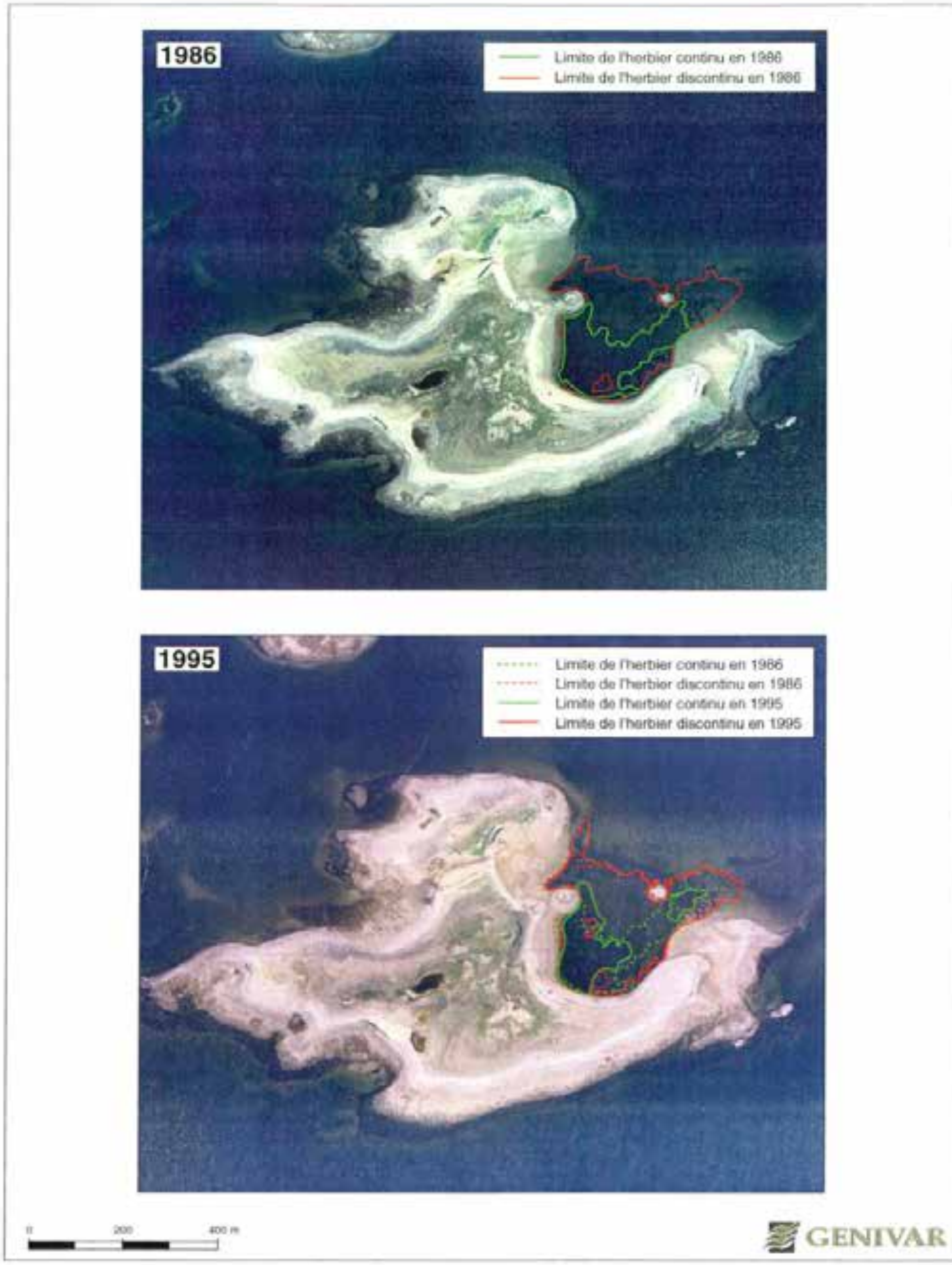


FIGURE 6. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 2.

Figure 7. Dense and low eelgrass meadows in site 2 (trapline CH07) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-28

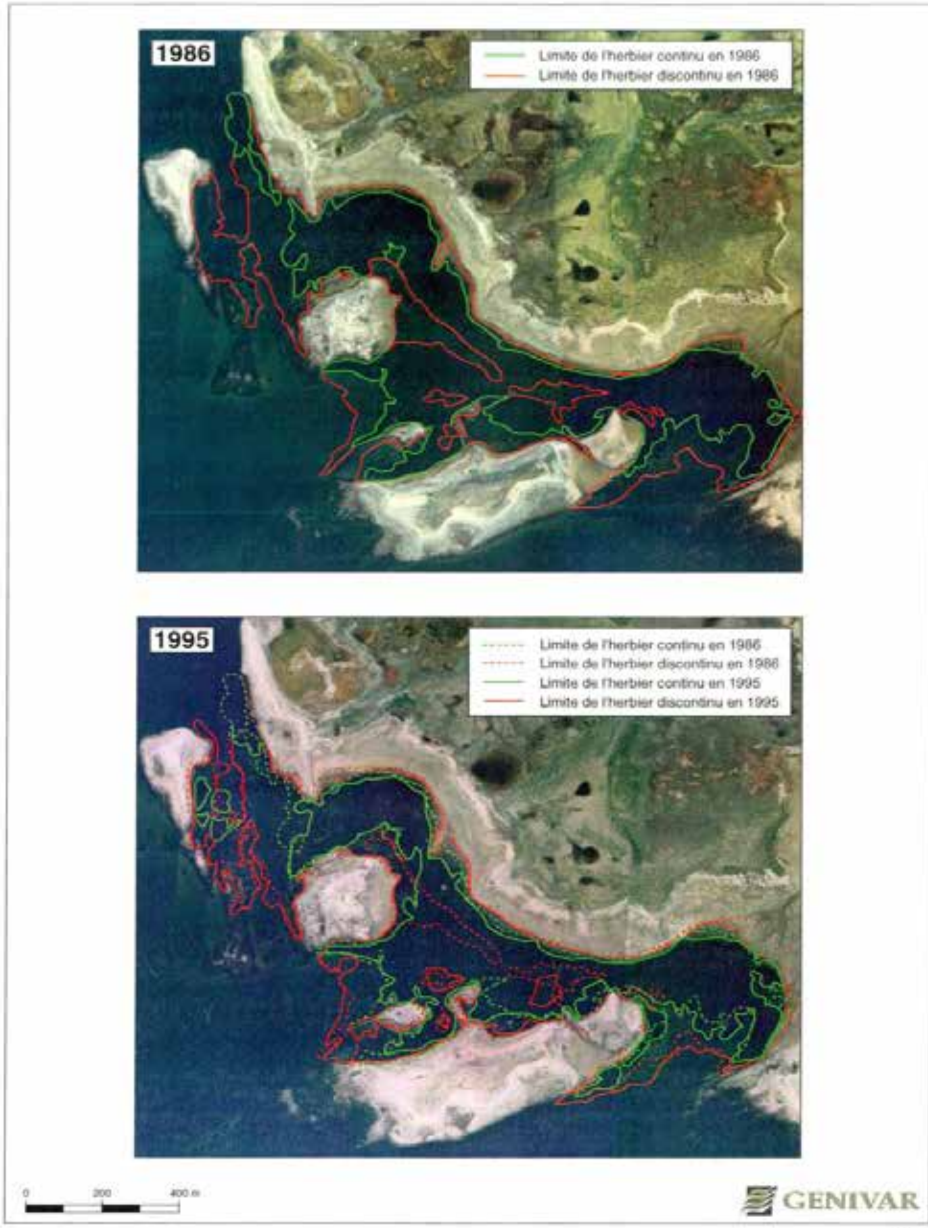


FIGURE 7. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 3.

Figure 8. Dense and low eelgrass meadows in site 3 (trapline CH07) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-29

FIGURE 8. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 4.

Figure 9. Dense and low eelgrass meadows in site 4 (trapline CH07) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-30

FIGURE 9. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 5.

Figure 10. Dense and low eelgrass meadows in site 5 (trapline CH07) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-31

FIGURE 10. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 6.

Figure 11. Dense and low eelgrass meadows in site 6 (trapline CH06) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-32

