Functional and Hydraulic Traits Plasticity of Boreal Tree Species Along a Latitudinal Climate and Permafrost Gradient in Northwestern North America

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1 Summary

- Boreal forests cover about one third of the world's forested area and undergo rapid changes in composition, structure, and function in response to environmental changes.
- Here we investigate the **inter- and intra-specific variability and plasticity** of boreal tree functional and hydraulic traits along a **2000-km latitudinal climate and permafrost gradient**. The study area is located in northwestern Canada and includes forests with no permafrost, over isolated, sporadic and discontinuous, to continuous permafrost, spanning from the southern- to the northern edge of the boreal forest ecozone.
- Focusing on the region's dominating boreal tree species, black spruce (*Picea mariana*) and larch (*Larix laricina*), we monitored **growing-season sap flux density** of ca. 200 individuals. Moreover, **leaf functional traits** (e.g., specific leaf area, SLA, leaf nitrogen concentration, *N*, maximum photosynthetic capacity, A_{max}, stomatal conductance to water, g_s) are also measured for selected individuals across the study domain.
- By jointly analyzing stem water use, leaf functional traits, and the prevailing environmental and micrometeorological conditions along the gradient, we **aim** to provide a detailed quantification of **black spruce and larch inter- and intra-specific trait variability**, and thus to **better understand boreal forest plasticity and resilience to ongoing environmental changes**.

2 Methods (1/5) –Overview

Structural Traits
- Height
- Crown area
- Crown depth
- Sapwood area
- Sapwood depth
- Huber value

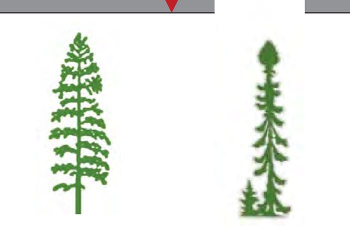
Functional Traits

Hydraulic traits
- Sap-flow-derived metrics of tree water use, i.e., crown conductance to water, G_C, G_C^{Max}

Leaf traits
- SLA
- *N*
- A_{max}
- g_s

Latitudinal Climate and Permafrost Gradient

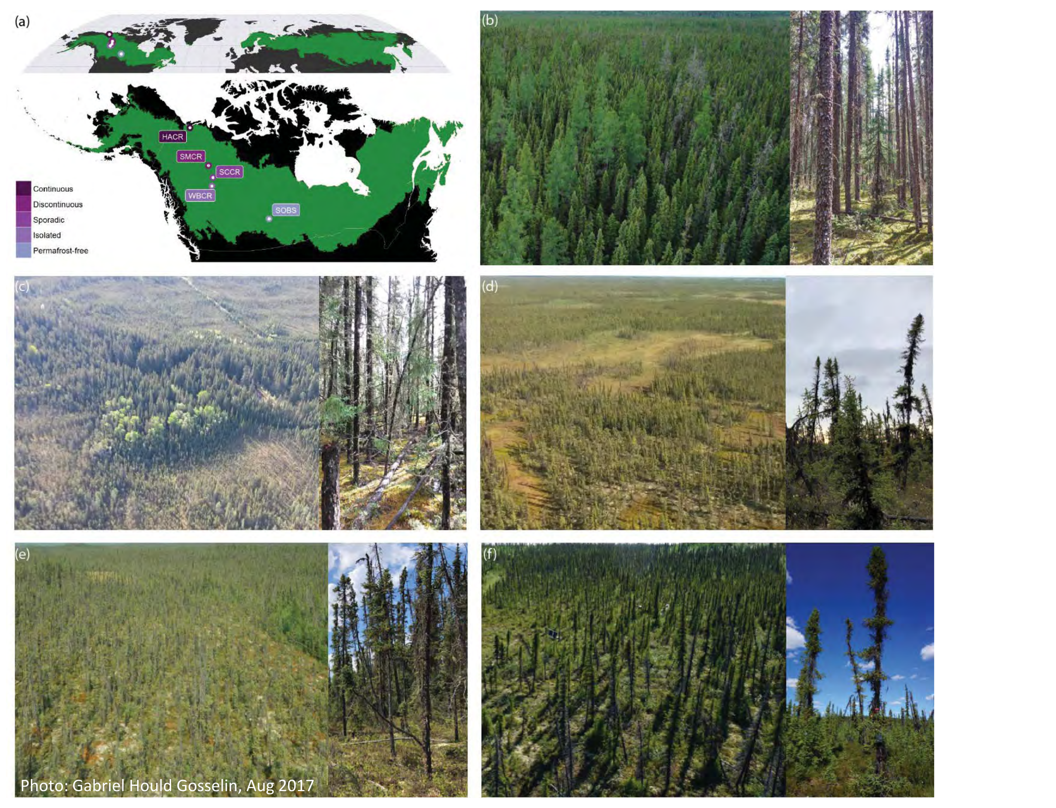
Permafrost: continuous, discontinuous, sporadic, isolated, permafrost free
Latitude: 53.9°N to 68.5°N
Mean annual air temperature: from -8.2 to 1.4 °C
Mean annual total precipitation: from 240 to 430 mm



