Leaf photosynthesis response of Salix species to environmental gradients in the High Arctic (Nunavut, Canada)

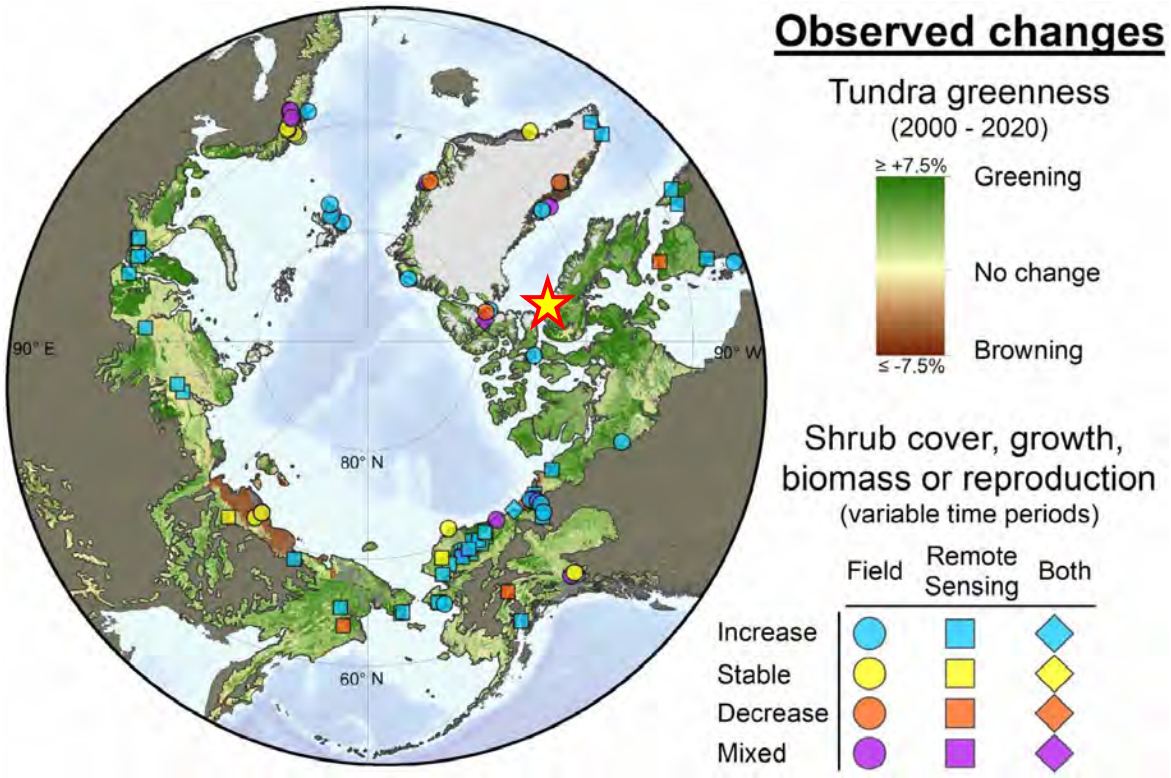
Vincent Maire, Jennifer Paillassa, Laurent Lamarque, Florence Gagné, Esther Lévesque

Centre d'études nordiques
Centre for Northern Studies

LEVF
LABORATOIRE D'ECOLOGIE VÉGÉTALE FONCTIONNELLE

UQTR
Université du Québec à Trois-Rivières

Arctic tundra greeness



Observed changes

Tundra greenness
(2000 - 2020)

≥ +7.5% Greening

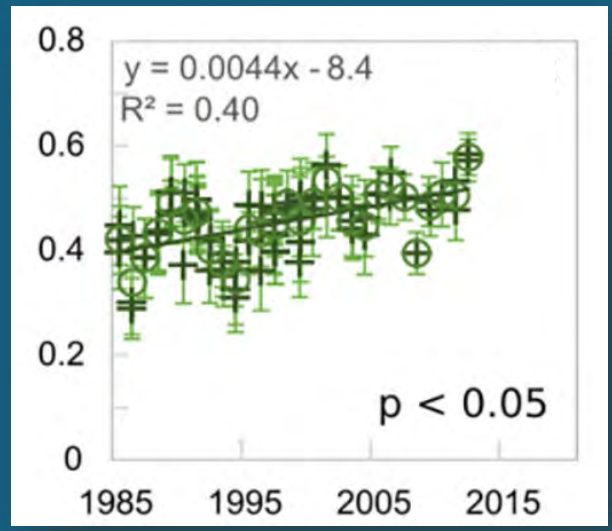
No change

≤ -7.5% Browning

Shrub cover, growth, biomass or reproduction
(variable time periods)

	Field	Remote Sensing	Both
Increase	●	■	◆
Stable	●	■	◆
Decrease	●	■	◆
Mixed	●	■	◆

Mekonnen et al 2021 ERL



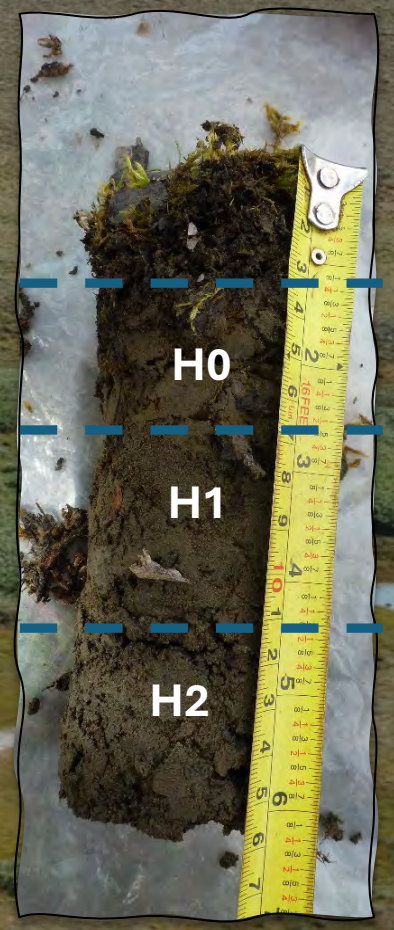
Crichton et al 2022 STE

Salix richardsonii in the High-Arctic tundra of Bylot island (East-Canada)

