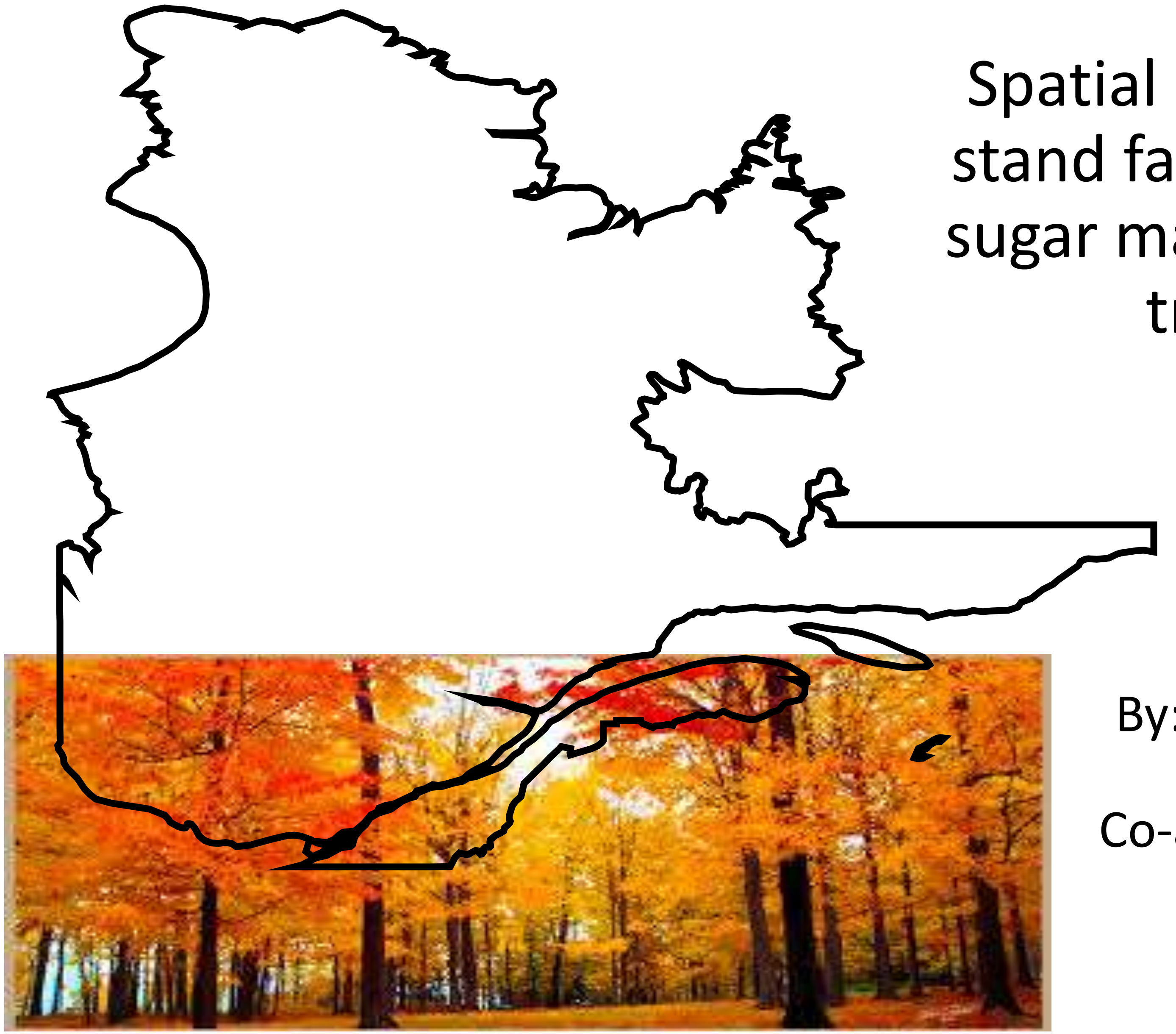

Spatial heterogeneity of climate and stand factors modulate the growth of sugar maple (*Acer saccharum* Marsh.) trees in eastern Canada

