# Nutrient inputs from subarctic rivers into the Hudson Bay system

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## Abstract

Little information exists concerning the riverine supply of inorganic nutrients and its consequences on primary production in the Hudson Bay system (HB), a large subarctic inland sea that is impacted by rapid climate change and anthropogenic disturbance. In order to provide a reference point by which future changes can be evaluated, we estimated fluxes of nitrate (N), phosphate (P) and silicate (Si) using contemporary and historical nutrient data in conjunction with discharge rates generated by 3 different global climate models. Several key points can be highlighted. Firstly, the N:P and Si:N molar ratios of river nutrient fluxes exhibit large contrasts between different sectors of HB, which is attributed to variable geological settings in the watersheds. Generally, low N:P and high Si:N ratios imply that river waters are characterized by a severe deficit of nitrate with respect to the needs of primary producers. Secondly, seasonality in nutrient concentrations and ratios were apparent in the sampled rivers at different times of years. While the regulation of river flow in the Nelson and La Grande rivers had no discernible impact on nutrient concentrations and ratios, it clearly shifted nutrient transports toward the winter when biological activity in the estuaries is reduced. Thirdly, the southwestern rivers made the largest contributions of each nutrient flux to the total annual nutrient deliveries, with the modest contributions from the south and east rivers, and with the lowest contributions from the northwestern rivers. Finally, the combined nitrate input by all rivers was nearly two orders of magnitude (ca. 2.0 × $10^{10}$ g N) lower than the estimated vertical re-supply of nitrate to the surface during winter in offshore waters of HB (ca. 1.2 × $10^{12}$ g N). The potential contribution of river nutrients to new primary production is therefore small at HB scale but can be significant locally.

## Objectives

1. Establish a first baseline of nutrient concentrations and ratios for several subarctic rivers in the HB.
2. Assess if the regulated rivers for the production of electricity differ from unregulated ones.
3. Estimate and compare discharge and nutrient fluxes for different rivers.