Impact on soil carbon sequestration

Active

Abandoned

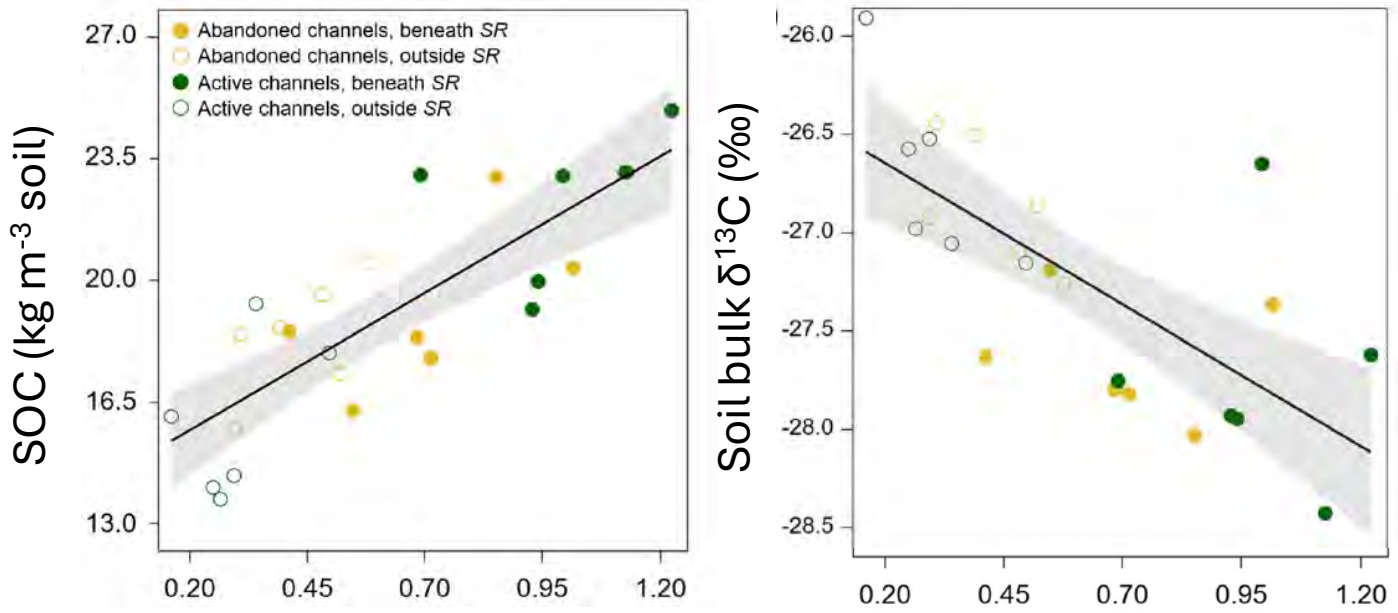


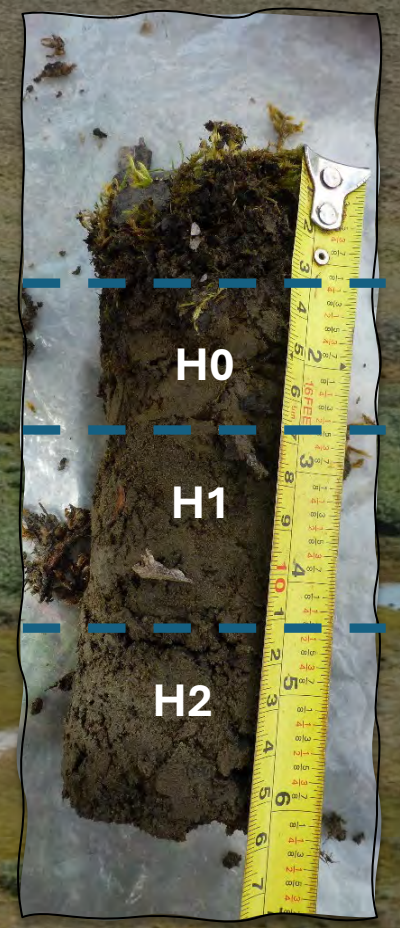
Lamarque, Lévesque, Maire et al 2023, Ecosystems

Salix richardsonii in the High-Arctic tundra of Bylot island (East-Canada)

Key role of leaf photosynthesis

Horizon: 0-15 cm





Lamarque, Lévesque, Maire et al 2023, Ecosystems

Carbon sequestration potential

Jennifer Paillassa
Thesis 2024

- What is the rate at which leaves acquire carbon?
- Does it vary between Salix species, and if so, how?
- Does it vary across environments, and if so, how?
- Is it optimised? Is this through acclimation or adaptation?

