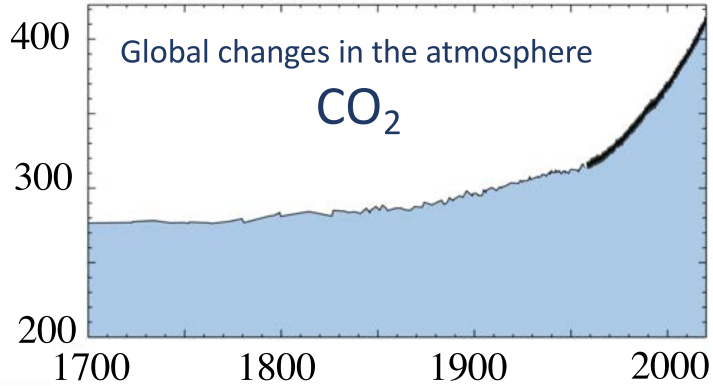


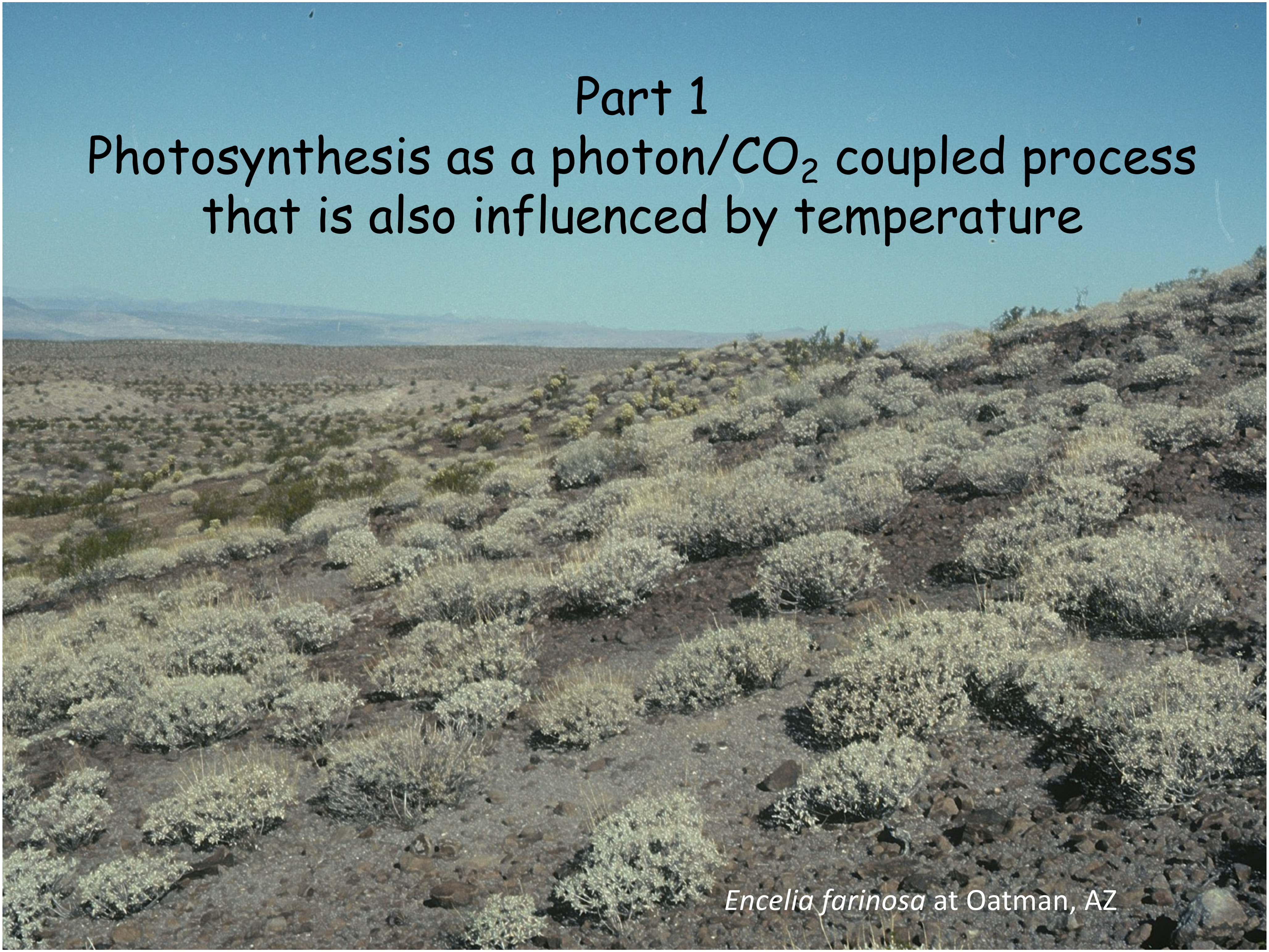
Topic 12

Photosynthetic Responses to Light and Temperature

Plant Ecology in a Changing World

Jim Ehleringer, University of Utah
http://plantecology.net

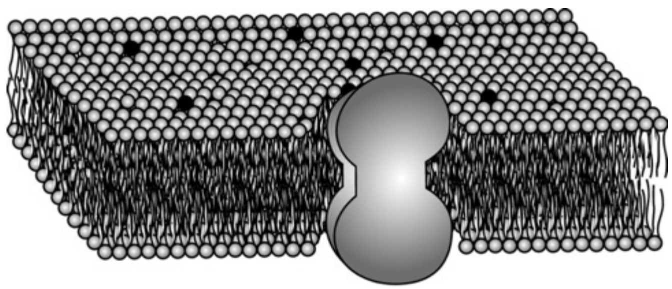
Part 1
Photosynthesis as a photon/CO_2 coupled process that is also influenced by temperature

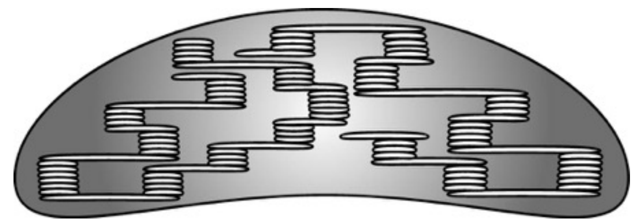


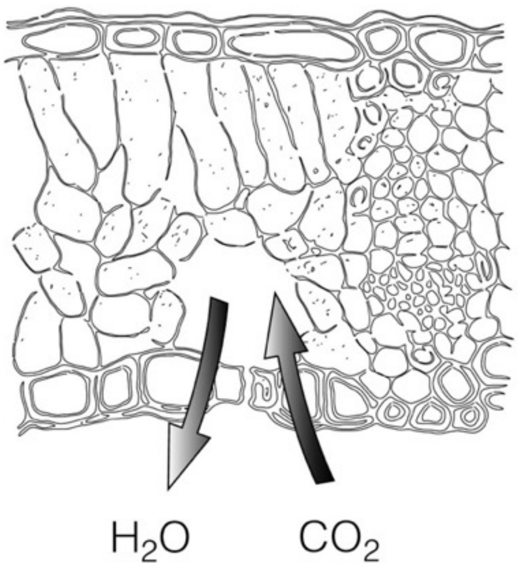
Encelia farinosa at Oatman, AZ