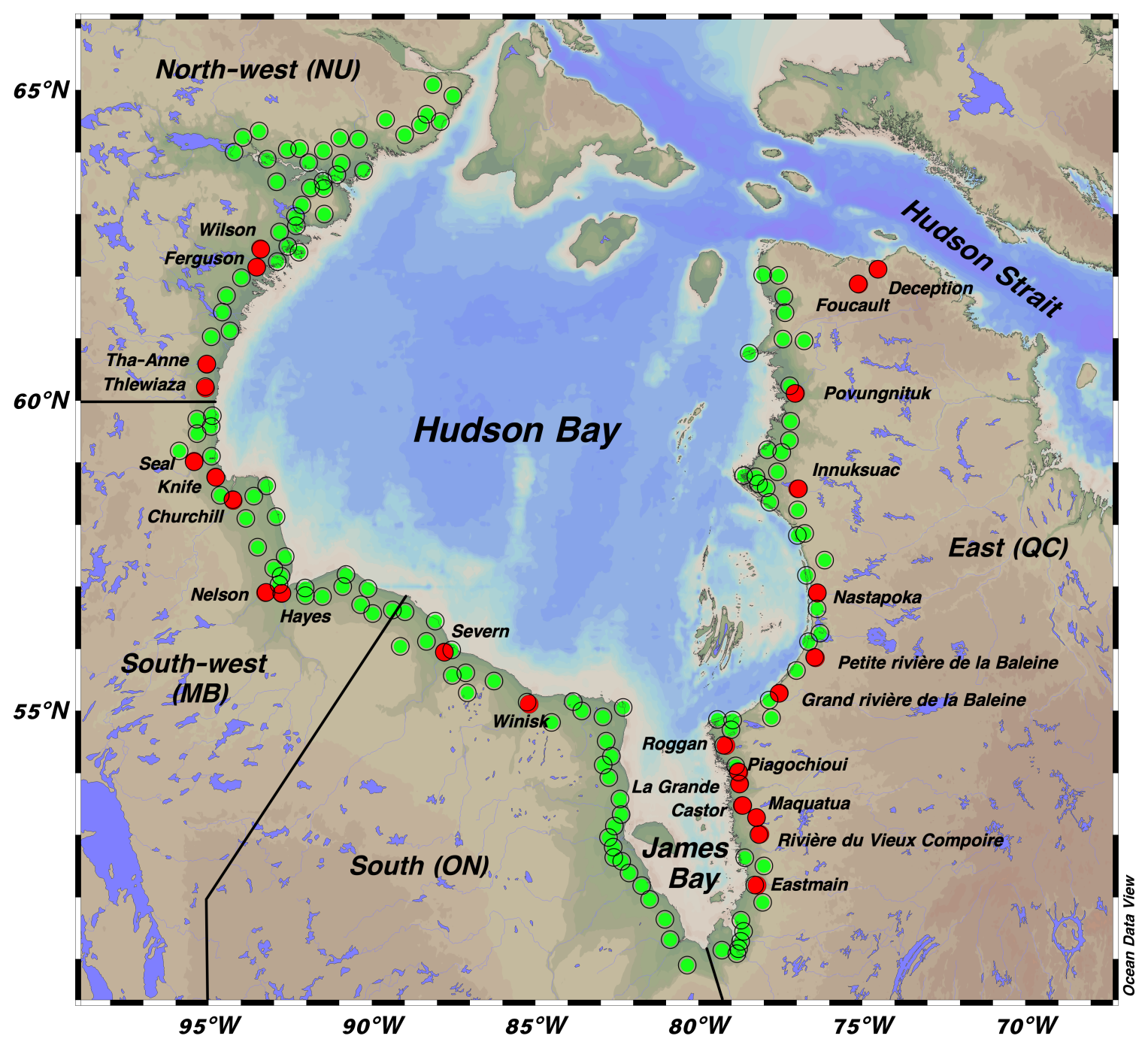

Figure 1. Map of rivers draining into the Hudson Bay system, showing those for which data are available for both discharge and nutrients (red circles) or discharge only (green circles). Abbreviations denote different territories or provinces - Nunavut (NU), Manitoba (MB), Ontario (ON) and Quebec (QC).

## Materials & methods

- Sources of nitrate (N), phosphate (P) and silicate (Si) data :
    1. Contemporary data from the BaySys (*Contributions of climate change and hydro-electric regulation to the variability and change of freshwater-marine coupling in the Hudson Bay System)* and COast-JB (*Spatio-temporal variations of oceanographic conditions along the eastern coast of James Bay*) projects.
    2. Historical data collected from the CAMP (*Coordinated Aquatic Monitoring Program*) and Conawapa GS (*The environmental field study and monitoring for the Conawapa Generation Station in the Nelson river*) projects (Manitoba Hydro).
    3. The literature.
- Daily streamflow for the period 2006-2015 was simulated with the *Hydrologic Predictions for the Environmen*t (HYPE) model, based on the:
    1. Geophysical Fluid Dynamics Laboratory Climate Model (GFDL-CM3)
    2. Model for Interdisciplinary Research on Climate (MIROC5)
    3. Meteorological Research Institute Coupled Atmosphere-Ocean GCM (MRI-CGCM3)
- Values were averaged separately for different:
    1. Different periods of the year corresponding roughly to seasons: winter (November - April), spring (May - June), summer (July - August) and fall (September - October).
    2. Four different sectors to allow for regional comparisons: north-west (Nunavut), south-west (Manitoba), south (Ontario) and east (Quebec).