CO_2 pathway in leaf photosynthesis

Three limitations

2. Mesophyll conductance
(CO_2 path from air to liquid)

H_2O_i

CO_{2_i}

g_m

CO_{2_c}

Transpiration

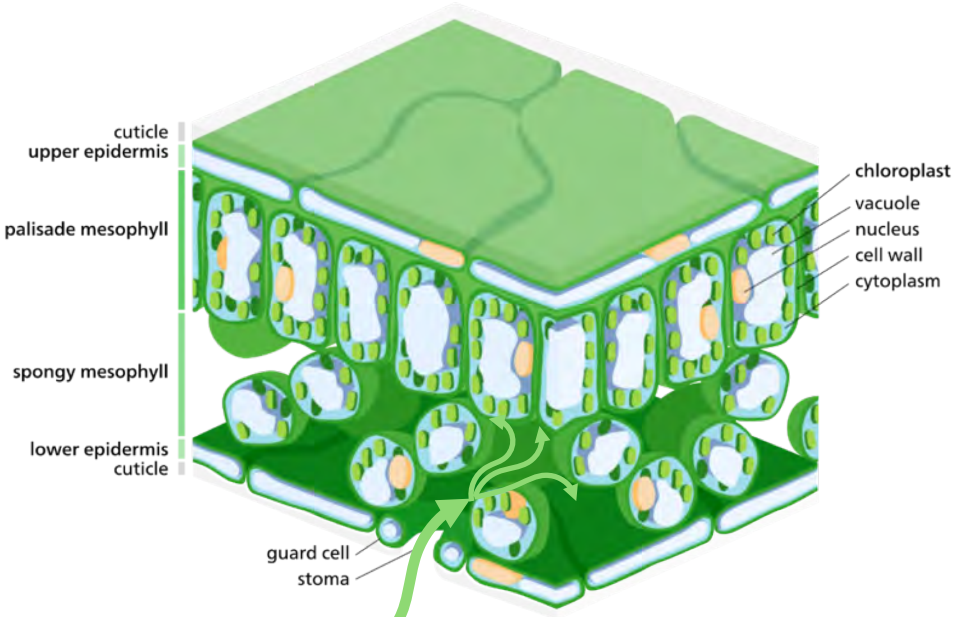
Stomatal conductance to H_2O

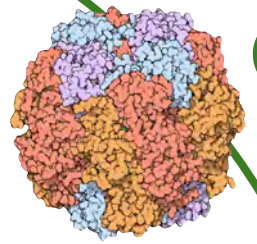
1. Stomatal conductance to CO_2

g_s

3. Carboxylation rate
(Rubisco enzyme)

V_{cmax}





H_2O_a CO_{2_a}

CO_2

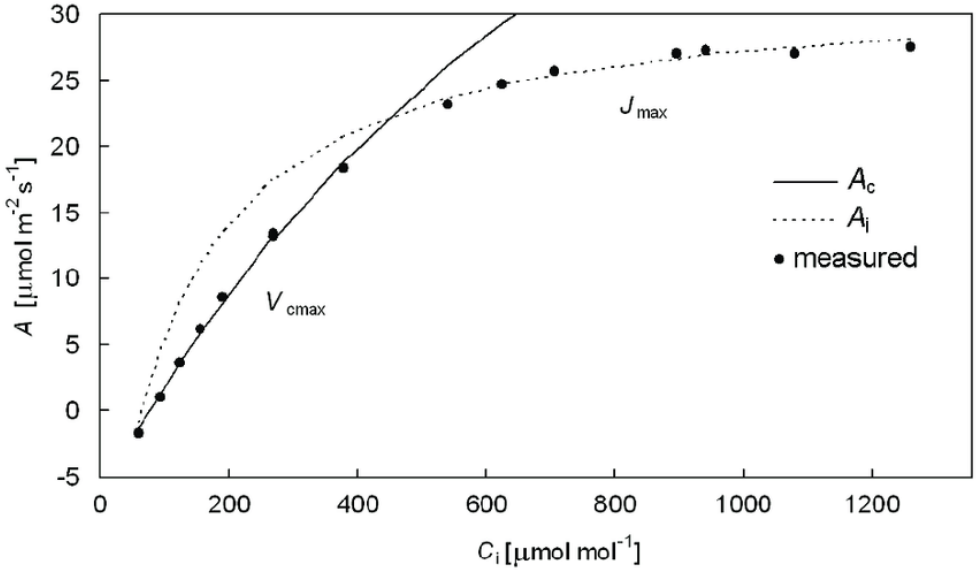
Sugar
$C_6H_{12}O^6$

ATMOSPHERE | STOMATA | MESOPHYLL | CHLOROPLASTE | PHLOEM

Methods
Measurements

Licor Li-6800

- n = 163
- Photosynthetic traits
  - According to Ethier & Livingston (2004) protocol
  - Under standardised conditions
    - Upper leaf
    - PPFD = 1000 µmol m^{-2} s^{-1}, T_{leaf} = 10°C
  - Three photosynthetic limitations
    - Vc_{max} (A-Ci curves)
    - g_m (A-PPFD curves)
    - g_s at 410 ppm [CO_2]
- Morphological & chemical traits
  - SLA, LDMC, Leaf Size
  - N_{area} & P_{area}



Methods

Experimental design

Salix arctica
Widespread

Salix reticulata
Mesic habitat

Salix richardsonii
Hydric habitat

Environmental gradient along the Qarlikturvik glacier valley:

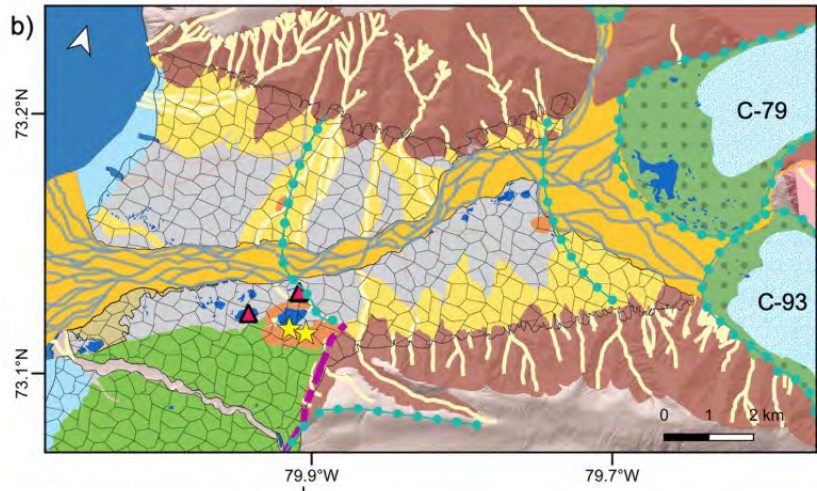
29 sites
*3 species
*2 individuals

n = 163

Paillassa, Maire et al 2024
Plant, Cell & Environment

Coulombe et al 2022
Cryospher

Qarlikturvik glacier valley

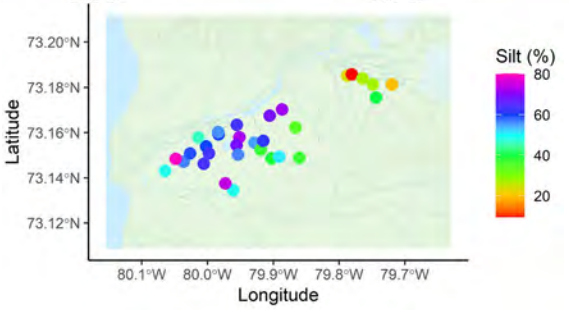


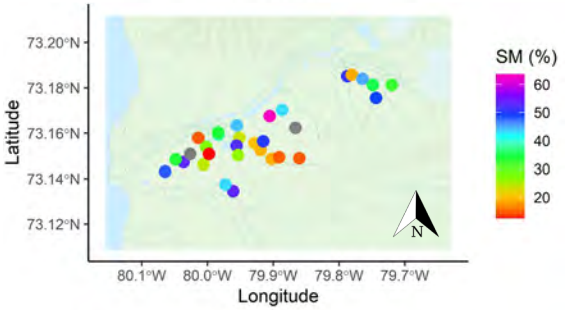
PCA of 15 variables shaped 3 environmental dimensions

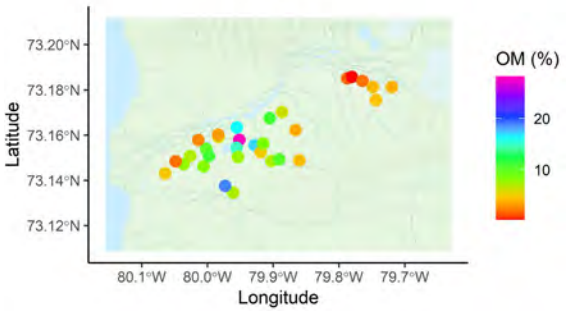
Silt
Nutrient-water retention dimension

Soil moisture
soil water accumulation dimension

Soil organic matter
C vs NP resource dimension







Result

High photosynthetic capacity (A_{sat})

- At ambient temperatures, A_{sat} of arctic Salix species is equivalent to worldwide values
- High rates permitted by very high leaf N content
- In agreement with a recent study

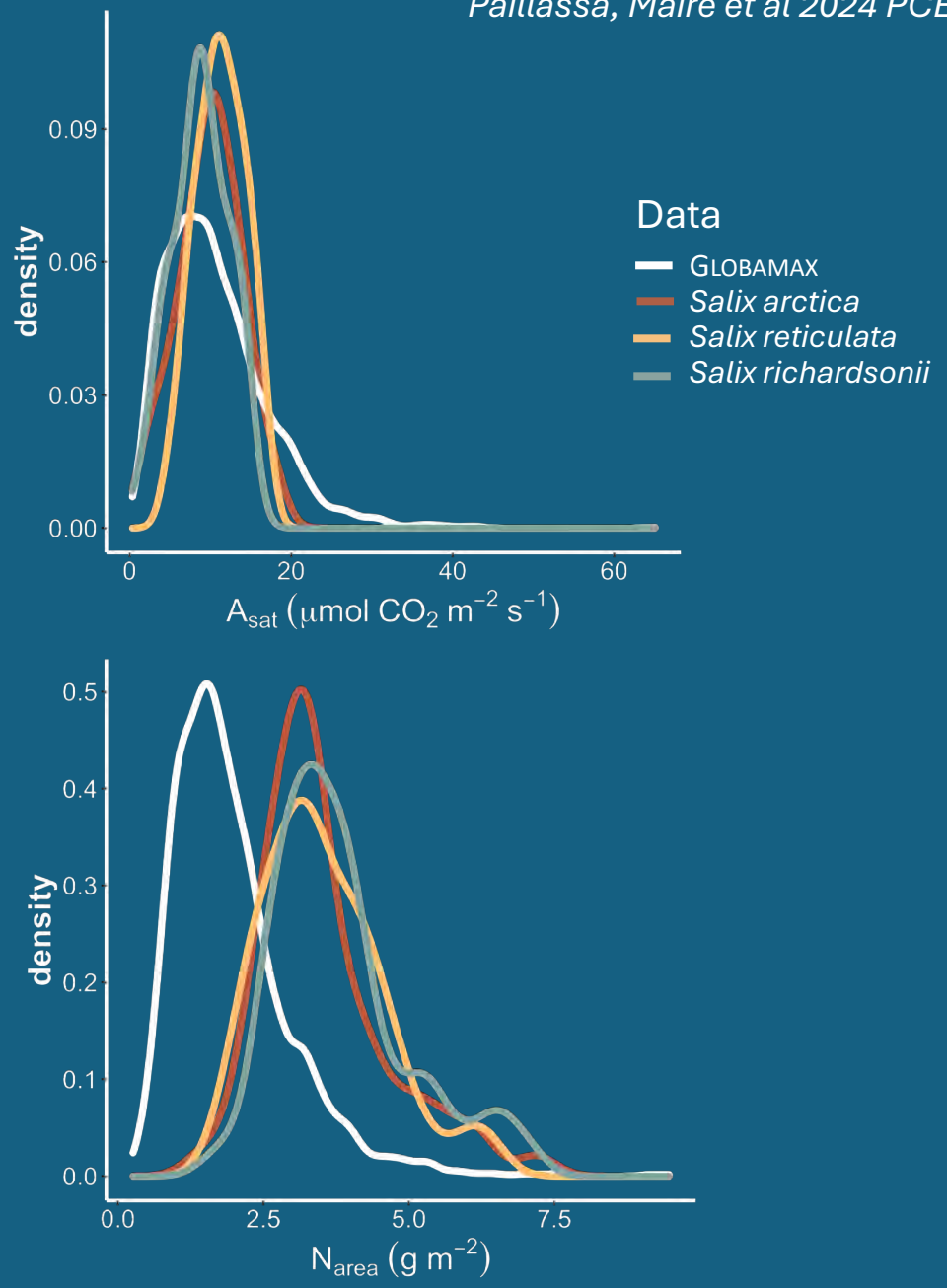
Article | Open access | Published: 21 February 2019

