Carbon dynamics and soil microbial functioning in high arctic shrub communities: a comparative study of *Dryas octopetala* and *Salix Polaris*

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Introduction

The Arctic is warming at an accelerated rate, driving intense environmental shifts and widespread vegetation changes known as Arctic greening (Reichle et al., 2018).
The Svalbard Archipelago is currently experiencing some of the strongest temperature rises globally. Warming is a primary driver of the expansion of woody dwarf shrubs (Karlsen et al., 2024; Van der Wal & Stien, 2014).
This ongoing "shrubification" fundamentally reshapes tundra structure, altering energy balances and plant-soil interactions in terms of carbon (C) and nitrogen (N) cycling. Simultaneously, Arctic soils are undergoing profound transformations, shifting from a system dominated by stable soil organic C toward the system with faster turnover rates. Because vegetation regulates local microenvironments and nutrient supply, expanding shrubs strongly dictate soil microbial activity and overall ecosystem C fluxes (such as GPP and R_{eco}).
However, while shrub communities are expanding, their species-specific physiological strategies - and how they distinctly control the High Arctic C balance - remain still poorly studied.

Aims

This study evaluates the ecophysiological performance and changes in C balance of two dominant dwarf shrub communities (*Dryas octopetala* L. and *Salix polaris* Wahlenb.) in Ny-Ålesund, Svalbard Islands from 2021 to 2024.
Using an integrated multi-proxy approach - combining gas fluxes, elemental composition and stable isotopes in both plants and soil, alongside leaf reflectance and litter decomposition experiments - we quantified how distinct species-specific traits modulate High Arctic shrub community functioning and plant-soil interactions under rapid climate change.

Methods

Fieldwork was conducted during the peak growing season (July 2021–2024) in Ny-Ålesund, Svalbard, across 18 plots representing *Dryas octopetala*, *Salix polaris* and bare soil. Ecosystem CO_2 fluxes (Net Ecosystem Productivity, Ecosystem Respiration and Gross Primary Production, respectively NEP, R_{eco} and GPP) were measured using portable IRGAs (EGM-5, PP system), partitioned into plant and soil components, and normalized by green vegetation area. Flux responses were analyzed alongside continuous environmental drivers under distinct "full sun" (PAR ≥ 800 µmol m^{-2} s^{-1}) and "cloud" (PAR < 800 µmol m^{-2} s^{-1}) conditions. To assess plant ecophysiological strategies, field-based leaf spectral reflectance (NDVI, MCARI, PRI and Greeness) was combined with elemental (%C, %N) and stable isotope ($\delta^{13}C$, $\delta^{15}N$) analyses of plant and soil samples, enabling the estimation of intrinsic water-use efficiency (iWUE). Finally, soil microbial functioning was evaluated through a two-year in situ litter decomposition experiment, tracking the mass loss, decay rates (*k*), and C/N isotopic shifts of two chemically contrasting local substrates (LL – labile litter - vs. RL - recalcitrant litter).

Take-home messages

- **Divergent ecological strategies**: Dryas and Salix adopt contrasting life strategies to thrive in the High Arctic tundra. Dryas relies on high interannual plasticity and strict nutrient conservation to maximize C assimilation, whereas Salix maintains stable water-use efficiency and conservative temporal dynamics.
- **Decoupling of form and function**: declining optical indices like NDVI and MCARI does not necessarily imply a loss of productivity. Dryas maintained a superior C sink capacity despite a weakening optical signal, demonstrating that physiological efficiency can override canopy appearance.
- **Acclimation to climate change:** the ability of Dryas to adjust its water-use traits and maximize C fluxes under changing environmental conditions (e.g., full sun vs. cloud) suggests a strong capacity to acclimate to a warming Arctic environment.
- **Drivers of soil biogeochemistry:** while both shrubs act as ecosystem engineers by doubling soil C and N compared to bare soil, they establish microbial communities efficient in decomposition of recalcitrant organic matter, with possible long-term consequences for soil C stability.

