MINUTES OF THE MEETING STEERING COMMITTEE (SC)

Meeting No^o 62 Wednesday, October 18, 2023 9:30 AM to 12:00 PM Videoconference on TEAMS

Attendance:	Luc Duquette	Hydro-Québec	
	Jean-Philippe Gilbert	Hydro-Québec	
	Carine Durocher	Hydro-Québec	
	Johanna Ménélas	Hydro-Québec	
	Daniel Brosseau	Hydro-Québec	
	Marc Dunn	Niskamoon Corporation	
	Ernie Rabbitskin	Niskamoon Corporation	
	Mélanie Leblanc	Niskamoon Corporation	
	Louie Kanatewat	Cree Nation of Chisasibi	
	John Lameboy	Cree Nation of Chisasibi	
	Ernest Moses	Cree Nation of Waskaganish	
	Félix Boulanger	EMRWB representative	
	Geraldine Mark	Cree Nation of Wemindji	
Guest:	Jens Ehn	University of Manitoba	
	Lindsay Carlson	University of Saskatchewan	
	Zou Zou Kuzyk	University of Manitoba	
	Stephanie Varty	Eeyou Marine Region Wildlife Board	
Absence:	James Bobbish	Cree Nation of Chisasibi	
	Graeme Morin	Cree Nation Government	
	Josée Lefebvre	Canadian Wildlife Service	
	Roderick Pachano	Cree Nation of Chisasibi	
	Robbie Tapiatic	Cree Nation of Chisasibi	
	Gregory Mayappo	Cree Nation of Eastmain	

MEETING CHAIR AND SECRETARY

Marc Dunn chaired the meeting, and Johanna Ménélas acted as the meeting secretary.

PROPOSED AGENDA

1. Approval of the Agenda

- 2. Approval of the minutes from the previous meetings:
 - o January 12, 2022 Noº 45
 - August 31, 2022 No^o 50
 - September 21, 2022 Noº 51
 - October 27, 2022 No^o 52
 - December 8, 2022 No^o 53
- 3. Review of the manuscript
 - "Influence of altered freshwater discharge on the seasonality of nutrient distributions near La Grande River, northeastern James Bay" by Alessia C. Guzzi, Christine Michel, Jean-Éric Tremblay, Joel P. Heath, Jens K. Ehn, and Zou Zou Kuzyk.
 - "Stable Isotopes of Landfast Sea Ice as a Record of La Grande River Under-Ice Plume Spreading" by A. Diaz, Z. A. Kuzyk, A. Guzzi, K. Gupta, T. Papakyriakou, and J. K. Ehn.
- 4. Update on Timeline for Phase I Research Video Summary
- 5. Presentation on Atlantic Brant Research
- 6. Update on the Prospective for CHCRP Phase II
- 7. Update on the Finalization of Phase I and Research Data Collection by Niskamoon
- 8. Miscellaneous
- 9. Summary and Next Steps
- 10. Next Meeting

1. Approval of the Agenda

The Chair reviewed the agenda, and no additional points were proposed. Thus, the agenda was approved as presented.

The Chair suggested moving forward with point 3 to accommodate Jens Ehn (Mr. Ehn).

2. Approval of the minutes from the previous meetings:

- o January 12, 2022 Noº 45
- August 31, 2022 No^o 50
- September 21, 2022 No^o 51
- October 27, 2022 No^o 52
- December 8, 2022 No^o 53

Luc Duquette (**Mr. Duquette**) recommended scheduling another meeting specifically to assess the minutes. Moreover, he expressed interest in obtaining an update on the erosion study.

3. Review of the manuscript

 "Influence of altered freshwater discharge on the seasonality of nutrient distributions near La Grande River, northeastern James Bay"

by Alessia C. Guzzi, Christine Michel, Jean-Éric Tremblay, Joel P. Heath, Jens K. Ehn, and Zou Zou Kuzyk.

Mr. Ehn proceeded to present the manuscript titled "Influence of altered freshwater discharge on the seasonality of nutrient distributions near La Grande River, northeastern James Bay" by providing an overview and elaborating on the summary. A copy of the manuscript is attached to these minutes for reference. He illuminated the content using diagrams from the manuscript.

Mr. Ehn presented findings related to stable isotopes and oxidants in water samples, explaining the ratio between oxygen isotopes 16 and 18. He discussed how the isotopic composition indicates the water's origin and highlighted the mix of river water and seawater in the samples.

The presentation also covered nutrient distributions, specifically nitrate and phosphate, in different seasons. The data revealed variations in nutrient levels, with winter showing nutrient outflow from the river, spring indicating biological production, and summer exhibiting a decrease in nutrient concentrations due to uptake by phytoplankton and eelgrass.

The main conclusion was that changes in freshwater discharge timing impact nutrient availability, influencing local production. Chair acknowledged the clarity of the summary but questioned if the eelgrass depletion could be linked to seasonal shifts.

John Lameboy (**Mr. Lameboy**) reminisced about past sampling experiences and questioned whether the area's salinity had changed over the years. Mr. Ehn explained that ice conditions and winter temperatures influenced freshwater spread and salinity levels.

Mr. Duquette inquired about sampling efforts in broader areas, and Mr. Ehn shared details of the extensive sampling along the west coast of Hudson Bay. Zou Zou Kuzyk (**Mrs. Kuzyk**) added information about tracking freshwater plumes southward.

Carine Durocher (**Mrs. Durocher**) raised concerns about generalizing La Grande River mouth findings to the entire coast, emphasizing the importance of additional southward sampling. Mr. Ehn mentioned ongoing projects exploring the influence of wind and ice conditions on freshwater flow.

Mrs. Kuzyk clarified the eelgrass team's confidence in their ability to adapt to nutrient changes, focusing on nitrogen and indicating potential impacts on phytoplankton rather than established eelgrass beds.

The discussion touched on phosphate levels near the river mouth and the possibility of eelgrass adapting to nutrient changes over time. Melanie Leblanc (**Mrs. Leblanc**) emphasized the need to investigate eelgrass root sampling to better understand nutrient uptake.

Decision: The Committee agreed to proceed with the manuscript, endorsing its submission for publication.

"Stable Isotopes of Landfast Sea Ice as a Record of La Grande River Under-Ice Plume Spreading" by A. Diaz, Z. A. Kuzyk, A. Guzzi, K. Gupta, T. Papakyriakou, and J. K. Ehn.

Mr. Ehn proceeded to present the manuscript titled " Stable Isotopes of Landfast Sea Ice as a Record of La Grande River Under-Ice Plume Spreading" by providing an overview and elaborating on the summary. Mr. Ehn presented the manuscript and clarified its connection with a previous article, addressing the use of stable isotope data in both. The manuscript aimed to analyze stable isotope data from ice cores to determine the influence of altered freshwater discharge on the seasonality of nutrient distributions near La Grande River in northeastern James Bay.

During the presentation, Mr. Ehn explained the methodology employed, emphasizing the differentiation between river water and ocean sea ice based on oxygen isotopes. The study involved sampling at various locations and depths, and the results were presented in diagrams illustrating the distribution of river water and seawater in the ice cores over time.

The Committee engaged in a discussion, with Mrs. Durocher seeking clarification on whether the ice cores reflected only the first layer of water below the ice. Mr. Ehn explained that the ice cores primarily reflected the conditions right underneath the ice, providing a snapshot of the water during the ice formation.

Mrs. Durocher further inquired about mapping the freshwater plume using the results, and Mr. Ehn explained the limitations of the study, noting that the method focused on the first layers of water and did not capture variations due to tides.

Mr. Lameboy expressed concerns about permissions, recalling instances where access to certain areas was not granted. The committee discussed the collaboration with the traplines and the acknowledgment of their support in the manuscript.

In response to Mr. Duquette's question about the comfort level of publishing the manuscript, the Committee agreed to proceed with the submission for publication, with the understanding that permission for sampling implies permission for publication. Mrs. Kuzyk assured that the acknowledgments would recognize the collaboration with the traplines.

The committee endorsed the manuscript for publication, emphasizing the importance of clear acknowledgments and permissions in research collaborations.

Decision: The Committee agreed to proceed with the manuscript with the editions that were discussed, endorsing its submission for publication.

4. Update on Timeline for Phase I Research Video Summary

Mrs. Leblanc provided a detailed explanation of the progress made regarding the video production. In February and March, the company delivered a recorded version of the video. After receiving comments, it was decided that further recorded versions would not be pursued, and instead, the focus would shift to revising the script to address concerns and comments. The Chair expressed concern about the modified version of the video. The decision was made to allow two weeks for comment review, with a deadline of November 1st. The Secretary would be responsible for collecting the comments, and if the comments were not significant, another meeting would not be required.

Additionally, Mrs. Kuzyk suggested that Lucie Salt conduct the voice-over for the video, which received agreement from the committee. Mrs. Kuzyk would return with a proposed timeline and requested support on how to conduct the recording. The Chair proposed involving Christopher as a resource, and Ernie Rabbitskin (**Mr. Rabbitskin**) suggested involving local resources for recording and sharing the video on social media. Mr. Ehn left the meeting during this discussion.

5. Presentation on Atlantic Brant Research

Lindsay Carlson (**Mrs. Carlson**) delivered a presentation titled "Ascribing the importance of Atlantic brant staging areas for holistic conservation planning," and a copy of the presentation is attached to these minutes for reference.

Mrs. Durocher inquired about the animated data, particularly noting lines of dots of the same color and speculating if they represented flight patterns. Mrs. Carlson clarified that each dot represented an individual brant, with lines indicating flight paths. The GPS data collected twice an hour illustrated flight patterns and stationary positions.

The Chair interjected with comments on the significance of the findings, suggesting a comparison with historical data, such as the Native Harvest Survey from the 1970s, to highlight the decline in brant abundance. He emphasized the importance of corroborating traditional knowledge with scientific data.

Mr. Lameboy shared personal experiences of sickness related to consuming brant and suggested investigating potential bacterial contamination in their northern migration areas. Mrs. Carlson expressed interest in collaboration to explore these health concerns further.

Jean-Philippe Gilbert (**Mr. Gilbert**) offered historical vegetation data around Rupert Bay and the Rupert estuary since 2002, proposing collaboration. Mrs. Carlson welcomed the offer, mentioning the possible shift in vegetation and its impact on brant habitat.