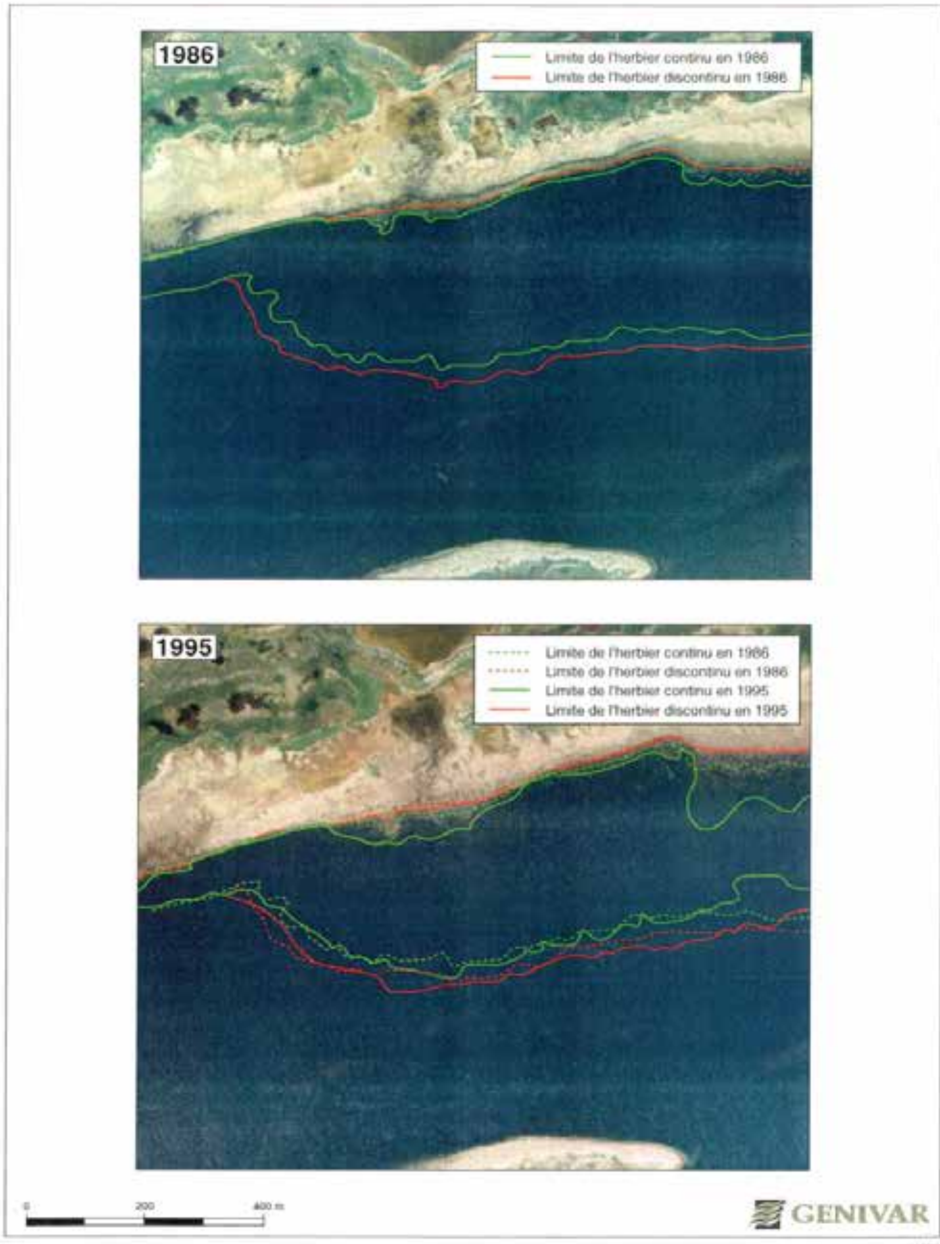


FIGURE 11. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 7.

Figure 10. Dense and low eelgrass meadows in site 7 (trapline CH05) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-33

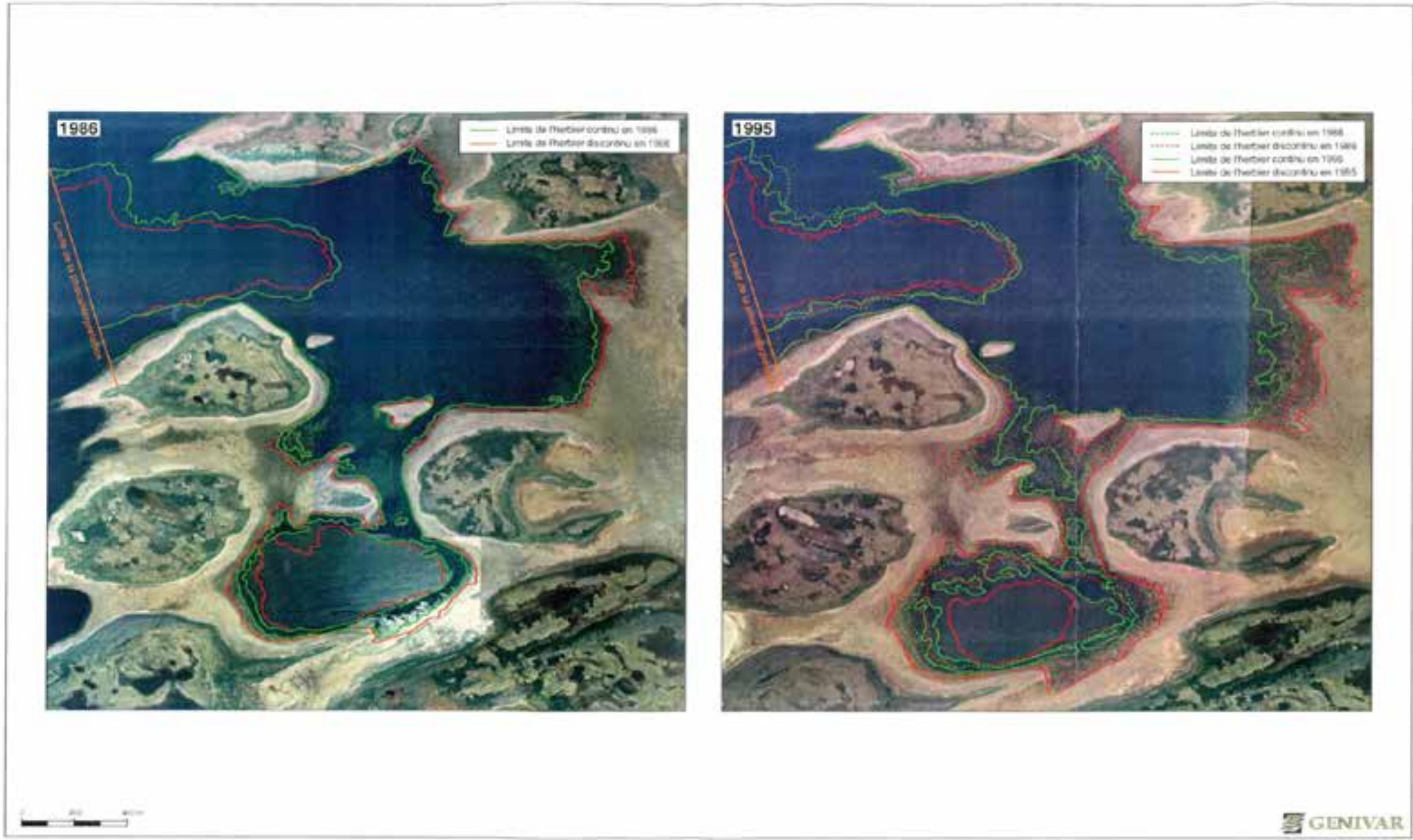


FIGURE 12. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 8.

Figure 11. Dense and low eelgrass meadows in site 8 (trapline CH05) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-34

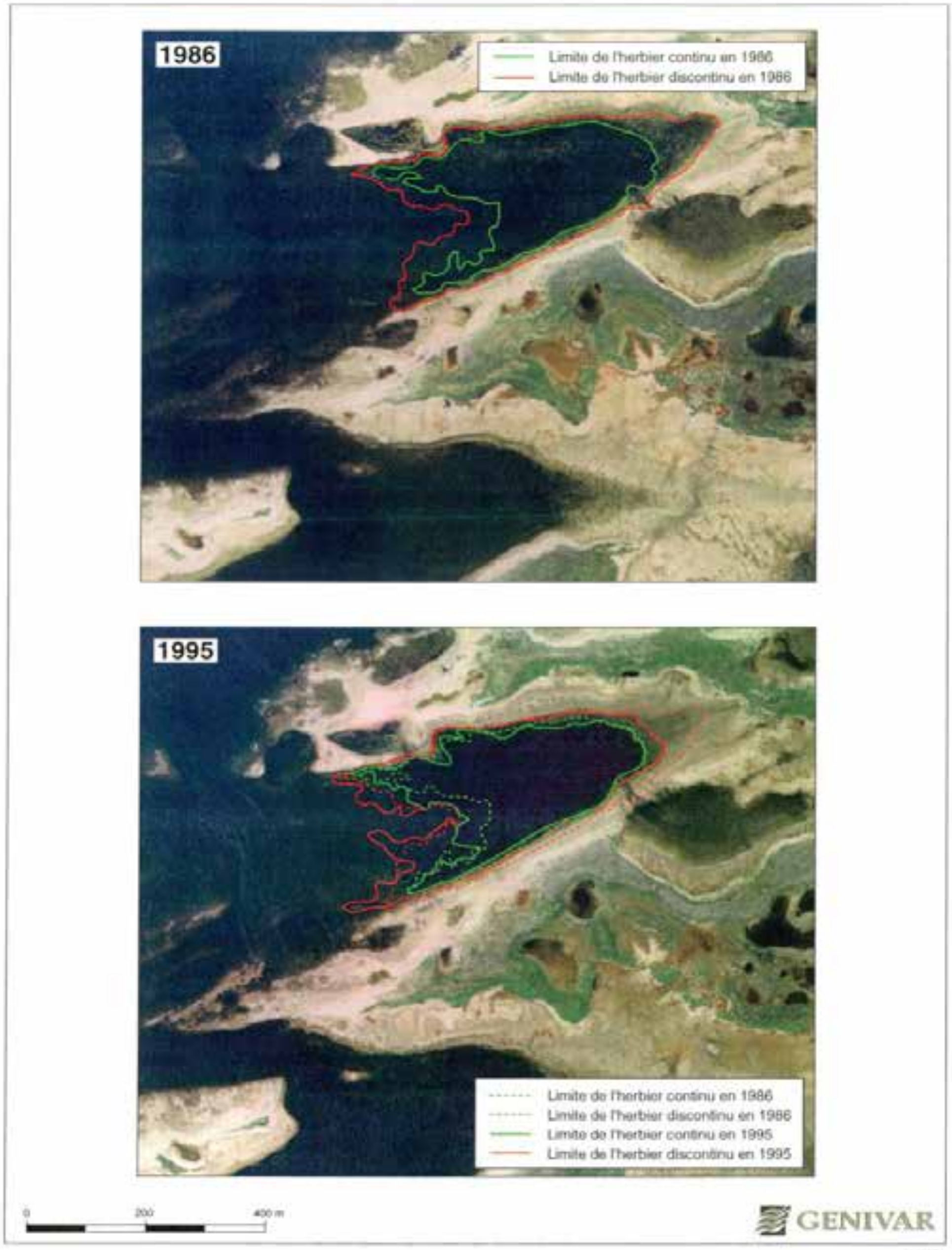


FIGURE 13. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 9.