Recall that photosynthesis is an integrated process that requires the near-simultaneous capture of two resources:

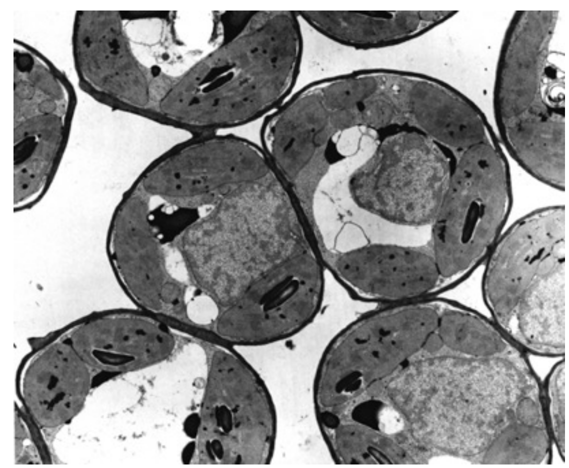
photons by chlorophyll pigments contained within the chloroplasts







CO_2 arriving at the chloroplasts by diffusion from the outside air through the stomates



Considering the integrated nature of photosynthesis,

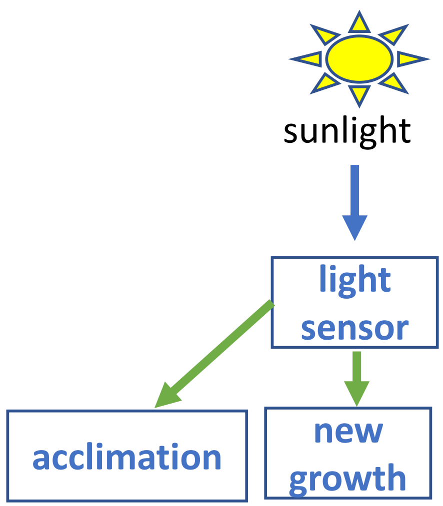
how do leaf structure and photosynthesis adjust to changes in the light environment?