Results and discussions

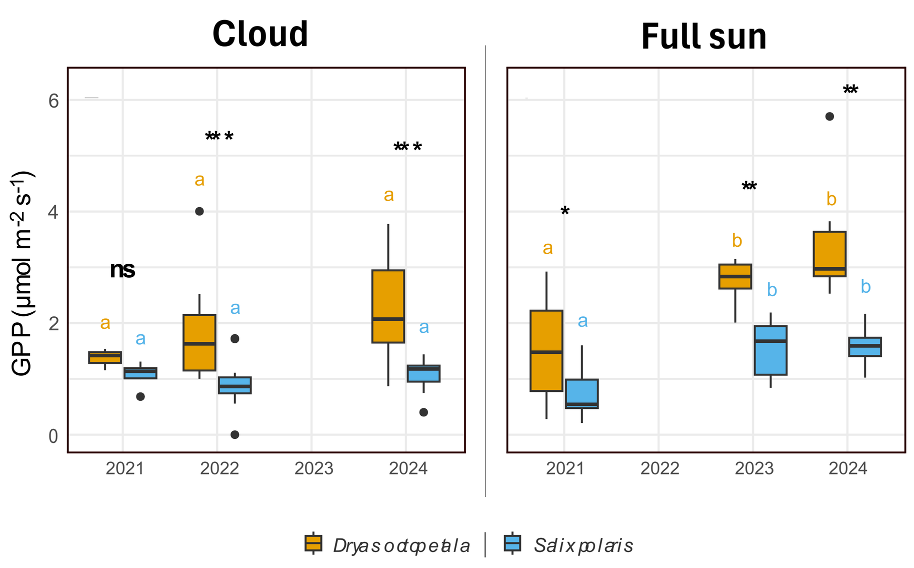

Fig. 1 – Boxplots display variability of GPP between Dryas and Salix across years

Carbon fluxes

- Dryas acted as a significantly stronger C sink compared to Salix, due to substantially higher GPP **[Fig. 1]**. This is related to its larger green area, significantly higher than Salix. Normalized GPP was higher in Dryas across years and light regimes, reflecting canopy/leaf-level efficiency beyond green-area effect.
- Dryas exhibited high interannual plasticity, maximizing fluxes in recent years under full sun conditions and suggesting acclimatation to changing environmental conditions, whereas Salix maintained a more conservative dynamic.

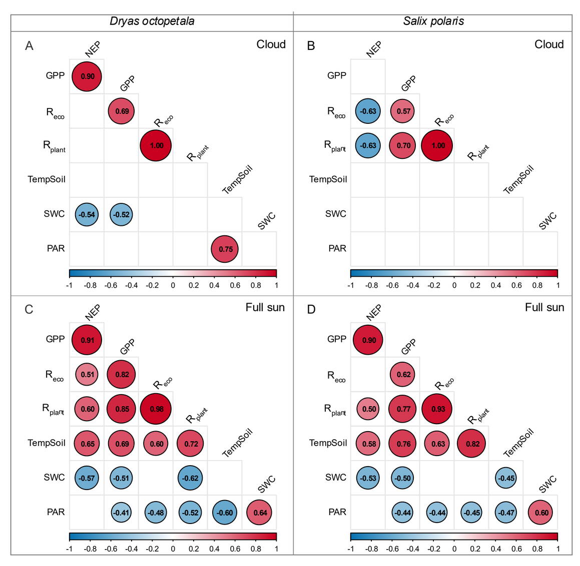

Fig. 2 – Pearson correlation heatmaps of C fluxes and environmental drivers for Dryas and Salix

Physiological plasticity

- Light conditions strongly modulated environmental controls **[Fig. 2]**. Under full sun conditions, soil temperature significantly stimulated ecosystem metabolism, while high SWC limited carbon assimilation. Under cloud conditions, C fluxes largely decoupled from physical drivers, confirming a general radiative limitation.
- Isotopic analyses of $\delta^{13}C$ indicated that Salix consistently operates with a higher iWUE and maintains lower intercellular CO_2 concentrations (ci/ca) **[Fig.3]**.
- Salix exhibited higher NDVI and PRI values. Both species showed a decline in canopy greenness by 2024, including a reduction in the MCARI chlorophyll index for Dryas.
- Despite the reduction in canopy optical indices, Dryas maintained higher C assimilation rates, indicating that physiological efficiency can decouple from optical proxies linked to canopy structure and pigment content.
- Salix showed stable water-use traits but fluctuating nutrient levels over time. In contrast, Dryas maintained highly stable elemental composition alongside temporal adjustments in water use. Both species showed overlapping $\delta^{15}N$ signatures, suggesting use of similar N sources.