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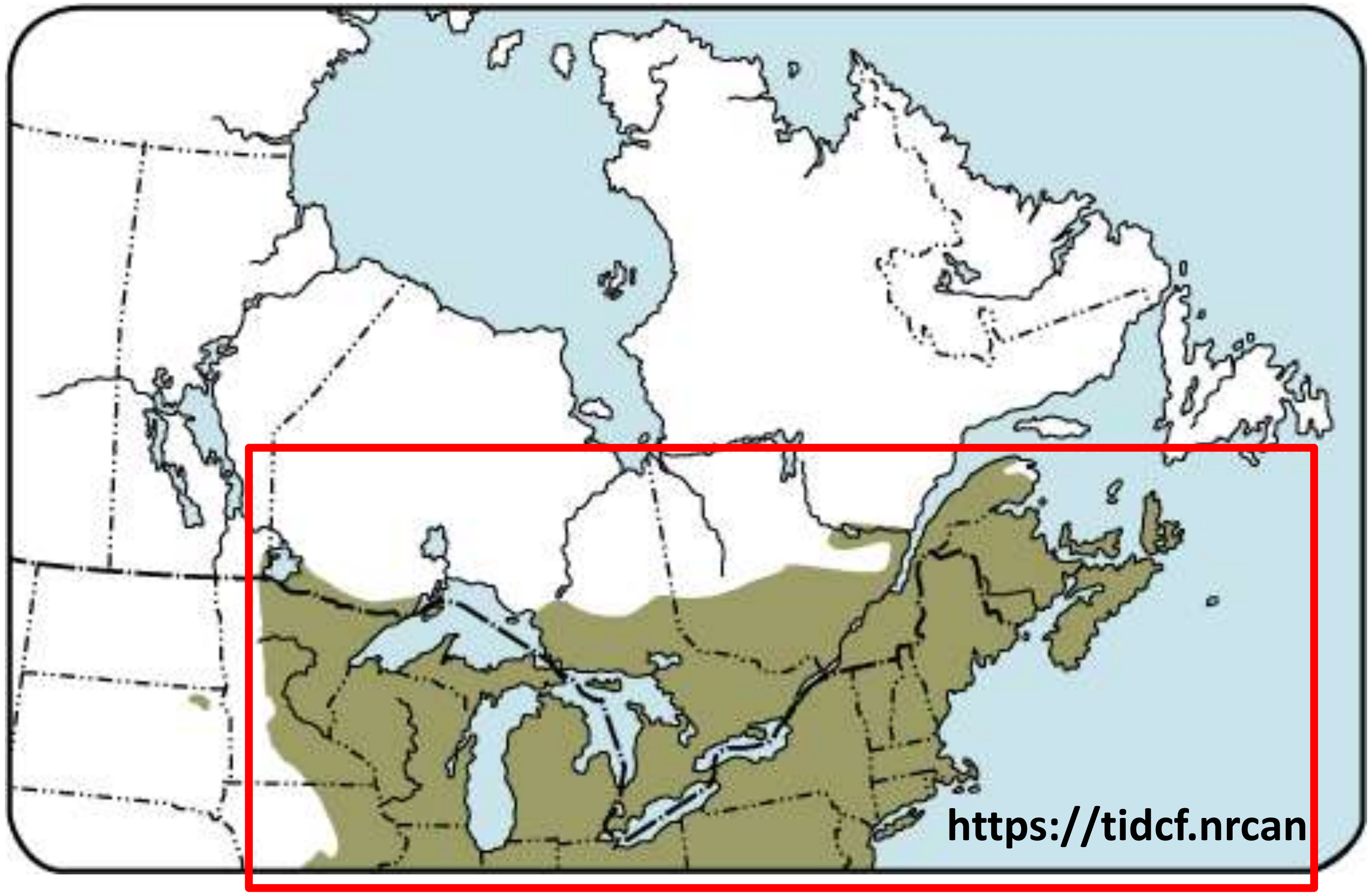
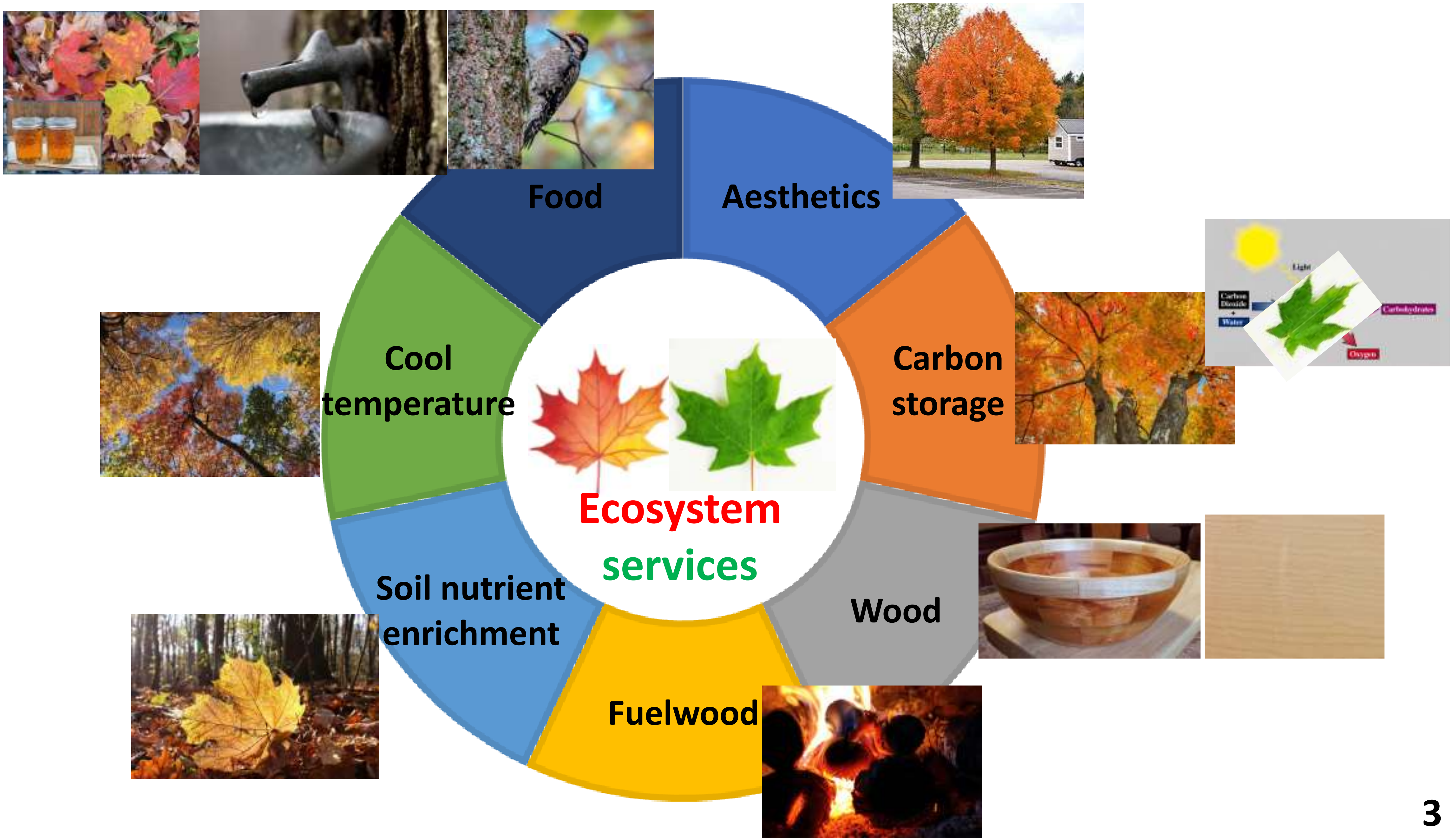
Sugar maple (*Acer saccharum* Marsh.) is native to the hardwood forests of eastern Canada and the eastern United States.