## Results & Discussion

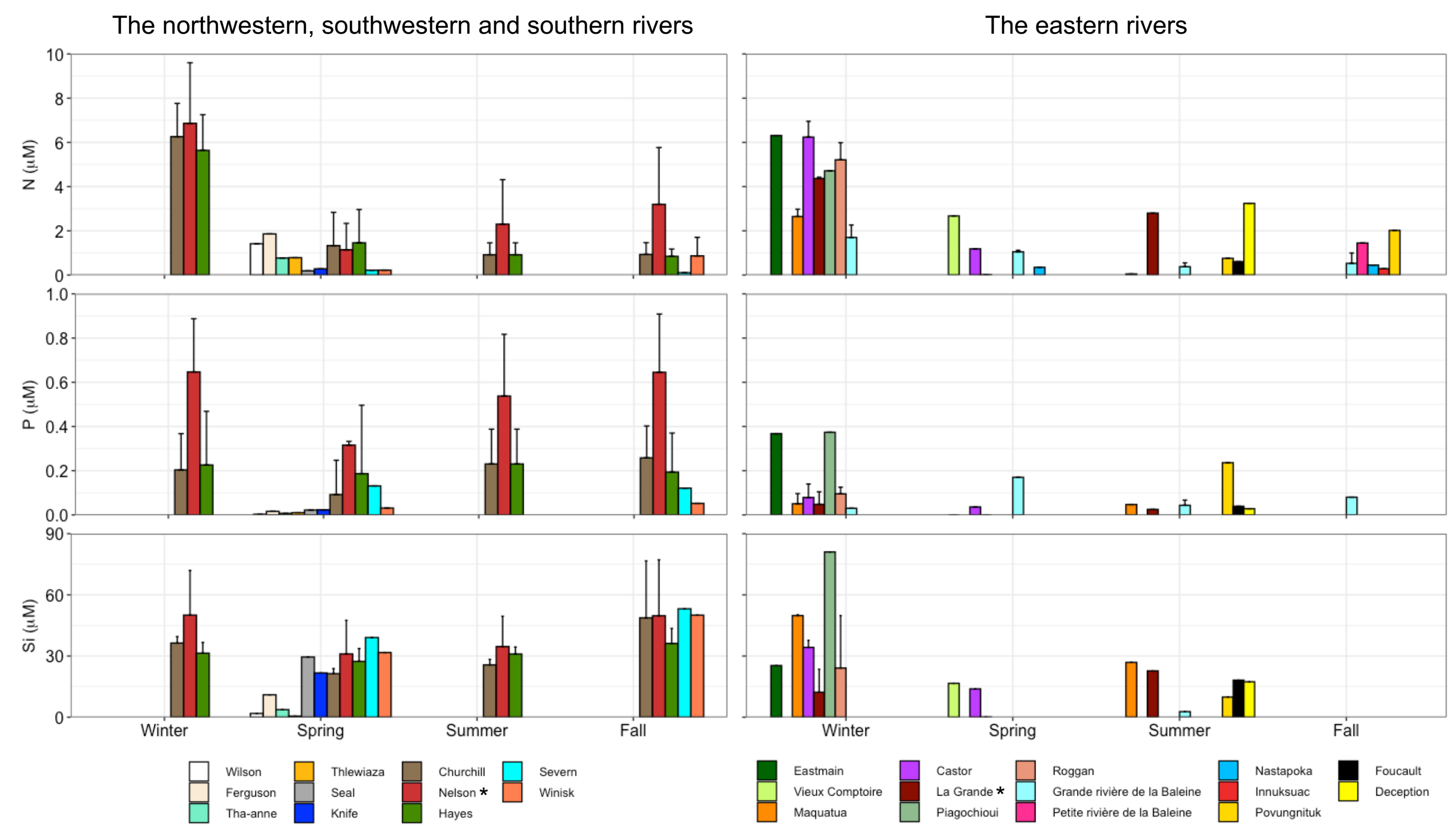

Figure 2. Seasonally-binned concentrations of nitrate (N), phosphate (P) and silicate (Si) for the 25 sampled rivers (left panels for the northwestern, southwestern and southern rivers, right panels for eastern rivers). Bars with no standard deviation are from rivers where sampling occurred on one occasion only. An asterisk indicates regulated rivers.