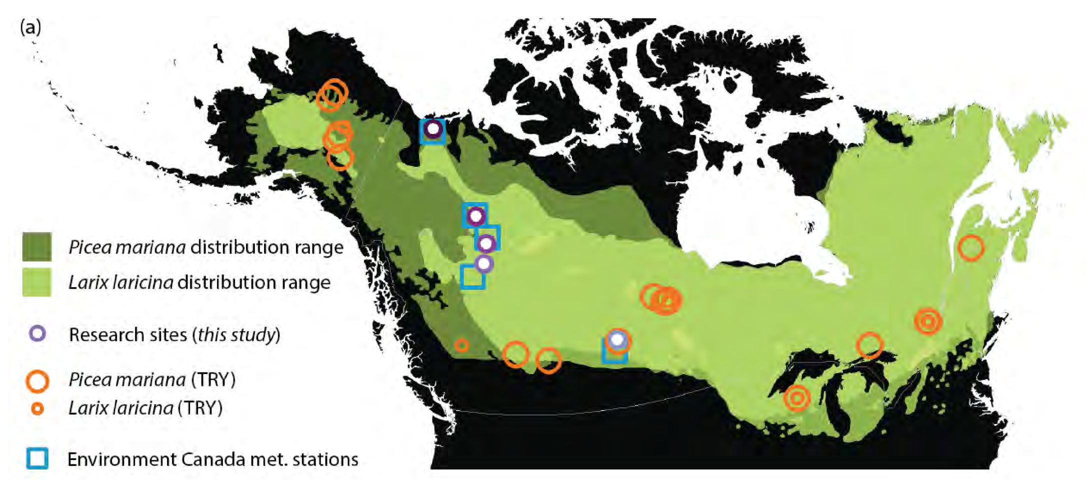
Resource allocation/use strategies

Boreal tree plasticity and resilience to environmental stress

3 Methods (2/5) –Study area

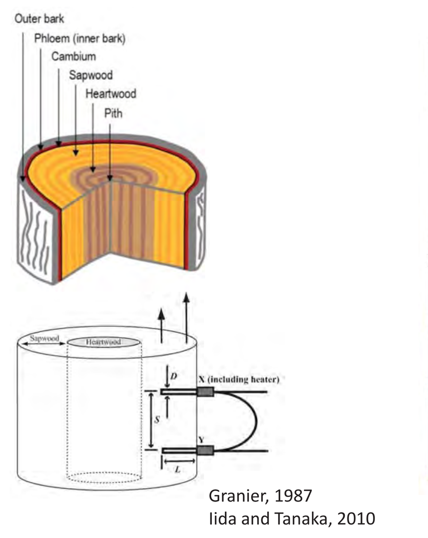


4 Methods (3/5) –Datasets

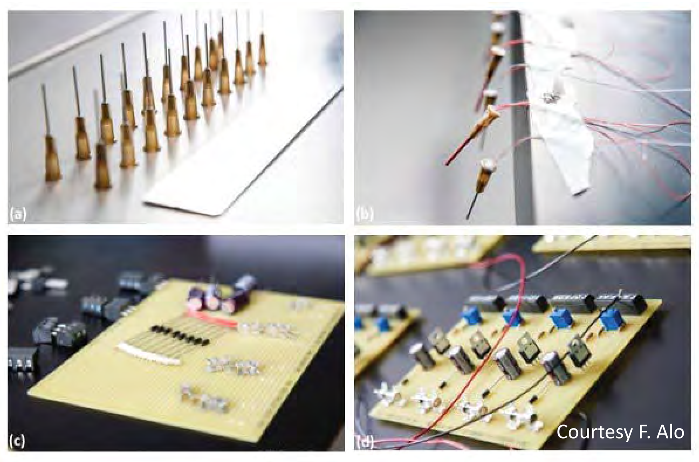


TRY database: Kattge et al., 2011
Shapefiles of species ranges were downloaded from https://github.com/wpetry/USTreeAtlas

