Eco-evolutionary Dynamics at the Northern Range Limit of Boreal Conifers

Research Synthesis & Key Findings

Ariane Langlois, Frédérique Bergeron, Lisa Nondier and Guillaume de Lafontaine – 2026

Canada Research Chair in integrative biology of northern flora, UQAR

Correspondence address: guillaume_delafontaine@uqar.ca

UQAR Université du Québec à Rimouski

Canada research chair in integrative biology of northern flora

Why was this study conducted?

At the northern limit of the Québec boreal forest, conifer species are responding to ongoing climate change. Under a warming climate, species may persist through local adaptation, experience demographic decline and extirpation, or shift their geographic distribution to the north, towards areas that provide newly suitable environmental conditions. However, it is suggested that the capacity for migration and/or local adaptation may be insufficient to keep pace with the current velocity of global environmental change.

Understanding how these processes interact at range margins is critical not only for predicting future species distributions, but also for anticipating ecosystem transformations that directly affect northern communities. Forest expansion is not a neutral ecological process: it reshapes landscapes, biodiversity, fire risk, and land access. For northern communities who value open tundra ecosystems, anticipating afforestation is necessary to support locally informed management and decision-making.

Current boreal tree expansion driven by global climate warming is part of a longer natural postglacial migration process. Since the last glacial period, boreal tree species have been migrating from south to north. This northward movement accelerated after the end of the Little Ice Age (1450–1850), a cold period during which tree migration slowed due to harsh climatic conditions.

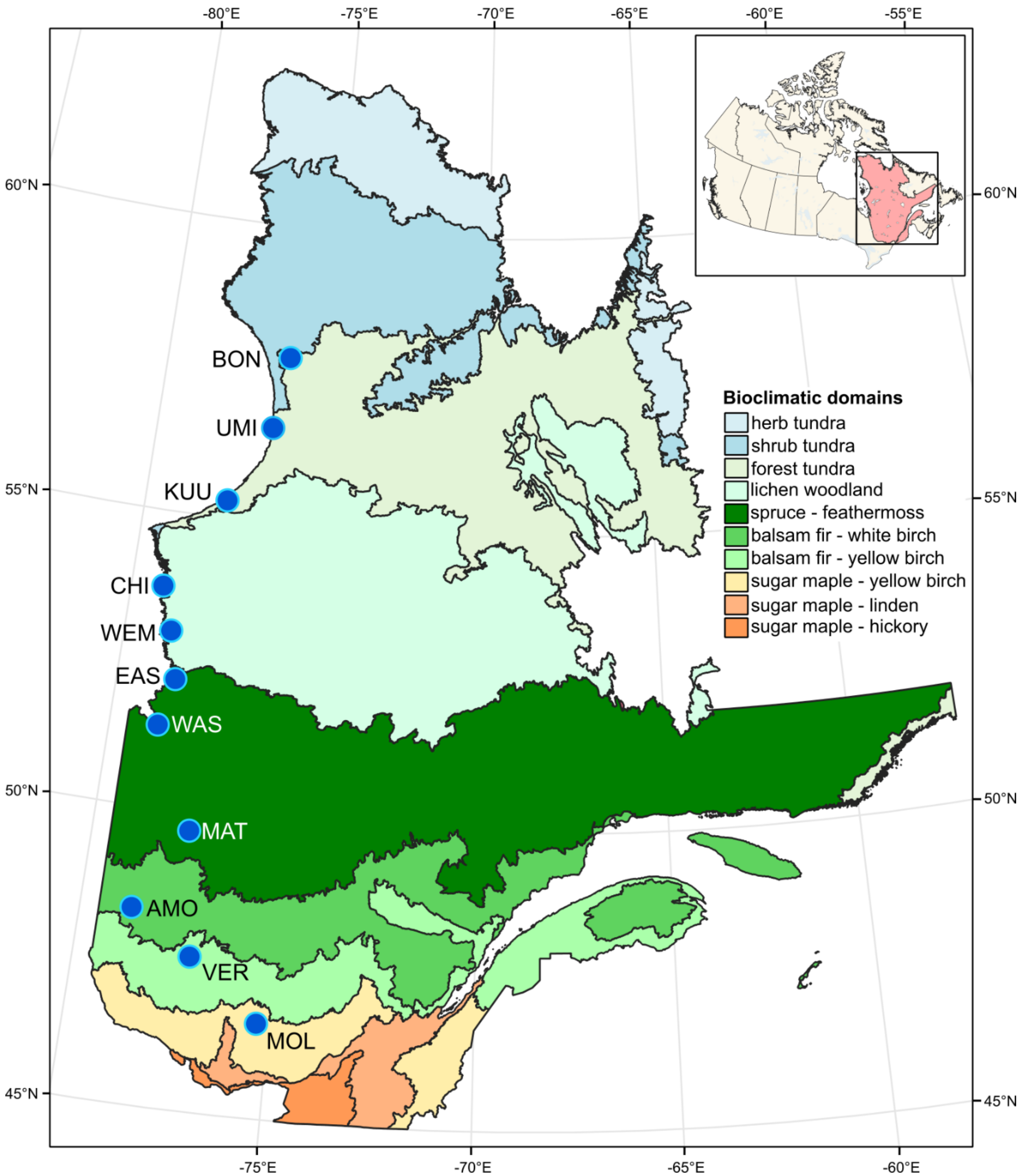
While species are tracking their new climatic envelope towards the north, key questions remain:

- Are northern populations **genetically** different from southern ones?
- Are **dispersal-related traits** amplified toward the north?
- Are there any differences in the adaptation between species (white, black spruce and tamarack)?

This study aimed to understand the **genetic and adaptive dynamics** associated with current latitudinal migration in boreal conifers.

Where was the study conducted?

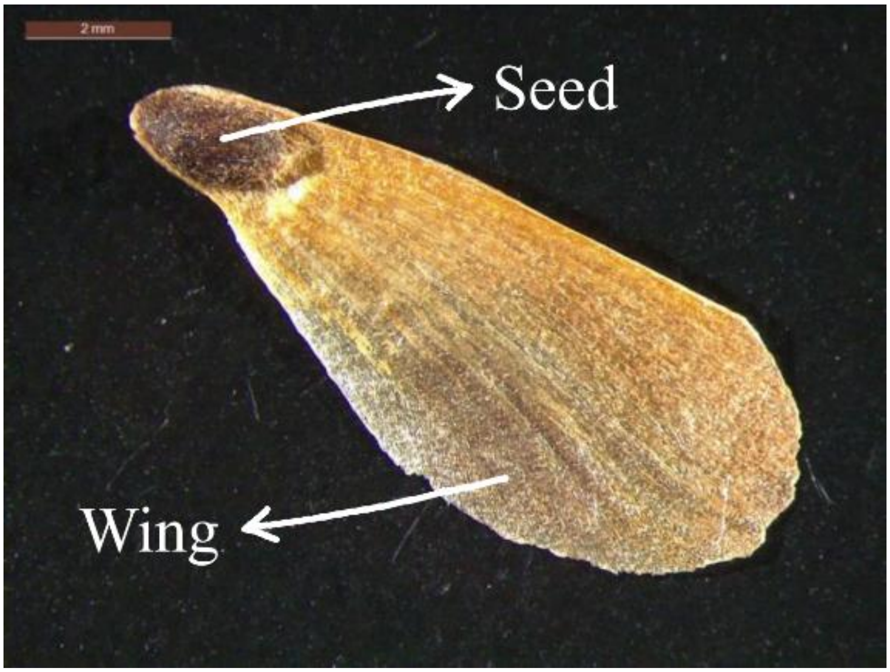
Sampling followed a **postglacial migration corridor** (1250 km) in western Québec. The latitudinal gradient extended from Mont-Laurier (temperate forest zone) to the northern limit Umiujaq (white spruce and tamarack) and Boniface River region (black spruce) through 11 sites.