Earth system models underestimate carbon fixation by plants in the high latitudes

Alexander J. Winkler ✉, Ranga B. Myneni, Georgii A. Alexandrov & Victor Brovkin

Nature Communications **10**, Article number: 885 (2019) | Cite this article

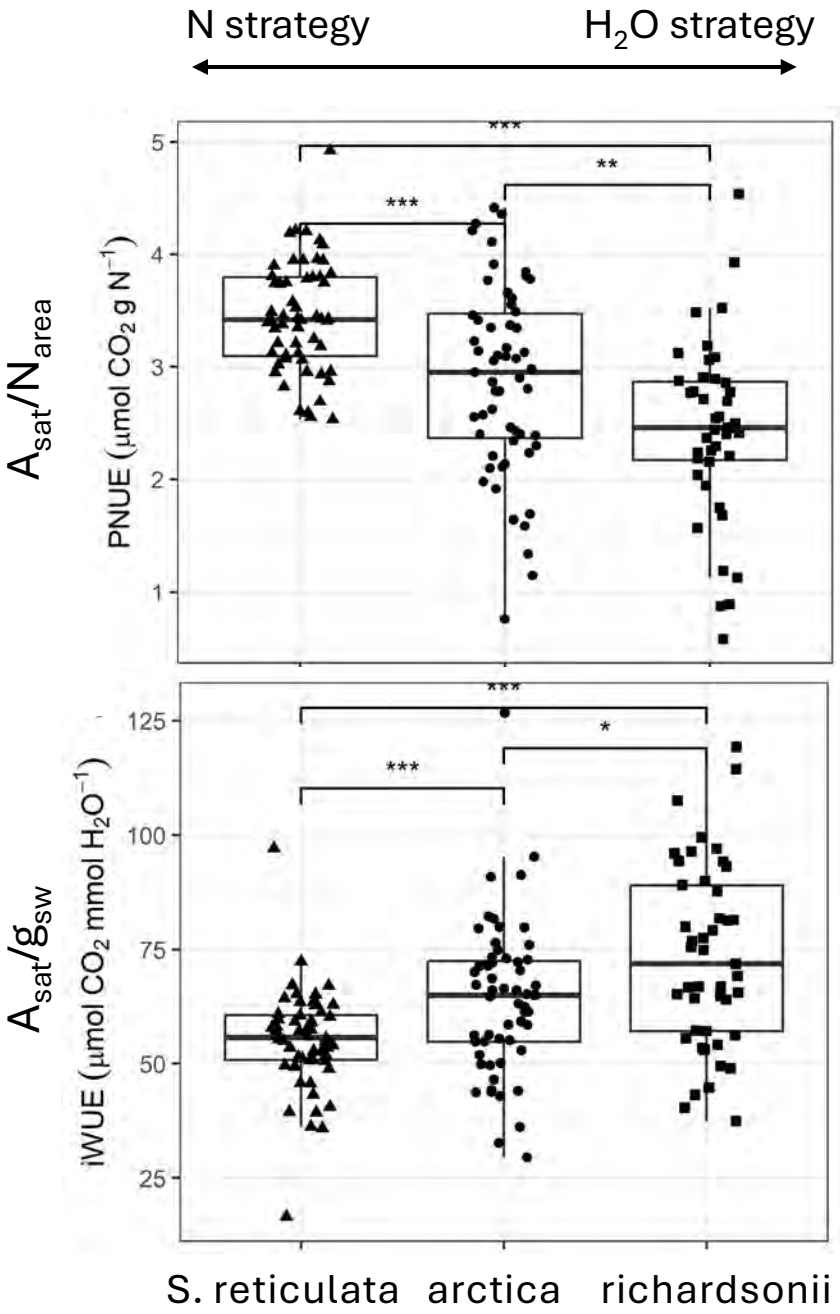
Maire et al 2015 GEB
Paillassa, Maire et al 2024 PCE