Mrs. Durocher asked about the factors attracting brant to Rupert Bay, to which Mrs. Carlson explained the hypotheses related to emergent vegetation maintained by other geese. The discussion delved into the puzzling behavior of brant bypassing available eelgrass.

Mr. Lameboy inquired if samples were collected on the West Coast, expressing interest in comparing eelgrass on the East and West Coasts. Mrs. Carlson explained limited sampling on the West Coast due to funding constraints but acknowledged its importance.

As members left the meeting, Mr. Duquette proposed deferring some agenda items to the next meeting due to time constraints. The discussion concluded with appreciation for Lindsay Carlson's informative presentation, with plans for future updates based on ongoing fieldwork.

6. Update on the Prospective for CHCRP Phase II

The Chair Leblanc provided an update on the prospective progress of the CHCRP Phase II. The Chair Leblanc inquired about the status of Hydro-Québec (**HQ**) in this process. Mr. Duquette responded, stating that a letter is currently on HQ's desk, but there has been no commitment regarding the funding amount. He mentioned that if the orientation of the project remains the same, there could be potential support.

The Chair Leblanc informed the committee that discussions were ongoing with partners, and a proposal was in the works. She expressed the desire to submit this proposal within the next 3-4 weeks, emphasizing the importance of having a letter of support. Furthermore, plans were underway for a community visit scheduled for the first week of December to inform the communities about the project and gather feedback.

7. Update on the Finalization of Phase I and Research Data Collection by Niskamoon

The Chair Leblanc provided an update on the ongoing finalization of Phase I and research data collection by Niskamoon. She mentioned that Niskamoon was in the process of securing additional space, and it was anticipated to be completed by December. There was an exception made for Cree knowledge. The details of this exception, however, were under current discussion.

Following this update, Mr. Duquette suggested adjourning the meeting, noting that several participants had already left.

8. Miscellaneous

This point was not addressed due to the departure of several members, and as a result, the meeting was adjourned.

9. Summary and Next Steps

This point was not addressed due to the departure of several members, and as a result, the meeting was adjourned.

10. Next Meeting

A discussion ensued regarding the scheduling of the next meeting. It was proposed that another session be held to review the minutes and to facilitate this, smaller groups would be formed to determine the most suitable date. The tentative timeline suggested a meeting in three to four weeks. Additionally, it was suggested that another meeting might be required in December to accommodate further manuscript presentations.

ADJOURNMENT OF THE MEETING

Considering the departure of several members, the meeting is adjourned at 11:50 AM.

The meeting secretary,

Johanna Ménélas

Dear members of the Steering Committee:

Please find attached a manuscript about how the altered freshwater discharge from La Grande has influenced the seasonality of nutrient distributions in northeastern James Bay. We used salinity, oxygen isotope ratio (δ 180), and nutrient (nitrate, phosphate) data collected from NE James Bay coastal waters during six campaigns spanning 2016 and 2017 to quantify sea-ice melt and river water content and assess their influence on nutrient distributions. River water supplies nutrients to the coastal waters but different amounts of nutrients during different seasons, depending on the concentrations of nutrients in the river water and the flow discharge. Our results showed that La Grande is the dominant source of freshwater to coastal waters in the study area (CH3 to CH5) during both winter and summer. The river is also an important source of nitrate to nitrogen-limited coastal waters. However, regulation of the flow has changed the timing of the natural nitrate inputs from the river. What was observed historically (predevelopment) in spring is observed in winter under the modified flow regime (post-development). Thus, high surface nitrate stocks are available to support primary production in winter, rather than during the growing season, which can begin only after the return of light. The main conclusion is that primary production dependent on nutrients in the water column (e.g., algae or phytoplankton) likely was impacted by the development (reduced in the local area), whereas eelgrass beds using nutrients from the sediments would not have been affected.

Influence of altered freshwater discharge on the seasonality of nutrient distributions near La Grande River, northeastern James Bay

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10 Abstract

11 In subarctic marine environments, winter is a time when nutrient stocks are replenished through physical 12 and biogeochemical processes, largely setting an upper limit on new primary production for the next growing season. In spring, freshwater-associated nutrient additions from sea-ice melt and river inflow 13 14 modify the marine nutrient stocks, especially in coastal areas. In northeastern James Bay (NEJB), Québec, 15 hydroelectric development of the La Grande River (LGR) has shifted the timing of peak freshwater 16 discharge from spring into winter, producing ten times the natural winter flows. Observations of coastal 17 water properties in this area are limited to a few studies, none of which simultaneously included nutrients 18 and freshwater tracers to distinguish the influence of river water from sea-ice melt. In this study, we used salinity, oxygen isotope ratio (δ^{18} O), and nutrient (nitrate, phosphate) data collected from NEJB coastal 19 20 waters during six campaigns spanning 2016 and 2017 to quantify sea-ice melt and river water content and 21 their influence on nutrient distributions within the region of freshwater influence of LGR. Our results 22 show that LGR is the dominant source of freshwater to coastal waters in both winter and summer and an 23 important source of nitrate to nitrogen-limited coastal waters. Regulation of the LGR has shifted natural 24 fluvial nitrate inputs, what was observed in spring (pre-development) is now observed in winter (postdevelopment). Thus, high surface nitrate stocks are available to support primary production in winter,
rather than during the growing season, which can begin only after the return of light. In NEJB, the timing
and magnitude of primary production, dependent on nutrients in the water column, is expected to have
been impacted by altered freshwater input, reducing overall production in local areas and potentially
increasing production further downstream with cascading effects on the marine ecosystem.

30 1. Introduction

31 The response of marine ecosystems to environmental change in subarctic environments depends on the 32 interactions between numerous controlling factors. These factors include, but are not limited to, a strong 33 seasonality in temperature, solar insolation, and consequently freshwater inputs and nutrient dynamics. 34 These factors control many aspects of the subarctic seasonal cycle. In the context of climate change, 35 whether projected future increases in primary production in Arctic marine areas (Rysgaard et al., 1999; 36 Arrigo et al., 2011) will be realized depends on whether freshwater additions to surface waters increase 37 vertical stratification and decrease nutrient availability during the growing season when there is sufficient 38 light (Tremblay and Gagnon, 2009; Bergeron and Tremblay, 2014). 39 In subarctic marine environments, during fall and winter, nutrients are resupplied to surface waters 40 through vertical mixing, driven by wind and brine-induced mixing (Kuzyk et al., 2010; Granskog et al., 41 2011). These nutrients remain relatively unused until spring (sea ice thinning and breakup), when

42 increased light availability helps stimulate primary production in the water column or within the ice.

43 Phytoplankton blooms typically begin in subarctic surface waters as soon as sufficient light has returned

44 to the under-ice environment (Mundy et al., 2011). The nutrient stock in the surface layer when spring

45 arrives thus sets the upper limit for new spring primary production, in the absence of additional nutrient

46 sources.

47 Coastal areas are subject to seasonality in both sea-ice (landfast) melt inputs and riverine discharge that 48 influence primary production in ways that differ from the offshore ocean, where sea ice melt is the 49 predominant freshwater source (Prinsenberg, 1988; Carmack et al., 2015). Furthermore, river runoff may 50 supply nutrients to coastal areas that are otherwise limiting in offshore waters (Granskog et al., 2005), 51 where sea-ice melt water is typically nutrient poor (Mundy et al., 2011).

52 In the Canadian subarctic, Hudson Bay and its southern extension James Bay are strongly influenced by river runoff, estimated at 630-870 km³ yr⁻¹ (Saucier et al., 2004; Dery et al., 2011; 2016), and sea-ice melt 53 (annual estimate 742 ± 10 km³ in Landy et al., 2017; about 100 km³ less in St-Laurent et al., 2011). 54 55 Hudson Bay is generally characterized as an oligotrophic system with relatively low productivity, in large 56 part due to the critical influence of freshwater in maintaining year-round stratification (Tremblay et al., 57 2019). The addition of freshwater, which peaks in spring/early summer (Prinsenberg, 1988) effectively 58 reduces the supply of deep-water nutrients to the euphotic zone (Anderson and Roff, 1980; Roff and 59 Legendre, 1986; Kuzyk et al., 2010; Ferland et al., 2011, Tremblay et al., 2019). This increases the 60 importance of riverine nutrient delivery directly to surface waters at the start of the growing season.

James Bay, which directly receives about 300 km³ yr⁻¹ river water into an area of only 68,000 km² 61 62 (Ridenour et al., 2019), has been essentially unstudied in terms of freshwater and nutrient cycling since 63 the 1970s. Most of the work during the late 1970s presented baseline studies of coastal water properties 64 before the beginning of the La Grande Complex hydroelectric development (Messier et al., 1986; Ingram 65 and Larouche, 1987). One conclusion from this early work was that hydroelectric development would 66 strongly modify seasonal flows and freshwater distributions in the coastal environment of the northeastern 67 James Bay (NEJB). However, because the La Grande River (LGR) did not significantly supply essential 68 nutrients for primary producers (nitrate and phosphate) in James Bay including the La Grande estuary, 69 they expected no changes in plankton production related to nutrient availability (Grainger and McSween, 70 1976; Messier et al., 1986).

71 After fifty years, oceanographic studies in James Bay have begun anew (cf. Mundy et al., 2021; Peck et 72 al., 2022; de Melo et al., 2022), in part to address community and First Nations concerns about observed 73 environmental changes along coastal areas of the bay, including declines in seagrasses (Zostera marina, commonly known as eelgrass). The objectives of this study are to help alleviate persisting baseline data 74 75 gaps; characterize the freshwater and nutrient distributions in the NEJB coastal area under contemporary 76 flow regimes during summer and winter; assess how the modifications to LGR have affected nutrient 77 stocks in the coastal environment; and discuss potential impacts on primary production. To accomplish 78 these objectives, we first quantify freshwater source contributions during each season using salinity and oxygen isotope ratio (δ^{18} O) tracer data. Next, we examine nutrient-salinity and nutrient-nutrient 79 80 relationships to explore the fate of the nutrients in the coastal waters (conservative mixing versus 81 biological drawdown) and identify the limiting nutrient(s). Finally, we quantify the direct contribution of 82 river water to nutrient stocks in both winter and summer. This provides insight into how the altered 83 hydrograph of the LGR has affected the nutrient stocks potentially available to support primary 84 production in this area in spring.