It is a late succession deciduous tree species with unique and diverse ecosystem services (Copenheaver et al., 2020).

North America Distribution Map of Sugar Maple

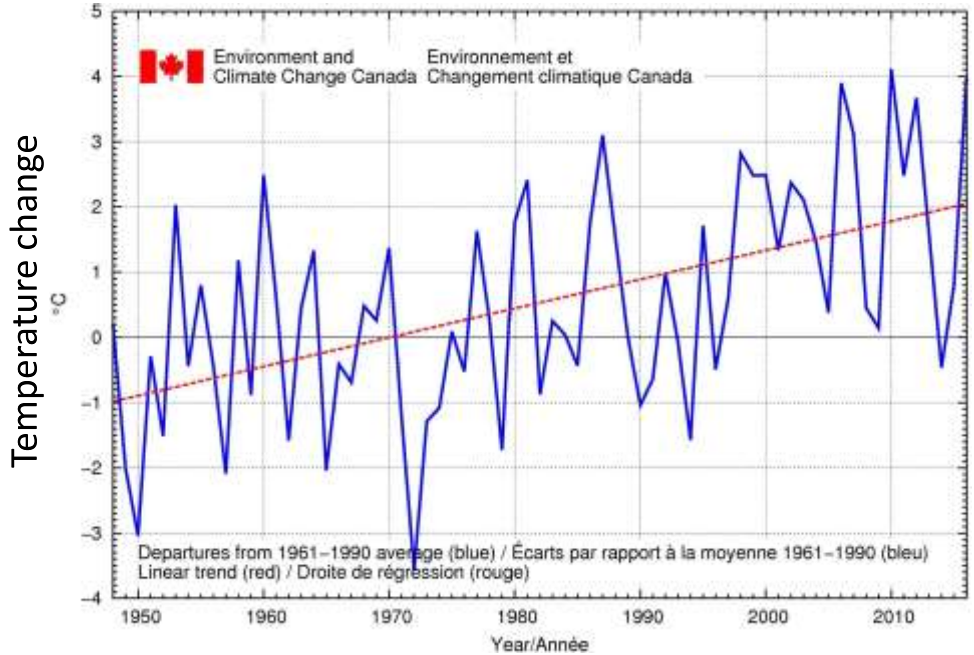



Food
Aesthetics
Cool temperature
Carbon storage
Ecosystem services
Soil nutrient enrichment
Wood
Fuelwood

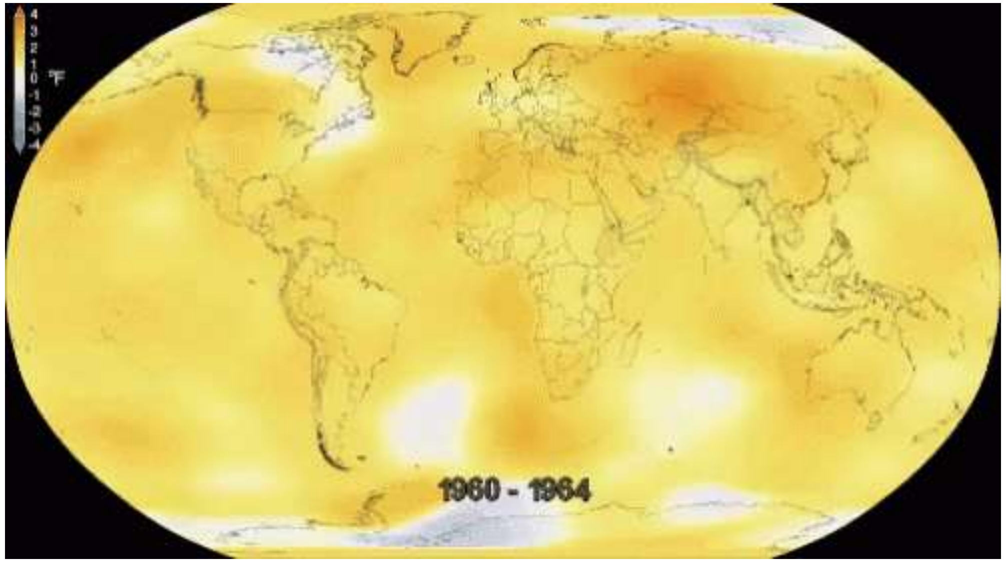
Tree growth in cool temperate forests is generally limited by low temperatures.