5 Methods (4/5) –Sap flow



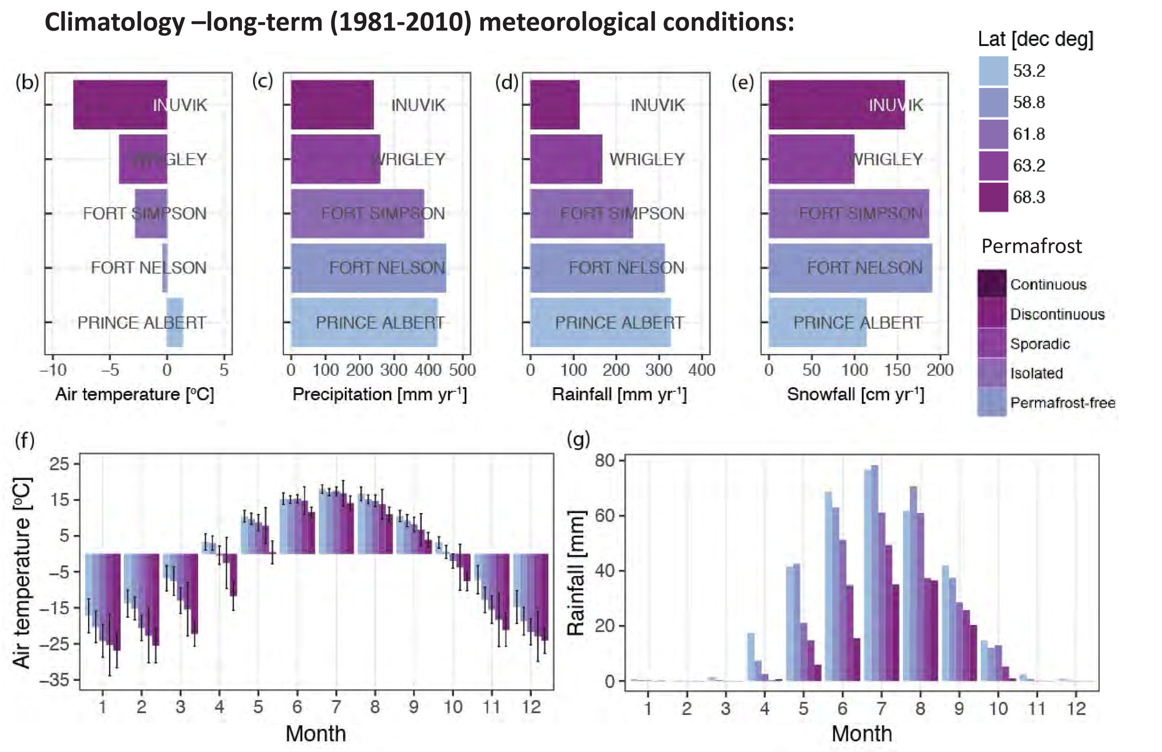
Granier, 1987
Iida and Tanaka, 2010



Thermal dissipation (Granier) sap flux density probes: each sensor consists of a pair of 20 mm long, 2 mm diameter probes inserted in the conductive xylem (sapwood) about 10 cm apart. The upper probe is constantly heated and the temperature difference between the two probes is recorded (Granier, 1987).

6 Methods (5/5) –Climate and permafrost gradient

Climatology –long-term (1981-2010) meteorological conditions:



7 Results (1/4) –Boreal tree form and function

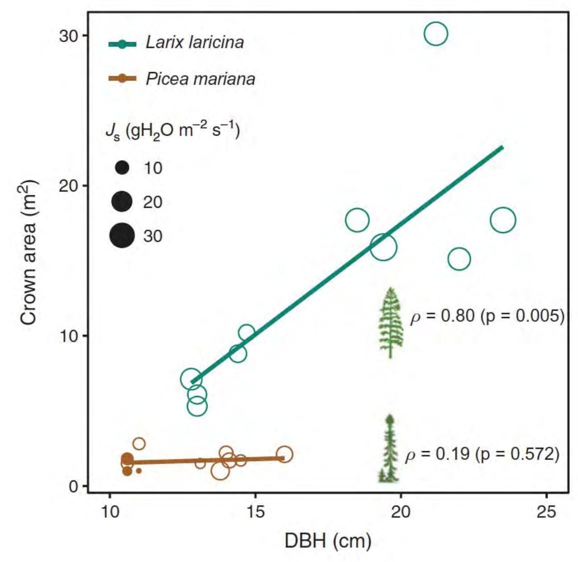
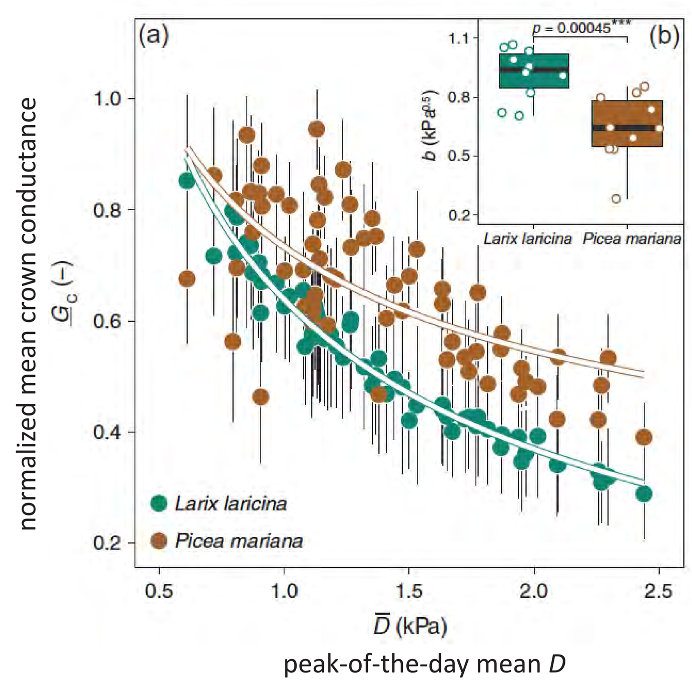


Table 2. Pearson correlation coefficients (ρ) with *P*-values in parentheses between mean half-hourly sap flux density (J_s) averaged throughout the study period and tree diameter at the breast height (DBH), tree height and projected crown area, as well as the time lag (h) when ρ between J_s and half-hourly vapour pressure deficit (*D*) and photosynthetically active radiation (PAR) is maximum, for *Larix laricina* and *Picea mariana*.

		Species	
		Larix laricina	*Picea mariana*
J_s	DBH	$\rho = 0.74$ ($P = 0.015$)	$\rho = 0.59$ ($P = 0.054$)
	Height	$\rho = 0.55$ ($P = 0.098$)	$\rho = 0.40$ ($P = 0.219$)
	Crown area	$\rho = 0.60$ ($P = 0.068$)	$\rho = 0.05$ ($P = 0.873$)
J_s	*D*	lag = −1.0 h (ρ=0.87)	lag = 0.0 h ($\rho = 0.88$)
	PAR	lag = 1.0 h (ρ=0.89)	lag = 2.0 h ($\rho = 0.94$)

At the southern edge of the boreal forest ecozone (SOBS study site), **larch** and **black spruce** are characterized by distinct crown architectures: the former has a wider canopy and larger projected crown area which increases linearly with stem diameter while the latter has a narrower canopy architecture and higher leaf clumping with packed needles located close to the trunk, resulting in a smaller projected crown area. These morphological differences result also in distinct tree water use for the two co-occurring species (Pappas et al., 2018).

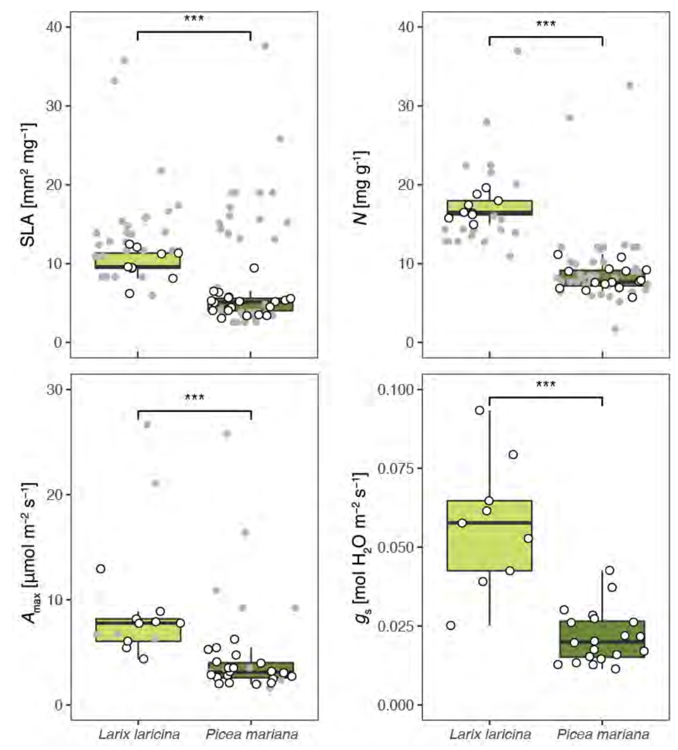
8 Results (2/4) –Boreal tree water use



Recent findings from the southern edge of the boreal forest ecozone (SOBS study site) indicate diverging water use and stomatal regulation strategies of larch and black spruce.