Recognize that there can be changes in ***light quantity*** and ***light quality***

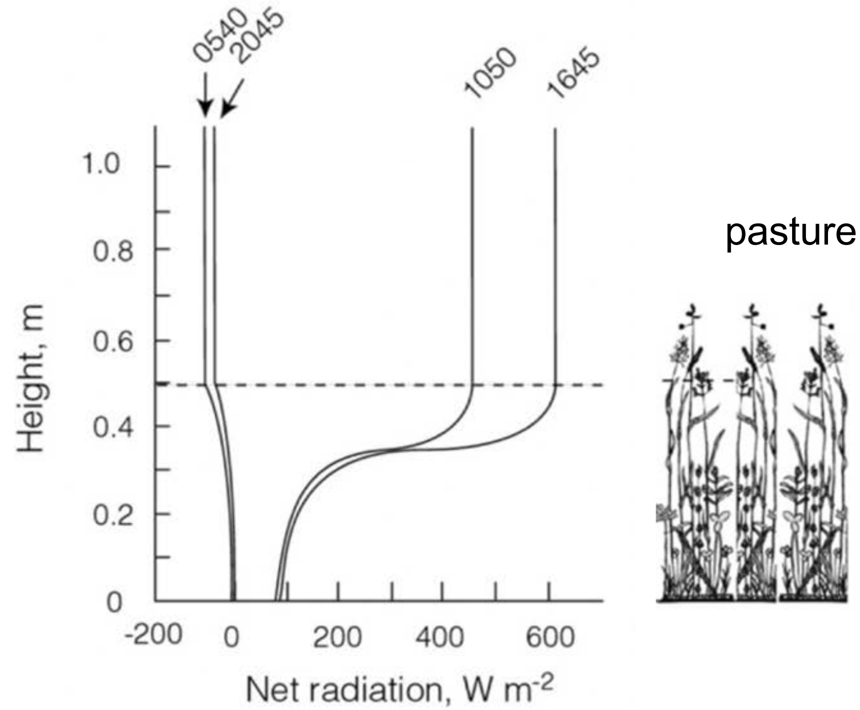
- time of day (e.g., morning, midday, afternoon)
- season of the year (e.g., spring/summer/fall)
- leaf position within the canopy (e.g., top, middle, bottom)

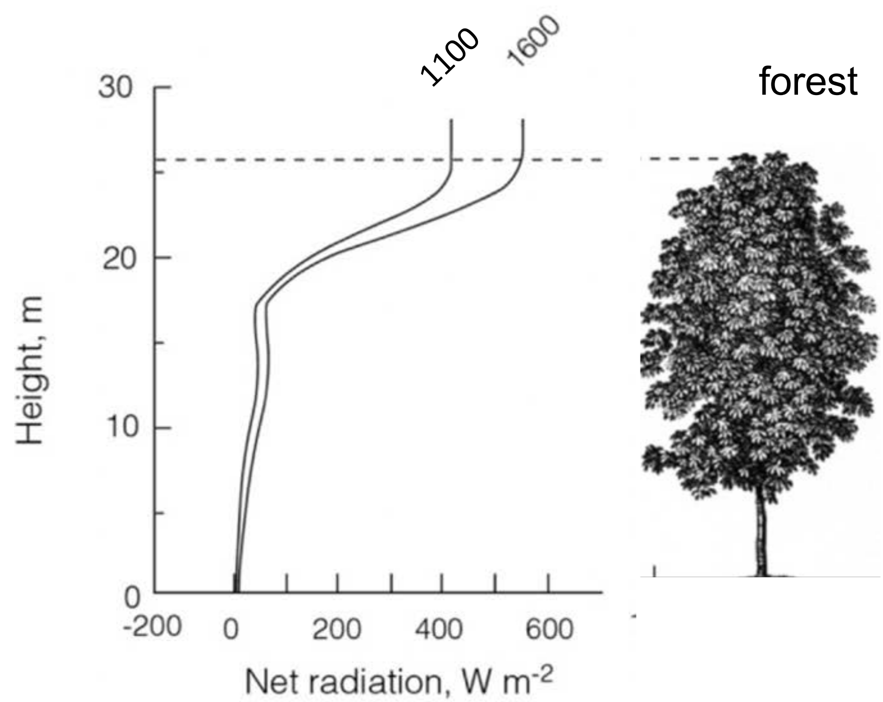
Remember plants have two light sensors that can inform an existing leaf or a meristem developing a new leaf

