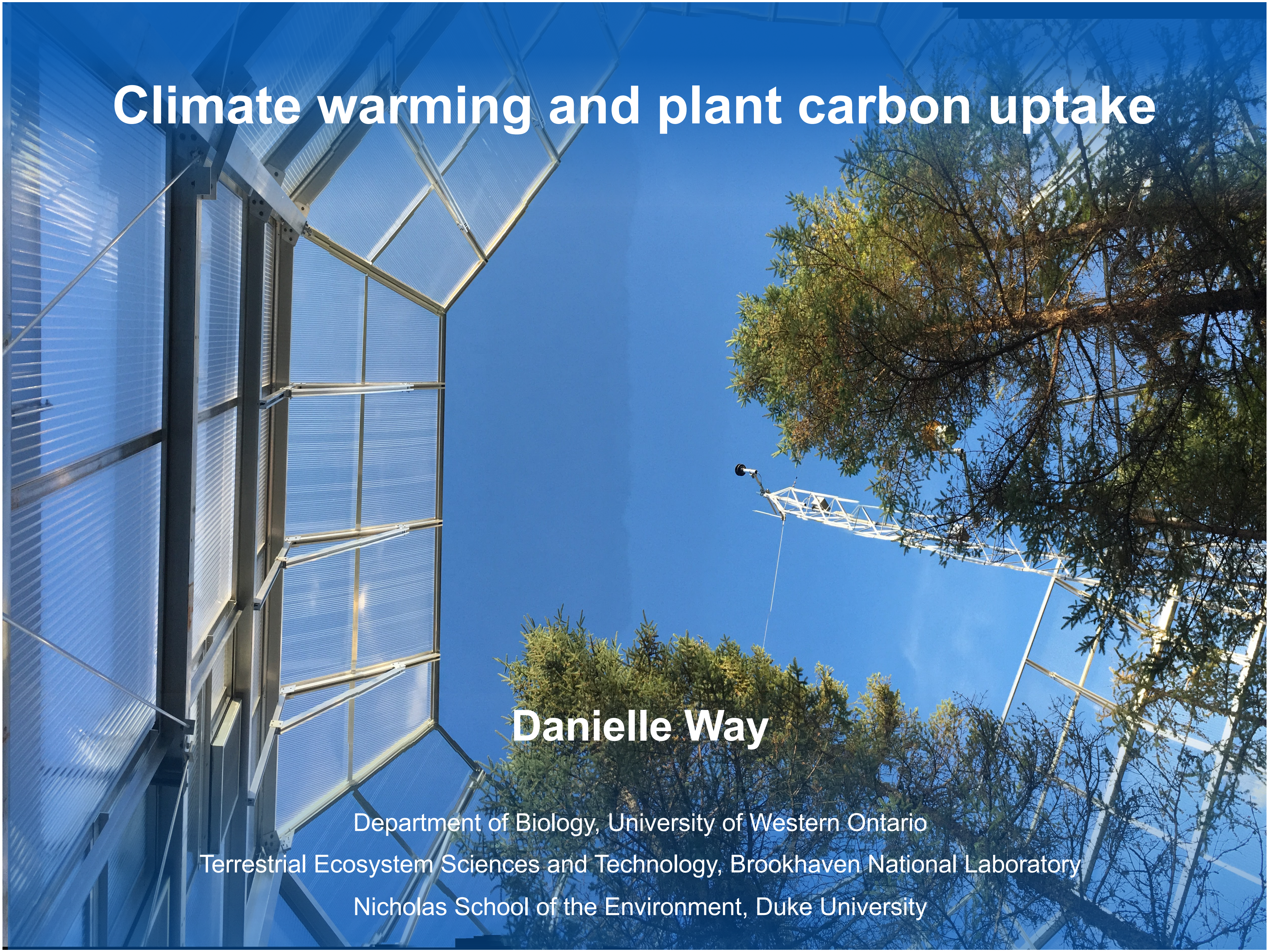


# Climate warming and plant carbon uptake

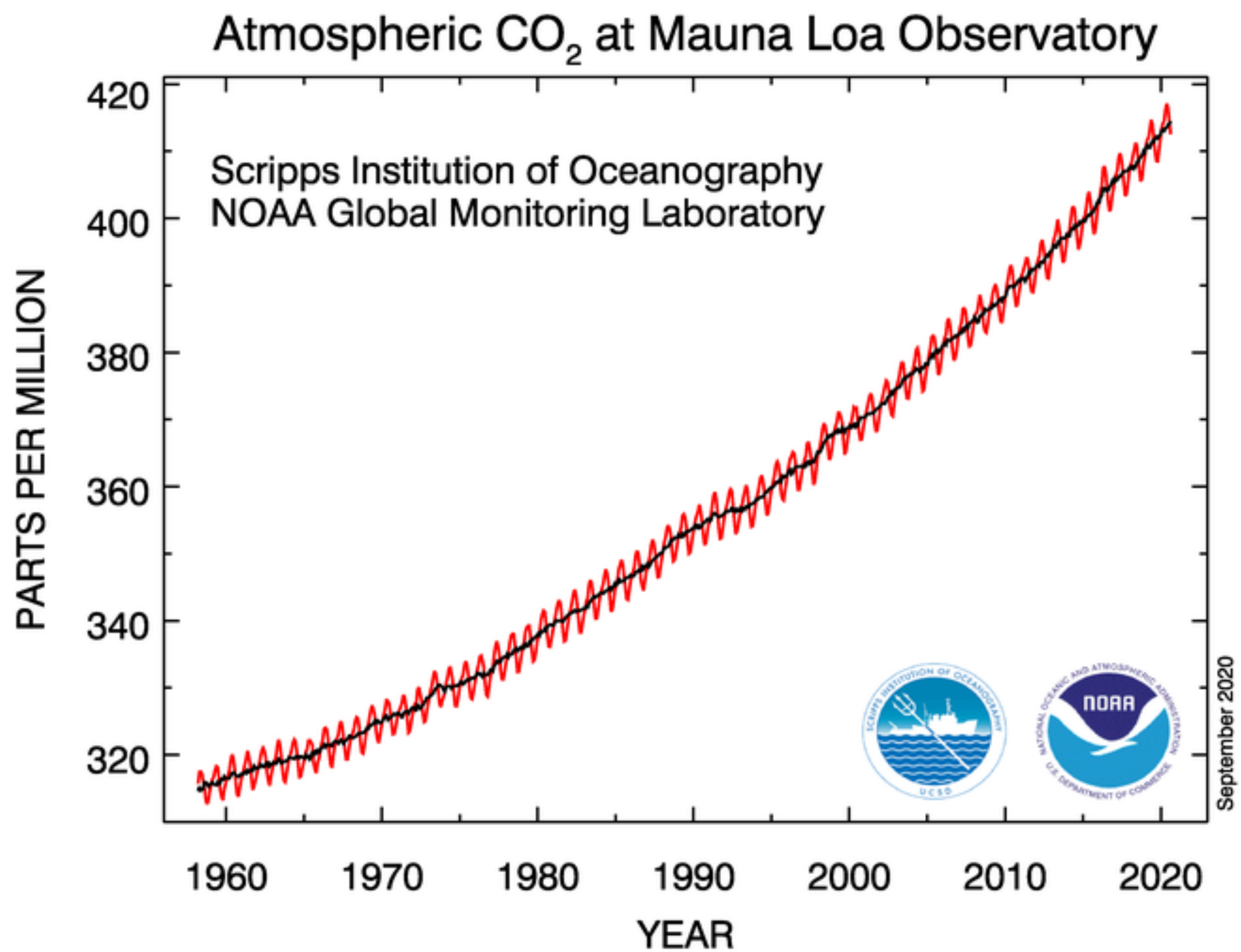
**Danielle Way**

Department of Biology, University of Western Ontario

Terrestrial Ecosystem Sciences and Technology, Brookhaven National Laboratory

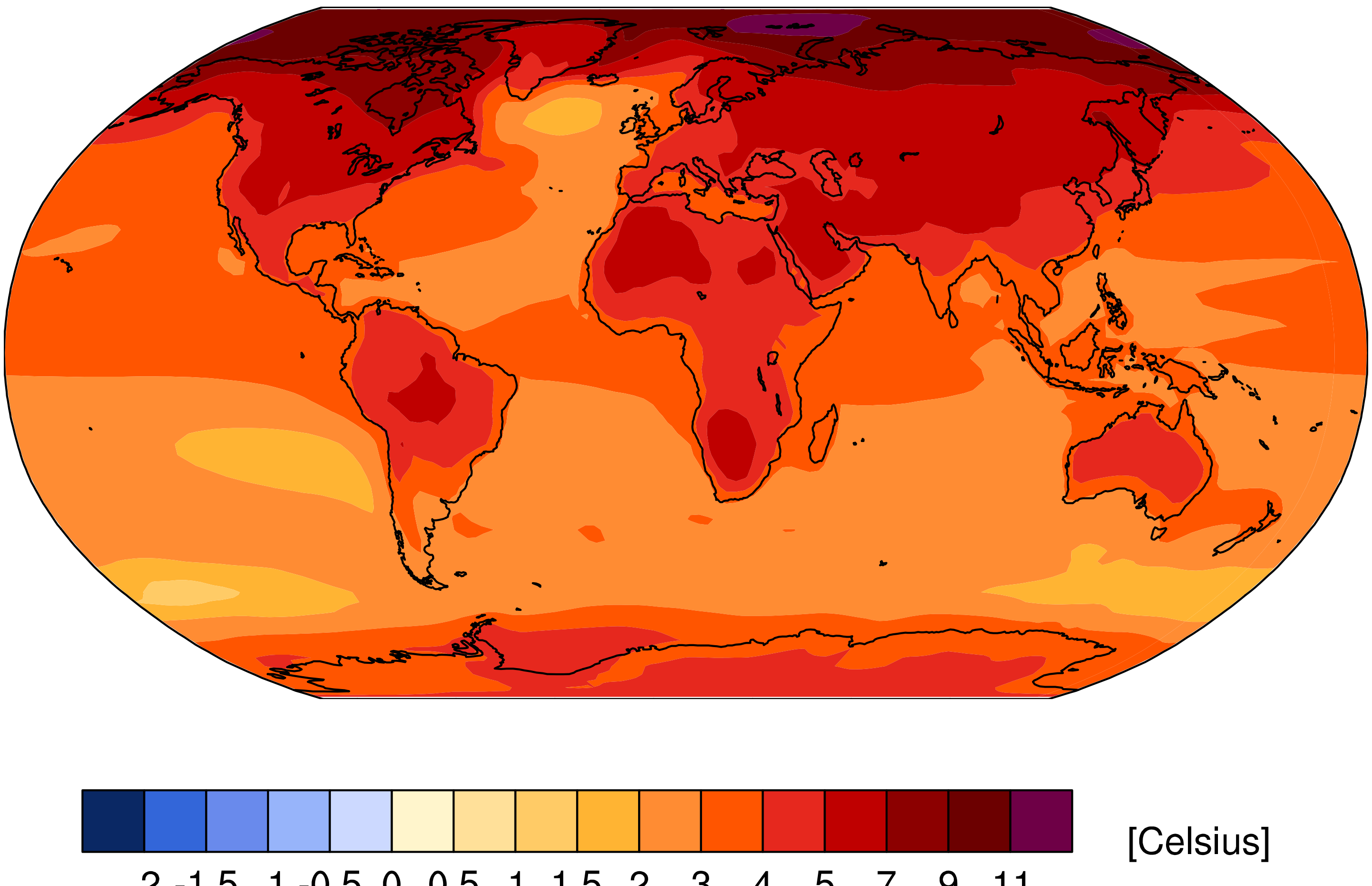
Nicholas School of the Environment, Duke University