For the same level of $\overline{D}$, black spruce maintains higher values of G_C in comparison to larch, highlighting interspecific differences in their water use (Pappas et al., 2018).

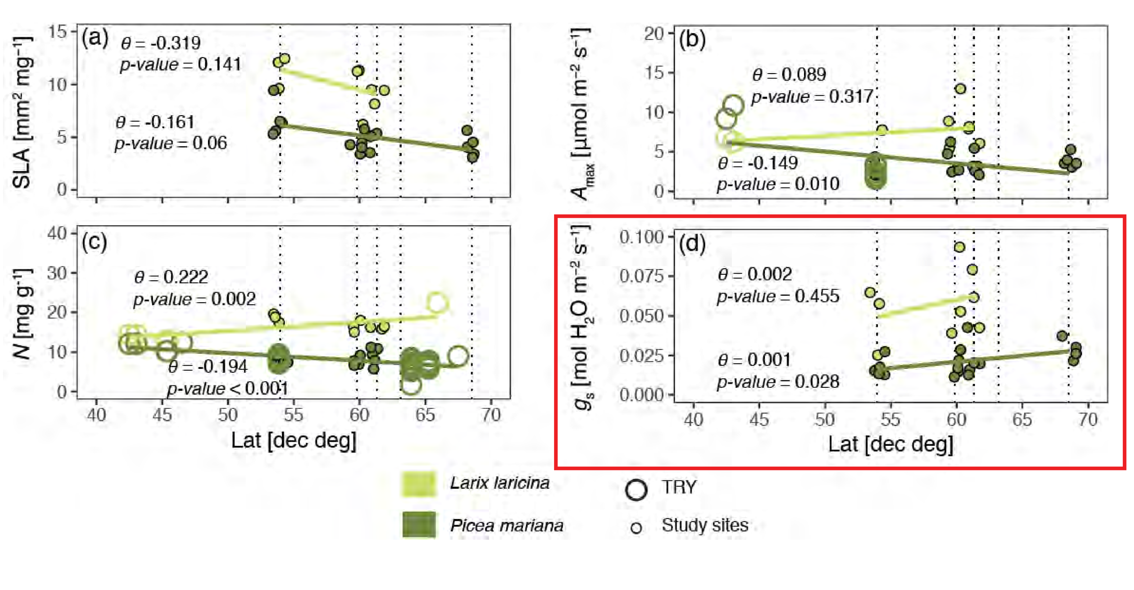
9 Results (3/4) –Traits coordination



The diverging water-use strategies observed at the southern edge of the boreal forest ecozone (SOBS study site; Pappas et al., 2018) reflect also the diverging traits strategies of larch and black spruce along the 'fast–slow' plant economics spectrum (Reich 2014).

Larch is characterized by a 'fast' traits strategy (i.e., early successional, deciduous leaf phenology, high rates of resource acquisition and use) while black spruce is characterized by a 'slow' traits strategy (i.e., long leaf lifespans, slow rates of resource acquisition and use) (e.g., Niinemets and Valladares 2006, Pappas et al., 2018).

10 Results (4/4) –Traits plasticity



As we move to higher latitudes, boreal tree species adjust their hydraulic and functional traits to account for (1) lower temperatures and light conditions, and (2) shorter growing seasons (Pappas et al., *in prep.*).

11 Next steps

Recent findings from the southern edge of the boreal forest ecozone (SOBS study site; Pappas et al., 2018) highlight the:

1. *whole-plant traits coordination of boreal tree species:* Larch tends to increase its height faster and its crown architecture is more efficient in harvesting light, also facilitating xylem water conductance while showing low shade and drought tolerance and relatively isohydric behaviour. In contrast, black spruce is a slow-growing evergreen conifer, characterized by higher shade and drought tolerance and anisohydric water-use strategy.
2. *complementarity in tree form and function:* Although boreal forest tree species diversity may be relatively low, its functional diversity can be substantial. Diverse boreal tree hydraulic functioning could potentially act complementarily at the ecosystem level with implications for understanding boreal forests' water and carbon dynamics and resilience to environmental stress.

We aim at extrapolating our findings from the southern boreal forest to the northern study sites and testing the following **hypothesis**:

Boreal tree species at high latitudes adjust their hydraulic functioning (i.e., leaf- and crown-level stomatal conductance to water, g_s and G_C respectively) in order to optimize water use under harsher environmental conditions and shorter growing seasons.

12 References

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Photo: Ashley Matheny, May 2016