Figure 12. Dense and low eelgrass meadows in site 9 (trapline CH05) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-35

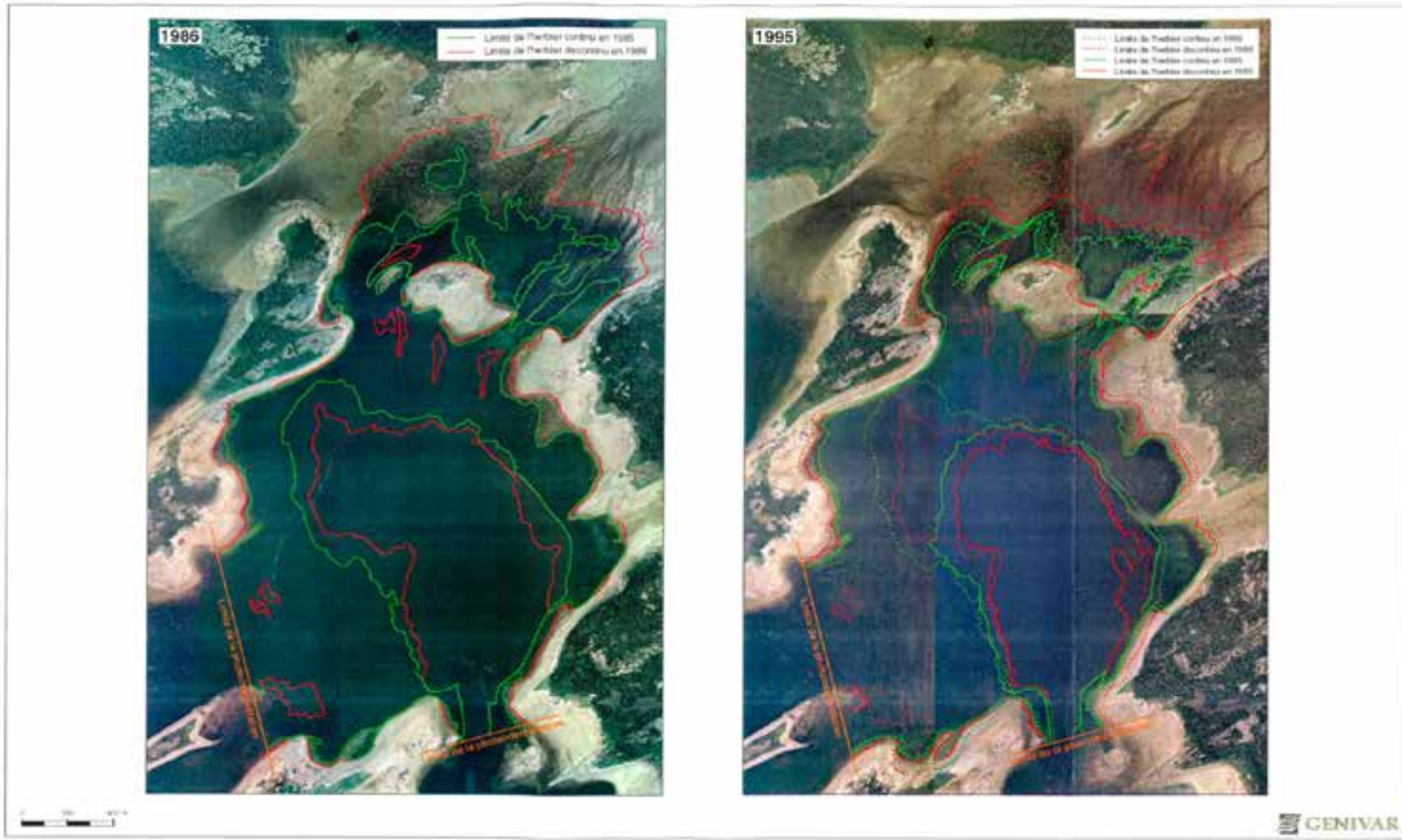


FIGURE 14. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 10

Figure 13. Dense and low eelgrass meadows in site 10 (trapline CH04 – Bay of Many Islands) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-36

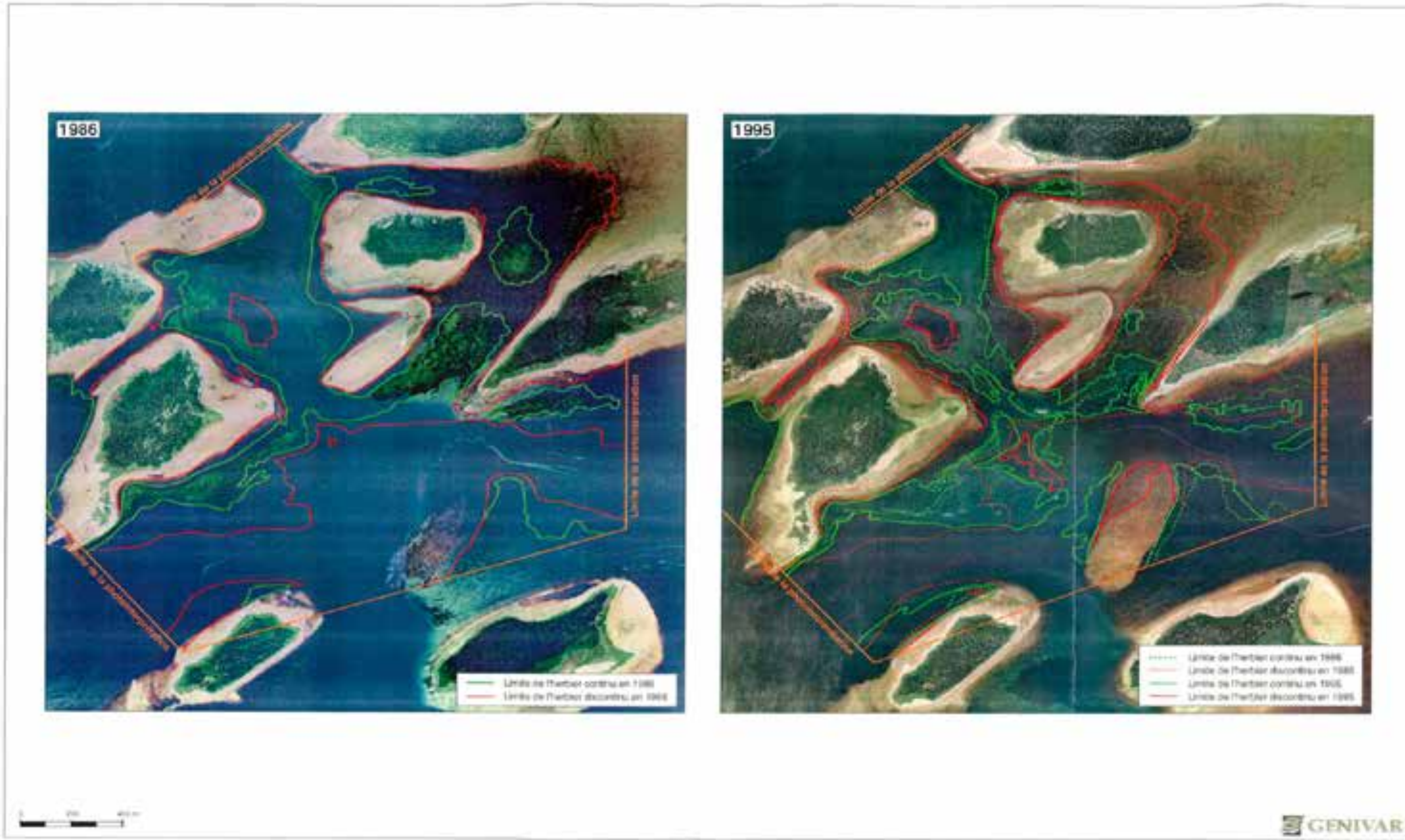


FIGURE 15. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 11.

Figure 14. Dense and low eelgrass meadows in site 11 (trapline CH34 -Dead Duck Bay) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-37

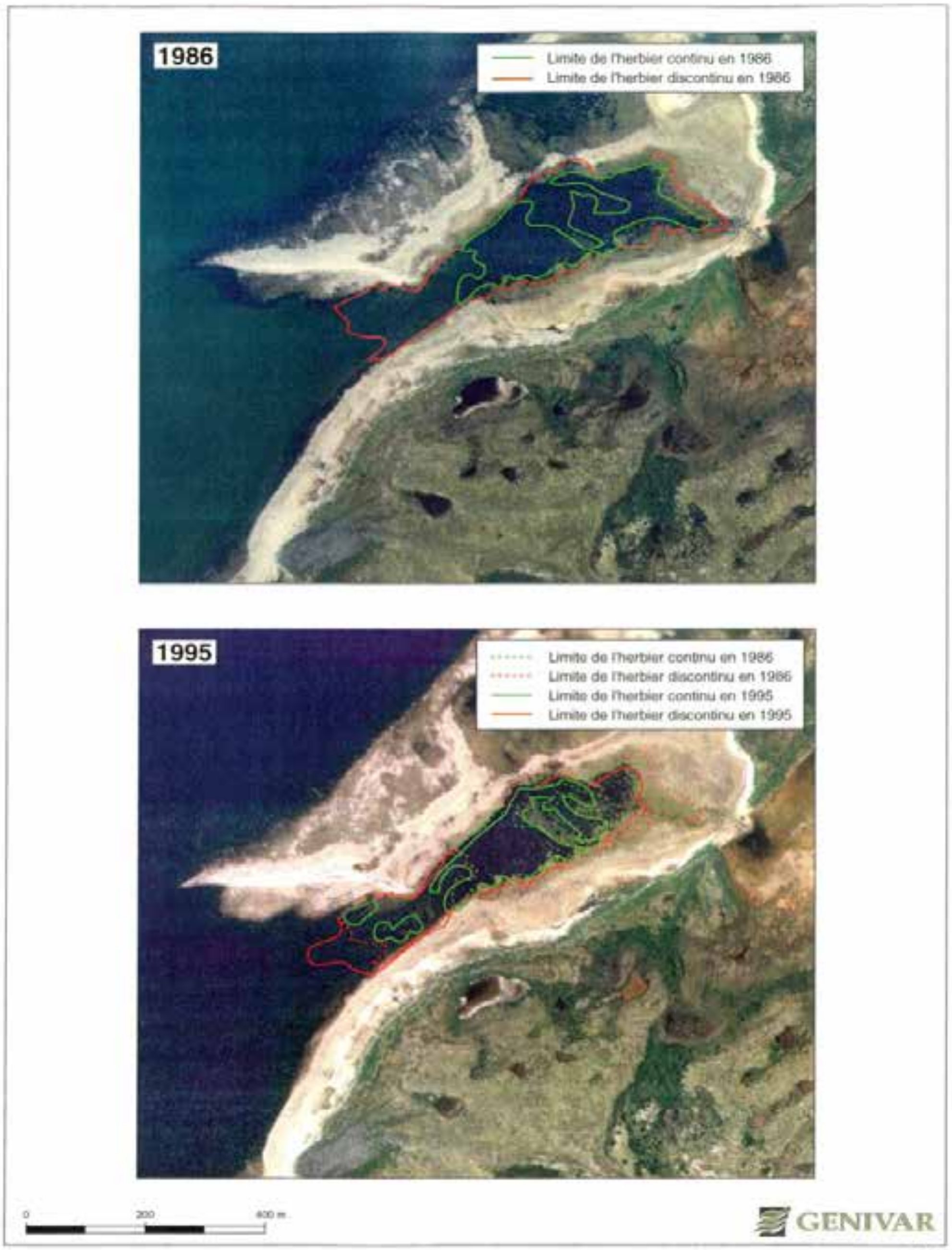


FIGURE 16. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 12.