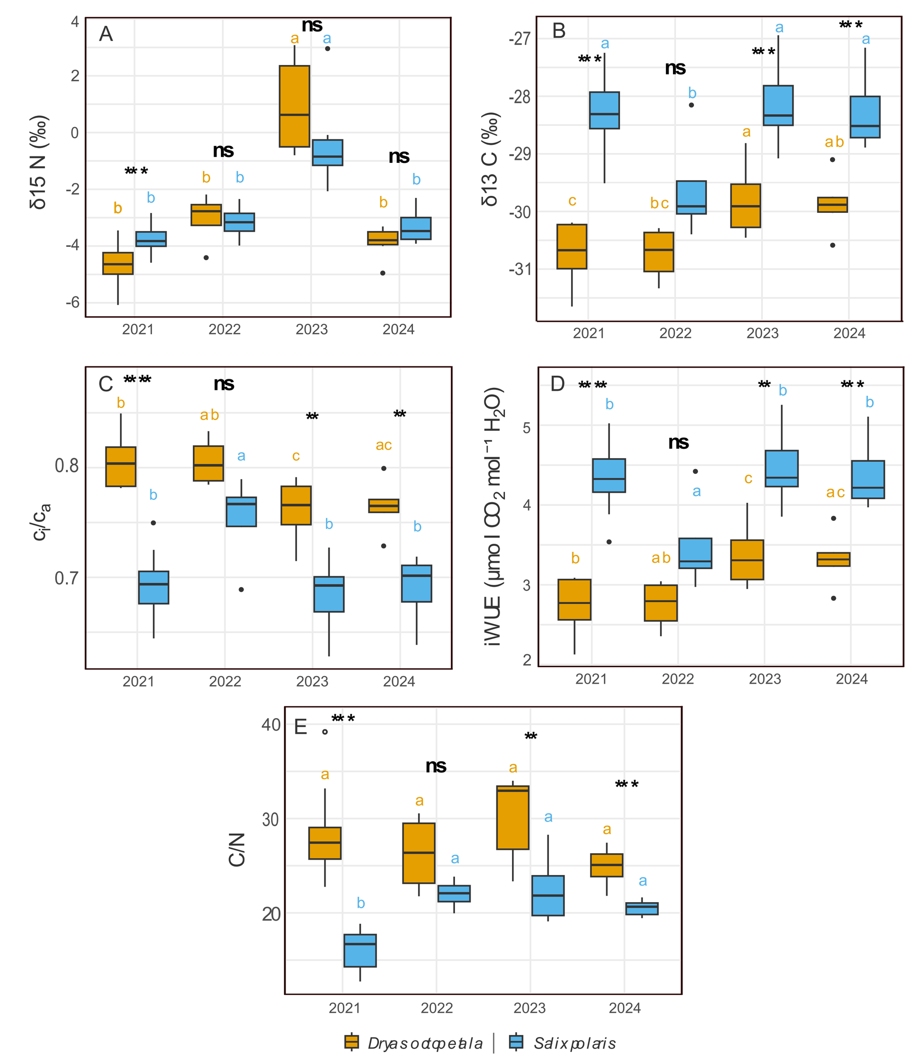

Fig. 3 – Boxplots display variability of $\delta^{13}C$ (A), $\delta^{15}N$ (B), ci/ca (C), iWUE (D) and C/N ratio (E) between Dryas and Salix

Litter decomposition

- Recalcitrant litter differed from labile litter primary in the concentration of lignin.
- Field litter incubation confirmed that recalcitrant litter decays at a significantly slower rate compared to labile litter, promoting its long-term C stabilization in the active layer
- Microbial communities in planted soil decomposed more efficiently RL and LL in respect to bare soil **[Fig. 4]**.
- Both Dryas and Salix communities successfully engineer their local microenvironment, doubling soil organic C and total N concentrations compared to adjacent bare soil.

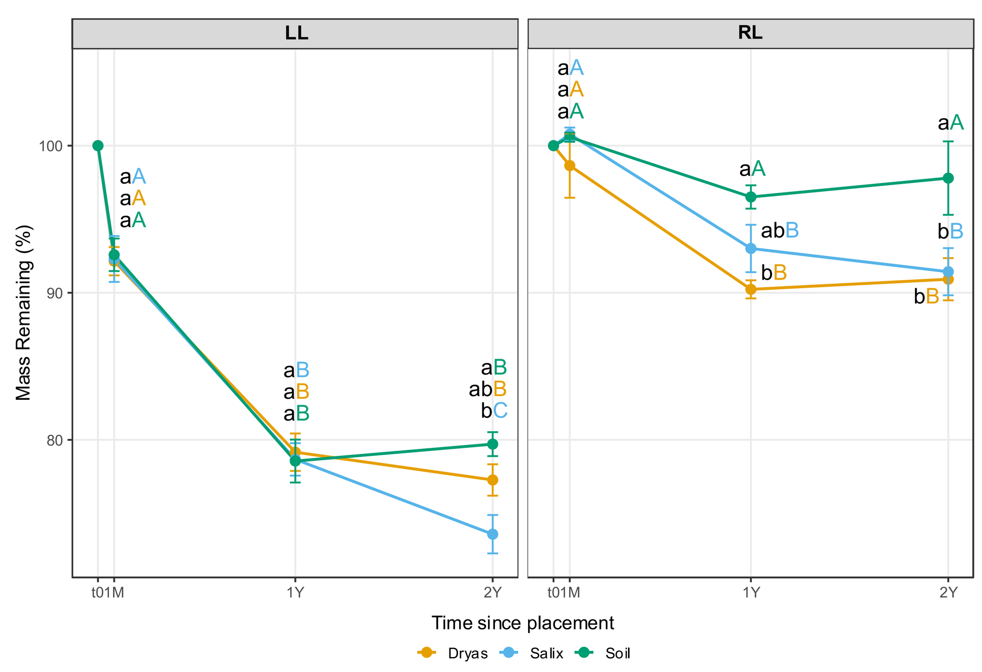

Fig. 4 – Remaining mass of LL and RL litter in Dryas, Salix and Soil plots in two years of incubation

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