Main method:

Dispersal trait: How far can the seeds travel?

Tree migration depends on seed movement. In wind-dispersed conifers, one important trait influencing how far a seed can travel is wing loading — the ratio between seed mass and wing area.



White spruce samara

- At each site, we collected 10 female cones from white spruce and black spruce during the summers of 2022 and 2023.
- We extracted the winged seeds from the cones.
- For each seed, we measured its mass and the size of its wing.

Genetics : How are populations structured?

We also wanted to understand how populations are genetically structured along the gradient from south to north.

At each site:

- We sampled 15 individuals of white spruce, black spruce, and tamarack.
- DNA was extracted from plant tissue.
- Individuals were genotyped using a genome-wide approach (DArTseq), allowing us to analyze thousands of genetic markers.

Why combine traits and genetics?

By measuring both dispersal traits and genetic diversity, we can better understand the ecological and evolutionary mechanisms driving northward expansion. Seed traits tell us about the potential for movement. Genetics tells us about past migration, connectivity, and evolutionary processes. Together, these approaches provide a more complete picture of how boreal trees are responding to environmental change at their northern limit.

What did we observe?

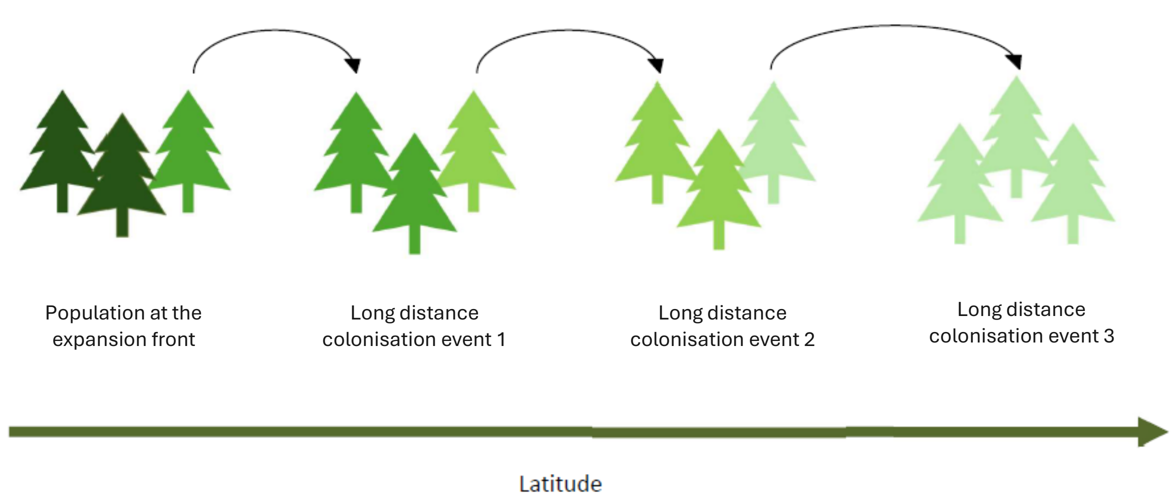
All species studied are expanding into the tundra.