Figure 15. Dense and low eelgrass meadows in site 12 (trapline CH34) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-38

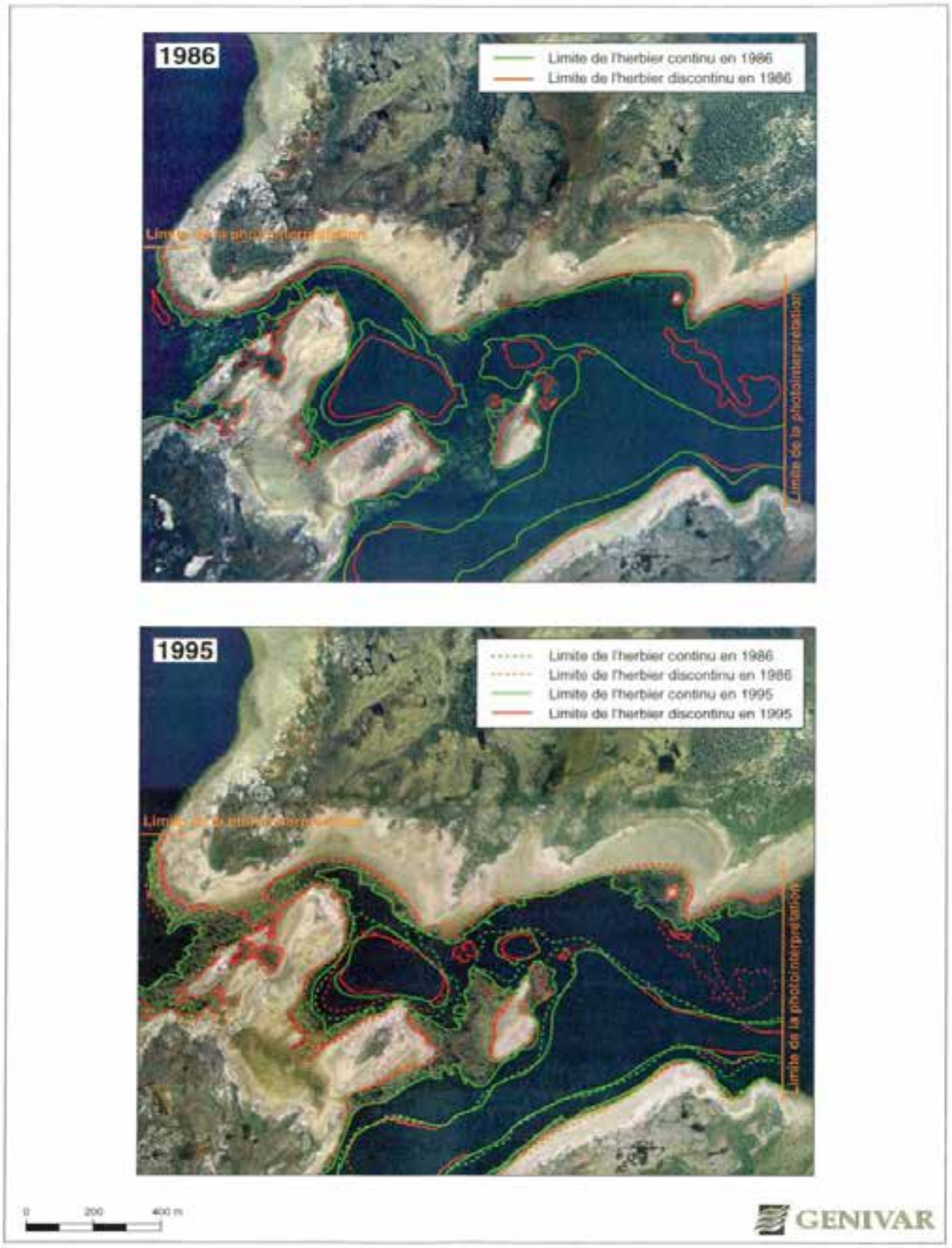


FIGURE 17. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 13.

Figure 16. Dense and low eelgrass meadows in site 13 (trapline CH37) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed).*

C-39

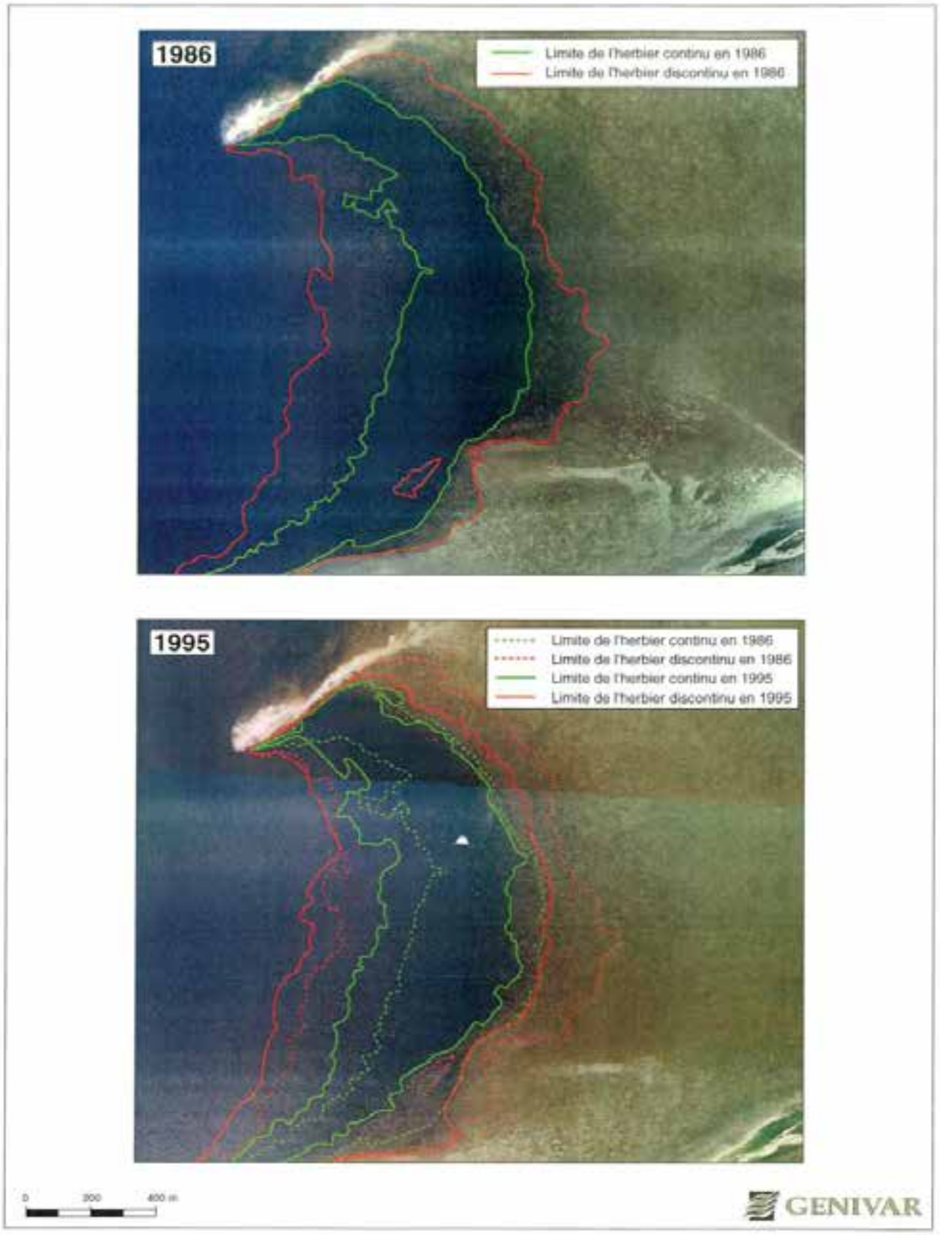


FIGURE 18. Évolution des zostéraies continues et discontinues de 1986 à 1995 au site 14.

Figure 17. Dense and low eelgrass meadows in site 14 (trapline VC30) in 1985 to 1995. (*Limite de l'herbier continue = boundaries of dense and continuous eelgrass bed; limite de l'herbier discontinue = boundaries of low density and discontinuous eelgrass bed)*.

C-40

Table 2. Mean (±SE) areas (ha) of dense eelgrass beds (DE) and low density eelgrass beds (LE) at the fourteen sites and evaluation of gains and losses, calculated from 1986 and 1995 color aerial photos at the 1:10,000 scale (data from Lalumière et al., 1996). DE corresponds to a continuous cover of eelgrass or to a discontinuous cover where the coverage of the eelgrass is greater than 50 % and LDE corresponds to patchy coverage where the proportion of bare areas exceeds 50%.