# $CO_2$ has increased 50% since Industrial Revolution



# Temperatures have increased >0.8 ° C

Annual mean surface air temperature change

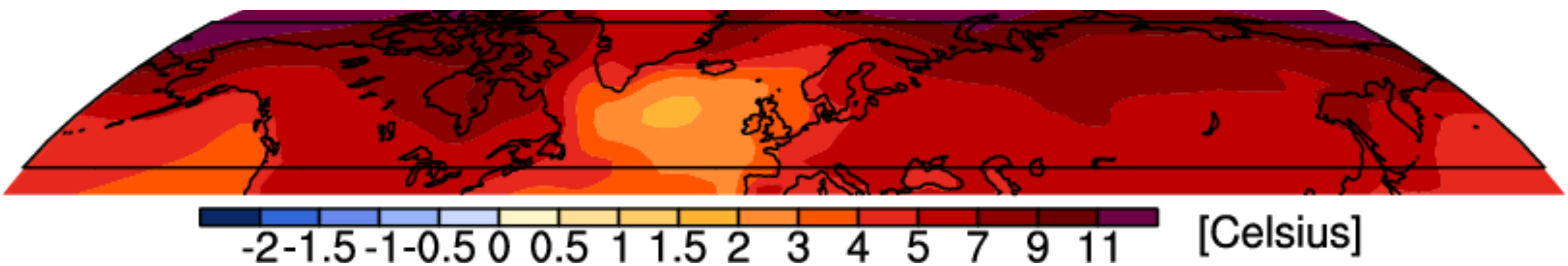



IPCC (2013)

# Models and climate change

- Predictions of future climates need to account for large C fluxes from vegetation
- These fluxes are dictated by physiological processes such as photosynthesis and respiration

Mean annual temperature change RCP 8.5 2081-2100




IPCC (2013)

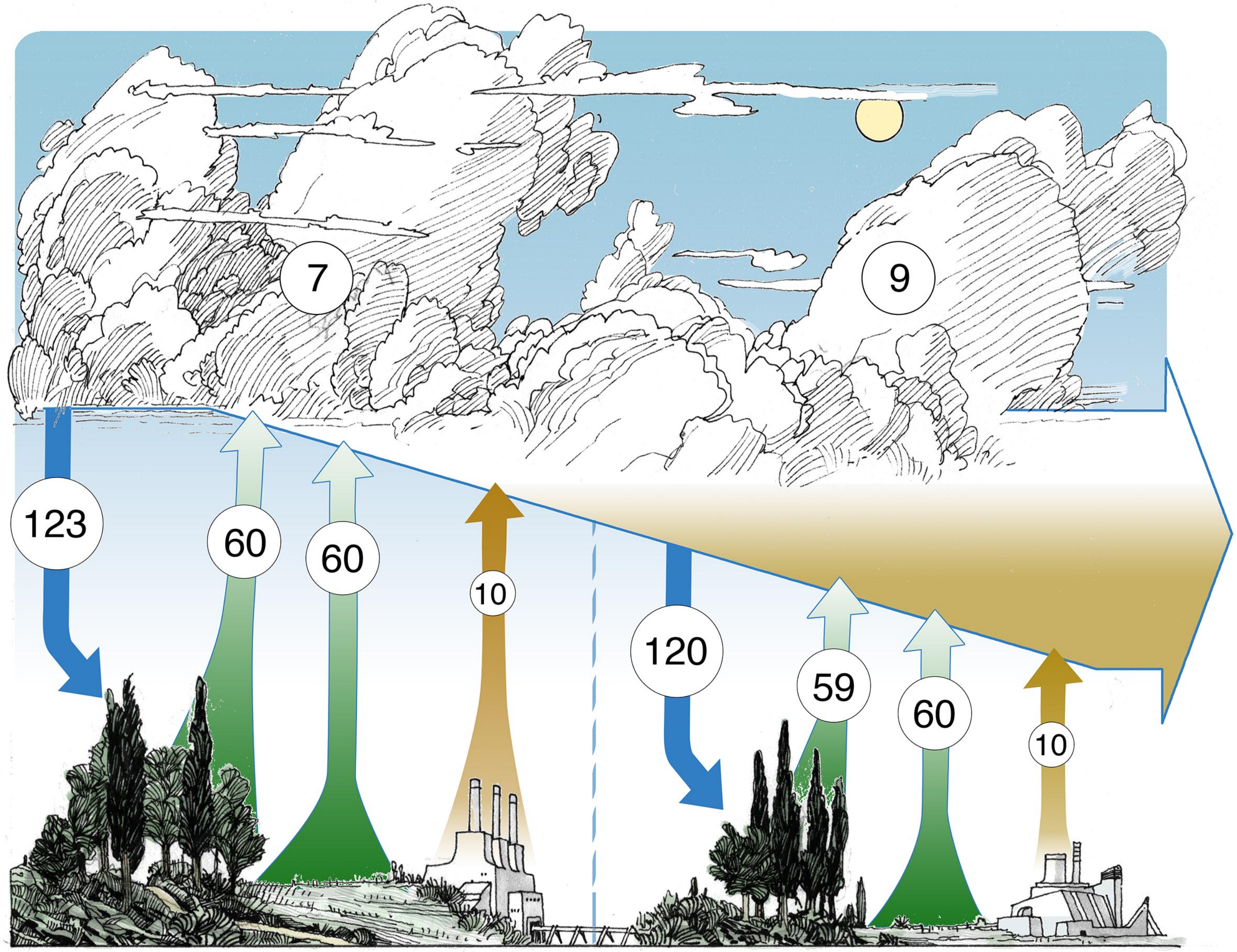
# Vegetation C fluxes are large

**Photosynthesis**
**~123 Gt C/year**

**Autotrophic respiration**
**~60 Gt C/yr**

**Heterotrophic respiration**
**~60 Gt C/yr**

# Plant C fluxes are affected by, and affect, climate

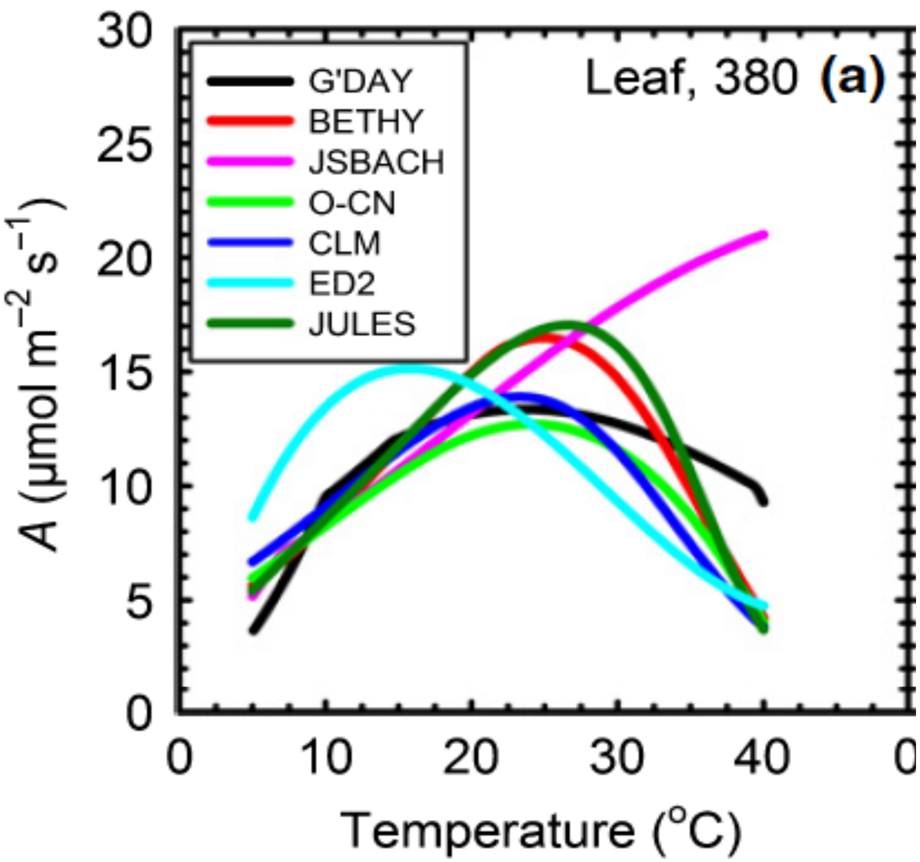



Gt C per year

Dusenge, Duarte and Way (2019) New Phytologist

# Uncertainty in how to model C fluxes

- IPCC models assume different photosynthetic responses to temperature




Rogers et al. (2017) New Phytologist

# Outline

- Patterns of temperature effects on photosynthesis
- Diversity of temperature effects on photosynthesis
- Where do we go from here?