85 2. Study area

James Bay is located well below the Arctic Circle but it experiences a climate and sea-ice cycle similar to that of continental shelves bordering the Arctic Ocean (Hochheim and Barber, 2010; Andrews et al., 2018). The climate is cold with daily average temperatures ranging from -23.2°C in winter to +14.2°C in summer (1981-2010 data from La Grande Rivière A weather station, Environment and Climate Change Canada). Sea-ice formation typically begins in November, and forms across the bay area, and breakup occurs in May-June (Galbraith and Larouche, 2011; Taha et al., 2019).

The seawater in Hudson Bay generally originates in the Arctic Ocean. Surface waters from Hudson Bay enter James Bay along the western coast and circulate cyclonically within James Bay, exiting along the eastern coast back into Hudson Bay (Figure 1) (Prinsenberg, 1982; Ridenour et al., 2019). As the water

95 circulates James Bay, it continues to be transformed by addition of freshwater, resulting in lower surface 96 salinity on the eastern side of the Bay compared to the western side (Prinsenberg 1984). The surface 97 salinity distribution is affected both by sea ice melt and riverine discharge (Prinsenberg, 1988). 98 The study area is located along the northeastern coast of James Bay between the latitudes 53.6°N and 99 54.6°N (Figure 1) which is an area influenced by the LGR discharge. The LGR was naturally the largest 100 river along the Québec coastline and has increased in size since completion of the third phase of 101 hydroelectric development (Rupert River diversion, 2009-2012) and now dominates regional discharge in 102 all months of the year, especially in winter (Figure 2). Flows diverted into the LGR complex originated in 103 the Eastmain, Rupert, and Opinaca Rivers of southeastern James Bay and the Caniapiscau River, which 104 naturally discharged into Ungava Bay (Hernández-Henríquez et al., 2010; Déry et al. 2016). Peak flows from La Grande River now occur between January and March, at 4000-6000 m³ s⁻¹ (Peck et al., 2022), 105 whereas prior to development, peak discharge (~3800 m³ s⁻¹ averaged for 1975-1977) occurred during the 106 107 spring freshet period around June (Messier et al., 1986; Hernández-Henríquez et al., 2010).



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109 Figure 1. Map of James Bay and surrounding areas. General circulation pattern is indicated by black 110 arrows and the rough extent of the study area is outlined in the red rectangle.



Figure 2. Average monthly discharge of thirteen major rivers along the Québec coastline after development of the La Grande River complex (post 2012). From de Melo (2022).

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114 The sustained high flows during winter discharging into the landfast-ice covered coastal environment (see Figure 3a) lead to formation of a large, low surface salinity (< 5), under-ice river plume, with a "core" 115 area (highly stratified and surface salinity < 5) of $\sim 1200 \text{ km}^2$ and diluted waters extending throughout 116 117 NEJB to southern Hudson Bay (Eastwood et al., 2020; Peck et al., 2022). Initially, the plume core area 118 scaled with discharge (Ingram and Larouche, 1987; Li and Ingram, 2007), but the configuration of the 119 coast and width of landfast sea ice constrains further expansion without vertical mixing. More recent 120 increases in winter discharge have led to higher currents and a faster freshwater flushing rate through the 121 core area. Peck et al. (2022) estimated that it now takes only about 10 days at mean winter discharge of 122 $4800 \text{ m}^3 \text{ s}^{-1}$ to fill the core plume area. In contrast to winter flows, the peak June flows $(3094 \pm 543 \text{ m}^3 \text{ s}^{-1})$ 123 over 2013-2019; del Giorgio, pers. comm.), which would be highest in natural conditions, are at the low end of the observed natural range (2400 m³ s⁻¹ to 6100 m³ s⁻¹ for 1960-1978; Messier et al., 1986). 124

125 The current work is part of a multidisciplinary study of the eelgrass and coastal environment in NEJB

- 126 entitled the Coastal Habitat Comprehensive Research Program (CHCRP)
- 127 (https://www.eeyoucoastalhabitat.ca/?fbclid=IwAR3QfMTyDP4Z-
- 128 NBqFsO1Gea3vKIDHWtXxFaYB3UY6SeCKWkbCFGHe32aclg). The NEJB region in which the LGR

129 development has taken place is known as Eevou Istchee (Cree homeland), and this study was conducted 130 in partnership with the Cree Nation of Chisasibi. Community research partners contributed to the study 131 design and field sampling, and shared knowledge about water circulation and the ice environment. A 132 motivation for the study was the concern amongst Cree community members about the impacts of the 133 increased LGR plume on the health of eelgrass (Zostera marina), which historically occurred as vast 134 meadows along the NEJB coast including a large embayment called Bay of Many Islands (BoMI) ~40 km 135 north of the river mouth (CNC, 2015; Lalumière et al., 1994). Eelgrass biomass and extent declined dramatically during the late 1990s and to date the meadows have failed to recover (Leblanc et al., 2023). 136 A recent study by Leblanc et al. (2022) found that high discharge from LGR, early ice breakup and 137 138 warming waters negatively affect eelgrass biomass at some beds in the NEJB area.



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Figure 3. View of the sampling stations for this study in winter (left) and summer (right). Satellite images were sourced from NASA Worldview from January 20, 2016 (left) and July 4, 2017 (right).

142 Sampling stations are shown in red (2016) and blue (2017). Points that appear larger in winter indicate 143 stations that were visited more than once. General background flow direction is identified by the blue

144 arrow (left). In winter (left), landfast ice edge is traced in blue, mobile pack ice lies seaward of the

145 landfast ice and open water (flaw leads) appear as dark areas.

146 3. Methods

147 *3.1 Sample collection*

148 Water samples were collected during three periods in both 2016 and 2017, referred to as early winter 149 (January), late winter (April) and summer (August/early September). Sampling stations extended north 150 and to a lesser extent south of the La Grande River where it discharges at the community of Chisasibi 151 (Figure 3). All stations were within 25 km of the shore and within the limit of the landfast ice. In 2016, 38 152 stations were visited over three sampling trips in early winter, late winter, and summer. In 2017, 47 153 stations were sampled over four separate sampling trips but spanning the same three seasons. Stations 154 varied spatially between the two years because of ice conditions and a shift in focus from capturing the 155 LGR plume extent in 2016 (north-south) to understanding its flow inshore to smaller bays known for 156 eelgrass presence in 2017.

Winter sampling was conducted using the landfast ice as a platform. Upon arrival at a station by 157 158 snowmobile, a hole was drilled through the landfast ice with an auger, cleared free of slush, and then the 159 instruments and water sampler were deployed. An ice fishing tent was typically installed over the hole 160 during cold and/or windy conditions. In summer, sampling took place from freighter canoes and 161 instruments and the water sampler were deployed directly from the side of the canoe. Conductivity, 162 temperature, depth (CTD) profiles were obtained with either, but most often with both, an Idronaut Ocean 163 Seven 304 Plus or a Sontek Castaway CTD profiler. Instrument accuracies, as stated by the manufacturers 164 are $\pm 0.05^{\circ}$ C, $0.25\% \pm 5 \,\mu$ S/cm for conductivity, and ± 0.1 for salinity for the Castaway, and $\pm 0.002^{\circ}$ C 165 and ± 0.003 mS/cm for the Idronaut Ocean Seven 304 Plus. The CTD data were used only in a supporting 166 role in this study but informed a parallel study on the hydrography of the plume (Peck et al., 2022).

167 Various depths in the water column were sampled at each site with the use of a Kemmerer water sampler, 168 which was deployed with a pre-marked rope (1 m intervals) and a weight at the bottom. At stations < 5 m 169 deep, only surface samples were collected, except for one station with bottom depth 3.5 m where surface and 3 m samples were collected. At all other stations, surface and near-bottom (within 1 m) water was
collected. In addition, samples were collected within 1m above and below the halocline (usually at nearbottom) when one was observed. These sampling depths were determined using the Castaway CTD
profiles that can be viewed immediately after casts.

174 *3.2 Sample analysis*

175 Water samples were processed within a few hours of collection in a temporary, clean laboratory space, 176 free of materials that would contaminate samples. Samples were properly stored or frozen for later 177 analysis in various university laboratories. All samples were analyzed for macronutrient concentrations (nitrate and phosphate results are examined in this study), salinity, and oxygen isotope ratio (δ^{18} O). δ^{18} O 178 179 samples were collected into new 20 mL scintillation vials, with no headspace, tightly capped and sealed 180 with parafilm, and then stored at 4°C. The samples were analyzed at Jás Veizer Stable Isotope Laboratory 181 (formerly GG Hatch) at the University of Ottawa using a Gasbench attached to a DeltaPlus XP isotope 182 ratio mass spectrometer (ThermoFinnigan, Germany). Subsamples (0.6 mL) were pipetted into an 183 Exetainer, and, together with internal standards, flushed with a gas mixture of 2% CO₂ in helium using 184 the Gasbench. Exetainers were left to equilibrate at +25°C for 18 h minimum. Values are expressed in 185 standard δ^{18} O notation (in per mil or ‰ units) with the V-SMOW (Vienna Standard Mean Seawater) as 186 reference value. Analytical instrument precision was ± 0.15 %. Water samples for salinity were collected 187 into clean 125 mL Boston Round glass bottles, tightly capped and sealed with parafilm. Salinity was 188 measured using a Guildline Autosal 8400 salinometer with a precision better than 0.002 at the Marine 189 Productivity laboratory at the Freshwater Institute (FWI), Fisheries and Oceans (DFO), Winnipeg. 190 Samples were standardized against IAPSO Standard Sea Water. Nutrient samples were collected after 191 filtration through a pre-combusted (5-8 hours at 500°C) glass fiber filter (Whatman GF/F 25mm, nominal 192 pore size 0.7 um) held in an acid-washed (10% HCl) syringe style filter holder. The filtrate was collected 193 into 15 mL acid-washed (10% HCl) polyethylene tubes, after three sample rinse. Samples were frozen 194 at -20°C until samples were analyzed using a Bran and Luebbe Autoanalyzer III following standard

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195 colorimetric methods (Grasshoff et al., 1999) at Université Laval, Québec. Analytical detection limits for 196 the nutrient concentrations used in this study are $0.03 \ \mu\text{M}$ for NO₃⁻ (nitrate), and $0.05 \ \mu\text{M}$ for PO₄³⁻ 197 (phosphate).