Dispersal trait

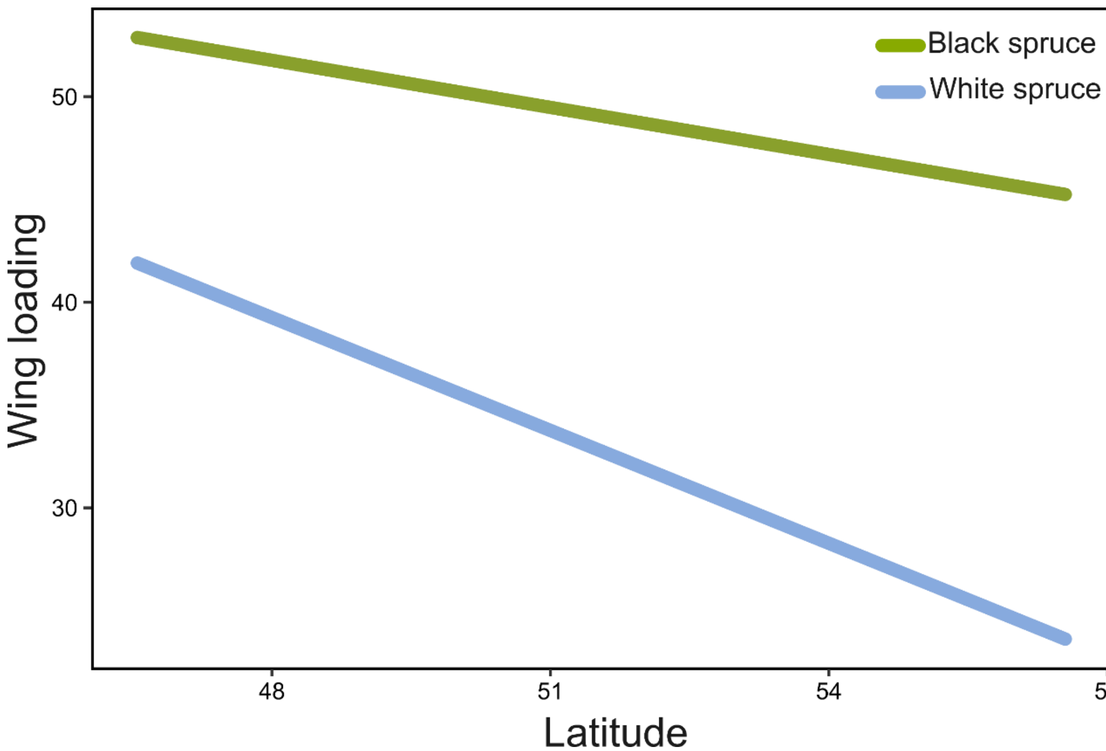
Wing loading decreases from south to north. In simple terms, this means that seeds produced by northern trees are lighter relative to the size of their wings, which helps them them travel farther with the wind. As a result, dispersal capacity appears to be greater in the northernmost populations located at the expansion front.

This pattern is consistent with a process known as **spatial sorting**. Spatial sorting occurs during range expansion, when individuals that disperse farther are more likely to reach and establish at the leading edge of the population. Over successive generations, these strong dispersers tend to accumulate at the colonization front.

The figure below illustrates this idea. Trees represented in pale color are those that dispersed the farthest. Because they move more quickly and establish beyond others, they gradually accumulate at the expansion front. This explains why individuals at the leading edge often show enhanced dispersal traits compared to those located further south.