# Outline

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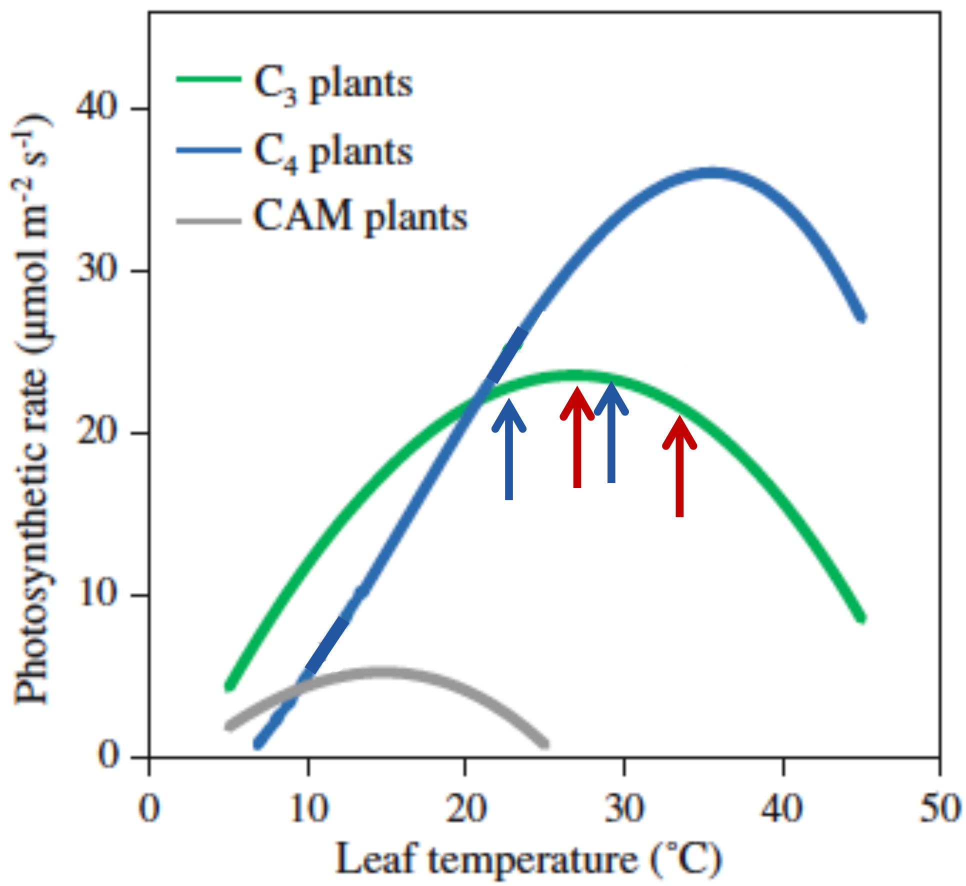
# Photosynthesis is temperature-dependent

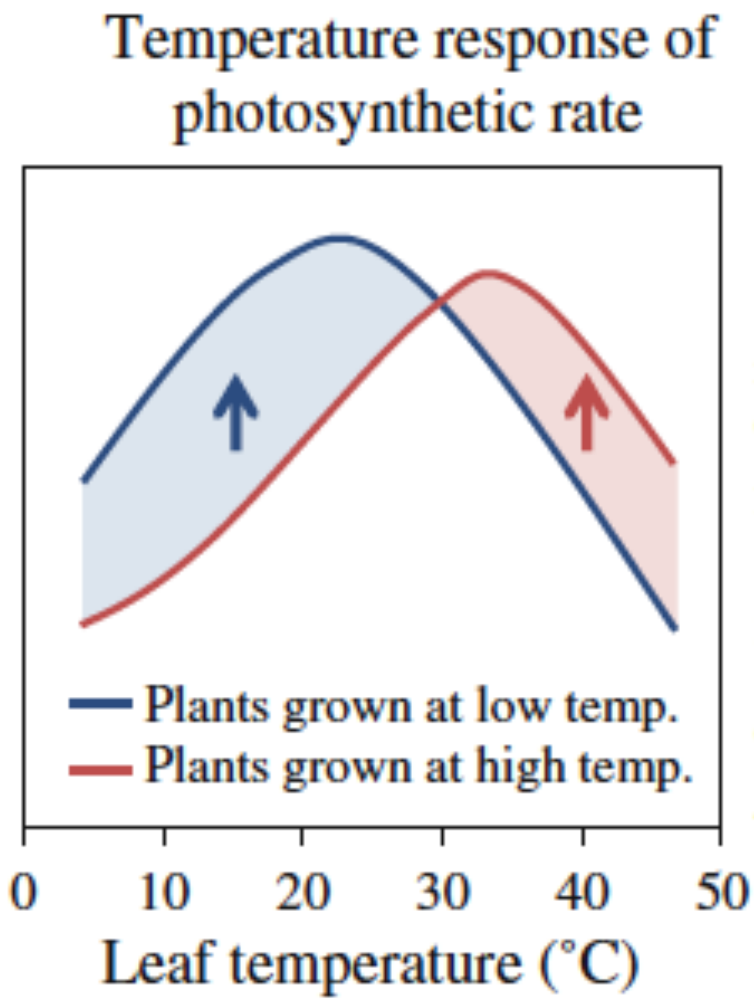
- Photosynthesis increases to a thermal optimum as enzyme efficiency increases, then decreases at higher temperatures

- Direct effect of warming depends on where you start...



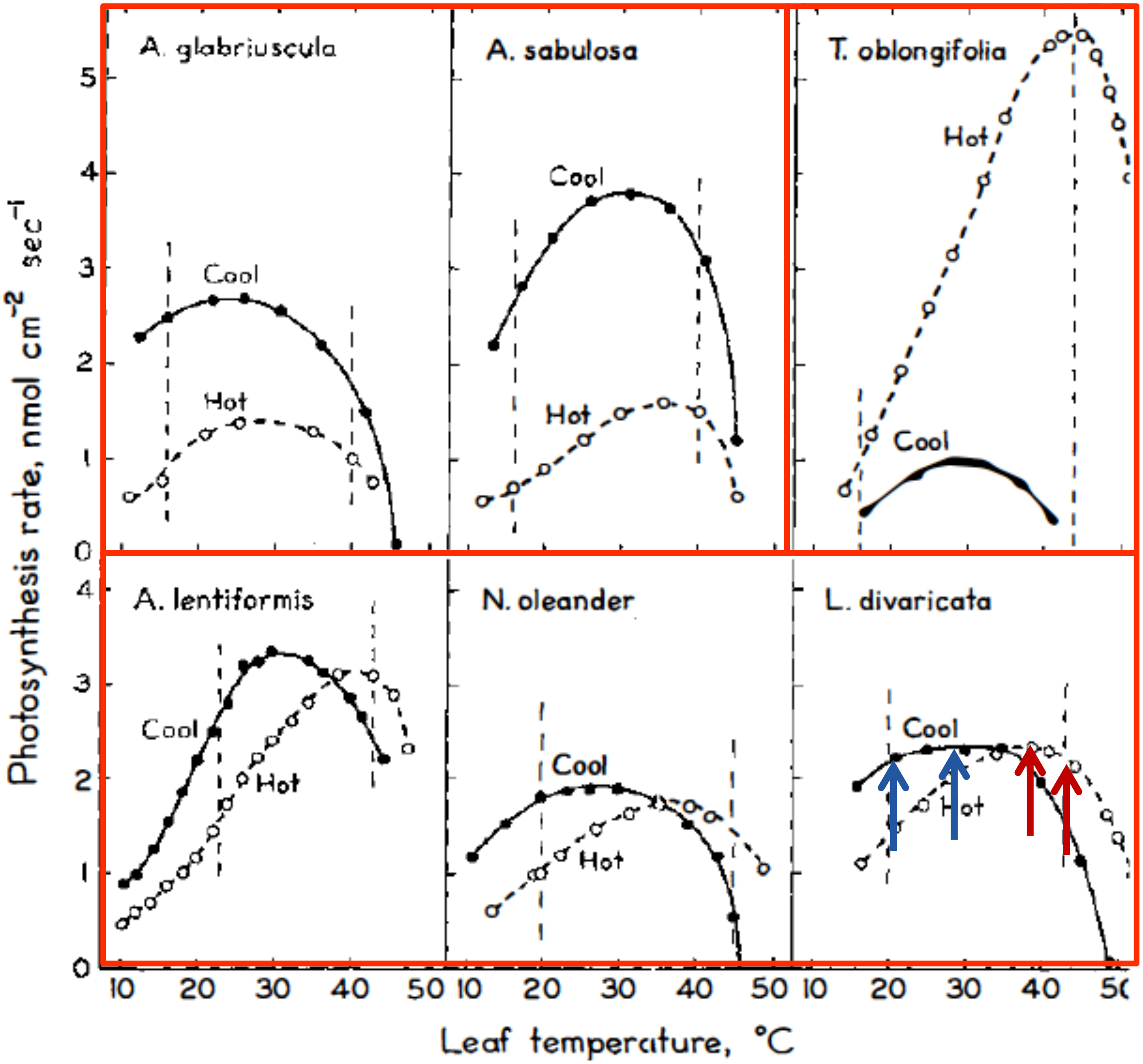

Yamori, Hikosaka and Way (2014) Photosynthesis Research

# Photosynthesis acclimates to warming




Yamori, Hikosaka and Way (2014) Photosynthesis Research

# Photosynthesis acclimates to warming




$A_{growth}$

$T_{opt}$

Berry and Björkman (1980) Annual Review of Plant Physiology

# Photosynthesis acclimates to warming

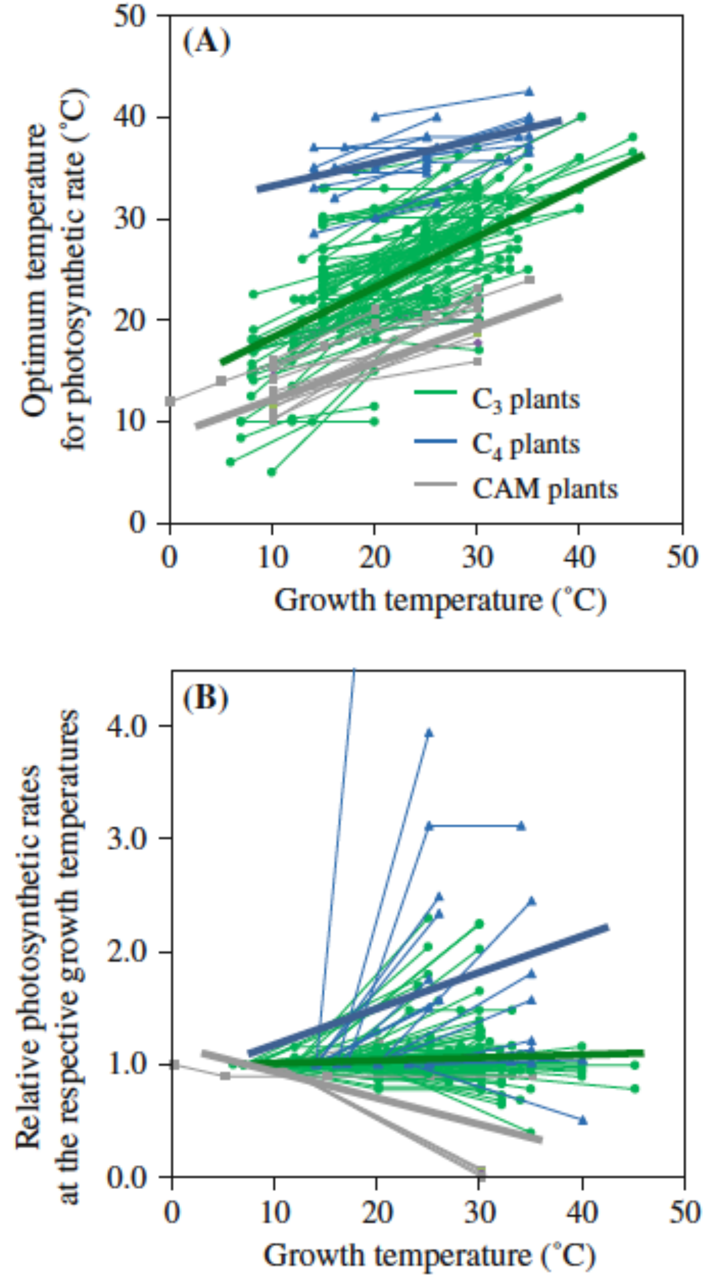
- Across 130 species, most maintain photosynthetic rate at the new growth temperature ($A_{growth}$)
- Most species increase the thermal optimum of photosynthesis ($T_{opt}$)
- Only about half do both