198 *3.3 Data analysis*

199 To ensure accuracy of sampling depths, bottle salinity results were matched with CTD salinity readings.

200 This was done to avoid discrepancies potentially caused by currents altering the depth at which the

201 Kemmerer was ultimately closed since the CTD and Kemmerer sampler were deployed independently.

202 Statistical analysis was conducted with the use of R programming language. Relationships between

203 seasons (early winter, late winter and summer) were analyzed for each parameter to determine seasonal

204 patterns using regression analysis. Analysis of variance (ANOVA) was used to test the significance of the

205 variance between slopes and y-intercepts of the winter and summer salinity- δ^{18} O relationships. Paired t-

206 tests were used to determine the significance of differences between water mass fractions calculated with

207 salinity and δ^{18} O pairs and those fractions calculated with just salinity, to inform the final nutrient stock 208 calculations (described in Section 5.4).

209 *3.4 Water mass fraction*

To quantify the contributions of each freshwater type, traditional tracers, δ^{18} O and salinity, were used 210 (Tan and Strain, 1980; Östlund and Hut, 1984). Tandem properties, δ^{18} O and salinity, provide a way to 211 212 distinguish between the freshening influence of river water, which is fresh and isotopically light, and sea-213 ice melt, which is nearly fresh and isotopically heavy, like seawater (e.g., see Tan and Strain, 1980). We 214 followed the method developed by Östlund and Hut (1984), wherein three linear equations are used 215 together with a selection of end-members appropriate to the dataset to calculate the fractional 216 contributions of three source waters to each water sample (Östlund and Hut, 1984). In this study we 217 calculated the fractions of runoff/riverine input (RW), sea-ice melt (SIM), and ambient seawater (SW) for each sample. Sea-ice provides a different signal than runoff, which can only add positive amounts of
isotopically light water to the system. Sea ice freezes in winter, withdrawing freshwater from seawater
that is enriched in ¹⁸O and leaving salt behind (brine) that is depleted in ¹⁸O compared to the source water.
During the summer melt period, this low-salinity ice-melt is returned to the water column. Accordingly, a
calculated fraction of SIM may be either positive or negative with the latter indicating a higher than
expected salinity, associated with brine inputs from sea ice formation (Granskog et al. 2011; Eastwood et
al., 2020).

225 Three linear equations to determine the fractions, F, are as follows:

 $F_{SW} + F_{RW} + F_{SIM} = 1$

$$F_{SW}S_{SW} + F_{RW}S_{RW} + F_{SIM}S_{SIM} = S$$

 $F_{SW}X_{SW} + F_{RW}X_{RW} + F_{SIM}X_{SIM} = X$

where F = fraction of the associated subscript, S = salinity, and X = δ^{18} O. Subscripts SW, RW, and SIM denote ambient seawater, riverine runoff, and sea-ice melt/brine, respectively (modified from Östlund and Hut, 1984). Each S and X value in the above equations represents an appropriate water type end-member based on this dataset.

4. Results

234 4.1 Surface distributions of salinity, $\delta^{18}O$, and nutrients

- Bay of Many Islands (BoMI), surface salinity increased to about 12 and δ^{18} O increased to around -9‰
- 238 (Figure 4a, b). Nitrate concentrations varied from 2 to 5 µM, with lowest values observed in inshore
- 239 waters of BoMI (Figure 4c). Phosphate distributions were similar to salinity and δ^{18} O, with very low

²³⁵ During the early winters of 2016 and 2017, surface waters along the NEJB coast had very low salinity (~<

^{236 3)} and δ^{18} O around -13‰ for 30-40 km northward of the LGR mouth. Immediately further north, near

240 concentrations (< 0.1μ M) near the river mouth and concentrations reaching about 0.5 μ M further north 241 (Figure 4d).

242 During late winter, surface distributions of salinity, $\delta^{18}O$, nitrate and phosphate remained similar to early

243 winter. Some new sampling sites south of the LGR mouth, that were visited for the first time, were found

to have very low surface salinity (< 5) and δ^{18} O < -12‰, nitrate between 4 and 5 μ M, and phosphate

 $245 < 0.1 \mu$ M (Figure 4e-h). A new site north of BoMI near the mouth of the Roggan River showed a surface

salinity of 1.8, δ^{18} O of -13.4‰, and nitrate and phosphate concentrations of 5.1 µM and 0.4 µM,

respectively.

248 We did not have the opportunity to revisit some of the early winter inshore sites in BoMI that had low

249 nitrate. More stations in late winter were sampled for salinity and δ^{18} O analysis than for nutrients

250 (compare Figure 4e, f and Figure 4g, h).

Summer surface distributions of salinity, δ^{18} O, nitrate and phosphate differed from those in early and late winter. Only a few sites near the LGR had very low salinity (<5) and δ^{18} O (<-11‰) (Figure 4i, j). Surface salinity increased rapidly with distance from the river mouth and almost every site that was visited during both summer and winter had higher surface salinity in summer (compare Figure 4a, e and Figure 4i). The station near the Roggan River had a summer surface salinity of 20.5. The median nitrate concentration in surface waters during summer was < 0.01 μ M (n=45), whereas phosphate concentrations in surface waters varied from 0 to 0.45 μ M with no obvious spatial pattern (Figure 4k, l).



258 Figure 4. Maps of surface water salinity, δ^{18} O, nitrate, and phosphate, during winter (a-d), late

winter (e-h), and summer (i-l). La Grande River labeled as LGR, Roggan River labeled as Roggan R.
and Bay of Many Islands labeled as BoMI in (a) for reference.

261 4.2 Vertical profiles of salinity, $\delta^{l8}O$, and nutrients

262 During both early winter and late winter, the water column beneath the ice cover was strongly stratified 263 such that salinity increased abruptly with water depth (Figure 5a,e). The observed salinity reached 264 maximum values of 25.32 in early winter and 25.86 in late winter in the deepest waters sampled within the study area (20-25 m). The most saline subsurface samples had δ^{18} O values during winter of -4.9% 265 266 (Figure 5b,f). In contrast, nitrate concentrations generally decreased with depth, from surface values of 267 about 5 µM to 2-3 µM in the deepest samples (Figure 5c,g). There were a few unusual surface and near-268 surface samples from the upper 10 m with nitrate concentrations of only 2-3 µM (Figure 5c). Phosphate 269 concentrations increased with depth from surface values $< 0.1 \ \mu\text{M}$ to 0.6-0.7 μM in the deepest samples 270 (Figure 5d). During summer, we observed a wide range in salinity and δ^{18} O at the surface (top 1 m) but relatively 271 uniform conditions in the subsurface waters (Figure 5e,f). At depths between 3 and 10 m, salinity ranged 272 273 between 17.5-20.7, with one exception having salinity of 22.0 (Figure 5i). Nitrate concentrations were 274 near zero in samples from all depths except in three shallow and two deep water samples, where 275 concentrations reached as high as 3.0 µM (Figure 5j). Phosphate varied between about 0 and 0.5 µM with no obvious relationship to water depth (Figure 5i), but subsurface values were generally lower than what 276

277 was observed during winter.



278

Figure 5. Depth profiles of salinity, δ^{18} O, nitrate and phosphate during separate seasons. Where panels a-d represent early winter, panels e-h represent late winter, and panels i-l represent summer.

281 5. Discussion

282 5.1 Seasonal differences in surface salinity along the coast

283 Surface salinity along the NEJB coast varied greatly between winter and summer (Figure 4a, e, i) largely

because of differences in the thickness and extent of the plume of the LGR, which is controlled not only

- 285 by the volume of river discharge but also by the reduction in wind-driven mixing in the presence of
- landfast ice (cf., Peck et al., 2022; Ingram and Larouche, 1987; Messier et al., 1986; 1989). During 2016
- and 2017, the winter discharge of the LGR, averaged 4800 m³ s⁻¹ (Peck et al., 2022), which due to
- regulation exceeded the summer discharge average of 3010 m³ s⁻¹ (De Melo et al., 2022). The core area of
- the plume was estimated to range from 1200 km² in winter to 120 km² in summer (Messier et al., 1989;

Peck et al., 2022). This aligns with our winter observations of a fresh (salinity < 5) surface layer, about 3-
5 m thick, with a sharp transition to the underlying brackish water (salinity >15) within the core plume
area (Figure 5a, e).

293 The winter water samples from BoMI lay within the region of freshwater influence of the LGR but 294 outside the unmixed core of the plume, hence their higher surface salinities (Figure 4a,e). During winters 295 2016 and 2017, the core of the plume extended northward to the southern margin of the BoMI region. Our 296 results show weaker stratification within the BoMI area with winter surface salinities of 8.8-13.6, several 297 units lower than summer values (Figures 4a, e, i) and consistent with CTD observations (Peck et al., 298 2022). The study region includes many small rivers (compared to LGR) that are not expected to 299 significantly influence the regional coastal salinity, particularly in winter when these unregulated, and 300 largely frozen, rivers are characterized by low flow rates (Orlova and Branfireun, 2014; de Melo et al., 2022). However, these rivers can still have a very localized impact on salinity, δ^{18} O and nutrients. For 301 302 example, the low surface salinity observed near the Roggan River, located north of BoMI, (Figure 3), was 303 likely a result of this localized influence (Figure 4e, i). Roggan River is the second largest river in the study area, with a winter discharge of about 64 m³ s⁻¹, that is, 1-2% of LGR (de Melo et al., 2022). 304

305 5.2 Identification of primary water types using tracers

Examining the linear relationship between δ^{18} O and salinity (Figure 6), it is evident that there are two 306 307 primary water types influencing the coastal waters of NEJB within any given season: ambient seawater 308 and LGR discharge, and that mixing occurs between the two. Early winter and late winter samples lie 309 below and to the right of the summer samples, and when combined (early and late), winter samples are 310 significantly different from the summer relationship (Figure 6). The v-intercept of the regression line for 311 all winter values combined is significantly different than that for summer values (p < 0.001), whereas 312 slopes of the two regressions are not significantly different (p = 0.16). Table 1 provides statistics of the 313 apparent end-member properties for the two primary water types considering just two seasons, winter



321



322

Figure 6. Relationships between salinity and δ^{18} O for the three seasons of the study. Black dashed line represents the regression for early and late winter combined, and black solid line represents the

325 regression for summer. All points are coloured and shaped according to the three seasons of collection.

326

327 Table 1. Average and standard deviation for La Grande River (LGR) water and seawater

328 properties by season. The seawater water type is representative of the most saline samples in the 329 northeast James Bay study area. Early and late winter data were combined to calculate average winter 330 values. Number of observations (n) is indicated in parentheses.