- Concentrations of N and Si showed seasonal patterns, with the highest values in winter or the higher levels in winter and fall.
- P concentrations were generally low and similar in all seasons.
- Differences in nutrient concentrations reflect the variable geological (rock formations, climate) and biological (land cover, vegetation and microbial activity) settings of the rivers and their drainage basins.

- Significant difference in nutrient concentrations was not observed between the regulated and unregulated rivers.
- The regulation of river flow had no discernible impact on nutrient concentrations.

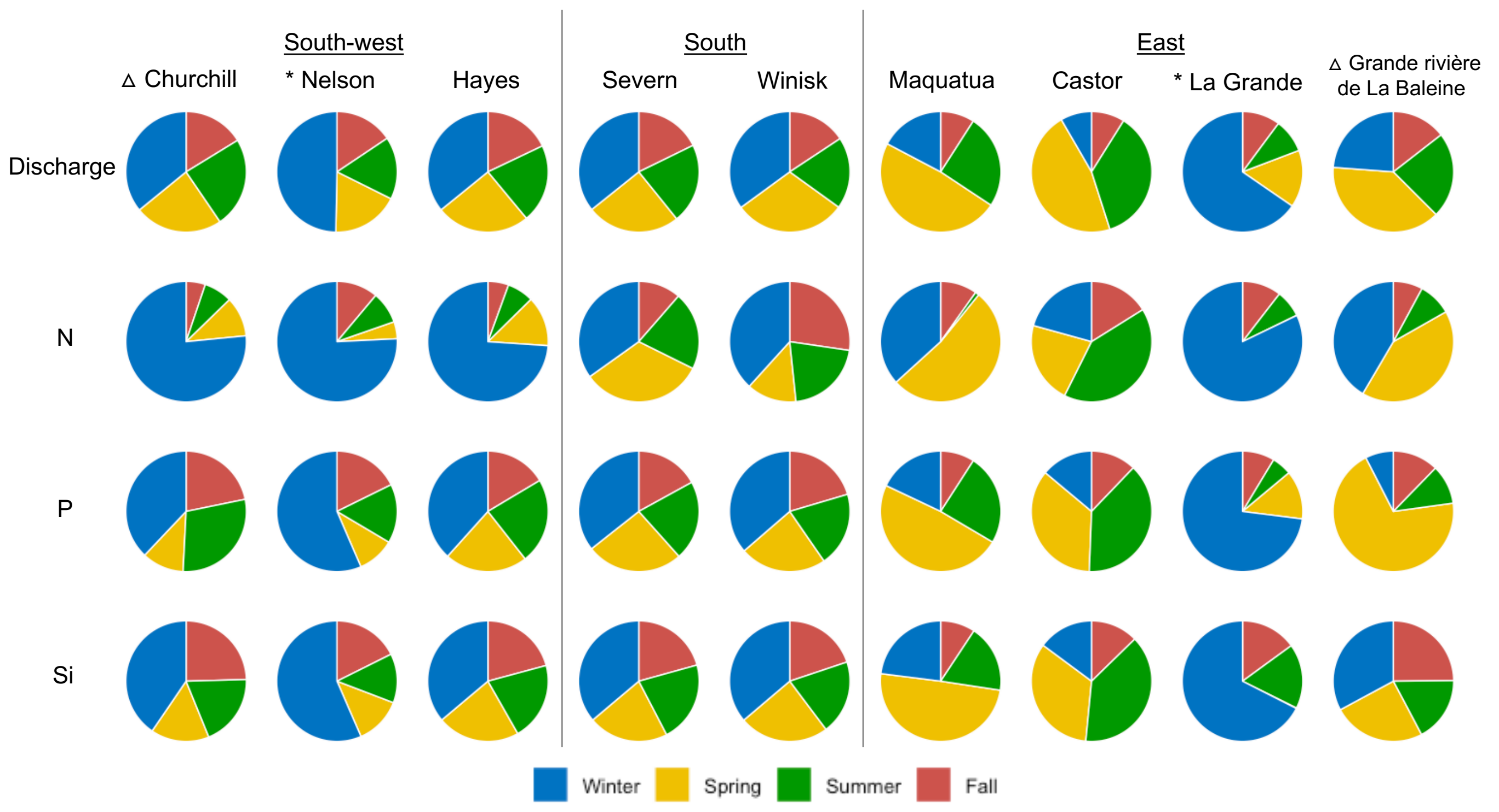

Figure 3. Seasonal partitioning of discharge (average of the 3 models) and nutrient transports for 9 rivers in the Hudson Bay system (N = nitrate, P = phosphate, Si = silicate). Regulated and partially diverted rivers are denoted with an asterisk and a triangle, respectively.