However, rapid temperature rises and changes in precipitation have raised concerns about the species' ability to thrive and provide ecosystem services in the future.

- *E.g., cold season warming has shortened the sugaring season, reduced the concentration of sucrose in maple sap, and promoted the spread of pests, which is impacting the maple syrup industry (Moreau et al., 2019; Rapp et al., 2019).*



Global temperature changes



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Historical growth assessment

- ❑ Mix of decrease, increase and no changes in tree growth+**established and assumed causes.**

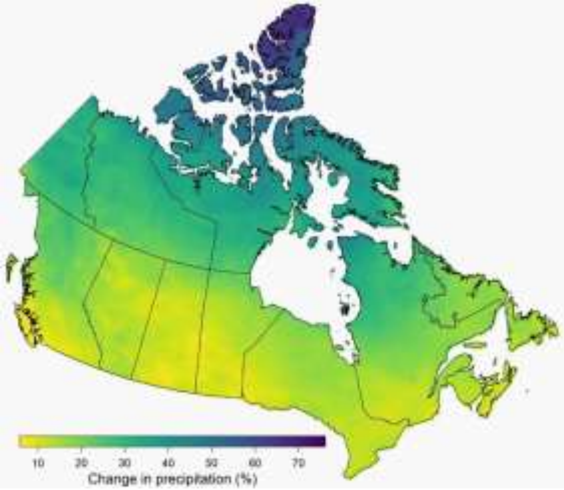
→ **Growth decline**

Soil acidification, freezing temperatures, drought and insect defoliation.

Duchesne et al. 2002; Sullivan et al. 2013; Bishop et al., 2015; Bal et al., 2018

→ **Growth increase**

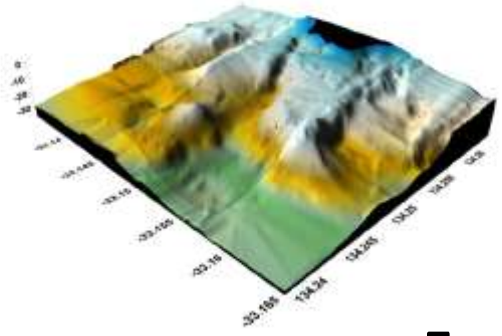
Increase precipitation/soil moisture availability and warmer temperature – longer growing season – mediated by topographic and stand factors.



→ **No growth changes**

Period of low growth is compensated by periods of high growth.

Kosiba et al., 2017; Copenheaver et al., 2020; Wang & Ibáñez, 2022.



It is important to know how sugar maple trees have responded to the changes that have taken place in their environment in order to forecast the response of the forests to climate change.

Information is lacking on the impacts of local climate and site conditions on the growth of sugar maple trees in eastern Canada.

The study sought to ascertain how environmental differences in growing conditions influence the growth of sugar maple trees in eastern Canada.

Hypothesis

H1 – Changes in the environment favored an increase in the growth of sugar maple trees.

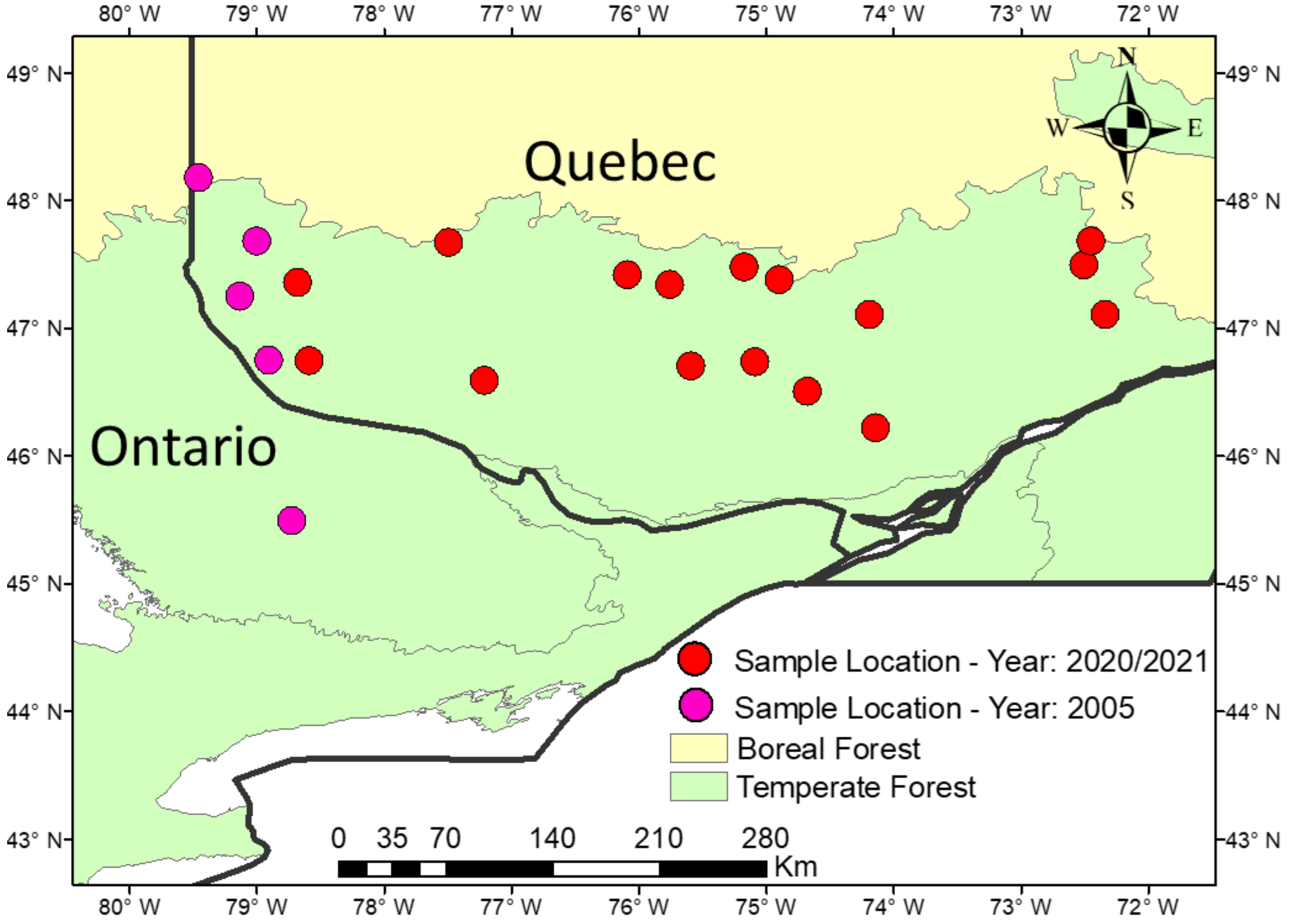
H2 – Average growth of sugar maple trees is modulated by local climate and stand conditions (e.g. terrain slope, altitude and competition).