Water Type $\delta^{18}O$ (‰) Salinity 0.03 ± 0.01 (2) La Grande River -14.07 ± 0.30 (2) Winter Seawater 25.61 ± 0.2 (5) -4.92 ± 0.5 (5) La Grande River 0.03 ± 0.01 (4) -12.52 ± 0.2 (4) Summer Seawater 22.45 ± 0.2 (4) -5.05 ± 0.5 (4)

331

Despite a nearly three-unit difference in the salinity of ambient seawater between winter and summer, 332 there is no significant difference in the δ^{18} O value of the most saline samples. However, the significant 333 difference in *y-intercept values* (p-value < 0.001, see Figure 6) at -13.83‰ for winter and -12.68‰ for 334 335 summer reflects the seasonal change in LGR δ^{18} O values (Table 1). Winter isotopic depletion is typical 336 for large northern rivers (Cooper et al., 2008; Pavlov et al., 2016) including rivers in Hudson Bay, of 337 which several show similar magnitude changes (about 1.5%) between winter and summer (Granskog et al., 2011). A change in river water δ^{18} O alone would have brought about a change in both intercept *and* 338 339 slope in the δ^{18} O-salinity relationships, all else remaining the same. However, we found no significant 340 difference in the slopes of the regressions between seasons (0.35‰ and 0.33‰ per unit salinity for winter 341 and summer, respectively; Figure 6). The summer freshening of the ambient seawater without significant change in δ^{18} O (Table 1) results in the slope of the line remaining the same and the summer mixing line 342 343 appears as shifted above and to the left of the winter mixing line (Figure 6). 344 The apparent freshening of ambient seawater between winter and summer cannot be attributed to addition 345 of river water considering the δ^{18} O values in LGR and those observed in small local rivers like the

346 Roggan River. Furthermore, in the context of the regional cyclonic circulation (Prinsenberg, 1988), all

- 347 sampled rivers "upstream" of the study area in southwest Hudson Bay have highly depleted δ^{18} O values

348 (between -13.59‰ and -10.30‰) similar to LGR (Granskog et al., 2011; Eastwood et al., 2020; Burt et 349 al., 2016). We attribute the summertime freshening of the ambient seawater with no associated change in δ^{18} O to addition of sea ice melt (SIM) to the source seawater somewhere upstream of the study area. 350 351 Landfast sea ice in southern Hudson Bay is formed annually and has low salinity (typically 0-6) and δ^{18} O 352 about 2‰ higher than that of the seawater from which it is formed (Eastwood et al., 2020). To estimate 353 the SIM percent contribution required to explain the summer freshening in the study area, we take the observed properties of sea ice in southern Hudson Bay as being representative (i.e., salinity of 0-6, δ^{18} O 354 between -4‰ and -0.5‰; Eastwood et al., 2020), together with the winter salinity and δ^{18} O values of the 355 356 LGR (0.03, -14.07‰) and those of the ambient seawater (25.61, -4.92‰), to solve the linear equations of 357 Östlund and Hut (1984). We estimate that the ambient summer seawater in the study area could be 358 produced by a mixture of about 10%-15% SIM with the ambient winter seawater. This estimate of the 359 SIM fraction in the summer water mass in NEJB exceeds a previous estimate of 5% SIM in typical 360 Hudson Bay surface waters during summer (Granskog et al., 2011) but is in good agreement with a more 361 recent estimate of ca 10% SIM for surface waters southeast of the Belcher Islands (Eastwood et al., 2020). 362 A significant contribution of SIM to summer surface waters in northern James Bay has long been 363 proposed (cf., Prinsenberg, 1984) but could not be quantified with salinity as the sole tracer. The addition 364 of SIM to surface waters may occur anywhere in Hudson Bay, but recent observations point to a potential 365 proximal source (to James Bay) in the long-lasting sea ice that tends to collect up and slowly melt 366 throughout summer in southwest Hudson Bay and northwest James Bay (Barber et al., 2021). A large ice 367 concentration develops in this area in some years due to advection of ice from northern areas by winds 368 and ocean currents. Because of its radiative properties and feedbacks to atmospheric forcings (e.g., albedo 369 effect), the ice typically lasts in this area well into July, and sometimes into August (see, for example, 370 Figure 2 in Etkin, 1991), although recent dates of ice loss have significantly advanced (cf., Andrews et al., 371 2018). Galbraith and Larouche (2011) found that this region had the latest breakup of sea ice of Hudson 372 Bay, on average, between 1971 and 2009. Observations of the long-lasting ice in southwestern Hudson

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373 Bay in late June 2019 found that it contained very thick floes (some more than 18 m) with near-zero 374 salinity ice that had already rejected its brine (Barber et al., 2021). The thickness and low salinity of the 375 long-lasting ice supports its role as a larger source of freshwater to James Bay. Protracted additions of 376 sea-ice melt from the thick and long-lasting ice mass into the surface water flowing into northwest James 377 Bay could explain the 10-15% apparent SIM contribution to summer seawater observed in the NEJB 378 study area in August, which was more than a month after the local sea ice and ice in southern James Bay 379 had disappeared. We note that the influence of Hudson Bay SIM in NEJB may be subject to large 380 interannual variability. As noted by Galbraith and Larouche (2011) and explored by Kirillov et al. (2020), 381 winter ice advection has two modes: NNW winds coupled with reversals in the general cyclonic 382 circulation during some winters lead to thicker ice in southern Hudson Bay, whereas enhanced WNW 383 winds and cyclonic circulation in other winters leads to thicker ice in eastern Hudson Bay.

384 *5.3 Influence of brine addition*

385 While the main variation in the salinity- δ 18O relationship is between winter and summer (Figure 6), 386 subtle shifts in the position of early winter and late winter samples relative to the winter mixing line 387 suggest compositional changes related to brine rejection during sea-ice formation. During late winter, 388 several high salinity samples lie slightly under the mixing line (Figure 6), which is consistent with 389 addition of brine (cf., Macdonald et al., 1995). To quantify the apparent brine addition between early and 390 late winter, we assume a landfast sea ice salinity of 4.0 and δ 180 value of -2.9‰ (based on values in 391 Eastwood et al., 2020) and combined them with the ambient seawater and LGR properties for the winter 392 period (Table 1) to solve the equations of Östlund and Hut (1984) for each water sample. Figure 7 shows 393 the calculated fraction of river water (Frw), fraction of seawater (Fsw), and fraction of sea-ice melt (Fsim) 394 as percentages for samples from early winter and late winter. The position of samples relative to the Fsim 395 vertex indicate a relative decrease in Fsim or addition of brine between early winter and late winter. Mean 396 values of Fsim across all samples decreased from 0.045 in early winter to -0.010 in late winter indicating 397 a fractional increase in the brine content of 0.055. This fractional increase in brine represents the

equivalent of 0.275 m of brine addition to a 5 m surface water layer (0.055 x 5 m = 0.275 m), or allowing for the 10% expansion upon freezing, roughly 0.30 m of in situ sea-ice growth.

400 However, much less thermodynamic ice growth of the landfast ice was observed at the sampling sites 401 between early winter and late winter. Mean ice thicknesses were 70 cm \pm 15 cm (n = 9) and 74 cm \pm 17 402 cm (n = 13) in January and April 2017, respectively. The landfast ice that may have grown between our 403 early winter and late winter sampling periods also would be considered an upper limit for local brine 404 rejection because, in the core plume area, river water would have been incorporated into the landfast ice 405 as it grew (cf., Macdonald et al., 1995; Kuzyk et al., 2008). We lack ice cores, and the associated samples 406 of salinity and δ^{18} O, from the sampling sites during this period that would allow us to quantify the amount 407 of river water that was incorporated into the landfast ice. We attribute the large apparent brine addition to 408 fast ice growth in the recurrent flaw lead that forms along the outer edge of the landfast ice (Figure 3; and 409 see Eastwood et al., 2020). There were several large storms during winters 2016 and 2017 with easterly 410 winds that would have blown the pack ice offshore and opened the flaw lead (Peck et al., 2022), 411 promoting new sea-ice formation. Considering that tens of centimeters of thermodynamic ice growth can 412 occur in a week's time when surface waters are directly exposed to cold air temperatures (Anderson, 413 1961), the overestimate of sea-ice growth (~30 cm vs. only ~ 4 cm of apparent *in situ* ice growth) based 414 on water properties under the landfast ice can reasonably be explained by advection of brine produced in 415 the flaw lead.





Figure 7. Relative percentages calculated from the fractions of river water, seawater, and sea ice melt in each winter water sample. Where Frw = Fraction of river water, Fsw = Fraction of seawater, and Fsim = Fraction of sea-ice melt in each water sample collected in early winter (circles) and late winter (squares).

421 5.4 Influence of river water on nutrient distributions

Statistical analysis reveals that > 93% of the variation in δ^{18} O observations, in both winter and summer, is 422 423 explained by the mixing of RW and SW, with SIM playing a relatively smaller role. LGR was also 424 identified as the dominant RW source within the coastal domain of NEJB. Thus, we proceed with using 425 salinity alone to assess the influence of freshwater (LGR) on nutrient distributions within the study area. 426 We avoid quantitative comparisons of those samples for which the regression residuals indicate a third 427 freshwater source might cause large error. In Figure 8, zero salinity is thus representative of LGR waters 428 and increasing salinity coincides with increasing ambient seawater contribution in the water sample. 429 Nitrate concentrations in surface waters during late winter decreased with distance from LGR (Figure 4g) 430 and decreased vertically with increasing depth in the water column (Figure 5g). These observations along with the significant linear relationships between nitrate and salinity ($R^2 = 0.67$, p < 0.001; Figure 8a) 431 432 reflect the dominant influence of the LGR on nutrient concentrations, at a time of year when biological

433 uptake was presumably negligible or very low under ice cover (Tremblay and Gagnon, 2009). During early winter, unexpectedly low nitrate concentrations at some inshore locations in BoMI ($\leq 2.7 \mu$ M) at 434 salinity values 2-18 decrease the significance of the relationship (p = 0.01), compared to late winter. This 435 436 may be due to denitrification in sediments and/or nitrogen uptake by aquatic plants such as eelgrass 437 (Zostera marina) but we have no direct evidence of either process. Using our results to calculate N* 438 values (Gruber and Sarmiento, 1997), which give the amount of nitrate needed to make up the optimal 439 N:P ratio for phytoplankton (Tremblay et al., 2015), we see that areas outside of the core plume (in BoMI 440 and south of LGR) have greater nitrate deficit, implying greater likelihood of denitrification occurring 441 compared to the core plume area (Figure S1).