| | $A_{growth}$ | $T_{opt}$ | $A_{constructive}$ |
|---|---|---|---|
| All | 68 % (115/169) | 72 % (163/227) | 51 % (76/150) |
| C3 herb | 68 % (70/103) | 75 % (78/104) | 53 % (51/97) |
| C4 | 94 % (17/18) | 47 % (9/19) | 50 % (9/18) |
| Deciduous tree | 92 % (12/13) | 95 % (21/22) | 86 % (6/7) |
| Evergreen tree | 46 % (16/35) | 67 % (55/82) | 36 % (10/28) |

Way and Yamori (2014) Photosynthesis Research

# Photosynthesis acclimates to warming

- Increasing growth temperature increases the photosynthetic thermal optimum
- But thermal acclimation doesn't always improve net $CO_2$ assimilation rates




Yamori, Hikosaka and Way (2014) Photosynthesis Research

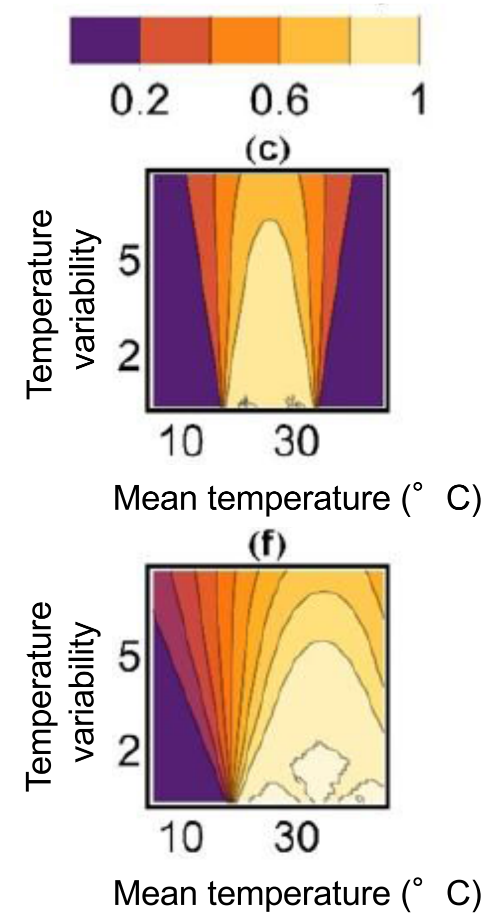
# Thermal acclimation improves C gain

- Acclimated plants are more likely to operate near their maximum photosynthetic rates

Photosynthesis>0.8*Max. photosynthesis

Non-acclimated

Acclimated



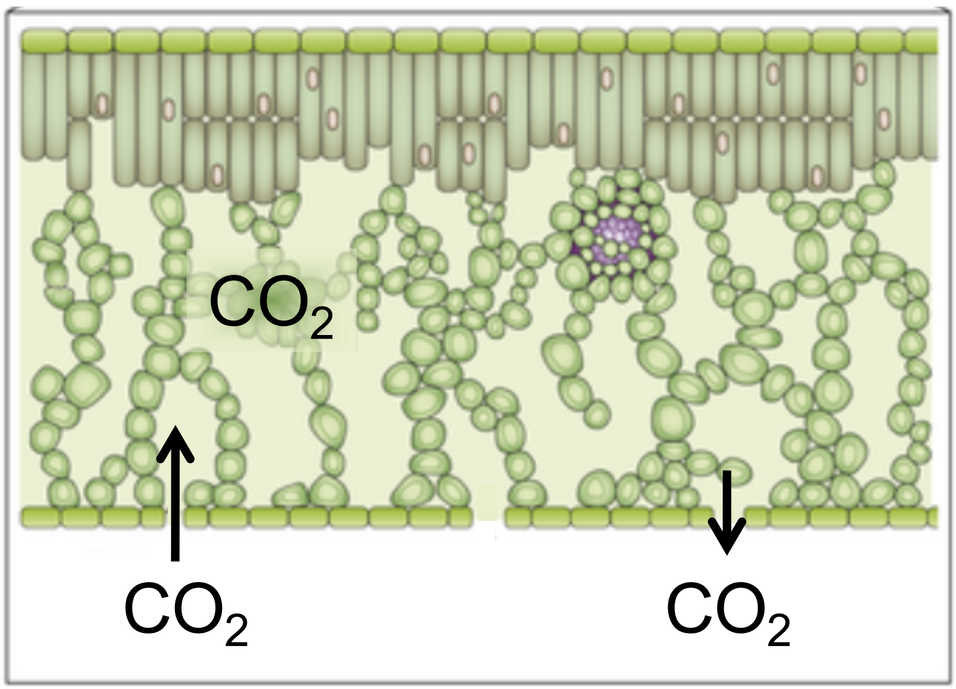

Vico et al. (2019) Plant, Cell & Environment

# So thermal acclimation is good...

...but how does it happen?

# How does photosynthesis thermally acclimate?

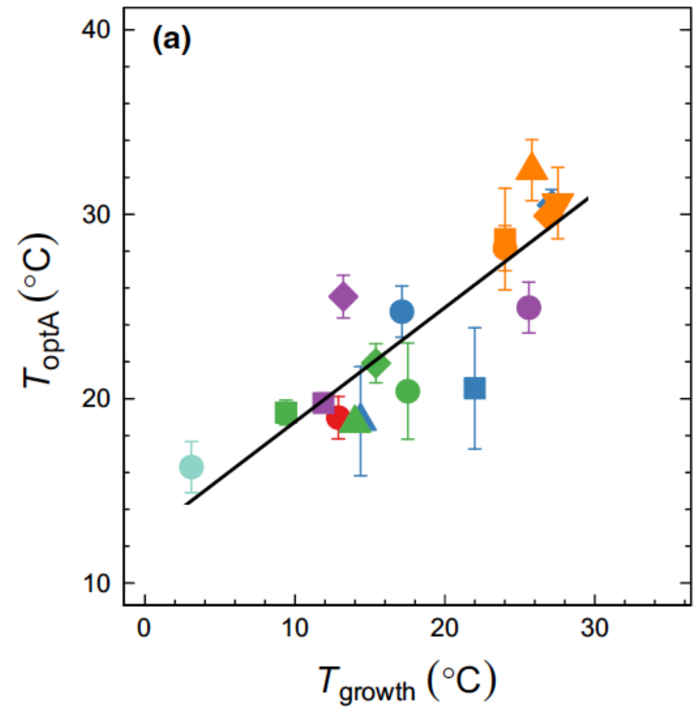
- Changes in net photosynthesis are underlain by changes in stomatal conductance, photosynthetic capacity and respiration




Way (2019) Nature Ecology and Evolution

# Biochemical demand drives thermal acclimation

- 141 $C_3$ species from around the globe
- Compared impact of stomatal conductance, photosynthetic capacity and respiration on the thermal optimum of photosynthesis

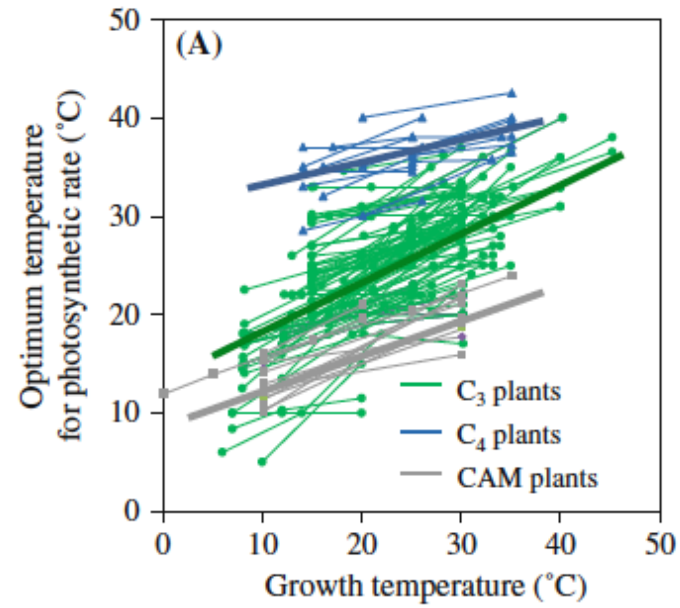



Kumarathunge et al. (2019) New Phytologist

# Biochemical demand drives thermal acclimation

- Variation in the photosynthetic thermal optimum was largely explained by acclimation of $V_{cmax}$

- Mainly due to acclimation of the thermal sensitivity of $V_{cmax}$




Kumarathunge et al. (2019) New Phytologist

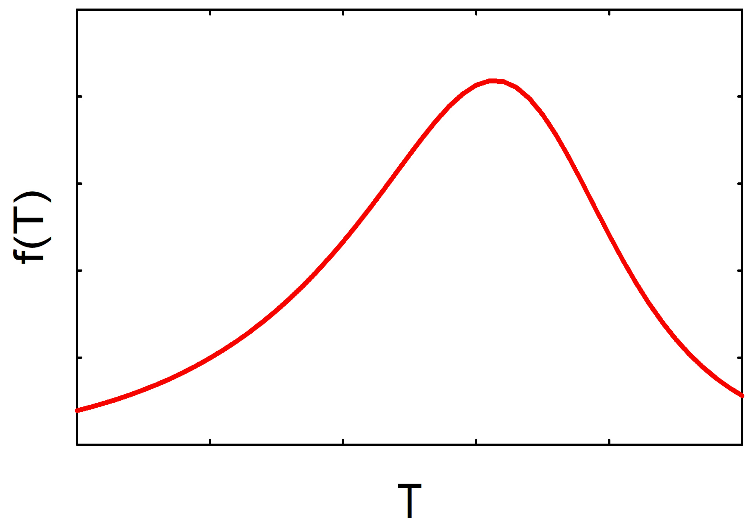
# The modified Arrhenius equation

- Temperature sensitivity of $V_{cmax}$ is modeled with a modified Arrhenius function

$$f(T) = k_{25} \exp\left[\frac{E_a(T-298)}{298RT}\right] \frac{1+exp\left(\frac{298\Delta S - H_d}{298R}\right)}{1+exp\left(\frac{T\Delta S - H_d}{TR}\right)}$$