- Partially diverted and unregulated rivers: more than 35% of the annual discharge for the Churchill, Hayes, Severn, and Winisk rivers occurred during winter, whereas 39% of the discharge for the Grande rivière de la Baleine and small eastern rivers (Maquatua, Castor) occurred during spring.
- Regulated rivers: annual discharge is clearly shifted toward the winter period due to peak demand for hydropower production. The shift is more pronounced for the La Grande river than for the Nelson river owing to their different regulation schemes (large storage reservoirs in the former, run-of-river in the latter).

- The seasonality in P and Si fluxes was generally similar to that of discharge, with minor and sometimes major differences during spring and summer.
- By contrast, the seasonality in N flux was not strongly coupled to the seasonality of discharge, possibly due to a greater retention of this nutrient by biological processes in freshwater systems during the vegetative season.

### Acknowledgements

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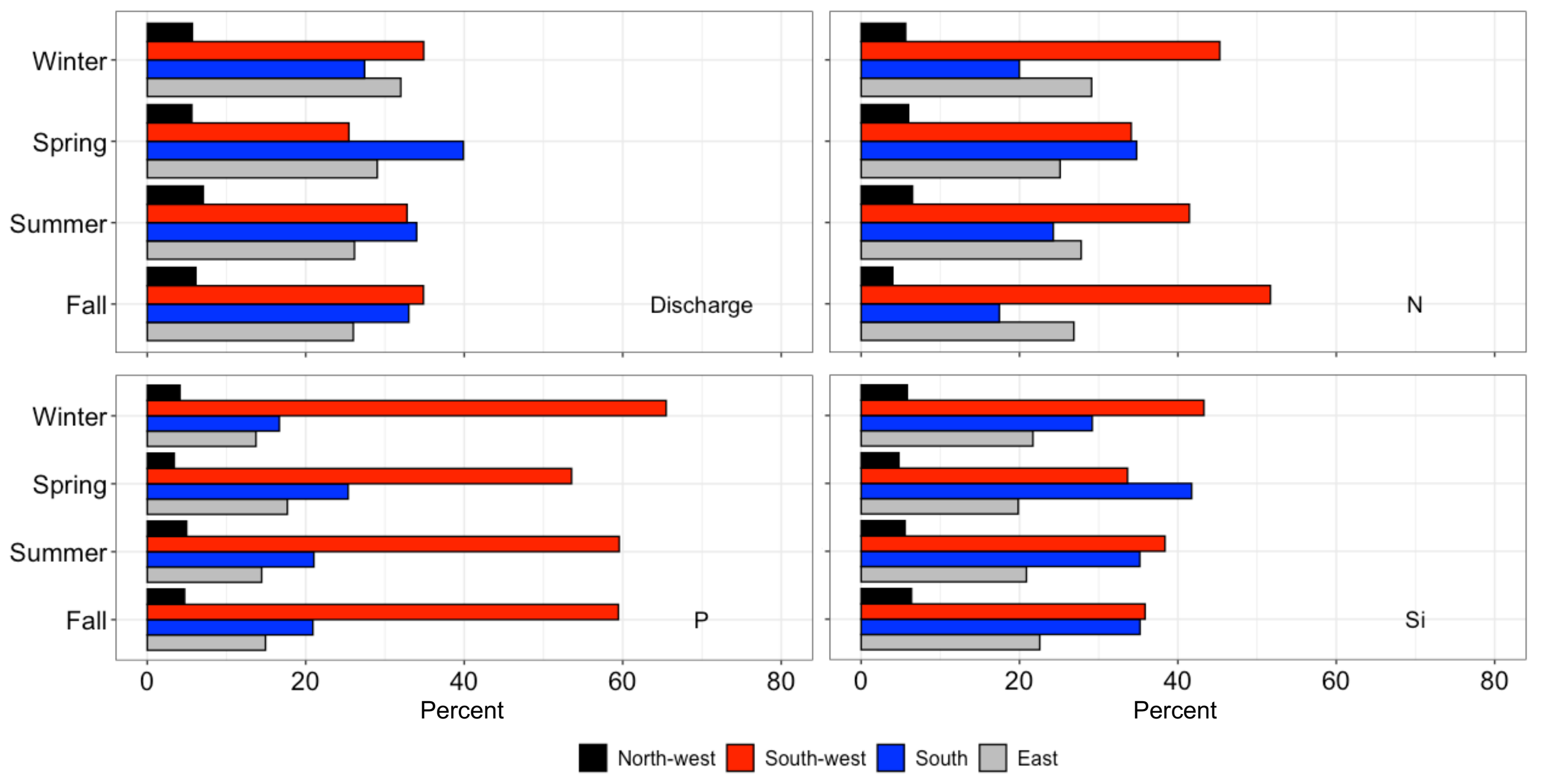