442 Although the nitrate concentration of 4.5 μ M measured in the LGR during winter was not particularly 443 high and lies within the higher range of nine previously sampled Hudson Bay rivers (average of $3.77 \pm$ 444 2.1 μ M; Kuzyk et al., 2010), this concentration is higher than what we observe in the ambient seawater 445 $(3.18 \pm 0.2 \,\mu\text{M} \text{ (n=5); Table 2)}$. The concentration in the ambient seawater was lower than what was 446 measured in subsurface (30-50 m) residual winter waters in southern Hudson Bay (Granskog et al., 2011) 447 and at the entrance to James Bay in fall conditions (\sim 5-7 μ M, Kuzyk et al., 2010). These comparisons 448 imply that the source waters for the NEJB coast were drawn from above 30 m water depth, which has low 449 nitrate concentrations ($<3-4 \mu M$) due to biological uptake in the surface mixed layer throughout summer 450 (Ferland et al., 2011) and poor winter nutrient replenishment because of persistent stratification by 451 freshwater during winter (Eastwood et al., 2020).



452

- 453 Figure 8. Relationships between salinity and nitrate (a), and salinity and phosphate (b). Points are
- 454 coloured and shaped according to season of collection (early winter, late winter, summer).

455

456 Table 2. Average and standard deviation for La Grande River water and seawater nutrient

457 concentrations by season. The seawater water type is representative of the most saline samples in the 458 northeast James Bay study area. Early and late winter data were combined to calculate average winter 459 values. Number of observations (n) is indicated in parentheses.

	Water Type	Nitrate (µM)	Phosphate (µM)
Winter	La Grande River	4.53 ± 0.001 (2)	$0.11 \pm 0.03(2)$
	Seawater	3.18 ± 0.2 (5)	0.66 ± 0.04 (5)
Summer	La Grande River	2.76 ± 0.3 (3)	0.07 ± 0.05 (3)
Summer	Seawater	2.29*	0.45*

460 *Single sample

461 Phosphate concentrations in coastal surface waters were $< 0.1 \mu$ M during winter, explained by the near-462 zero concentrations in LGR during winter (Table 2). Positive phosphate-salinity relationships during both 463 early winter and late winter (R² = 0.95 and 0.98, respectively, both p < 0.001; Figure 8) and increasing 464 concentrations with depth reflect higher phosphate concentrations in the ambient seawater (Table 2).

465 During summer, nutrient distributions along the coast reflected both water-mass mixing and biological 466 uptake. Despite nitrate concentrations of 2.6 μ M – 3.1 μ M in LGR, surface nitrate concentrations along 467 the coast were generally very low (<0.6 μ M) and often at the limit of detection (Figure 4k). The high 468 surface concentrations were limited to the area closest to the river mouth. In contrast to nitrate, there was 469 no discernable spatial pattern in surface phosphate concentrations during summer and the range of 470 concentrations was similar to the winter periods (Figure 41). This points to nitrate (nitrogen) being the 471 potential limiting nutrient for primary production during the summer period. 472 The Redfield nitrogen: phosphorus (N:P) molar ratio (16:1) is used for assessing the limiting nutrient in a 473 given system in terms of planktonic producers (Redfield, 1958). Ratios less than or greater than 16,

474 respectively, indicate that nitrate or phosphate supply is limiting relative to the expected average nutrient

- 475 demand of phytoplankton. Eelgrass (*Zostera marina*), which is abundant in the BoMI inshore waters
- 476 (Lalumière et al., 1994), generally takes up N:P in a ratio of 20:1, and overall, a mean N:P ratio of 24:1

for seagrass species (Duarte, 1990). This greater nitrogen demand by eelgrass further increases the
probability of nitrogen being limiting for production in the study area.

479 During all seasons, the more saline samples were characterized by N:P ratios of about 4.9:1, whereas the 480 freshest samples were characterized by ratios of about 79:1. The ratios ranged between 0 and 237:1 across 481 all seasons for salinity < 10 (n = 42). This suggests that in BoMI and other far-field parts of the study area 482 under the LGR influence, where surface salinities were mostly >10, nitrate would be the limiting nutrient 483 upon the beginning of the ice-melt season (when light ceases to limit production), and in summer. This 484 limitation would impact both phytoplankton and eelgrass species, assuming no other nutrient supplements 485 such as uptake via roots. Our conclusions are consistent with the pronounced drawdown of nitrate to 486 values near the detection limit in virtually all samples during summer, except the very fresh samples right 487 at the river mouth, and the deepest samples (Figure 9). Within the core area of the winter plume, (surface 488 water salinity <5), phosphate would be the limiting nutrient upon the beginning of the ice-melt season, 489 and throughout summer. Note, however, that this area of potential phosphate limitation would scale according to the plume area (1200 km² in winter to 120 km² in summer; Peck et al., 2022). These data 490 491 indicate seasonality in potential nutrient limitation and spatial variability driven by plume extent. 492 Our finding of nitrate being the limiting macronutrient for primary production in water samples with 493 salinity > 10 is consistent with the nitrate limitation observed widely in Arctic surface waters where the 494 majority of N:P ratio calculations fall under 10 (datasets compiled for 2004-2016 by Ardyna et al., 2020). 495 In coastal regions of the Mackenzie Shelf and the Beaufort Sea (summer and October-December 496 conditions), N:P ratios in surface waters are relatively close to the Redfield ratio (13-15, Macdonald et al., 497 1987; Tremblay et al., 2008), whereas interior Hudson Bay is reported to have an average summer N:P 498 ratio of 2.29 indicating extreme nitrate deficiency (Ferland et al., 2011). The ambient seawater in NEJB 499 also demonstrates extremely oligotrophic conditions compared to southern Hudson Bay. However, the 500 difference between NEJB and interior Hudson Bay is that the LGR discharge provides a nitrate 501 supplement to coastal waters.

26



502

Figure 9. Relationship between phosphate and nitrate concentrations for all seasons. Colour gradient
 indicates salinity, and shapes represent season of collection (circle = early winter, square = late winter,
 triangle = Summer). Black solid line represents the Redfield Ratio (16N:1P).

506 5.5 Surface water nutrient stocks and source water contributions

507 Although our data suggest that LGR discharge could help alleviate nitrate limitation along the NEJB 508 coast, it remains difficult to evaluate the importance of LGR inputs to nutrient dynamics in the coastal 509 domain because of the seasonal and spatial variability of nutrient supply and demand. To quantitatively 510 assess the nutrient contribution of LGR across space and time, we calculated two quantitative types of 511 nutrient stocks for the surface layer of the water column using two quantitative methods, (i) observed 512 stocks, based on measured nutrient concentrations integrated over a 5 m water column; and (ii) expected 513 stocks based on observed nutrient concentrations identified for RW and SW endmembers (Table 2), 514 assuming no nutrient uptake. The expected nutrient stocks can be thought of as estimates of the initial 515 nutrient stocks, prior to biological uptake, as a function of the combined influence of river and ambient 516 seawater at that location. Note that SIM was not included in stock calculations because it was a significant 517 source of variation between winter and summer but not within each particular season, as described in 518 section 5.2. Calculations use the top 5 m of the water column because it represents the plume thickness in 519 winter based on our observations and showed the greatest seasonal variation in river influence. Six 520 offshore locations (Sites 1-6, Figure 10) that were sampled at least once in winter and once in summer (\pm

521 3 km between seasons), were selected along the coast at locations extending from 53 km north (Sites 1-3) 522 to 20 km south (Site 6) of the LGR. Sites 4 and 5 are located near the LGR with Site 5 further removed 523 from the river mouth and west of a small set of islands (Figure 10). We did not include locations that we 524 interpreted as having been influenced by small streams during summer, based on high residuals in the 525 salinity- δ^{18} O regression relationship.

In late winter, the surface layer of all sites was dominated by RW (Figure 10a). Because RW contained significant nitrate, all sites along the coast had large expected nitrate stocks of ~20-24 mmol m⁻² (Figure 10b). The SW-derived nitrate in the surface layer increased at the sites furthest north (Sites 1 and 2), in the frontal area of the plume (Peck et al., 2022), but at most contributed 40% of the total expected nitrate stock at the northernmost site. The observed stocks of nitrate were similar to the expected stocks, consistent with the absence of significant biological drawdown.

532 In contrast to nitrate, phosphate stocks varied largely between sites during late winter (Figure 10c).

533 Phosphate stocks were high at the northern sites with large SW supply and low at the sites nearer or south 534 of the LGR mouth (Sites 3-6) due to low RW contribution. Observed phosphate stocks in late winter were 535 lower than expected from conservative mixing of RW and SW. Possible explanations for this discrepancy 536 include biological uptake of phosphate (e.g., by perennial eelgrass) or abiotic losses via processes such as 537 sorption onto oxides in surface sediments (Sundby et al., 1992, van Raaphorst and Kloosterhuis, 1994), or 538 sorption with iron during flocculation around the halocline in estuarine mixing zones (Macdonald et al., 539 1987). The largest difference between observed and expected phosphate concentrations were observed at 540 Site 2, just outside of BoMI, an area known for its eelgrass beds (Lalumiere et al., 1994). However, this is 541 also the area where the LGR plume salinity increases rapidly with distance, and thus flocculation-induced 542 phosphate losses could also be expected.

543 In summer, the expected nitrate stocks were about half those in late winter (Figure 10b), in large part due 544 to the reduced RW contributions; they were similar across all the sites and supplied mostly by SW, except
545 at Site 4. Phosphate stocks in summer were higher than those observed in late winter and supplied almost entirely by SW (Figure 10c). Again, the exception was Site 4, with a relatively low summer phosphate 546 547 stock, supplied by 50% RW and 50% SW. The exceptional dominance of RW-derived nitrate at Site 4 is 548 consistent with the phosphate limitation observed in low salinity (< 10) waters (Figure 9) but may also be 549 related to the relatively short residence time of LGR waters in this area in both winter (~10 days; Peck et 550 al., 2022) and in summer (~ 0.6 days). This lends support to the importance of considering the stocks but 551 also the renewal rate near the river mouth. Additionally, areas further away from the river mouth have 552 different renewal rates by different processes, for example by diffusion through the surface halocline from 553 N-rich deeper waters.