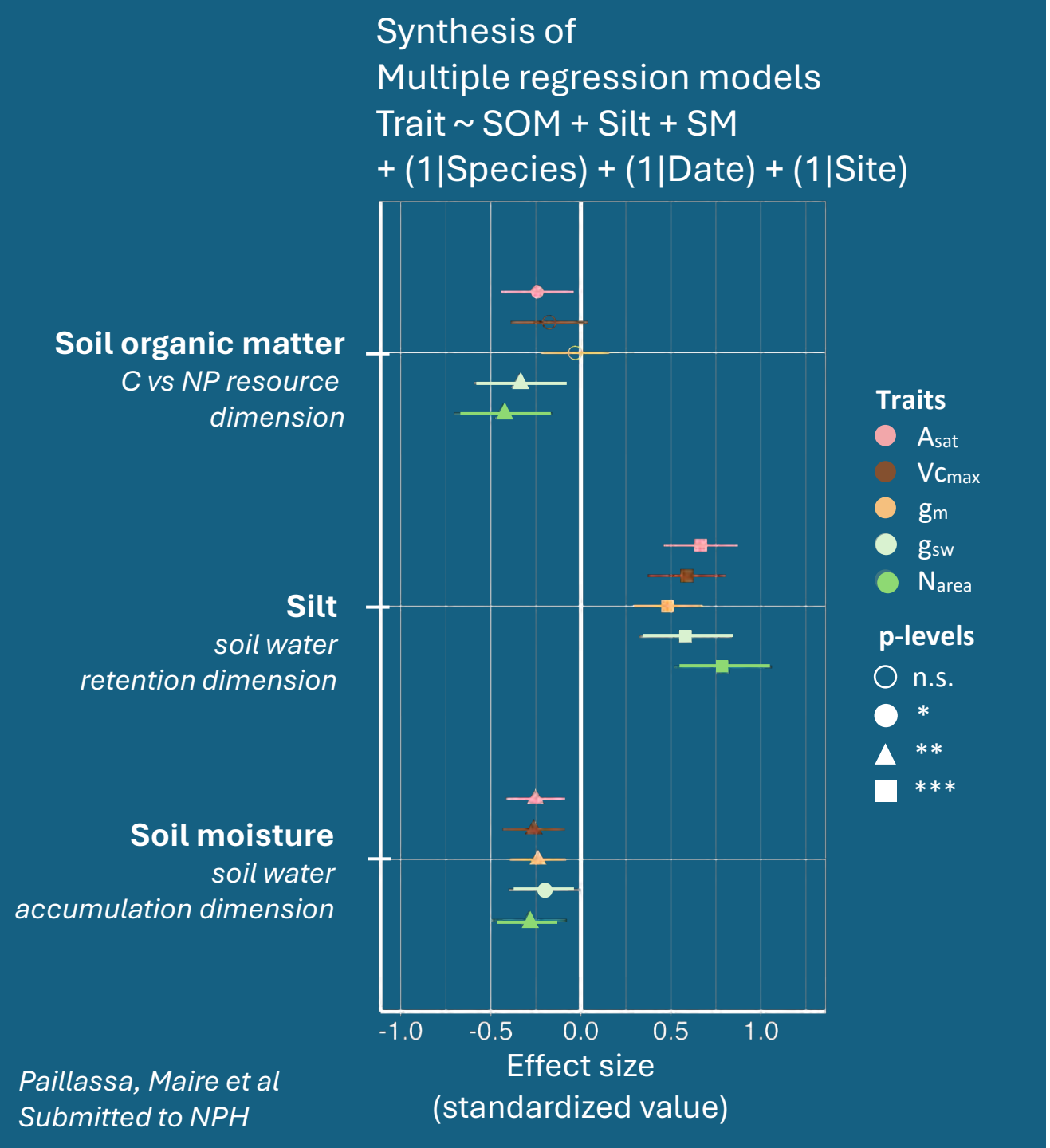


Result
Different strategies for high A_{sat}

- N strategy for *S. arctica* and *S. reticulata*
- H_2O strategy for *S. richardsonii*
- In agreement with their preferential habitat
  - Mesic for *S. arctica* and *S. reticulata*
  - Hydric for *S. richardsonii*

Paillassa, Maire et al
2024, Plant, Cell & Environment





Result

Responses to environment

- Silt content as a key environmental driver increasing A_{sat}
  - Relation to geomorphological processes.
- Decreasing A_{sat} with accumulation of OM and water in soils.
- Similar responses across species

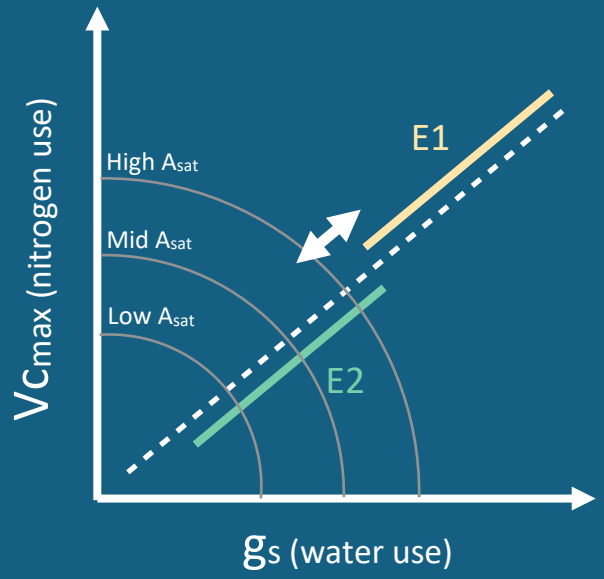
- **Coordination among photosynthetic limitations in their response to environment**

Theoritical approach
Acclimation vs adaptation

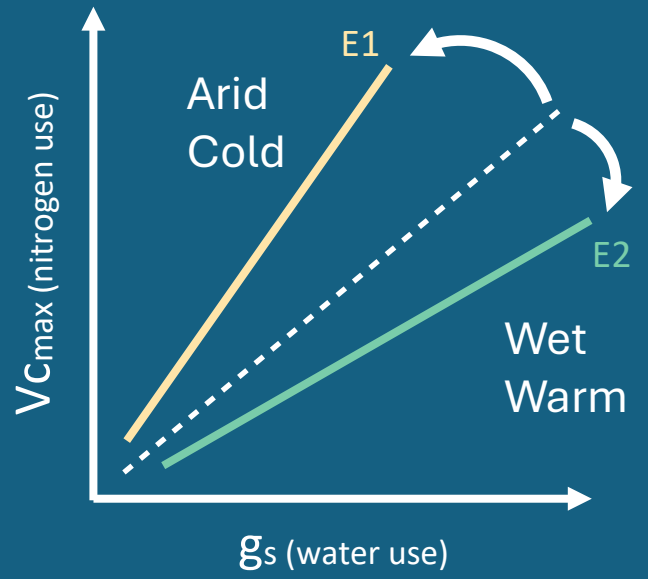
- Acclimation
  - A plant's ability to adjust its physiological or metabolic responses to short-term environmental changes.
  - Adjustments are often reversible
- Adaptation
  - Genetic changes that occur over successive generations in response to environmental selection pressures.
  - These genetic changes lead to heritable traits that improve the plant's survival and reproduction in its specific environment.