Figure 4. Seasonal contributions of different regions to total freshwater discharge and the seaward transport of riverine nitrate (N), phosphate (P) and silicate (Si) fluxes into the Hudson Bay system.

- Northwestern rivers accounted for less than 8 % of the bay-wide freshwater discharge, with a commensurate share of nutrient transports (4 to 6 %).
- Southwestern rivers contributed the most to N (41 to 52%) and P (54 to 65 %) transports.
- The southwest made the largest contribution to bay-wide riverine nutrient deliveries, followed by the south and the east (moderate) and finally the northwest (minor).

- This spatial pattern suggests that the impacts of freshwater-marine coupling on estuarine and coastal biogeochemistry are particularly important in the southwest.
- A major if not dominant portion of the annual loading of freshwater and nutrients at the bay-wide scale occurred during winter (41 % of discharge and 74, 51 and 47% of N, P and Si transports, respectively), thereby setting the stage for sizable spring blooms at the onset of the productive period.

- The N:P molar ratio of riverine nutrient transports was well below the canonical Redfield value of 16, except during winter.
- The Si:N molar ratio was systematically much higher than the average critical threshold of 1.
- From spring to fall, nutrient deliveries by rivers were characterized by a strong N deficit relative to microalgal demand, implying that a marine N source is required to enable the consumption of excess P and Si by the algae.