Because summer sampling occurred late in August, late in the growing season, we expected to observe low summer nutrient stocks compared to expected stocks (i.e., pre-biological uptake). Except for the river mouth Site 4, observed summer nitrate stocks were completely drawn down to zero or near-zero (Figure 10b). Summer phosphate stocks were also drawn down relative to expected stocks, but to varying degrees from site to site. This difference between nitrate and phosphate reinforces the notion of nitrate limitation north of LGR in summer.



561 Figure 10. Water type, nitrate and phosphate stocks in the top 5 m of the water column. Comparison 562 of late winter and summer in terms of a) depths of each water type (RW and SW) in the top 5 m of the 563 water column, b) expected stocks of nitrate in the top 5 m of the water column, and c) expected stocks of 564 phosphate in the top 5 m of the water column. Red shading shows the portion of each depth or stock derived from river water (RW) and blue shading shows the portion derived from seawater (SW). Black 565 566 diamonds on each bar show the observed stocks of nutrients at each site. Error bars are representative of standard deviation, calculated out through a series of error propagation equations. Map of six selected 567 568 sites for inventory calculations. Red points represent 2016 sites, and blue points represent 2017 sites. 569 Yellow points represent stations from winter 1975/1976. Map sourced from NASA Worldview from July 570 4, 2017.

- 571 5.6 Comparisons of pre- and post-development conditions
- 572 In the interest of assessing the effects of LGR development on freshwater and nutrient dynamics in the
- 573 NEJB coastal domain (cf., Maavara et al. 2020), historical data on salinity and nutrient concentrations
- 574 were compiled for the riverine and estuarine waters based on Messier et al. (1986) (n = 16, data collected
- 575 in 1978), and for the surrounding marine environment prior to hydroelectric activities (1974-1976) based

576 on Marine Environmental Data Service surveys (MEDS; https://www.meds-sdmm.dfo-mpo.gc.ca/isdm-

577 gdsi/index-eng.html). Additionally, salinity and nutrient data (1974-1975) were compiled for fourteen

- 578 sites in the La Grande estuary and six sites in offshore James Bay (Grainger and McSween, 1976). To our
- 579 knowledge, these are the only available nutrient data prior to 2016 in the study area.

584

585

- 580 The first notable difference in the pre- and post-development data was the low maximum salinity detected
- 581 in recent years, both in winter and summer, compared to pre-development observations. The 1974-1976
- 582 MEDS dataset shows that summer salinity ranged 23-25 in subsurface waters near the mouth of LGR,

583 whereas our data show a maximum summer salinity of 22.2 near the same location. In winter, maximum

salinity was 28 in 1975-1976, higher than the maximum of 26 observed in this study. The comparison of

subsurface water salinities at similar locations in 2016-2017 and 1974-1976 suggests that northeast James

586 Bay has experienced general freshening during recent decades. This aligns with indications of a climate-

driven freshening trend in western Hudson Bay during the past 20-30 years based on δ^{13} C isotope trends 587 588 in brachiopod shell calcite (Brand et al., 2014). However, similar analyses have not been completed for

589 James Bay. We cannot rule out that the lower winter salinity in NEJB is locally driven. Furthermore, the

lack of historical δ^{18} O data means it cannot be attributed to an increase in RW and/or SIM. 590

591 Another change revealed by the data comparison is that late-winter nitrate concentrations associated with

592 James Bay ambient seawater possibly have increased from the pre- ($\sim 2.6 \mu$ M, Grainger and McSween,

593 1976; Table 3) to post- $(3.2 \pm 0.2 \,\mu\text{M}, n = 5, \text{Table 2})$ development periods. Late winter phosphate

594 concentrations remained similar between the two periods (compare Tables 2 and 3). From this we can

595 infer that there is more RW incorporated into NEJB seawater at the regional scale during late winter,

596 because RW is a nitrate source while SIM is not. The data comparison provides evidence that nitrate

- 597 concentrations in the LGR are higher post-development. Messier et al. (1986) showed average pre-
- 598 development values of only 1.6 µM nitrate (compared to 4.53 µM today; Table 2; and see also de Melo et
- 599 al., 2022). These changes demonstrate increased N:P ratios in the LGR following development (N:P of
- 600 10.7 to 41.2) and increased N:P ratios in coastal waters (N:P of 3.8 to 4.8) that are influenced by the

- 601 winter discharge. This change in nutrient ratios in any coastal system is likely to impact the community
- 602 composition of primary producers, altering ecological pathways and food web transfers.

Table 3. Compiled winter pre-development (1974-1978) observations for salinity and nutrients in La

604 Grande River water and east James Bay seawater. Seawater nutrient values are taken from one station at 605 the deepest sampling depth (36.5 m). Source of data is indicated by superscript letter.

Water Type	Salinity	Nitrate (µM)	Phosphate (µM)	
La Grande River	0ª	1.6 ^b (1.6-2.1; n=16)	0.15 ^b (0.05-0.32; n=16)	
Seawater	28 ^a	2.6°	0.68°	

606 607

^bMessier et al., 1986

608 ^cGrainger and McSween, 1976

609 Using historical SW and RW nutrient data, together with surface salinity measured in late winter 1975-610 1976, Figure 11 shows the expected nutrient stocks for the pre-development period calculated using the 611 same method as described in section 5.5. For late winter of 1975-1976, we estimate RW contributions to 612 the surface (top 5 m) layer of up to 50% (Figure 11a), which is much lower than the post-development 613 period. Furthermore, the pre-development nitrate stocks were only about half those calculated from our 614 data (Figure 11b). In the core area of the plume (Sites 4 and 5) the difference relates to the higher nitrate 615 concentration in the RW and higher RW contribution to the surface layer post-development. SW-derived 616 nitrate made little contribution to the total nitrate stock in late winter at these sites. At Sites 1 and 2, SW-617 derived nitrate significantly contributed to the nitrate stock both pre- and post-development (Figure 11b). 618 Thus, the higher nitrate concentration in ambient seawater post-development also contributed to the 619 increase in nitrate stocks. In contrast to nitrate, the pre-development phosphate stocks were at least 1.3-620 fold higher than our current estimate (Figure 11c). This change simply reflects the higher RW 621 contribution to the surface layer. Nutrient stock distribution patterns north and south of the river mouth 622 were similar, pre-and post-development, for phosphate, but reversed for nitrate. Historically, nitrate 623 stocks were lowest at the river mouth and increased to the north and the south, but our recent data showed



624 that highest stocks were found within the core of the LGR plume.

625

626	Figure 11. Pre- and post-development comparison of water type depth and surface nutrient stocks
627	in winter. Calculated depth of each water type (RW and SW) at each station pre-development (1975-
628	1976) and post-development (2016-2017) in late winter (a). Pre-development nitrate (b) and phosphate (c)
629	stocks in the top 5m of the water column compared to post-development nitrate and phosphate stocks
630	apportioned by river water (RW, red) and seawater (SW, blue) contributions. Error bars are representative
631	of calculated standard deviation. Standard deviation was unable to be calculated for pre-development
632	values due to limited data availability.

633 5.7 Implications of an altered NEJB coastal domain on nutrient dynamics

634 Nutrient distributions in the NEJB coastal domain have been modified both in space and time by the

- 635 changes in LGR discharge. It is not possible to say what role, if any, large-scale processes such as
- 636 regional climate change and altered duration of the ice-covered season add to, or how they interact with,
- 637 the changes resulting from La Grande development in this study. Based on maximum salinity, it appears
- 638 that ambient seawater has freshened during both winter and summer, however we cannot attribute this to

639	SIM with the absence of δ^{18} O data from the 1970s. With the majority of freshwater that is released into
640	James Bay being exported from the Hudson Bay system within 4 years (Ridenour et al., 2019), sufficient
641	time has elapsed for the ambient salinity to have adjusted to changes in river discharge or the sea-ice
642	cycle that occurred over the period 1980-2012. The salinity of waters entering James Bay from Hudson
643	Bay may have varied during these three decades as well, in view of the fluctuations in the Arctic
644	freshwater flux (cf., Yang et al., 2016). With scarce oceanographic data for this region, modelling could
645	help explore the relative roles of large-scale processes and La Grande development in the apparent
646	freshening of NEJB coastal waters (cf., Ridenour et al., 2019; Lukovich et al., 2021).
647	Comparing the RW content and nutrient stocks of the surface layer pre- and post-development (Figure 11)
648	shows the overwhelming impact of the increased RW content in the winter surface layer. Because of the lack of wind
649	mixing, under-ice river plumes including that of the LGR are much larger and more strongly stratified
650	than open-water plumes for equivalent discharge (Ingram and Larouche, 1987; Li and Ingram, 2007; Peck
651	et al., 2022). Increases in winter river discharge thus acts differently and more profoundly on the
652	freshwater budgets of coastal waters than increases in discharge during ice-free periods (see also
653	Eastwood et al., 2020). In turn, the changes in river discharge and freshwater budgets exert strong effects
654	on nutrient conditions. Other recent works have emphasized the importance of the altered nutrient
655	composition of river water following damming, showing changes to the N:P ratios in regulated river
656	runoff and potential increases in P limitation in coastal waters (Maavara et al., 2020).
657	Outside the core of the plume, which is five or six times larger than it was under the natural winter flow
658	conditions of the 1970s (Ingram and Larouche 1987; Peck et al., 2022), there is now a larger amount of
659	RW present in surface waters and contributing to larger nitrate stocks in late winter compared to pre-
660	development conditions. We conclude that the development has led to a larger area of potential phosphate
661	limitation of primary production in late winter, once under-ice light limitation is lifted. More importantly,
662	the development has led to a buildup of nitrate stocks immediately before the productive period, from

663 what is a generally nitrate-limited system. This starkly contrasts the conclusions by Grainger and

McSween (1976), with limited data from natural conditions, that additional flow and more equal flow throughout the year would not have had a great influence on nitrate and phosphate levels in James Bay and the La Grande estuary.