		Area (ha) in 1986		**Area (ha) in 1995**		**Differential area (ha)**		
Site	**Trapline**	**Mean (±SE) DE**	**Mean (±SE) LDE**	**Mean (±SE) DE**	**Mean (±SE) LDE**	**Total**	**Dif. DE**	**Dif. LDE**
1	CH07	3.85 (0.06)	5.59 (0.12)	3.25 (0.06)	6.54 (0.12)	0.35	-0.60	0.95
2	CH07	2.83 (0.06)	4.85 (0.11)	2.17 (0.06)	5.33 (0.13)	-0.18	-0.66	0.48
3	CH07	34.55 (0.06)	26.96 (0.11)	32.52 (0.11)	28.48 (0.17)	-0.50	-2.02	1.53
4	CH07	7.64 (0.06)	14.26 (0.13)	11.03 (0.11)	11.29 (0.19)	0.81	3.38	-2.57
5	CH07	17.58 (006)	17.93 (0.11)	14.07 (0.12)	19.45 (0.16)	-1.98	-3.50	1.52
6	CH06	26.74 (0.12)	28.53 (0.06)	39.74 (0.00)	20.82 (0.06)	5.28	13.00	-7.71
7	CH05	21.95 (0.10)	3.99 (0.12)	19.91 (0.12)	5.82 (0.18)	-0.21	-2.05	1.84
8	CH05	129.16 (0.18)	30.21 (0.11)	105.84 (0.10)	60.99 (0.21)	7.46	-23.32	30.79
9	CH05	6.42 (0.06)	4.31 (0.11)	6.77 (0.06)	2.74 (0.11)	-1.22	0.35	-1.57
10	CH04	135.68 (0.17)	77.86 (0.21)	151.80 (0.14)	45.26 (0.20)	-16.48	16.12	-32.60
11	CH34	69.31 (0.06)	76.95 (0.21)	58.62 (0.06)	106.84 (0.26)	19.20	-10.69	29.89
12	CH34	2.67 (0.05)	3.09 (0.00)	2.42 (0.00)	3.20 (0.05)	-0.14	-0.25	0.11
13	CH37	56.32 (0.05)	16.25 (0.05)	46.99 (0.10)	27.90 (0.00)	2.32	-9.33	11.65
14	VC30	58.30 (0.12)	63.40 (0.16)	62.44 (0.06)	50.31 (0.13)	-8.94	4.14	-13.08
Total		**573.00**	**374.17**	**557.58**	**395.38**	**5.79**	**-15.42**	**21.22**

Eelgrass distribution 2011

Reference: CONSORTIUM WASKA-GENIVAR. 2011. Eastmain-1-A and Sarcelle Powerhouses and Rupert Diversion. Monitoring of Eelgrass on James Bay's North-East Coast. 2011 study report. Report by the Waska-GENIVAR Inc. consortium for Hydro-Québec Production. 57 p and appendices.

Methods (summary in Table 1):

Vertical color aerial photographs at a scale of 1:10 000 were taken in late July 2011 along flight lines covering 6 segments of the study area (Figure 18), from north to south: 1) Shave Point to Roggan River, 2) Attikuan Point, 3) Bay of Many Islands, 4) Tees Bay, 5) Dead Duck Bay, and 6) the mouth of the Castor River. The analysis consisted of delineating the outline of the eelgrass beds and plotting this information on a small scale map (1:2 km). The delineation is approximate because no validation dives were conducted in 2011.

- Eelgrass distribution and author's comments (see map below):
  - Only the inner boundaries of the beds (i.e., near the shoreline) were drawn. In most cases, it was impossible to draw the outer limits of the meadows (towards the open sea), because they were not visible on the aerial photographs. To achieve this, validation dives would have been necessary.
  - The authors state the map shows that there are relatively well-developed eelgrass beds in each of the coastal segments covered by the flight lines.
  - Compared to the pre-decline mapping (Lalumière et al., 1996), the authors state that the 2011 map shows that :
    - Dead Duck Bay and Bay of Many Islands (which are 28 km south and 34 km north of La Grande Riviere, respectively) are the most advanced in eelgrass recovery. They are currently almost comparable to what they were before the decline,
    - in Tees Bay and around the mouth of the Castor River, recovery continues, but the beds have not reached their pre-decline distribution and abundance,

- recovery of seagrass beds in the vicinity of Attikuan Point and between Shave Point and the Roggan River appears to be slower than elsewhere.

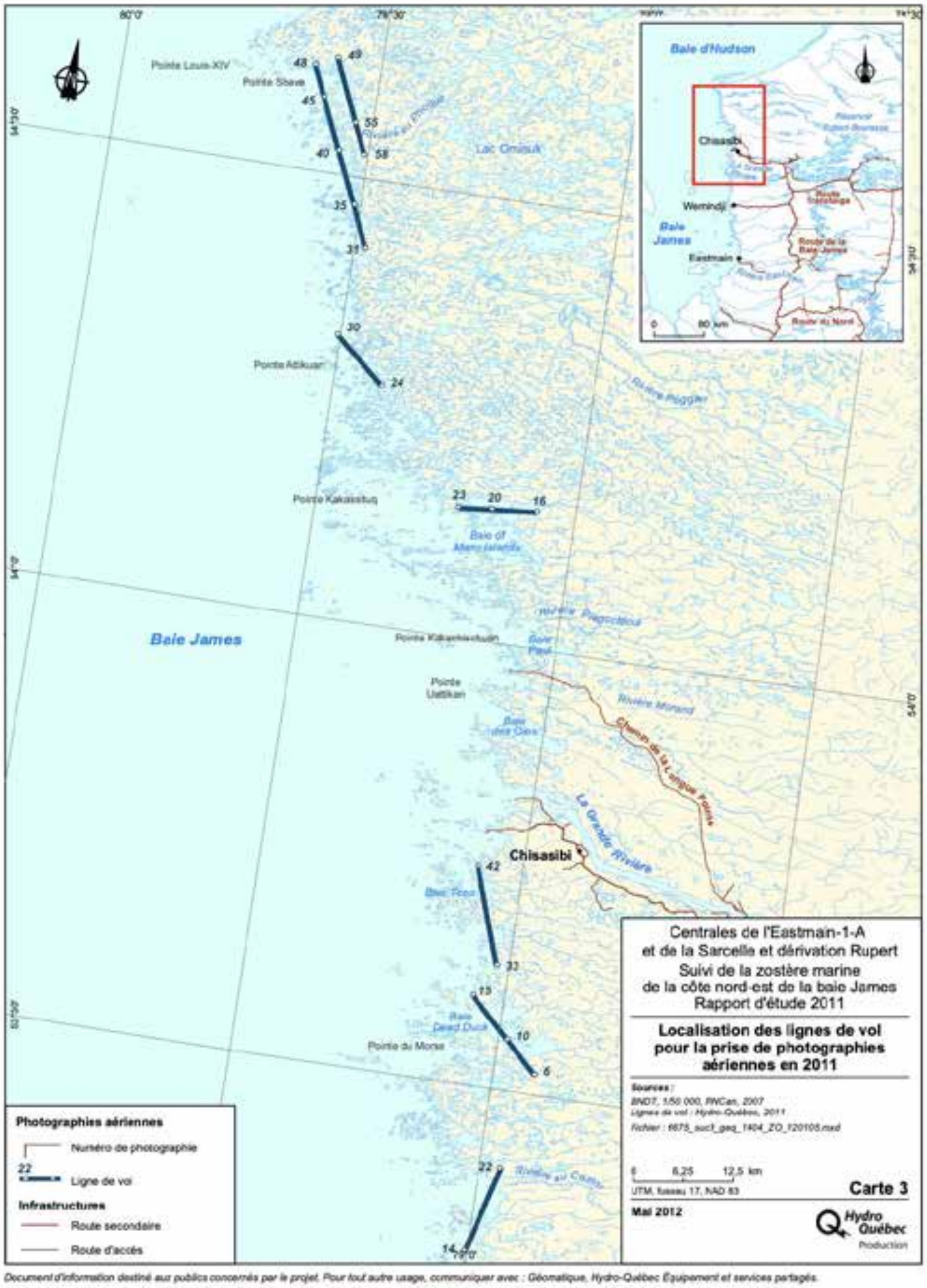


Figure 18. The position flight lines covering 6 segments along which were taken **v**ertical color aerial photographs at a scale of 1:10 000 in late July 2011.