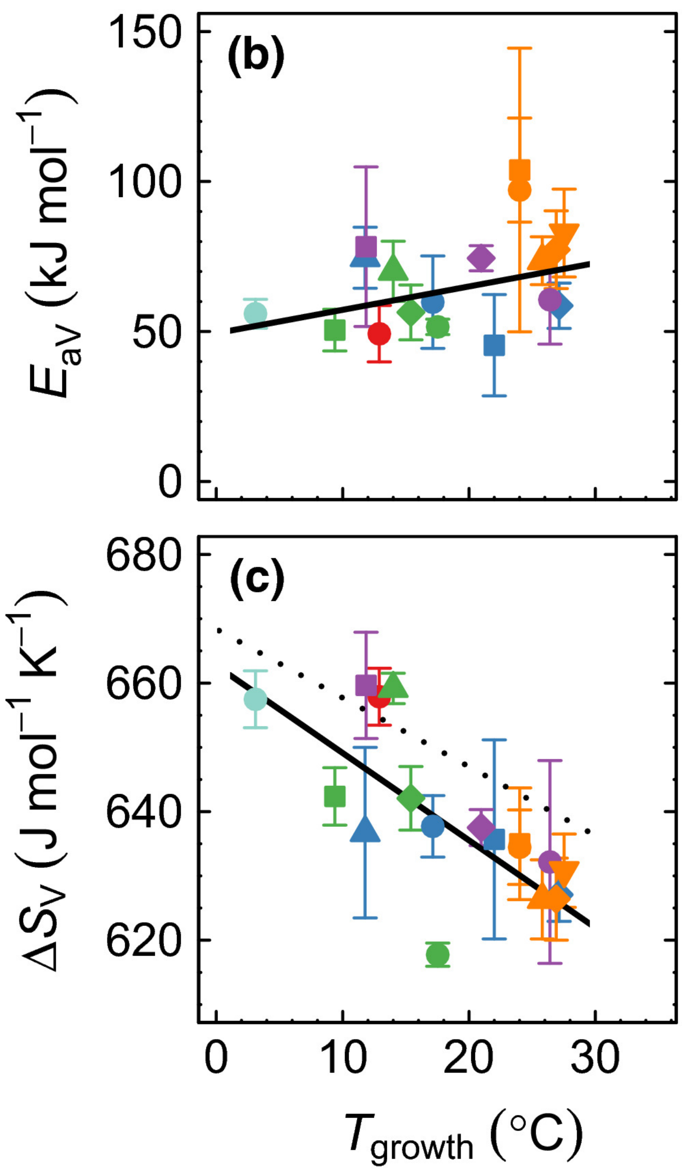
$k_{25}$ = $V_{cmax}$ at 25 ° C
$E_a$ = activation energy
$H_d$ = deactivation energy
$\Delta S$ = entropy parameter

R = universal gas constant
T = leaf temperature



# Biochemical demand drives thermal acclimation

- The activation energy and entropy parameter for $V_{cmax}$ change with growth temperature
- The biological meaning of this change is unclear




Kumarathunge et al. (2019) New Phytologist

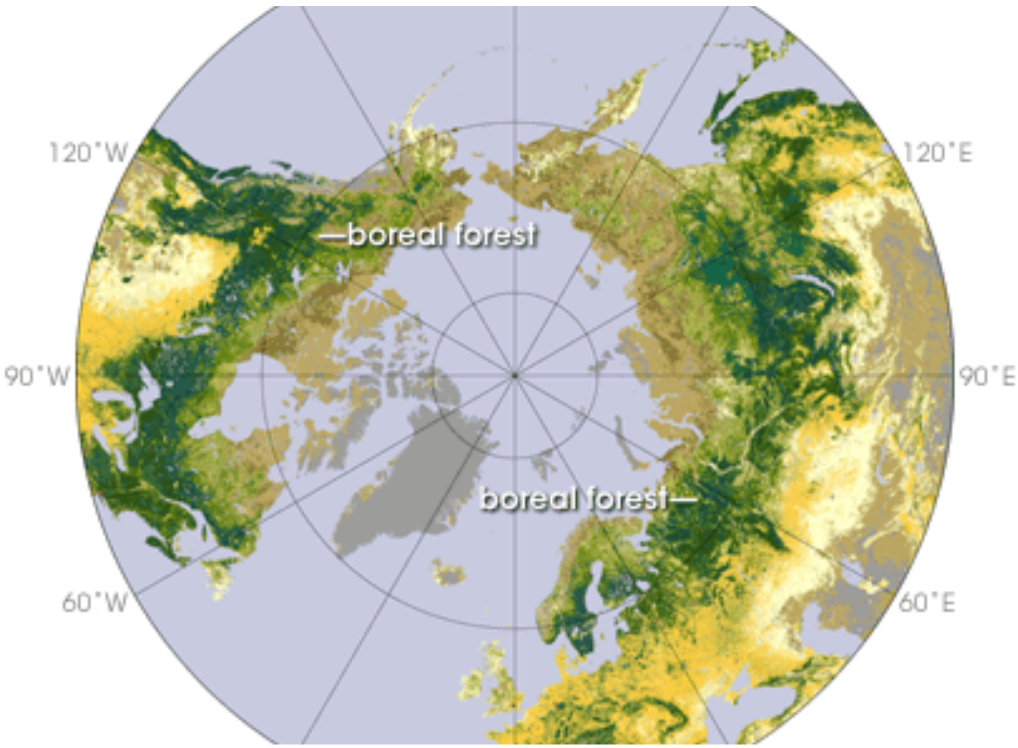
# Patterns of temperature effects on photosynthesis

- Temperature strongly affects photosynthesis
- Thermal acclimation improves photosynthetic performance, but only 50% of studies show strong thermal acclimation
- Acclimation in the thermal optimum of photosynthesis is related to changes in photosynthetic capacity, but how those changes occur is unclear

# Outline

- Patterns of temperature effects on photosynthesis
- Diversity of temperature effects on photosynthesis
- Where do we go from here?

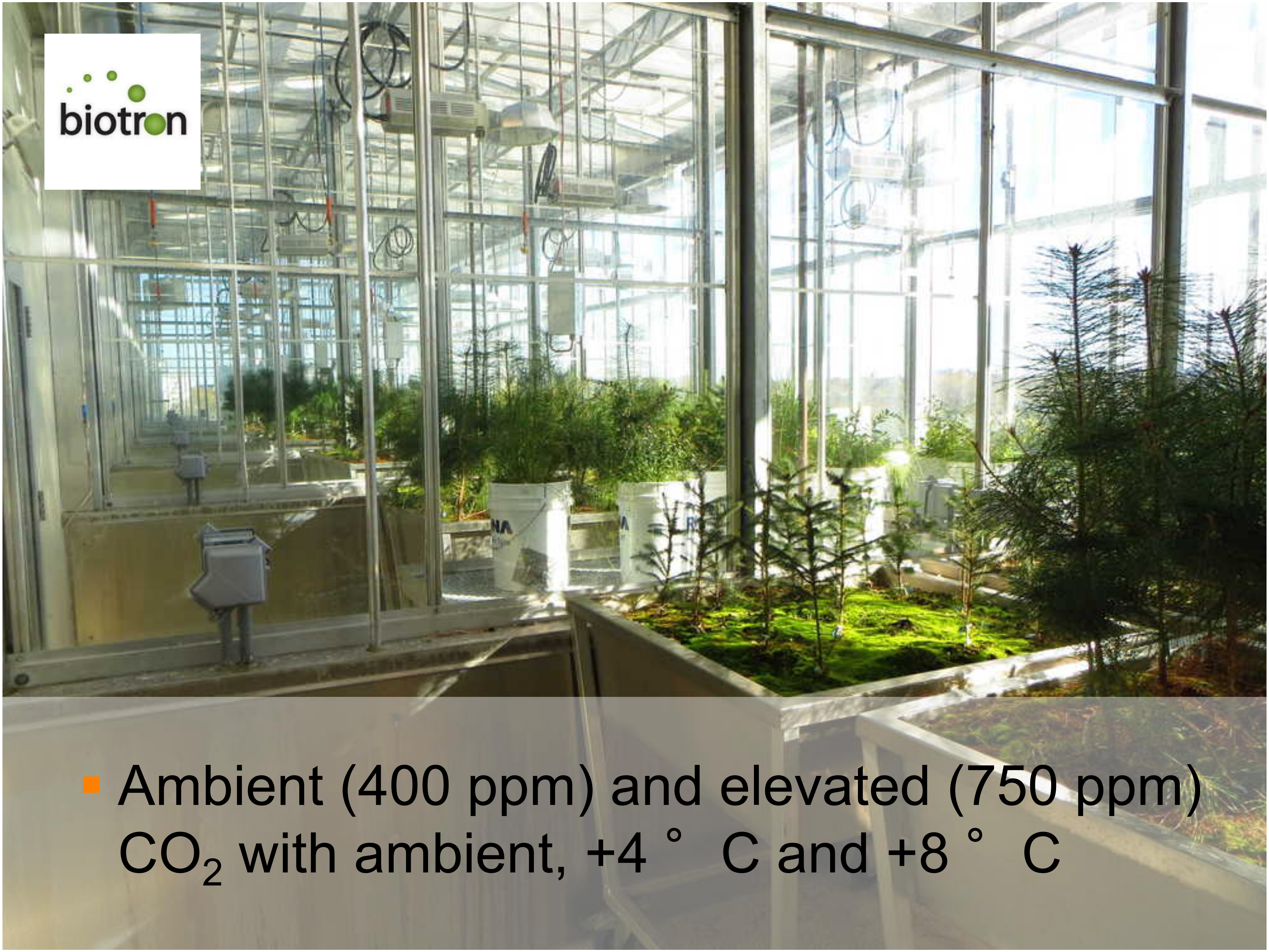
# Boreal forest: a key player in global C cycle




- 1/3 of the world's forest carbon stocks
- Relatively few tree species
- Dominant species have large impact on carbon fluxes