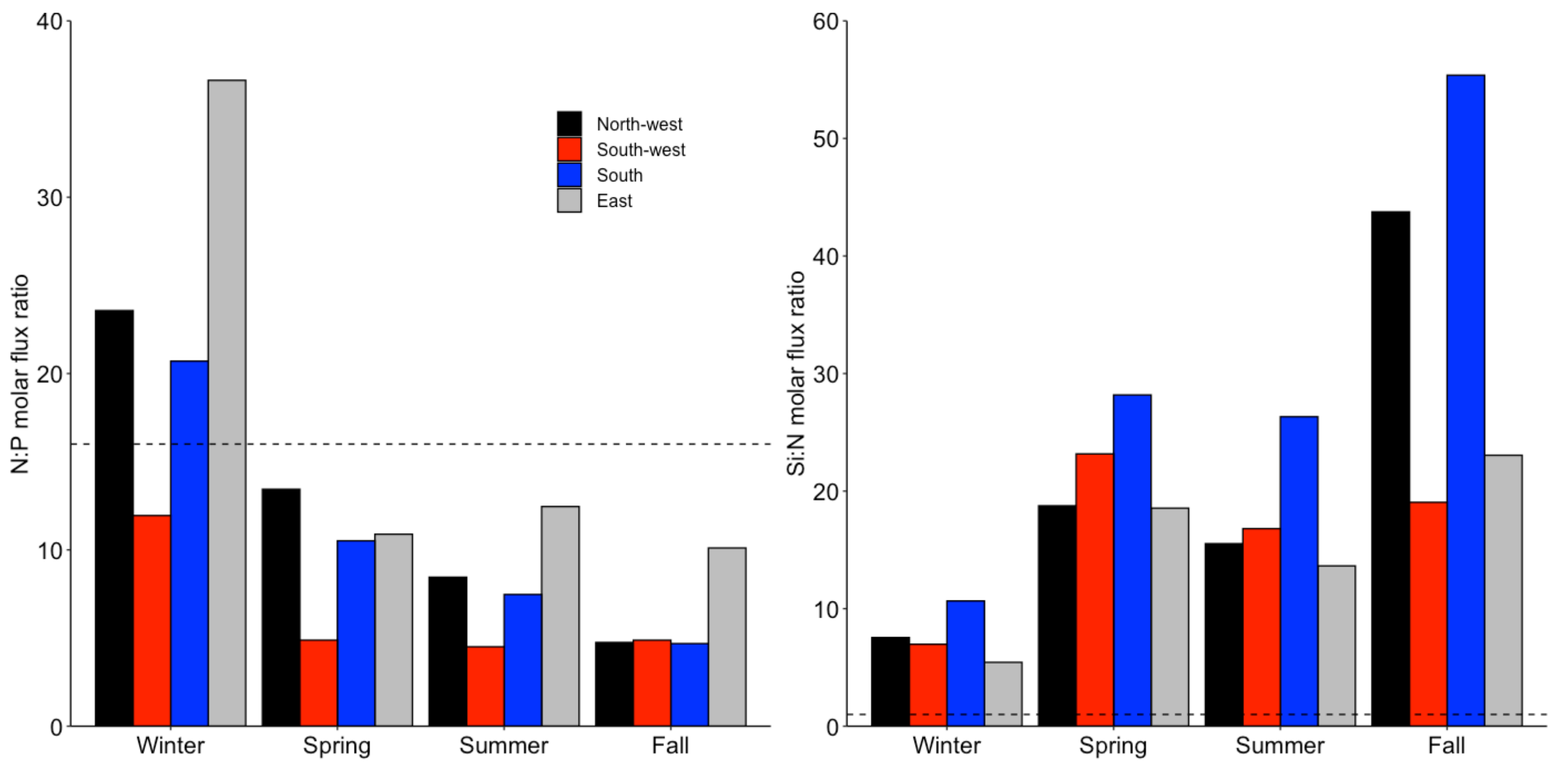

Figure 5. Seasonal comparison of the N:P (left panel) and Si:N (right panel) molar ratios of the freshwater discharged into the four different sectors of the Hudson Bay system. Horizontal dashed lines indicate the canonical Redfield value of 16 for N:P and the critical threshold of 1 for diatoms.