Least-cost theory for photosynthesis

Acclimation
=
Slope sliding



Adaptation
=
Slope change



Maire et al 2012 PONE;
Prentice, Maire et al 2013 ELE; Paillassa, Maire et al 2020 NPH

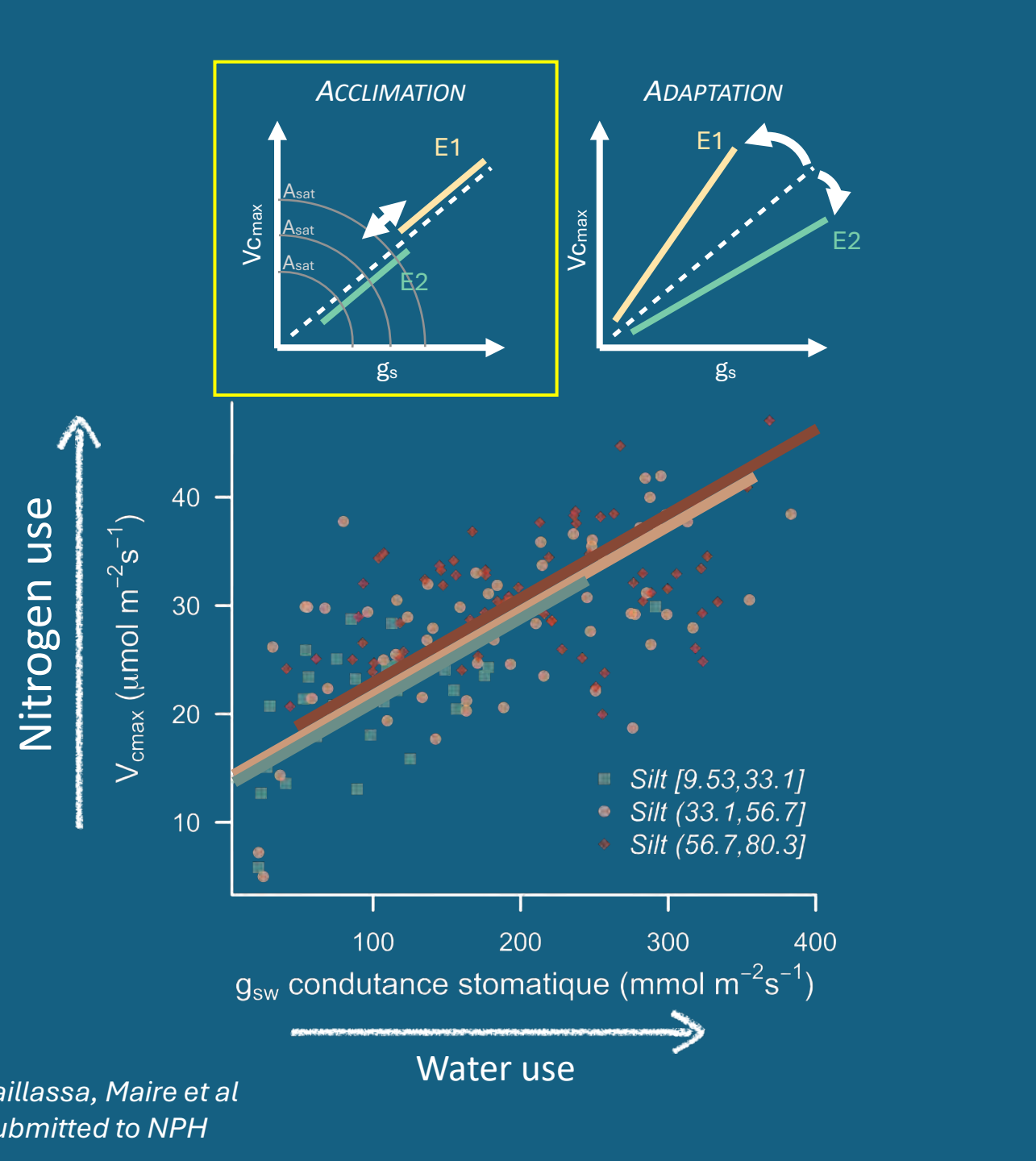
Result

Acclimation vs adaptation Overall

- Standard major axis regression (‘*smatr*’)
- Silt split into 3 E-groups (equistep method)
- No slope difference

=

- Acclimation overall along a glacier valley!