Study area

Samples collected in 21 random sites

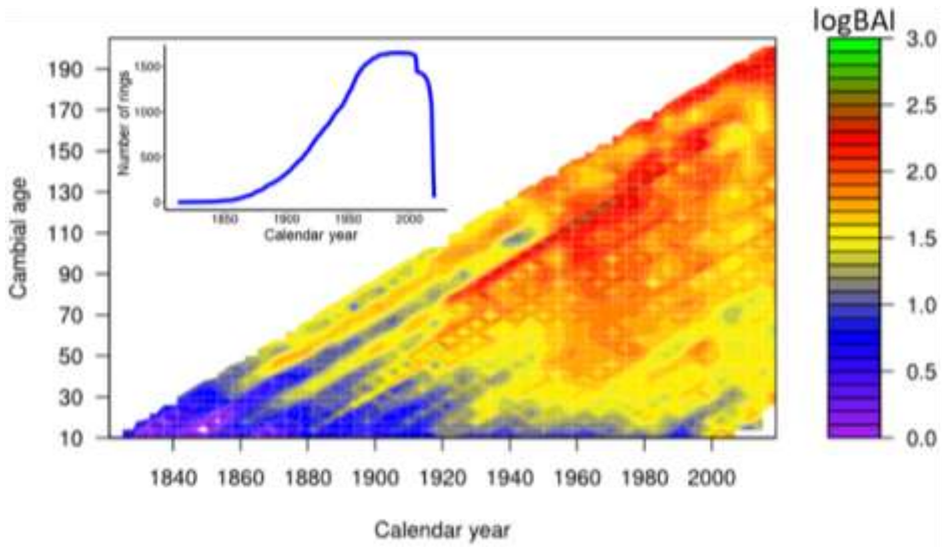
Data

- Increment cores (1,675 trees)
- Tree composition
- Altitude (m)
- Terrain slope (%)



Study area map

Analytical approach



Tree ontogeny & site variables

- Tree age (years)
- Tree basal area, BA (cm^2)
- Competition index (m^2ha^{-1})
- Terrain slope (%)
- Altitude (m)
- Joint (Latitude, Longitude)

+

Long-term averages of local seasonal climate variables *(summer, winter, autumn, spring)*

- Maximum temperature (Tmax)
- Minimum temperature (Tmin)
- Number of frost days (FrostDay)
- Vapour-pressure deficit (VPD)