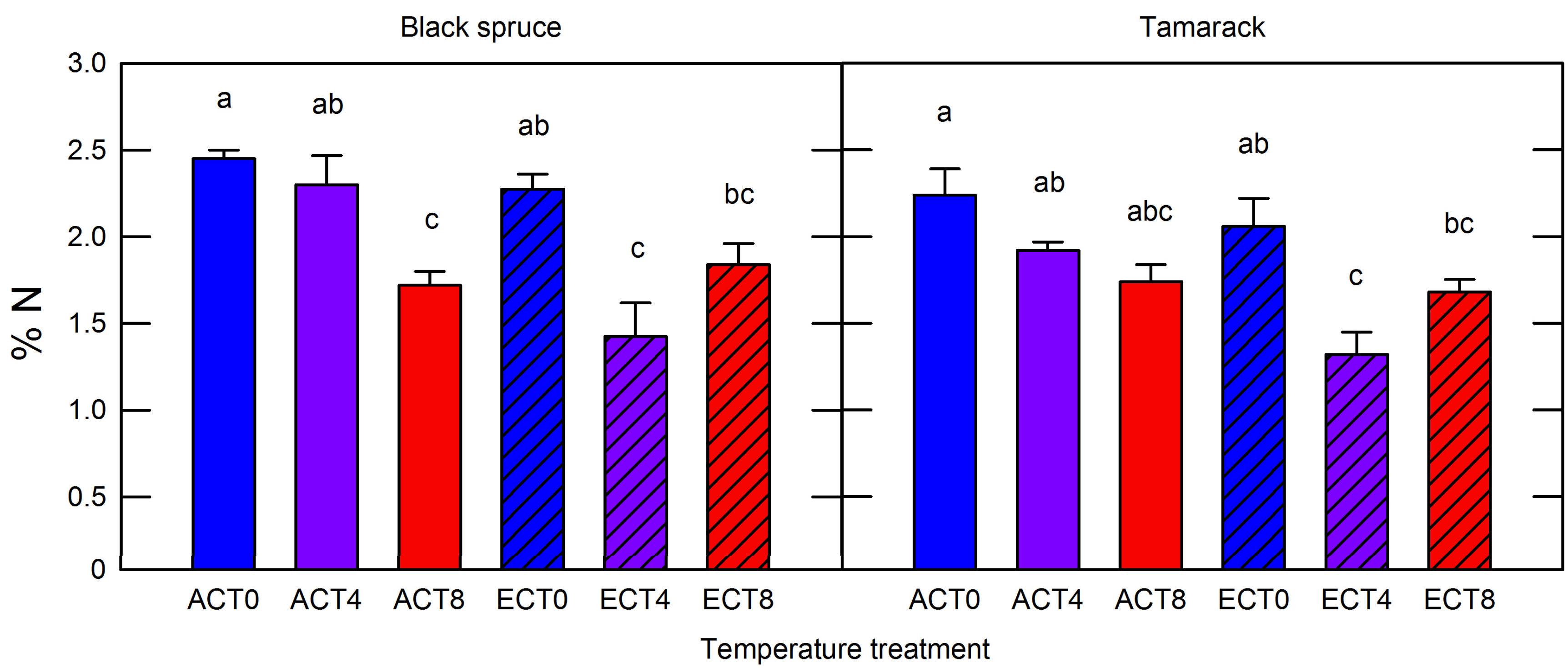
# Boreal forest: a key player in global C cycle

- Two common North American species:
  - Black spruce (evergreen)
  - Tamarack (deciduous)




- Ambient (400 ppm) and elevated (750 ppm) $CO_2$ with ambient, +4 ° C and +8 ° C

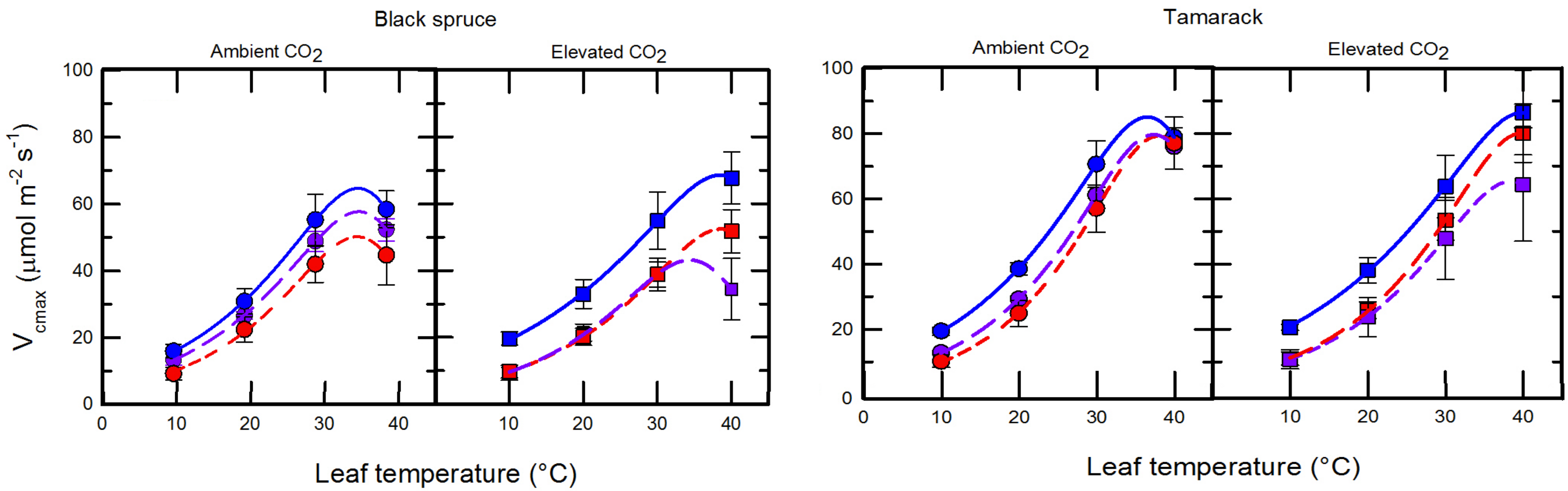
# Warming decreases leaf N




- Less N in warm-grown trees should correlate with lower enzyme content

Dusenge, Madhavji and Way (2020) Global Change Biology

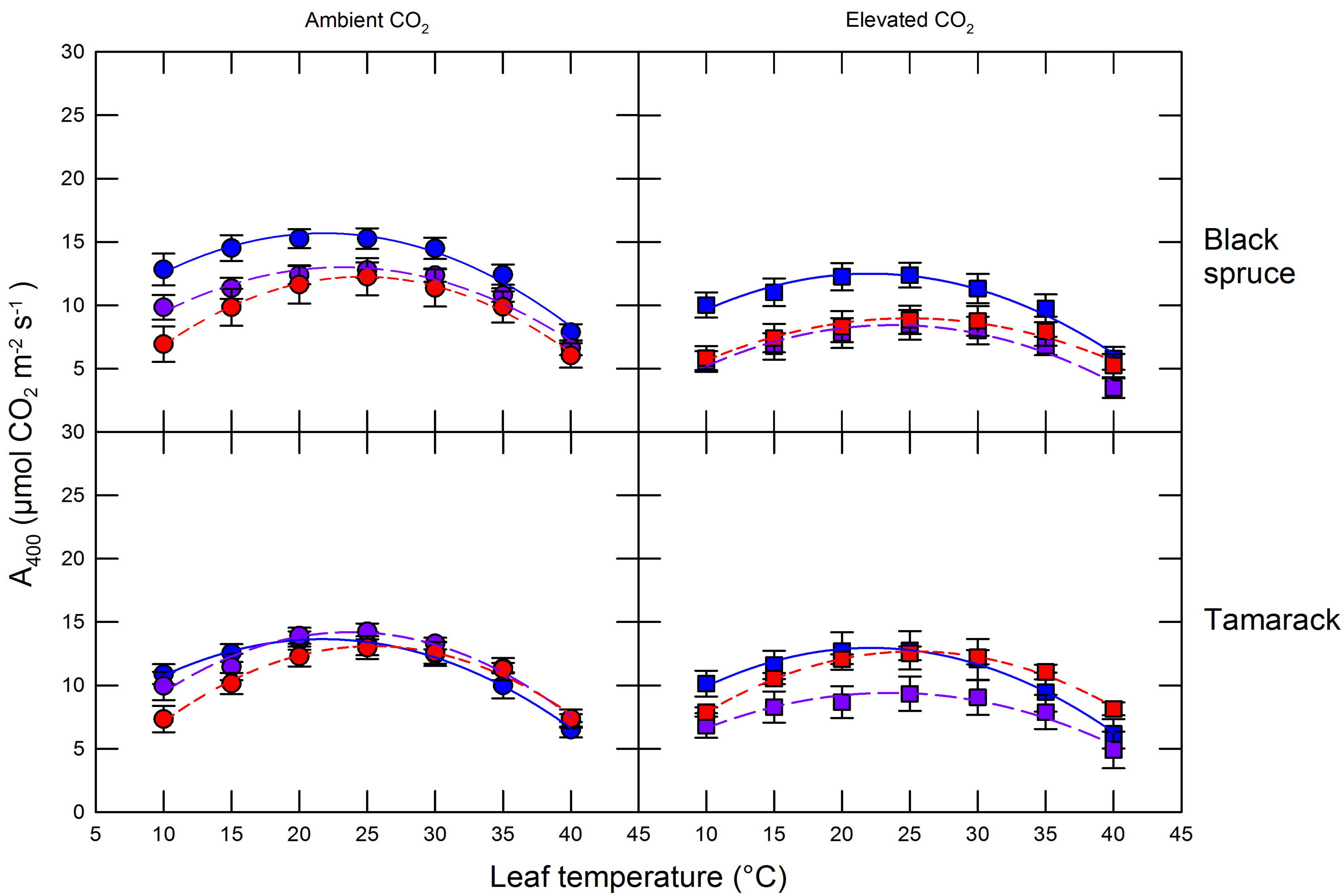
# Warming reduces photosynthetic capacity