C-44

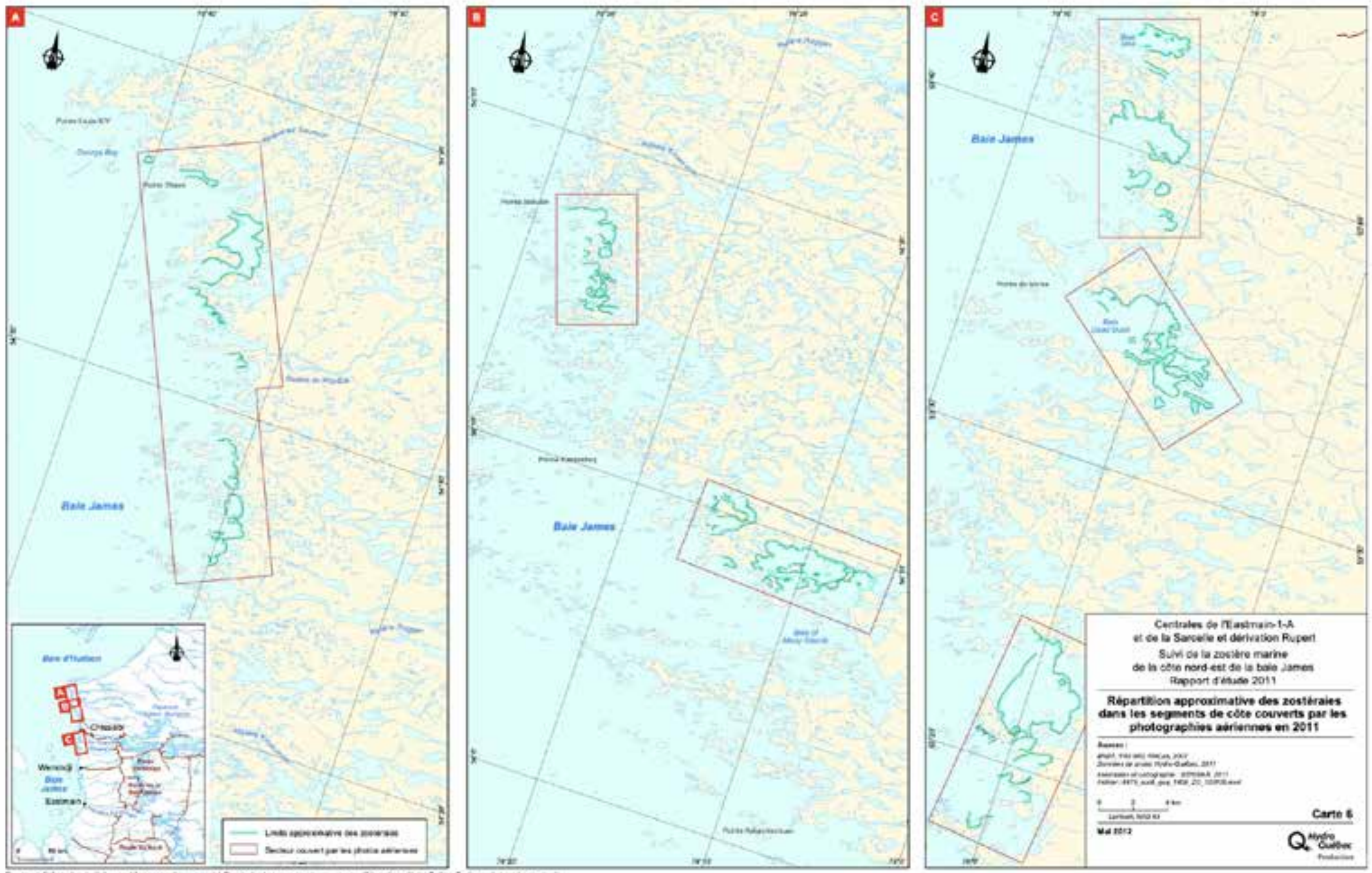


Figure 19. Approximate distribution of eelgrass along coastal segments surveyed in July 2011.

C-45

Eelgrass distribution 2014

Reference: CONSORTIUM GENIVAR-WASKA. 2017. Eastmain-1-A and Sarcelle Powerhouses and Rupert Diversion. Follow- up of Eelgrass Beds on the Northeast Coast of Baie James (James Bay) – Study Report 2014. Report prepared by Consortium GENIVAR-Waska for Hydro-Québec Production. 83 pages and appendices.

Methods (summary in Table 1):

Vertical, 1:10 000-scale color aerial photos were taken on August 20, 2014, along flight lines covering the following eight sections of the study area (see Figure 20 and 21), from north to south: 1) Shave Point to Roggan River, 2) Attikuan Point, 3) Bay of Many Islands, 4) Tees Bay, 5) Dead Duck Bay, and 6) the mouth of the Castor River. The analysis consisted in marking out the contour of continuous, abundant eelgrass beds as accurately as possible, and producing a small-scale map of the data (1:2km). The oblique photos taken in summer 2014 were used to delineate the boundaries of the eelgrass beds (see photos in CGW, 2017). The delineation is approximate because no validation dives were conducted in 2011.

- Eelgrass distribution and author's comments (see map below):
    - Figure 20 and 21 show the boundaries of the eelgrass beds within the eight coastal sections covered by 1:10 000-scale vertical aerial photography. Compared to previous follow-up years, the quality of the 2014 aerial photos allowed for more accurate delineation of the boundaries of eelgrass beds, which were found to be continuous and abundant. However, it was not possible to identify the boundaries of discontinuous or sparse eelgrass beds, as this would have required validation by snorkeling.
    - Compared to the pre-decline mapping (Lalumière et al., 1996), that authors state that the 2014 map shows that :
        - Eelgrass recovery was most significant in Dead Duck Bay and Bay of Many Islands, and coverage was found to be comparable to what it was before the decline (Figure 21),
        - Eelgrass is continuing to recover in Tees Bay, but had not yet reached the levels present there before the decline,

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- Although the distribution of continuous eelgrass beds between the Rivière au Saumon (Salmon River) and the Rivière au Phoque (Seal River) had increased, it was still not comparable to what it had been before;
- The eelgrass beds in other locations along the northeast coast seemed to be recovering more slowly than elsewhere.

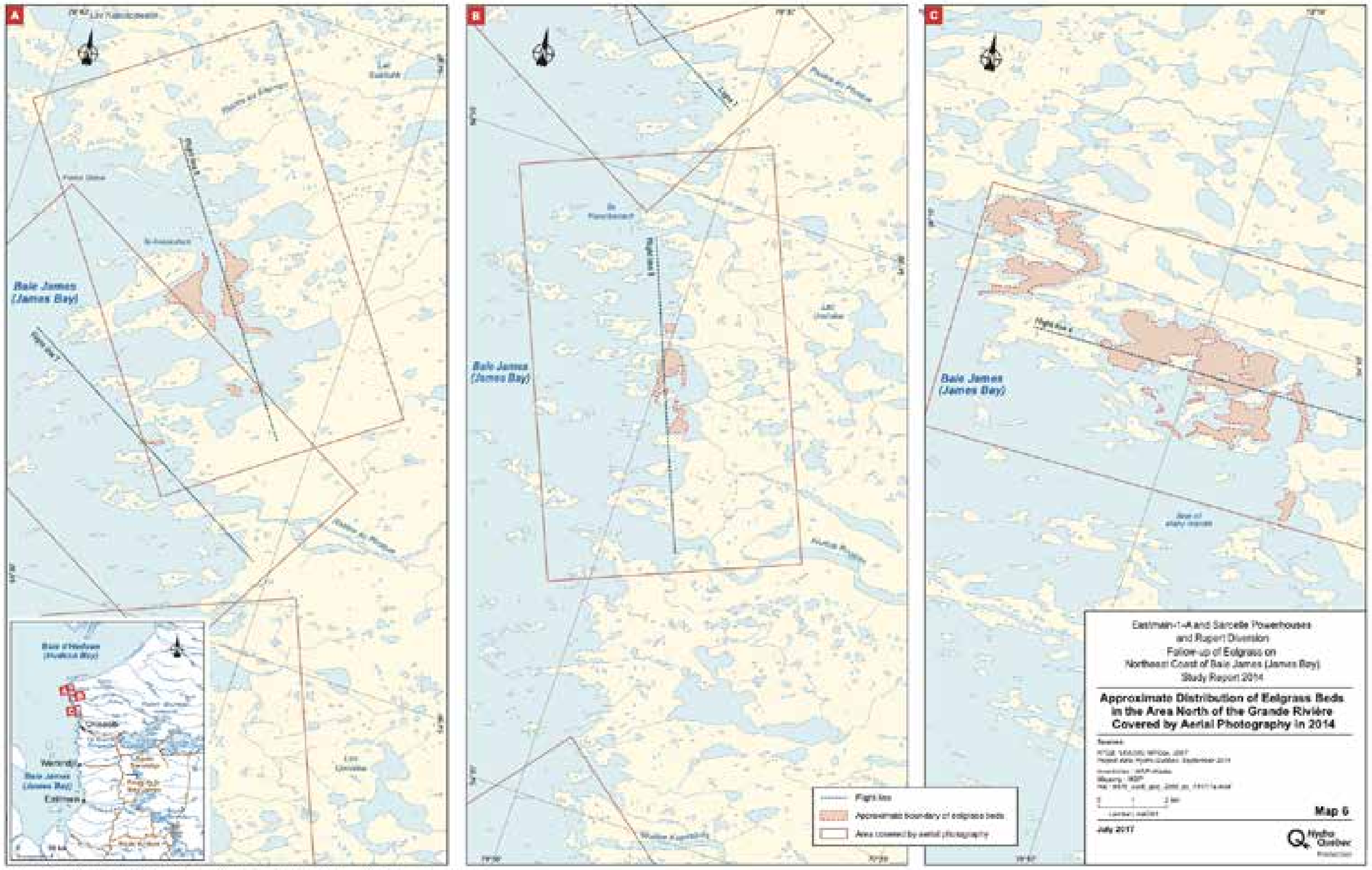

Figure 20. Approximate distribution of eelgrass beds in the area north of the La Grande River covered by aerial photography in 2014.