Concurvity

Tmin.AUT, VPD.SUM, FrostDay.SPR

Multi-model comparisons, AICc

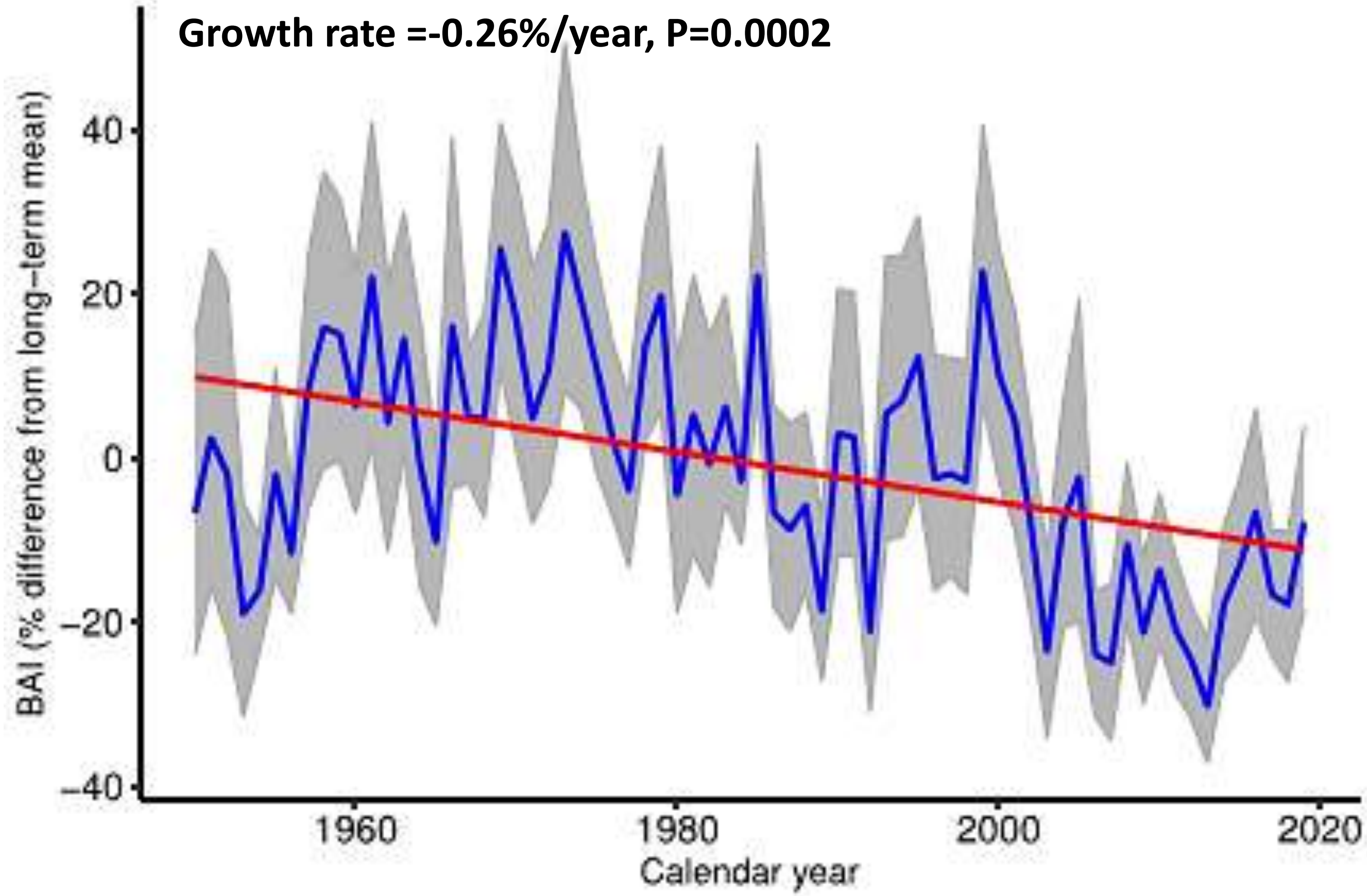
Non-linear mixed model (GAMM)

((Observed–Predicted)/Predicted) %
Growth changes (%/year)