- blue light receptor
- red light receptor

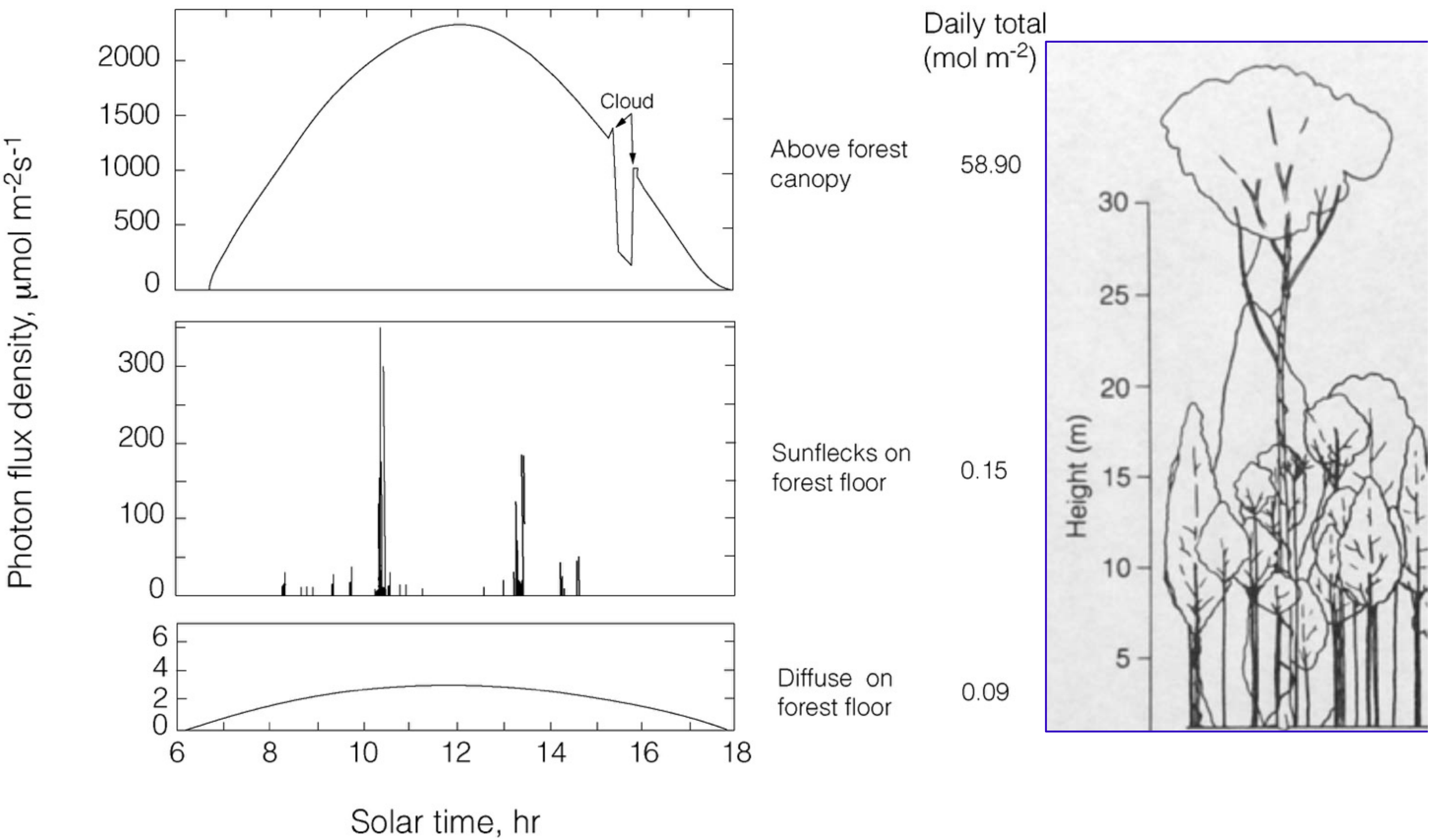


Changes in PFD throughout a canopy are large and influenced by leaf angles and the distribution of leaf area through the canopy.