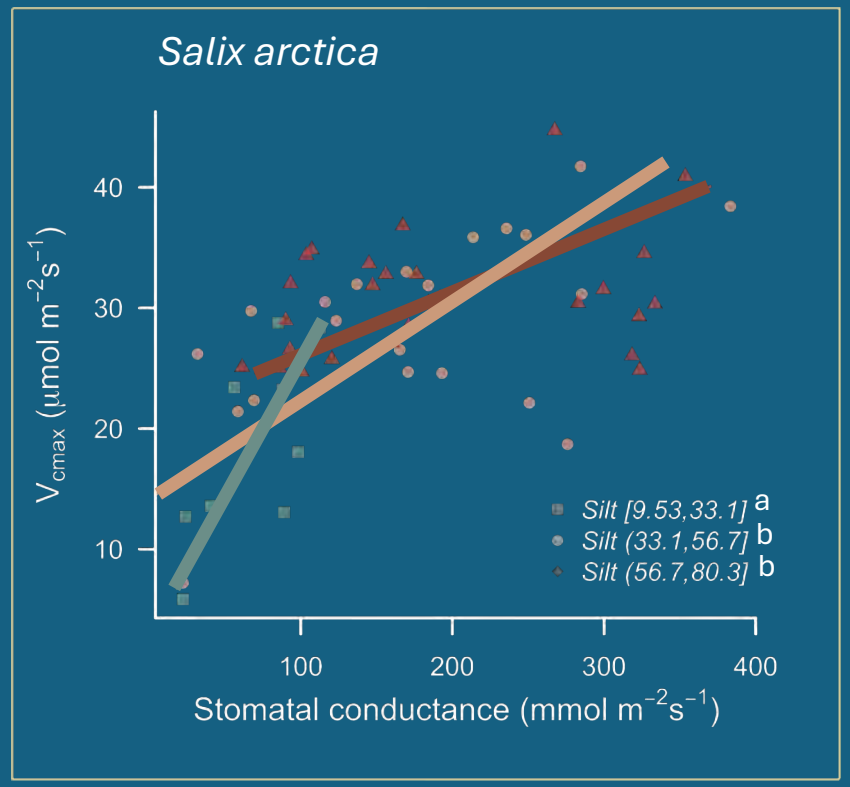


Paillassa, Maire et al
Submitted to NPH

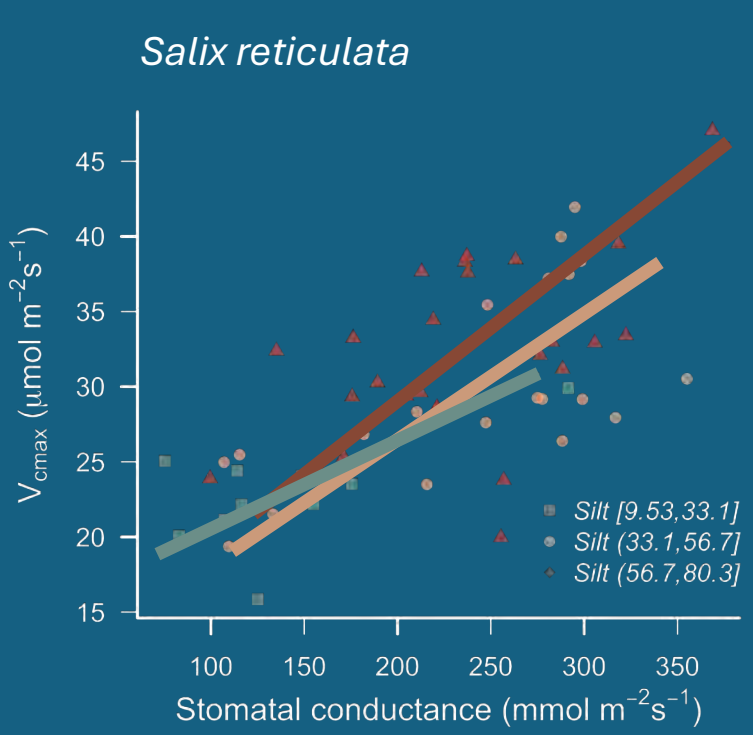
Between species

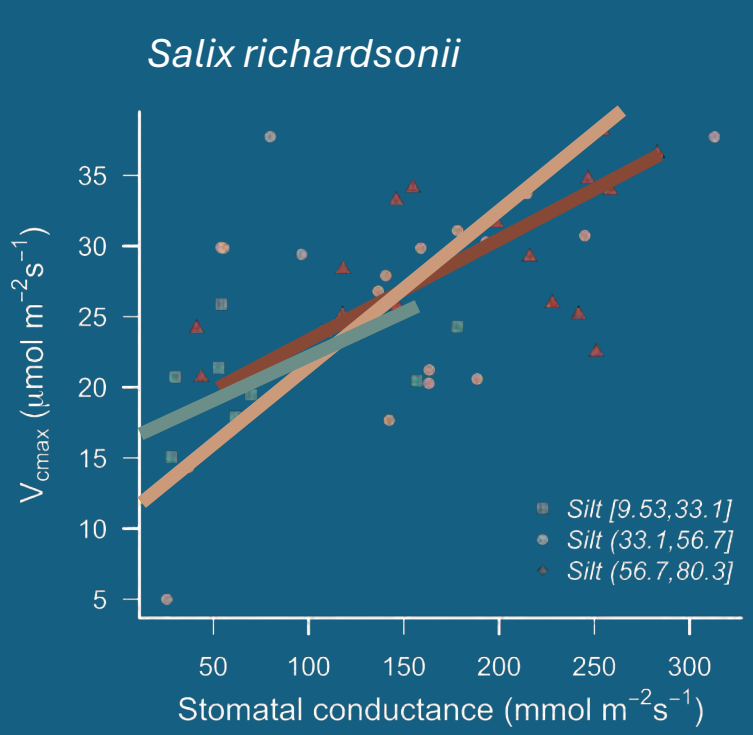
Paillassa, Maire et al
Submitted to NPH

ADAPTATION



ACCLIMATATION





- Between-species differences : Adaptation for *S. arctica*, Acclimation for *S. reticulata* and *S. richardsonii*
- Regarding *S. artica,*
  - At sites with high silt content, A_{sat} increases more rapidly with g_s than with Vc_{max}
  - Adaptation could be favoured by common sexual reproduction as observed in Greenland (microsatellite loci, Steltzer et al., 2008)
- Regarding *S. richardsonii,*
  - No adaptive pattern, despite the high capacity of seedling germination (Angers-Blondin et al., 2018).
  - At the northmost edge of its distribution, low adaptative ability are expected from the central-marginal & the spatial sorting theories (Pothier Guerra & de Lafontaine, 2024 ; Eckert et al., 2008).

Conclusion

- High A_{sat} value for Salix species (C input into soils)
- Two strategies for high Asat values (N & H_2O cycles)
- Framework to test adaptation vs acclimation to be further tested
- In comparison with other Salix species in Bylot, *S. richardsonii* has:
  - No higher photosynthetic capacity,
  - H_2O photosynthetic strategy
  - Higher leaf area development capacity,
  - Low photosynthetic adaptive ability at its northernmost distribution edge

What's next?

Florence Gagné
MSc

From individual to population

Merci à chacun !
Et aux nombreux facilitateurs de la recherche !