Spatial variability

Inverse distance weighted interpolation

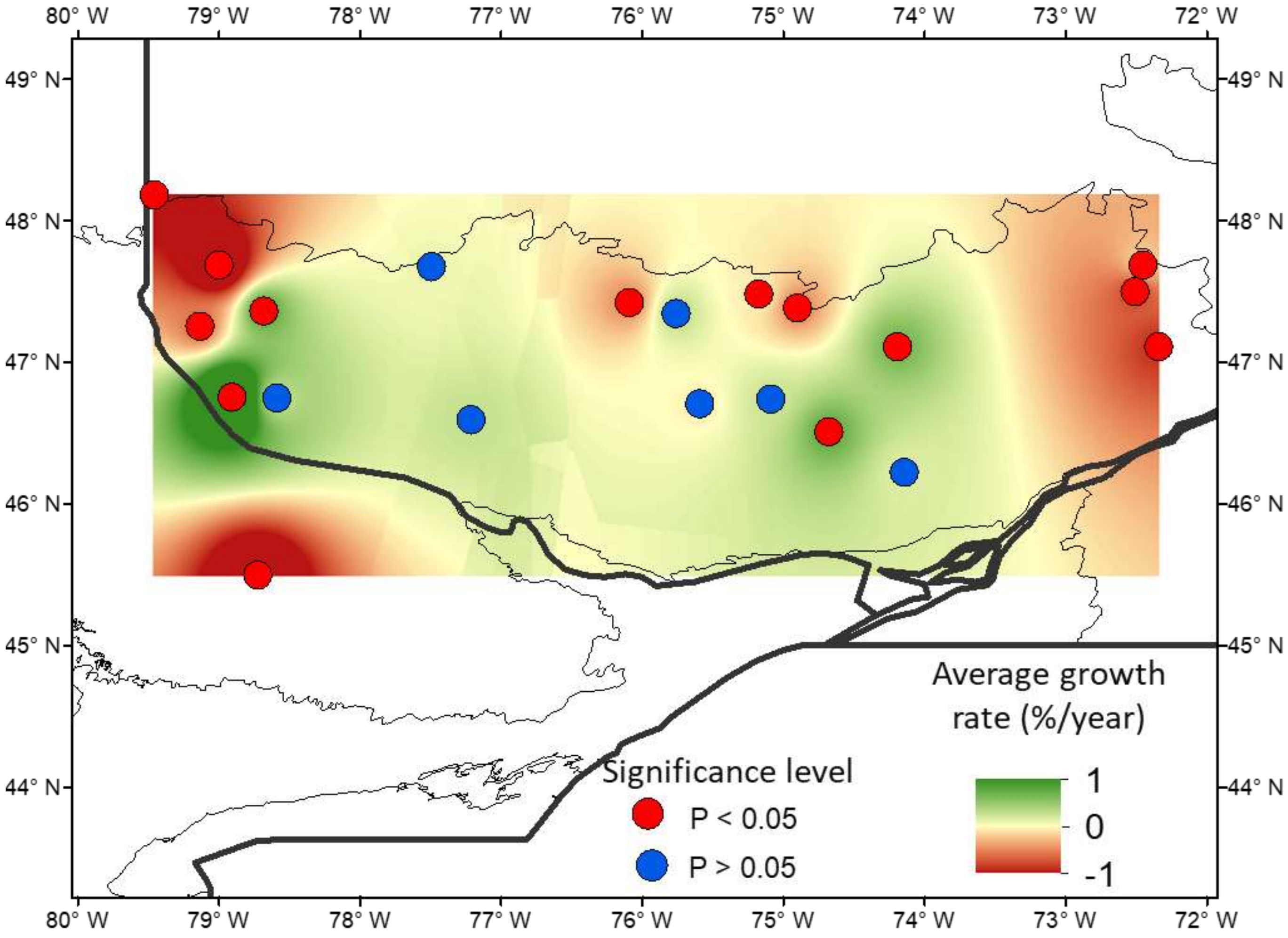
Changes in average tree growth



The basal growth of sugar maple declined over time, although it fluctuated widely between 1950 and 2020.

The growth decline was not uniform across the study area, indicating that local and regional growth rates can differ.

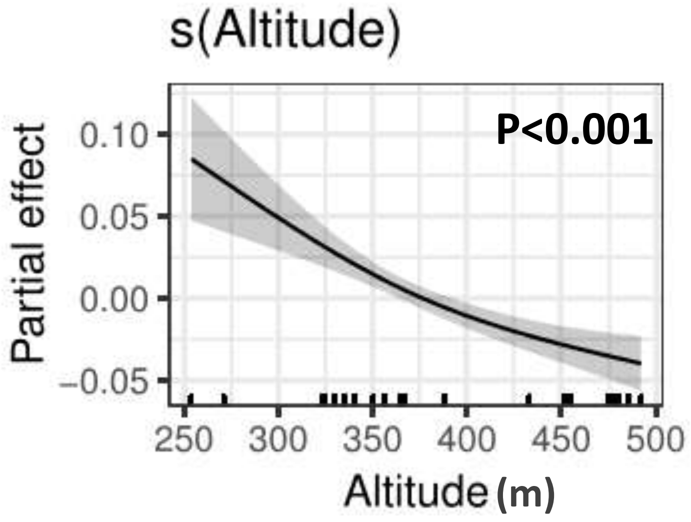
- Local growth responses (+/-) differs from the broad (average) geographic growth variation to mean climate.

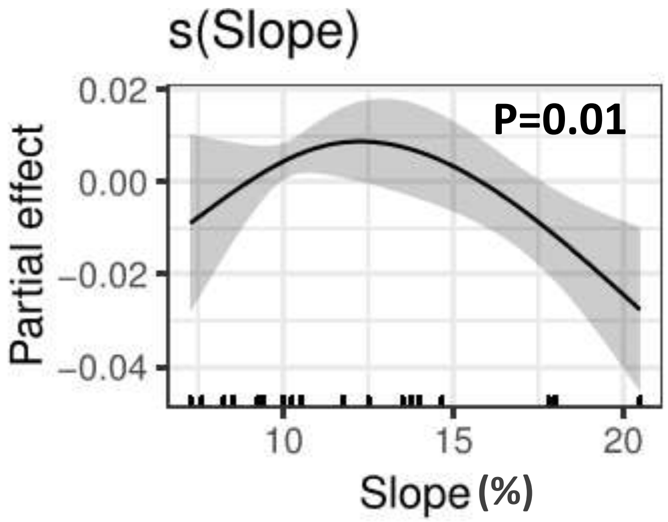


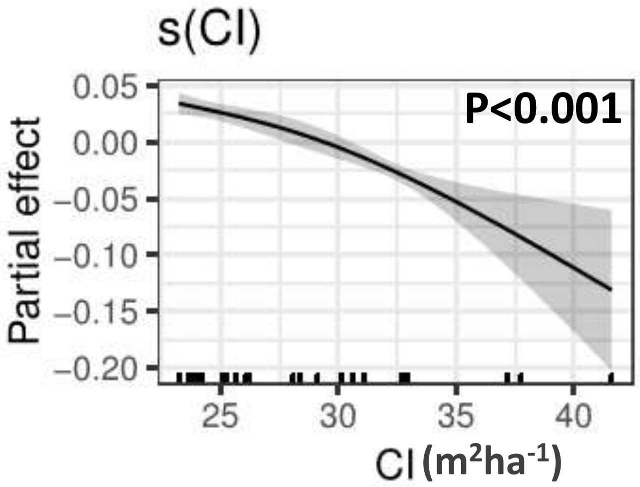
Correlation between growth rate and climatological means

Tmin.AUT	R=-0.10, P=0.72
VPD.SUM	**R=-0.53, P=0.01****
FrostDay.SPR	**R=-0.44, P=0.05***