- Photosynthetic capacity is reduced in warm-grown trees

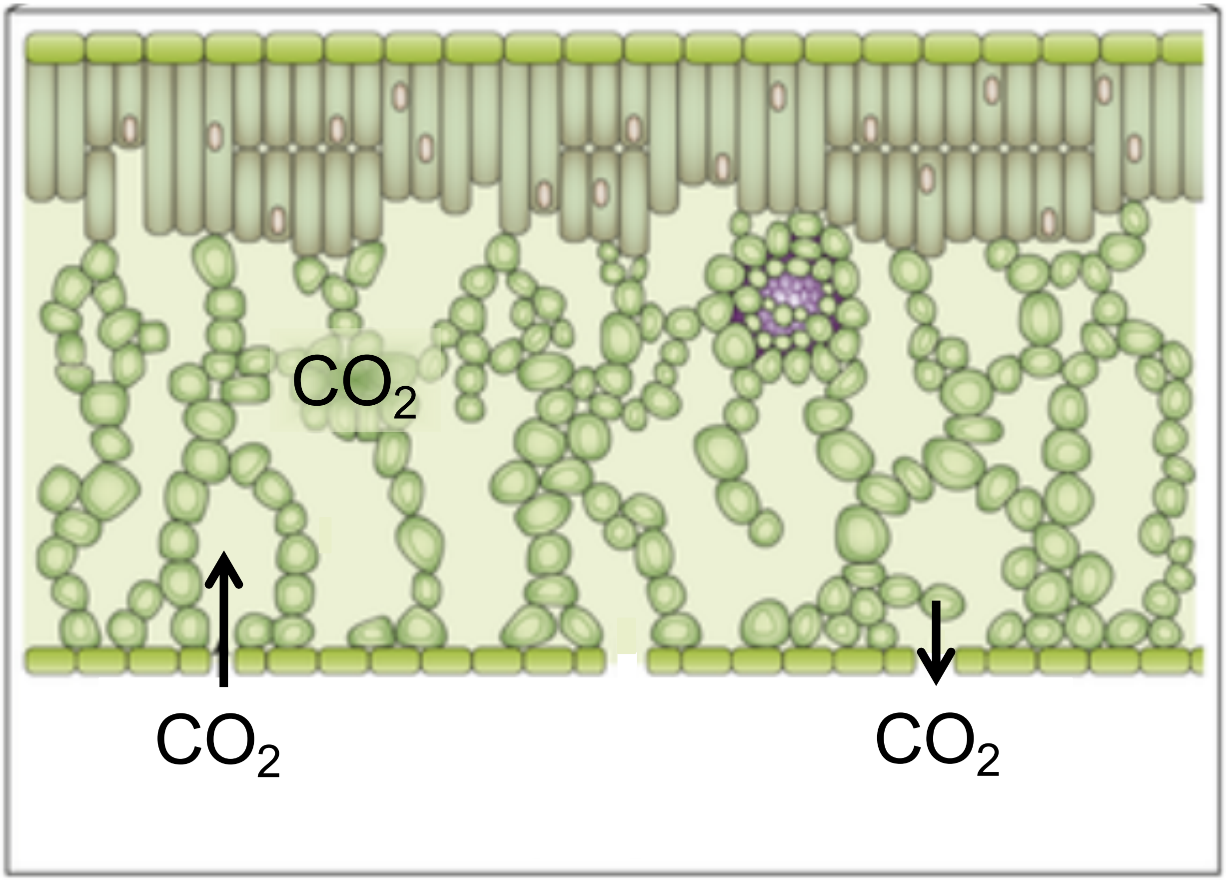
Dusenge, Madhavji and Way (2020) Global Change Biology

# Warming effects on photosynthesis vary



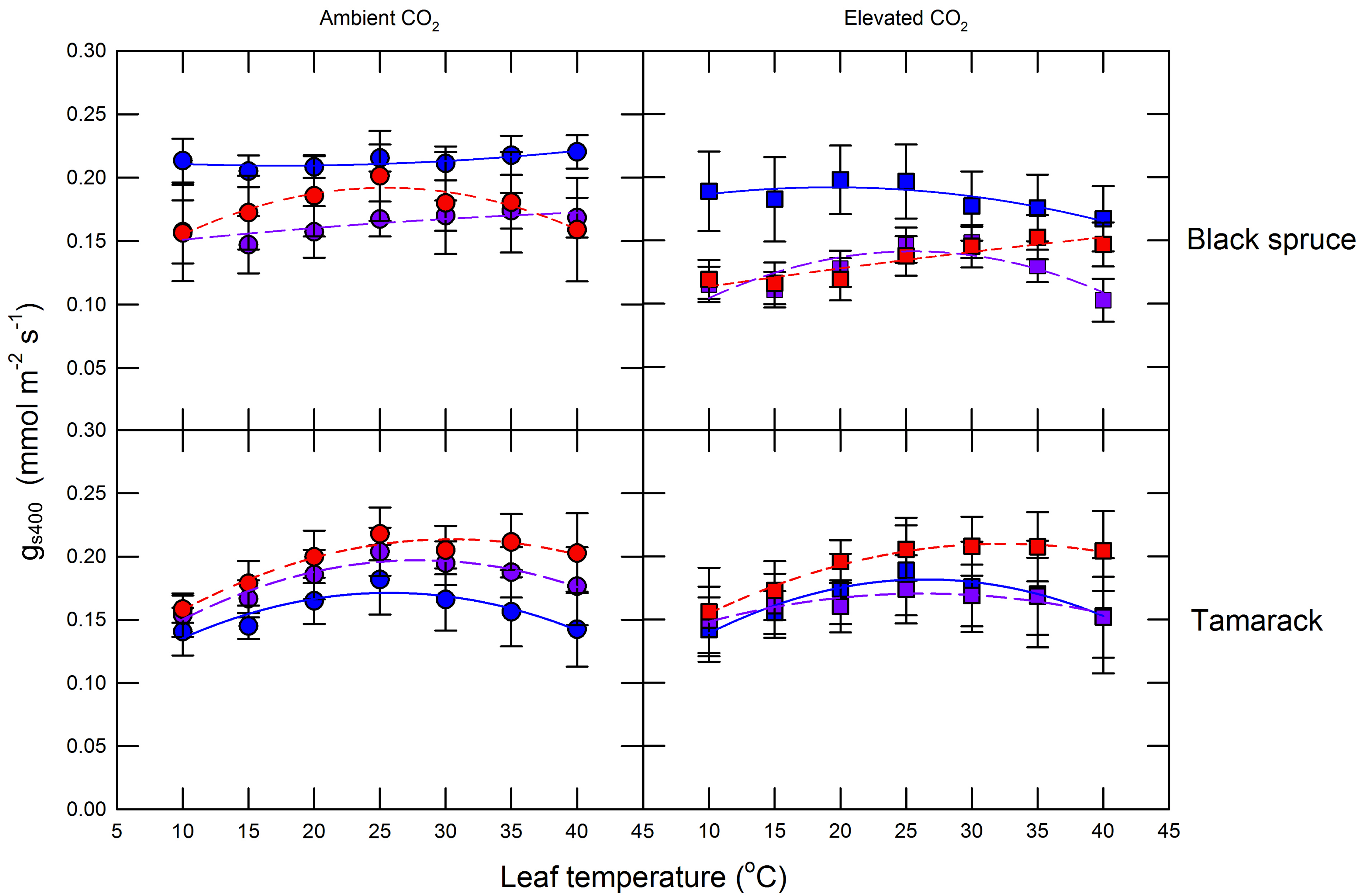

Dusenge, Madhavji and Way (2020) Global Change Biology

# How does photosynthesis thermally acclimate?




Way (2019) Nature Ecology and Evolution

# Warming impacts on stomatal conductance vary




Dusenge, Madhavji and Way (2020) Global Change Biology

# How realistic are pot experiments?

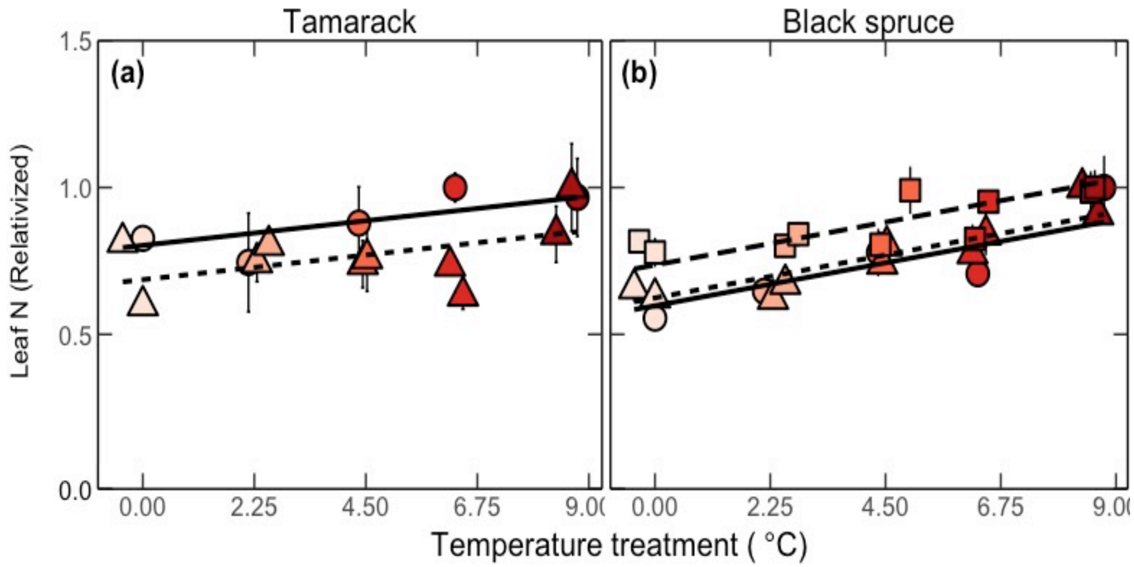
# Spruce and Peatland Responses Under Changing Environments