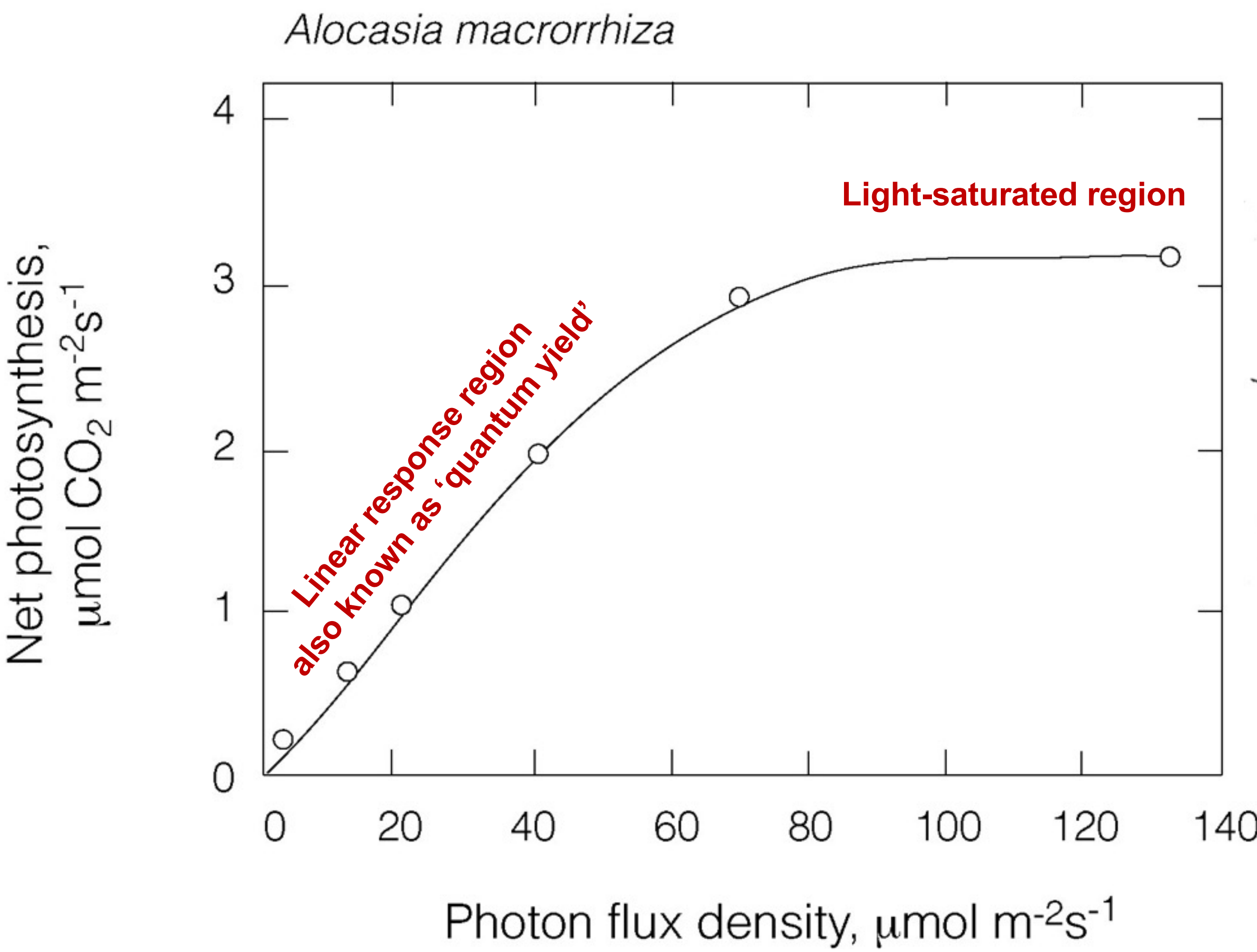




What is the shade PFD environment like in a rainforest?