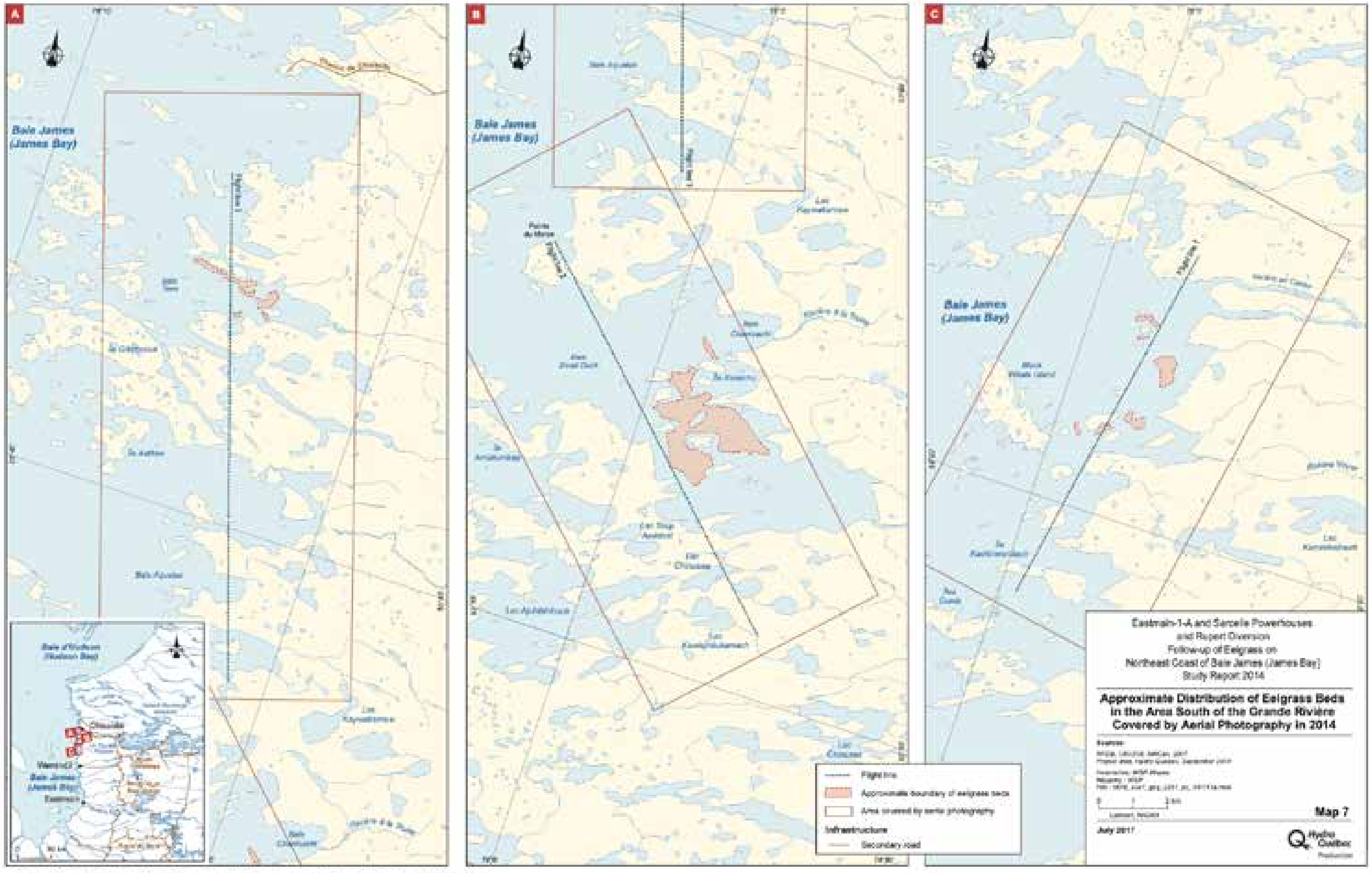

Figure 21. Approximate distribution of eelgrass beds in the area south of the La Grande River covered by aerial photography in 2014.

C-49

APPENDIX D:

AUV surveys for depth distribution of eelgrass beds

AUV surveys for depth distribution of eelgrass beds

Prepared by: Chris Peck, Jens Ehn, and Zou Zou Kuzyk, University of Manitoba

During the CHCRP, surveys of major eelgrass beds were conducted using a side-scan sonar mounted on an Autonomous Underwater Vehicle (AUV). The AUV is an OceanServer Iver2 and to survey the seabed, the AUV uses a high-resolution side scan sonar (L-3 Klein UUV-3500). The AUV also was equipped with Klien Starfish (425F) conductivity and temperature sensors and a 10-beam doppler velocity logger (DVL), which is used for underwater navigation and to determine the water depth of the AUV. Because the AUV was operated at the surface for this project, the AUV had frequent GPS updates and there was no need for navigation corrections in post processing. The side scan sonar was operated at both low and high frequencies. The range was changed (5 m-15 m) from site to site to try and get the best quality of data.

In summer 2018, the AUV was deployed at six sites. As we were still testing the use of the AUV in this environment and limited scientific study of the eelgrass had been completed, we ran it on transects along the coast of each bay so it could cover the most ground to find eelgrass beds. Surface salinity and temperature as well as water depth were logged for periods of 14 to 57 minutes allowing calculation of average conditions at each site (Table 3-1). Additionally, four usable sidescan sonar tracks were recorded, one in a small bay located near Wastikun Island (location 1), the La Grande River (location 2), Tees Bay (location 3) and a bay just south of Tees Bay (location 4). Figure 3-1 shows the location of these surveys.

In 2019, the team conducted seven additional AUV surveys at five traplines: CH7 (2), CH3 (1), CH33 (1), CH34(1), and CH38 (Table 3-2). At CH38, the side-scan sonar instrument onboard the

AUV malfunctioned, and no imagery was obtained despite four attempts. However, salinity and temperature were recorded.

Table D-1. AUV tracks recorded in summer 2018 and average (median) observed conditions from onboard CTD (bottom depth, sea surface temperature, sea surface salinity).

Site	Lat (N)	Long (W)	Deployment date	Duration (min:sec)	Avg Btm Depth (m)	Avg Temp (°C)	Avg Salinity
CH4	54.14839	79.1997	08/11/2018	20:13	1.5	15.3	17.9
	53.93731	79.0459	06/27/2018	14:10	6.0	10.1	10.7
Wast-1*	53.94387	79.0738	07/07/2018	34:34	2.7	10.4	9.7
LG mouth	53.83896	79.0161	07/01/2018	55:51	5.8	4.4	0.0
CH34	53.67002	79.0786	07/04/2018	59:32	7.5	8.7	21.9
Wast-2*	53.95467	79.1407	07/07/2018	58:55	7.7	9.3	8.0
ESP_11	52.98295	78.9011	07/29/2018	45:27	2.6	14.2	16.0
Big Rock	52.96023	78.8339	07/29/2018	42:15	2.4	16.0	19.7
VC11	52.93150	78.8865	07/29/2018	44:16	1.5	14.9	20.1
WM_Camp	53.06842	78.9493	07/30/2018	32:06	2.1	15.4	20.2

*Wast-1 is Wastikun Bay area of eelgrass; Wast-2 is Waskikun Bay (cross shore)

Table D-2. Details about the sites surveyed by AUV in 2019 including average surface water temperature and salinity.

Site	Lat (N)	Long (W)	Deployment date	Duration (min:sec)	Avg Temp. (°C)	Avg Salinity
CH38-2	53.25	-78.93	2019-08-12	50:50.0	10.6	19.7
CH38-1	53.28	-78.98	2019-08-12	30:24.9	10.0	19.6
CH34-1	53.58	-78.99	2019-08-16	45:11.7	10.9	19.2
CH7-1	54.61	-79.66	2019-08-24	54:54.9	12.3	18.6
CH3-1	53.94	-79.08	2019-08-28	48:16.0	16.2	11.1
CH7-2	54.59	-79.56	2019-08-24	00:37.1	13.3	17.5
CH33-1	53.73	-79.04	2019-08-09	24:20.9	9.2	18.4
VC17	52.67	-78.77	2019-08-22	08:35.4	14.7	17.7
VC12-3	52.86	-78.86	2019-08-21	04:53.3	15.0	14.8
VC11-3	52.99	-78.93	2019-08-21	22:00.6	15.5	17.4
VC13-2	52.76	-78.88	2019-08-20	07:00.2	11.9	19.0
VC14-3	52.58	-78.74	2019-08-20	33:13.4	16.3	16.8

To investigate depth distributions of eelgrass, a square grid of 20 m x 20 m was overlaid on the imagery. Each grid cell was classified by eye as one of: bare seabed (red), patchy eelgrass (yellow), and continuous (green) eelgrass. Water depths along the survey lines were retrieved and sorted into depth bins for each of the classified areas. Figures 3-2 to -8 show results for the surveys for which the data processing is complete.

Figure D-1. Map of the location of all AUV surveys. Yellow sites have been surveyed one year, 2018 or 2019, and blue sites are surveyed both years.

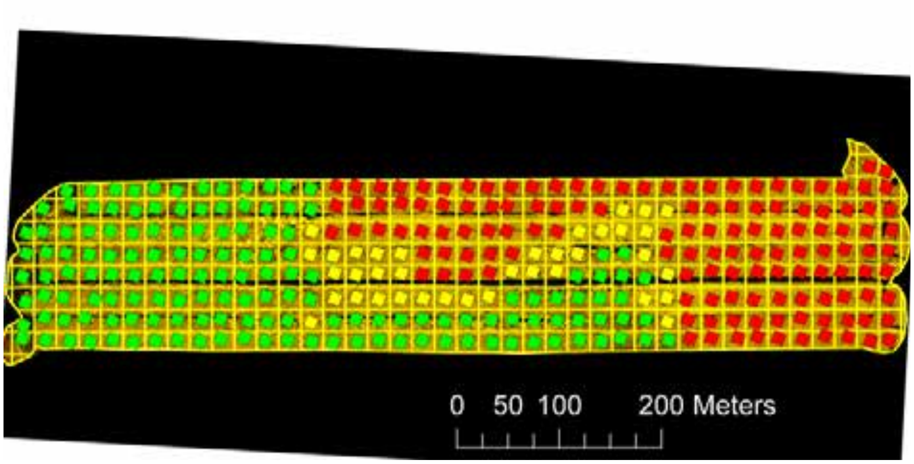

Figure D-2. Side scan sonar survey of CH4a showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

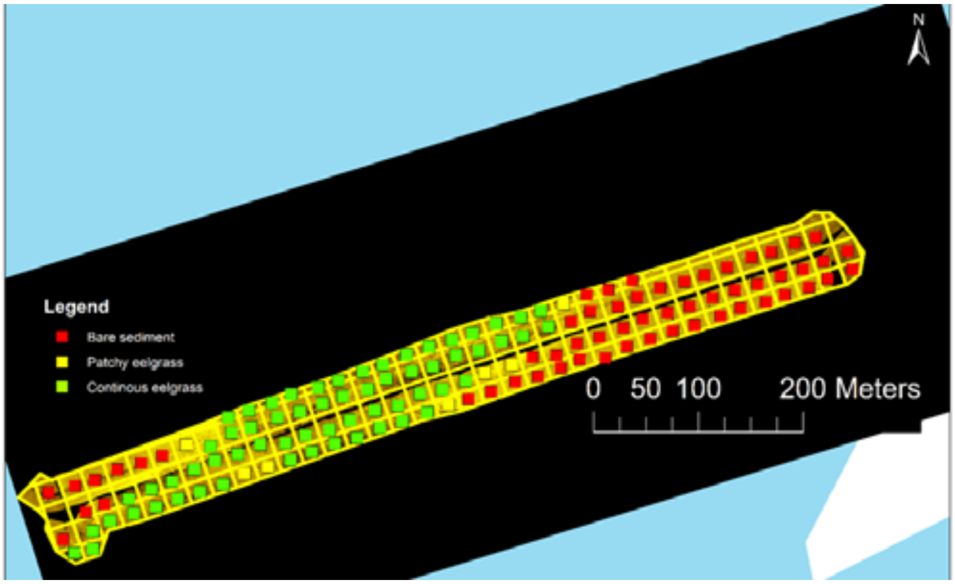

Figure D-3. Side scan sonar survey of CH4b showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