Effects of topographic and stands variables on the growth of maple trees







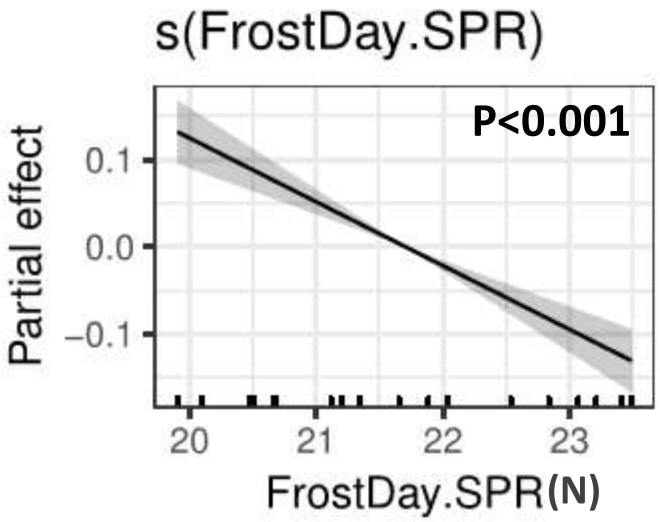
Basal area growth rate decreased with increased altitude probably due to thinner and more severely depleted soil nutrients, reduced air and soil temperatures and increased exposure to wind.

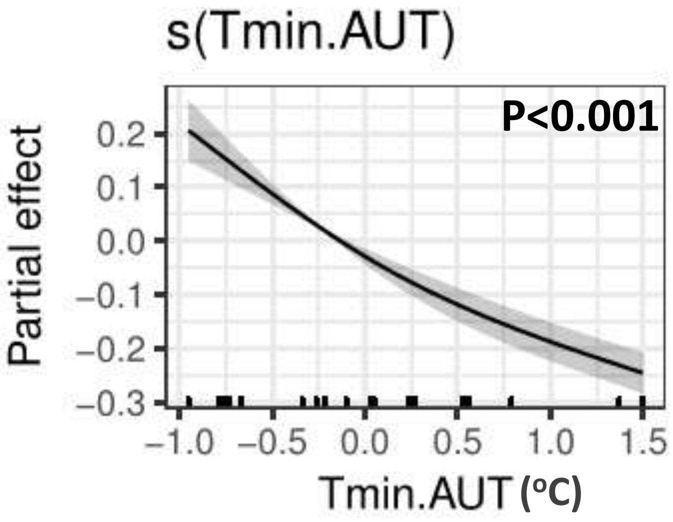
A slight increase in growth at slopes less than of 12% could be attributed to stable soil and root anchorage.

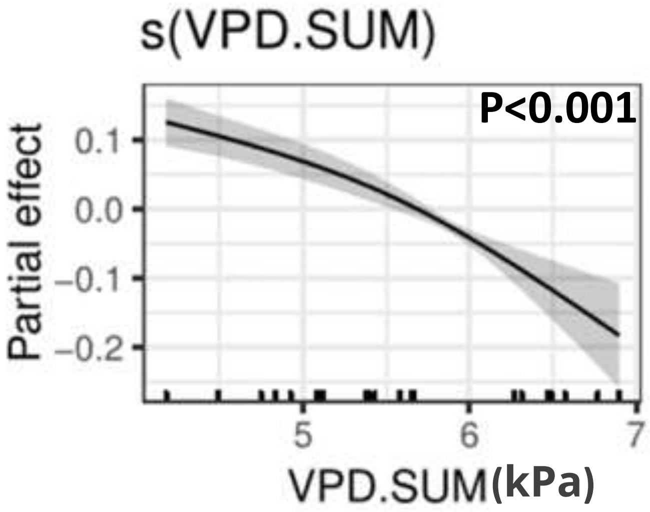
Basal area growth rate decreased with increased slope at slopes greater than ~12% probably due to soil instability, which is normally disturbed by running water, wind, and gravity.

Basal area growth rate decreased as competition increased maybe because the crowdedness of a tree's neighborhood reduced growing space, limiting access to light, water, and the physical space for roots and branches to expand.

Effects of local climate variables on the growth of maple trees







Increasing number of frost days
- increases duration of frigid temperatures cause damage to foliage and leaf buds.

- freezes the cells and tissues of the roots, preventing root pressure development and limiting water and nutrient uptake (Moreau et al., 2020)

Increased autumn minimum temperature decreased basal area growth rate because warmer autumn temperatures result in higher respiration rates and no increase in photosynthesis as the tree leaves had already fallen (Girardin et al., 2016)

Basal growth rate decreased with increased vapor pressure deficit due to decreased stomatal conductance leading to decreased photosynthesis.

- The location of the trees in the environment will compensate for the significant reduction in sugar maple growth.

- Low altitudes, gentle slopes, and less crowded stands, can mitigate sugar maple growth decline.
  - *Sugar maple stands can be thinned to reduce competition for water and light, promote larger canopy growth for photosynthesis, and increase tree stability.*

  - *Because extreme climate events such as cold snaps and droughts will become more common as climate change progresses, sugar maples will need to be gradually established in locations where temperatures are less frigid and moisture is readily available for growth.*

- In addition to climatic and tree/stand factors, the genetic makeup of individual trees controls the mechanisms of response to climate and utilization of environmental resources (Graignic et al., 2018). It is necessary to investigate the impact of this genetics on the growth response of sugar maple trees to climate change.

- As the climate continues to change, we hope to also gain a better understanding of sugar maple growth variability under different climate change scenarios.

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