# Spruce and Peatland Responses Under Changing Environments

Five temperature treatments:
0, 2.25, 4.5, 6.75 and 9 ° C

Three measurement campaigns; some data is relativized

# Warming increases leaf N

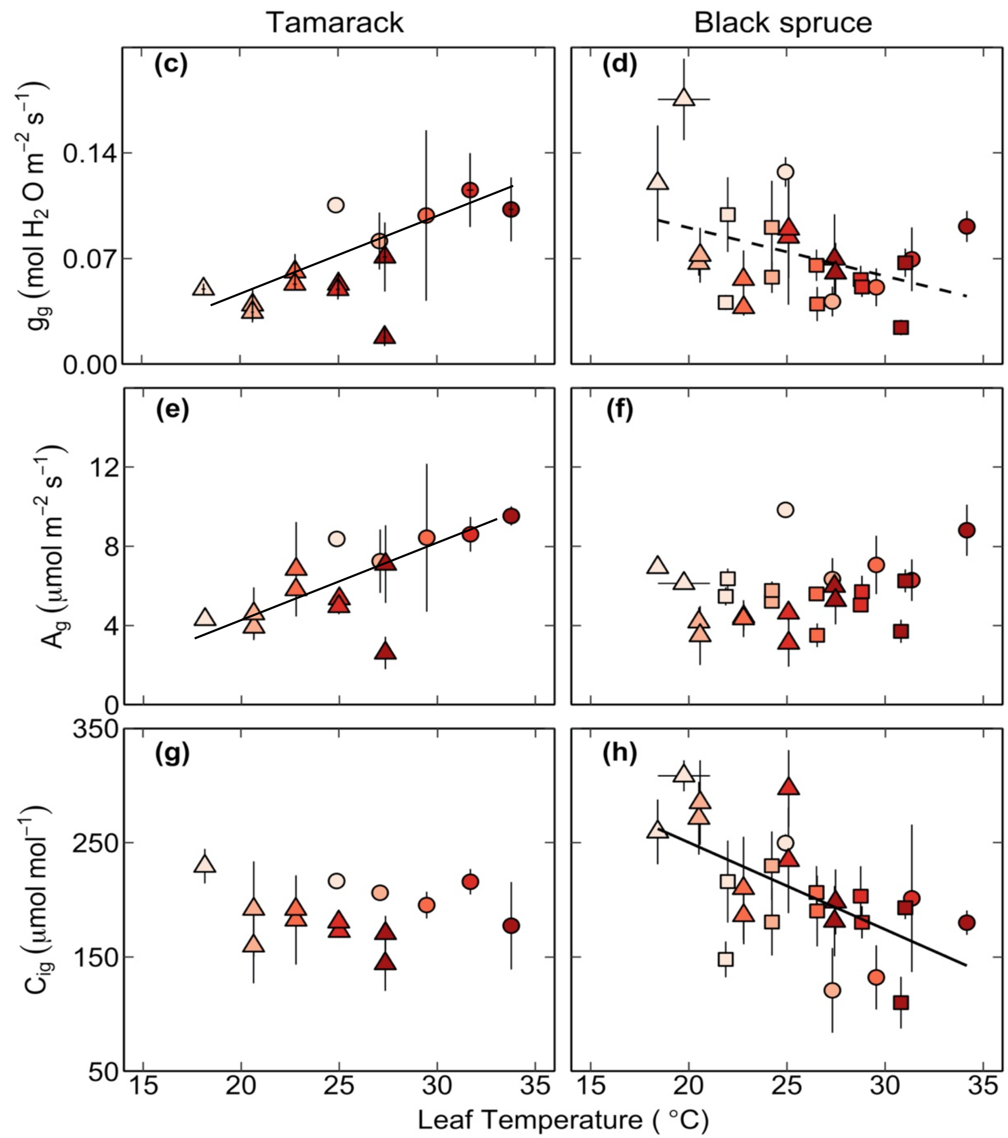



- Trees in warmer plots had higher leaf N
- Opposite of glasshouse study: warming effect on plants versus warming effects on ecosystems

Dusenge et al. (in review)

# Stomatal responses to warming differ among species

- Tamarack keeps its stomata open, reducing stomatal limitations for photosynthesis
- Spruce closes stomata under warming, limiting photosynthesis




Dusenge et al. (in review)

# Conclusions

- Stomatal responses to warming differed between species, which affects both C and water cycling
- Photosynthesis was less negatively affected by warming in tamarack than in spruce
- Could be related to plant functional type

# Outline

- Patterns of temperature effects on photosynthesis
- Diversity of temperature effects on photosynthesis
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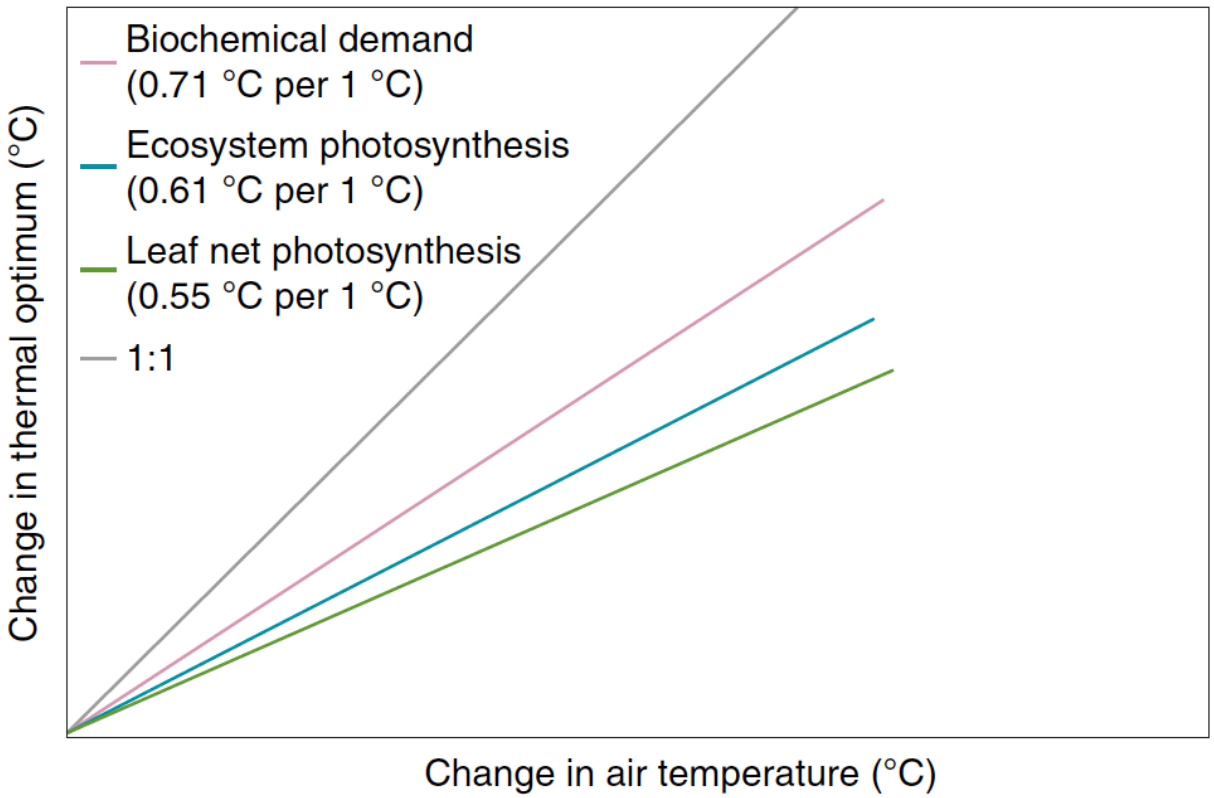
# Conclusions

- There are general patterns regarding how photosynthesis responds to warming




Way (2019) Nature Ecology and Evolution

# Conclusions

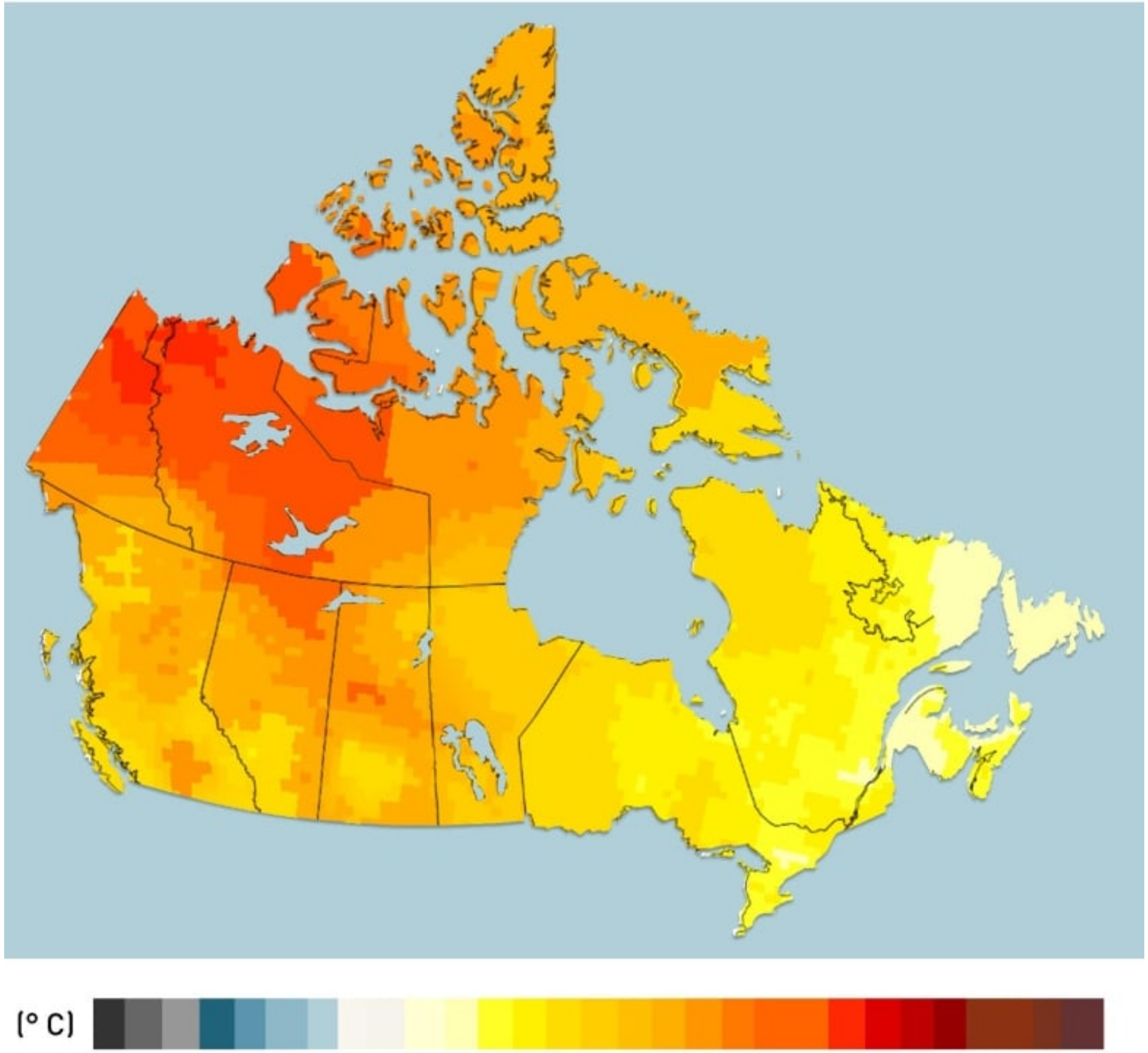
- There are general patterns regarding how photosynthesis responds to warming
- But there are also important differences between species and studies that we cannot yet predict
- Photosynthetic capacity is important for determining thermal acclimation
- But stomatal responses can generate strong differences between how species respond to warming

# CANADIANS

# FOR GLOBAL WARMING

# Observed changes in annual temperature

1948 and 2016




CBC NEWS

Source: Environment and Climate Change Canada

# Council of Canadian Academies


https://cca-reports.ca/reports/plant-health-risks/

# Acknowledgements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