D-4

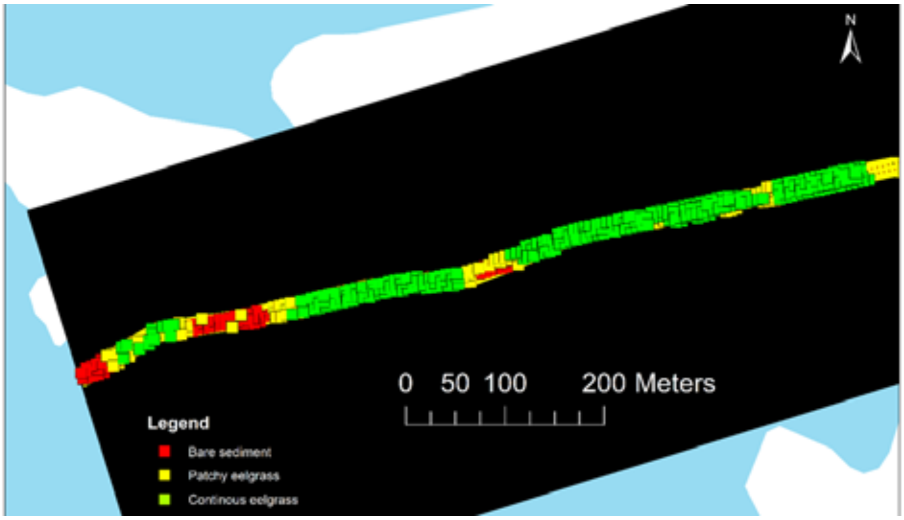

Figure D-4. Side scan sonar survey of CH33 showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

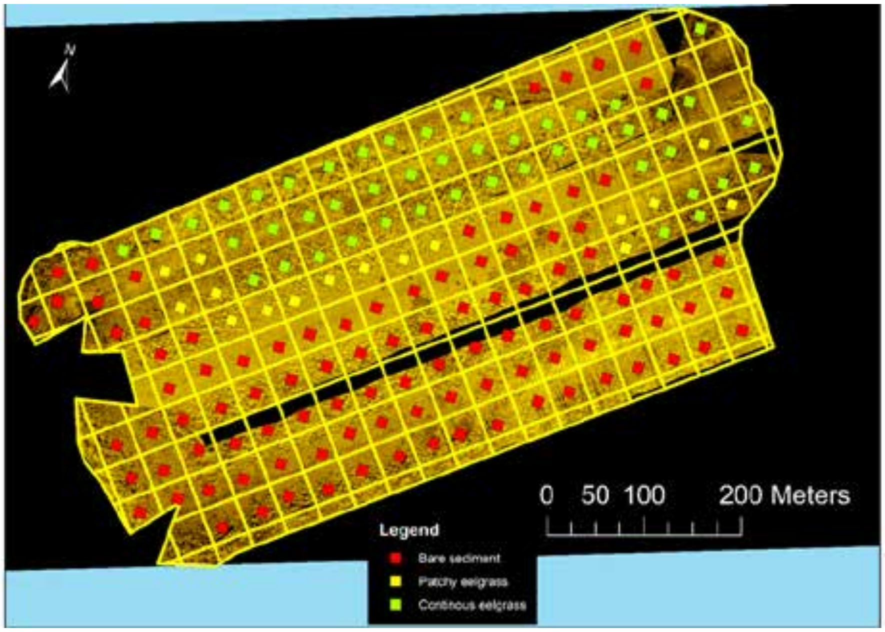

Figure D-5. Side scan sonar survey of VC10 showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

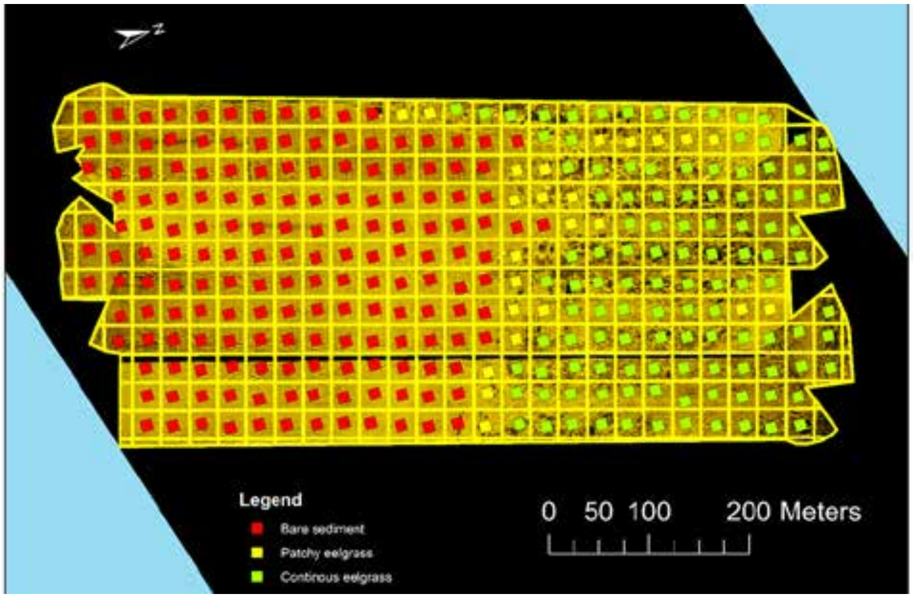

Figure D-6. Side scan sonar survey of VC11 showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

D-6

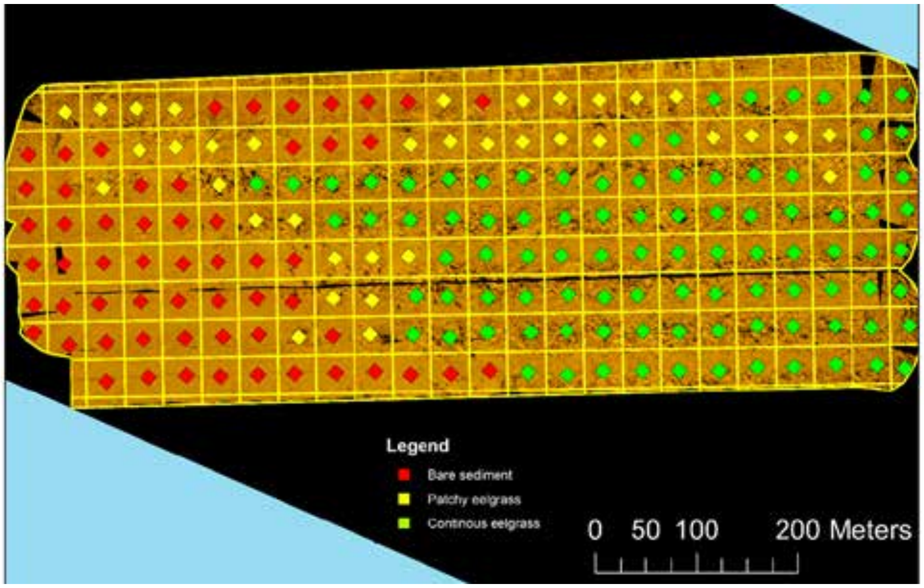

Figure D-7. Side scan sonar survey of VC17a showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

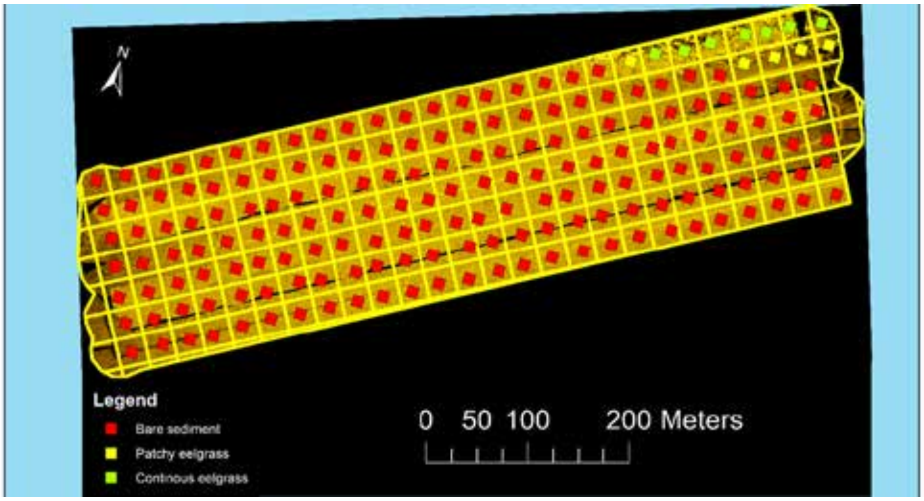

Figure D-8. Side scan sonar survey of VC17b showing three classifications: bare sediment (red), patchy eelgrass (yellow), continuous eelgrass (green).

D-7

APPENDIX E:

Publications from the CHCRP

Published scientific articles

Clyne et al. (2021). Use of LANDSAT-8 OLI Imagery and Local Indigenous Knowledge for Eelgrass Mapping in Eeyou Istchee. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences 53: 15-22. DOI: 10.5194/isprs-annals-V-3-2021- 15-2021.

de Melo, M. et al. (2022). Patterns in riverine carbon, nutrient and suspended solids to the Eastern James Bay: links to climate, hydrology and landscape. Biogeochemistry. DOI: 10.1007/s10533-022-00983-z.

Fink-Mercier et al. (2022). Concentrations and yields of total Hg and MeHg in large Boreal rivers to water and wetland coverage in the watersheds. Journal of Geophysical Research: Biogeosciences 127(5), e2022JG006892.

Fink-Mercier et al. (2022). Hydrology and seasonality shape the coupling of dissolved Hg and methyl Hg with DOC in boreal rivers in northern Québec. Water Resources Research, e2022WR033036.

Giroux et al. (2022). Canada Goose populations harvested in Eastern James Bay by Eeyou Istchee Cree hunters. Avian Conservation and Ecology, 17(1):5. DOI:10.5751/ACE-170105.

Leblanc et al. (2022). Limited recovery following a massive seagrass decline in subarctic eastern Canada. Global Change Biology. DOI: 10.1111/gcb.16499

Mabit et al. (2022). Empirical remote sensing algorithms to retrieve SPM and CDOM in Québec coastal waters. Frontiers in Remote Sensing. DOI: 10.3389/frsen.2022.834908

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