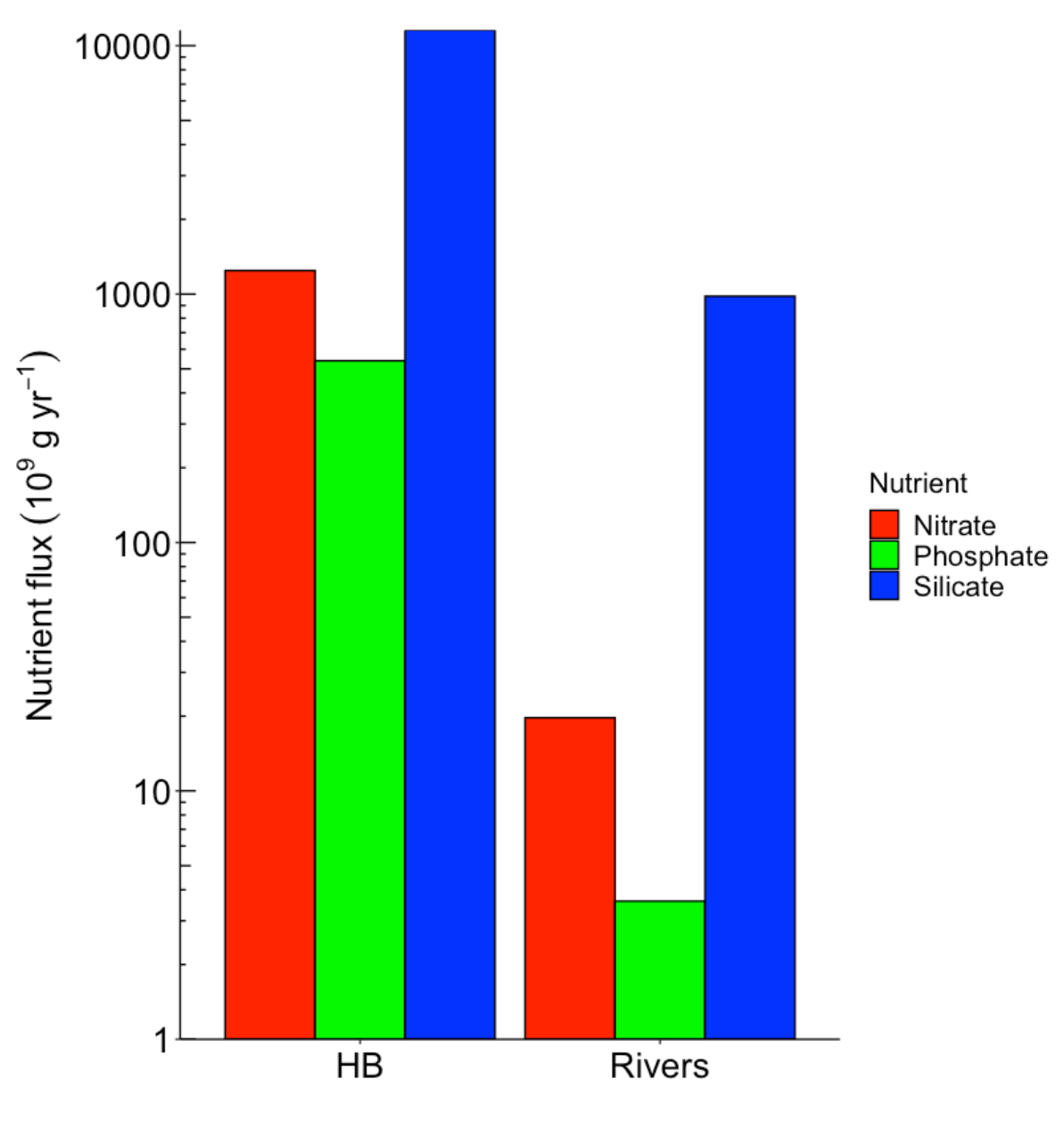

Figure 6. Comparison of annual nutrient deliveries by rivers and the vertical nutrient replenishment during winter offshore (HB).

- The combined nutrient inputs by all rivers were nearly two orders of magnitude lower than the estimated vertical re-supply of marine nutrients to the surface during winter in offshore waters.
    - ➢ Rivers: 2.0 × $10^{10}$ g N, 0.4 × $10^{10}$ g P and 98.1 × $10^{10}$ g Si (equivalent to 0.1 Tg C of new primary production)
    - ➢ Marine waters: 1.2 × $10^{12}$ g N, 0.5 × $10^{12}$ g P and 11.6 × $10^{12}$ g Si (7.7 Tg C of new primary production)
- The potential contribution of riverine nitrate to new primary production is small at the bay-wide scale but significant locally.

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