667 To address potential impacts on primary production, we present two potential scenarios regarding the fate 668 of the NEJB late winter nitrate stocks, which may vary from year to year with factors such as the timing 669 of ice breakup and increased irradiance. Ice breakup typically occurs sometime in late May or early June 670 in our study area (Taha et al., 2019), but can be as early as April, for example as a result of storms (Peck 671 et al., 2022). Upon breakup, the RW-derived nitrate previously confined to the surface plume is mixed 672 into the ambient coastal waters. Under a scenario of a late ice breakup, there is a longer winter period for 673 the large nitrate stocks to be exported under the landfast ice from NEJB towards and into southern 674 Hudson Bay, possibly supporting primary production downstream. The present export of nutrients from 675 NEJB implies that primary production would be lower compared to natural conditions when nitrate 676 delivery from the rivers would have peaked with spring freshet (de Melo et al., 2022) and presumably 677 supported a spring phytoplankton bloom.

678 Under a scenario of early ice breakup, when light conditions are suitable, we assume the large winter 679 nitrate stocks fuel spring phytoplankton production earlier in the year. In eastern Hudson Bay, the 680 productive period for ice algae typically occurs in April-May when sufficient light is available (Gosselin 681 et al., 1985, 1986, Michel et al. 1988) and under-ice blooms can occur in May-June (Michel et al. 1993). 682 It is unlikely that in pre-development times large winter nitrate stocks would have built up along the coast 683 as we see now, given the smaller under-ice plume with low flow conditions. The highest flows from 684 LGR, historically, were during the spring freshet. During our study, the late winter (March-April) discharge averaged ~3900-4600 m³ s⁻¹, comparable to the average June discharge under natural conditions 685 (3800 m³ s⁻¹ in 1975-1977) and during freshet flows (2400-6100 m³ s⁻¹ in 1960-1978; Messier et al., 686 687 1986). Thus, we propose that the shift of peak river discharge into winter now, which generates large 688 nitrate stocks, may enhance under-ice blooms and, all else being equal, give a competitive advantage to

phytoplankton rather than rooted vascular plants like eelgrass along the NEJB coast. Although, RW
associated phosphate stocks are low and thus may not support large phytoplankton blooms under the ice.
To better evaluate growth conditions of eelgrass in the study area, spring nutrient stocks should be
assessed together with nutrient supply from sediments.

693 The region of freshwater influence, surrounding the highly stratified region of the under-ice plume has 694 also increased in area with the increase in winter river discharge (Ingram and Larouche 1987; Peck et al., 695 2022). Our results show that late winter stocks of nutrients in the region of freshwater influence originate 696 from a combination of RW and SW, and that the late winter stock of nitrate has increased compared to 697 pre-development conditions because of the increased RW influence. If the photosynthetic activity of ice 698 algae is N-limited in the NEJB coastal domain, then additional RW would support increased production 699 by the ice algal community during late winter post-development, as these algae are well adapted to low 700 light conditions (Michel et al., 1988; 1996). However, increased RW content and lower salinity can also 701 negatively impact ice algae production due to the structure of the ice itself (Granskog et al., 2005).

702 6. Conclusions

703 The data we present fulfill knowledge gaps for coastal NEJB and provide a baseline with respect to SIM 704 and RW contributions in James Bay and, by extension, the broader Hudson Bay system. In this study, we 705 determined that the LGR is the dominant source of freshening in surface waters along the NEJB coast, 706 particularly when ice-covered. Summer ambient seawater is found to freshen considerably from winter, 707 which most likely occurs on a bay-wide scale as opposed to local SIM influence. Nitrate and phosphate 708 distributions along the coast show conservative mixing in winter but are influenced by both water mass 709 mixing and biological nutrient uptake in summer. Nutrient stock estimates reveal the dominant impact of 710 the LGR plume on nutrient conditions in winter, especially nitrate concentrations and associated stocks, 711 which were higher than those supplied by ambient seawater.

- 712 With development of the LGR that reversed the seasonality of river discharge and flattened the natural
- 713 hydrograph, current winter discharge is comparable to the natural spring freshet and current
- spring/summer discharge is reduced. This shift results in altered nutrient supply and nutrient ratios,
- further impacted by the dynamics of the landfast sea-ice cycle. We suggest future work to further assess
- the impact on primary production in this region as the changes we discuss here bear significant
- 717 implications for the magnitude and type of primary production blooms in the NEJB coastal region, and
- 718 potentially downstream in Hudson Bay.

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Supplemental material 974

975 Table S1. Statistical analysis of nutrient relationships with salinity during early winter (EW), late winter

976 (LW), all winter data combined, and summer. Asterisk (*) indicates statistically significant relationship.

977 N value indicates the sample size.

Parameter	Season	Slope (SE)	Intercept (SE)	p-value	R ²	n
	EW	-0.03 (0.01)	3.86 (0.18)	0.01*	0.16	42
Nitrate	LW	-0.04 (0.005)	4.39 (0.08)	< 0.001*	0.67	36
Millale	Winter	-0.03 (0.01)	4.06 (0.12)	< 0.001*	0.22	78
	Summer	-0.04 (0.01)	0.93 (0.22)	0.005*	0.13	66
	EW	0.02 (9x10 ⁻⁴)	0.02 (0.01)	< 0.001*	0.95	42
Phos p hate	LW	0.03 (7x10 ⁻⁴)	-0.003 (-0.20)	< 0.001*	0.98	36
Thosphate	Winter	0.02 (5x10 ⁻⁴)	0.01 (0.01)	< 0.001*	0.96	78
	Summer	0.01 (0.003)	-0.006 (0.04)	< 0.001*	0.27	66



979 980 Figure S 1. N* surface values during early winter, calculated with all available data in the study

981 area.

Ascribing the importance of Atlantic brant staging areas for holistic conservation planning





Presentation by: Lindsay Carlson

PI: Mitch Weegman

Collaborators: Ernie Rabbitskin, Ernest Moses, Marc Dunn, Melanie-Louise Leblanc, Fanny Noisette, Josée Lefebvre, Jim Leafloor, Ken Abraham, Frank Baldwin, Ted Nichols, Josh Stiller, Scott Gilliland, Al Hanson, Stuart Slattery



Small-bodied, long-lived goose that primarily uses marine/estuary environments

Unique among North American geese: do not use agricultural food sources

Constant adult survival, boom and bust productivity driving population variability

Atlantic brant (Branta bernicla hrota)



Migration



Breeding Foxe Basin mid-June through late August



Wintering

Jersey coasts

New York and New

late October through mid-May





Carry-over effects

Factors such as food quality and availability on wintering and staging areas, and weather and environmental conditions during migration can have "carry-over effects" on an individual's ability to successfully reproduce

These carry-over effects on individuals can cascade to population level "cross-seasonal effects" on productivity and population size

Tracking devices

Captured on wintering grounds on "upland" or freshwater inlet

Individuals meeting weight thresholds are fitted with Ornitela OrniTrack 25 global positioning system tri-axial acceleration (GPS-ACC) transmitters

- > Units deployed on more than 250 individuals
- ~ 50 per year, distributed along NY and NJ coasts

2018-2021 males only 2022-2023 50% male, 50% females

Capabilities:

- GPS data every 30 minutes
- Location accuracy <10 m
- ACC data every 6 minutes
- Can last > full annual cycle



Tracking devices

Tri-axial acceleration data collected in "bursts" which can be linked to behaviours

Benefits:

Categorize behaviours

- Quantify reproductive attempts/success
- Link with conditions at same scale

Limitations:

Check in via GSM network Unquantified effect on fitness



Research objectives

- 1. Sample eelgrass and common wetland forage vegetation in areas of brant feeding locations in eastern James Bay to build on existing study of eelgrass quality and distribution by the Coastal Habitat Comprehensive Research Project, but with focus on areas used by brant
- 2. Using locational and behavioral data, describe the behavior of brant in specific habitats (e.g., the proportion of time feeding versus resting) and link with variation in forage nutrient quality
- 3. Describe how climatic and environmental variables explain variation in behavior and energy expenditure during wintering, staging, and breeding periods; link environmental and behavioral covariates to productivity for a full annual cycle perspective

Objective 1

Worked with tallymen and land users to collect vegetation in areas of brant feeding during summers of 2022 and 2023

Visited 20 traplines with the help of 22 boat captains and assistants

Samples collected at 76 saltmarsh sites and 52 eelgrass sites









Vegetation collected will be analyzed for foliar carbon and nitrogen, which are indicators of forage quality for small, inefficient herbivores like geese

Research objectives

- 1. Sample eelgrass and common wetland forage vegetation in areas of brant feeding locations in eastern James Bay to build on existing study of eelgrass quality and distribution by the Coastal Habitat Comprehensive Research Project, but with focus on areas used by brant
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Objective 2

Selected "feeding" locations for sampling

Current work: Calculating energy expenditure due to movement, time feeding

Upcoming work: Quantify the relationship between brant habitat use and forage quality within the habitat



Research objectives

- 1. Sample eelgrass and common wetland forage vegetation in areas of brant feeding locations in eastern James Bay to build on existing study of eelgrass quality and distribution by the Coastal Habitat Comprehensive Research Project, but with focus on areas used by brant
- 2. Using locational and behavioral data, describe the behavior of brant in specific habitats (e.g., the proportion of time feeding versus resting) and link with variation in forage nutrient quality
- **3.** Describe how climatic and environmental variables explain variation in behavior and energy expenditure during wintering, staging, and breeding periods; link environmental and behavioral covariates to productivity for a full annual cycle perspective

Objective 3

Upcoming work: Quantify influence of winter and spring habitat and weather conditions on reproductive success to understand carry-over effects throughout the annual cycle

The model will allow us to predict implications of climate or land use change on this population under future scenarios



Outcomes of interest to the community

Gain knowledge of how brant area using the area, which types of food are most important to them, and how much time they spend foraging in different habitats

Improve understanding of eelgrass distribution and quality, as well as improve understanding of vegetation nutrient quality of other types of important forage vegetation

Predict how changing quality or availability of eelgrass may affect brant populations in the future; work to understand how that may affect other goose populations and future harvest opportunities for land users

Understand how events throughout the annual cycle carry over to reproduction \rightarrow direct conservation/management to areas of greatest impact

Unique approach to understanding behaviour/habitat interaction \rightarrow leveraging highresolution data from multiple sources

Framework for similar studies on a wide variety of species

Waskaganish traplines



Eastmain traplines



Wemindji traplines



Chisasibi traplines



Spring migrations

Julian dates:

121 – May 1

152 – June 1

182 – July 1


Fall migrations

Julian dates: 244 – Sept 1 274 – Oct 1 305 – Nov 1



Questions?

















Thank you for inviting me to present today! Please feel free to contact me regarding any questions, concerns, or suggestions at: lindsay.carlson@usask.ca