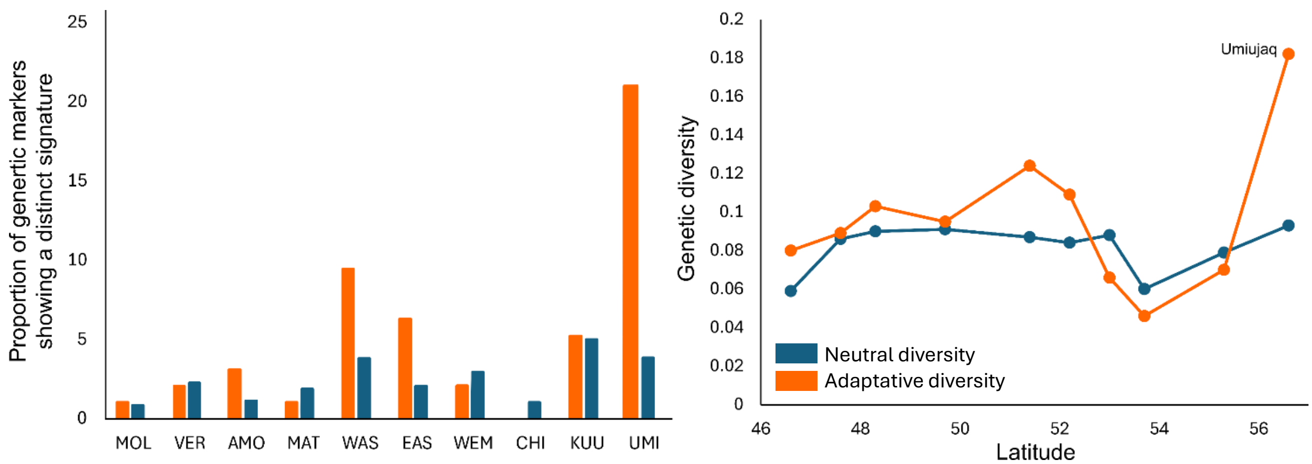


This pattern was observed in both white spruce and black spruce. However, it was particularly strong in **white spruce** because its postglacial migration is still ongoing, which makes the effects of spatial sorting more visible. **Black spruce**, however, reached its northern limit earlier, shifting selective pressures toward local adaptation rather than dispersal ability.



Genetics

For white spruce and tamarack, genetic diversity tends to increase in the northernmost sites we studied, a pattern that initially surprised us. We expected that new populations established by a limited number of individuals and carrying only a subset of the genetic variation present in the source population would lead to a gradual loss of genetic diversity toward the expansion front. However, our results reveal the opposite trend, suggesting that additional processes may help maintain or even increase genetic diversity in northern populations. The figure below shows adaptative and neutral diversity. The adaptative diversity is an indicator of a population's capacity to respond to environmental change



A higher adaptive diversity means that a population carries a wide range of genetic variants related to survival and reproduction. In other words, the population has many different biological "tools" available to cope with whatever the environment throws at it.

What does this mean for the territory?

If this tendency continues, the coastal areas that were previously unforested or only partially forested are likely to become increasingly covered by forest. The individuals found at the expansion front appear to be the most effective dispersers, as indicated by their wing-loading traits. They also seem to maintain sufficiently high adaptive diversity to cope with future environmental conditions, whether these involve drought, colder temperatures, or other climatic challenges.

What's next?

A study to assess the velocity of spruce migration is currently underway in the vicinity of Umiujaq.

Presentations and scientific outreach

Thesis

Bergeron F. 2025. Dynamique éco-évolutive chez deux espèces d'arbres boréaux en contexte d'expansion d'aire de répartition géographique. MSc thesis. Université du Université du Québec à Rimouski.

Seminar

de Lafontaine G. 2026. Where species survive or fail: Lessons from the edges of life in a warming climate. GenARCC Seminar, Online, 24 février 2026.

Angarita Ospina DM, de Lafontaine G. 2025. Migration speed of white spruce at its northern limit on the eastern coast of Hudson Bay in the context of climate change. 18e Colloque du CEF, Rimouski, 7 mai 2025.

Nondier L, de Lafontaine G. 2025. Dynamique éco-évolutive des conifères boréaux : entre adaptation et migration postglaciaire. 18e Colloque du CEF, Rimouski, 7 mai 2025.

de Lafontaine G. 2024. Dynamique éco-évolutive à la marge : réponses de la flore nordique face aux changements climatiques. Institut de recherche en biologie végétale (IRBV), Montréal, 28 novembre 2024.

Bergeron F, de Lafontaine G. 2024. Dynamique éco-évolutive au front de colonisation chez deux espèces d'arbres boréaux. 17e Colloque du CEF, Gatineau, 3 mai 2024.

Nondier L, de Lafontaine G. 2024. Signature génomique de la migration des conifères boréaux. 17e Colloque du CEF, Gatineau, 2 mai 2024.

Nondier L, de Lafontaine G. 2024. Signature génomique de la migration des conifères boréaux… En route vers le Nord ! Colloque du CEN 2024, Québec, 15 février 2024.

Bergeron F, de Lafontaine G. 2023. Potentiel de migration nordique : les samares de conifères dans une course à la colonisation? Colloque du CEN 2023, Rimouski, 16 février 2023.

Nondier L, de Lafontaine G. 2023. Prends ton bagage génétique, on part vers le nord! Colloque du CEN 2023, Rimouski, 16 février 2023.