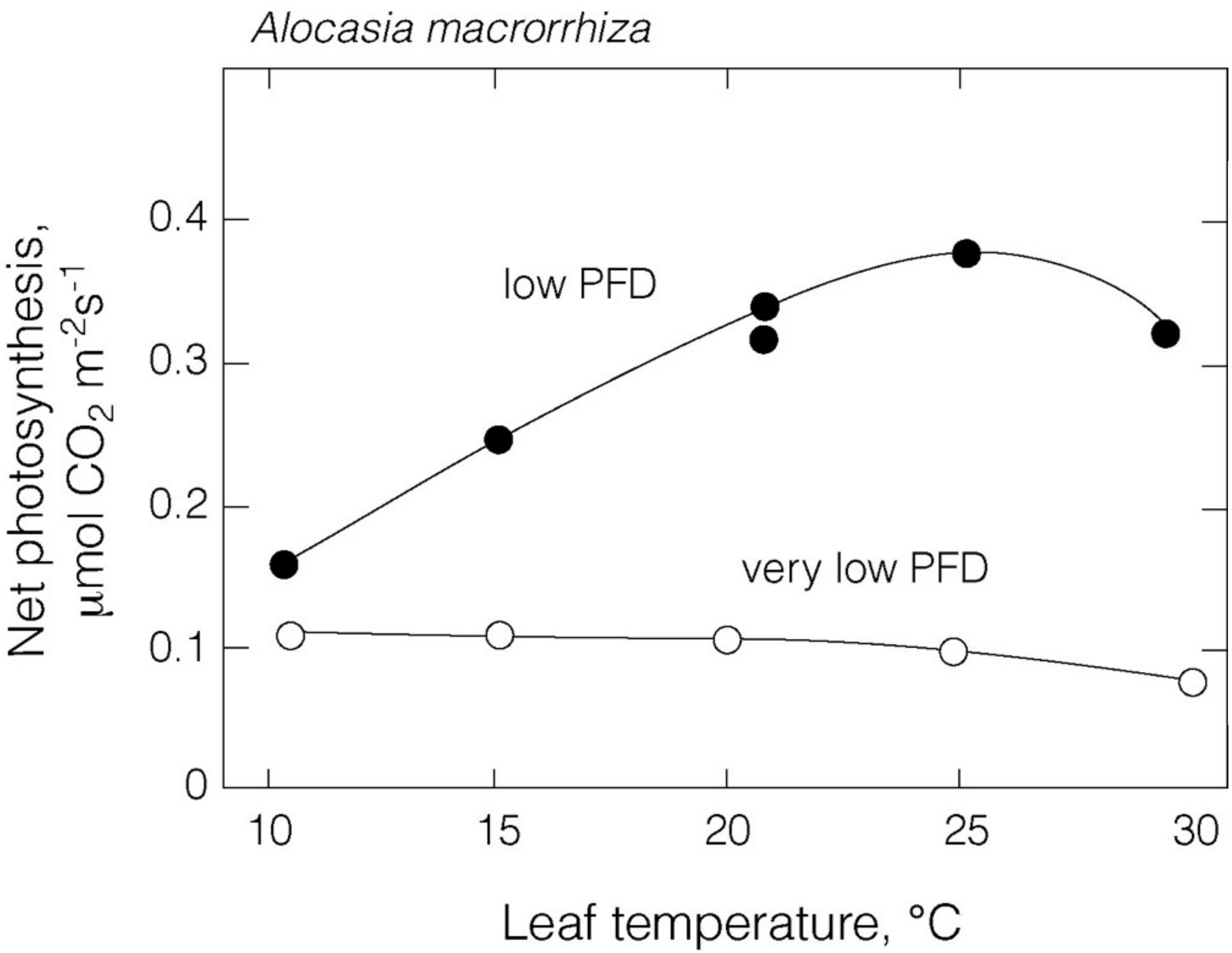


Leaf-level net photosynthesis is measured at net CO_2 uptake



a shade forest species

And in a low PFD (deep shade) environment, net photosynthesis appears much less temperature sensitive than at higher PFD levels



a shade forest species

Several concepts inform us about how
leaves/plants can respond to a change in their environment

Responses within a plant (***genotype***)

- biochemical **regulation** (short term – seconds to minutes)
- **acclimation** (***phenotype***) (medium term – days to weeks)

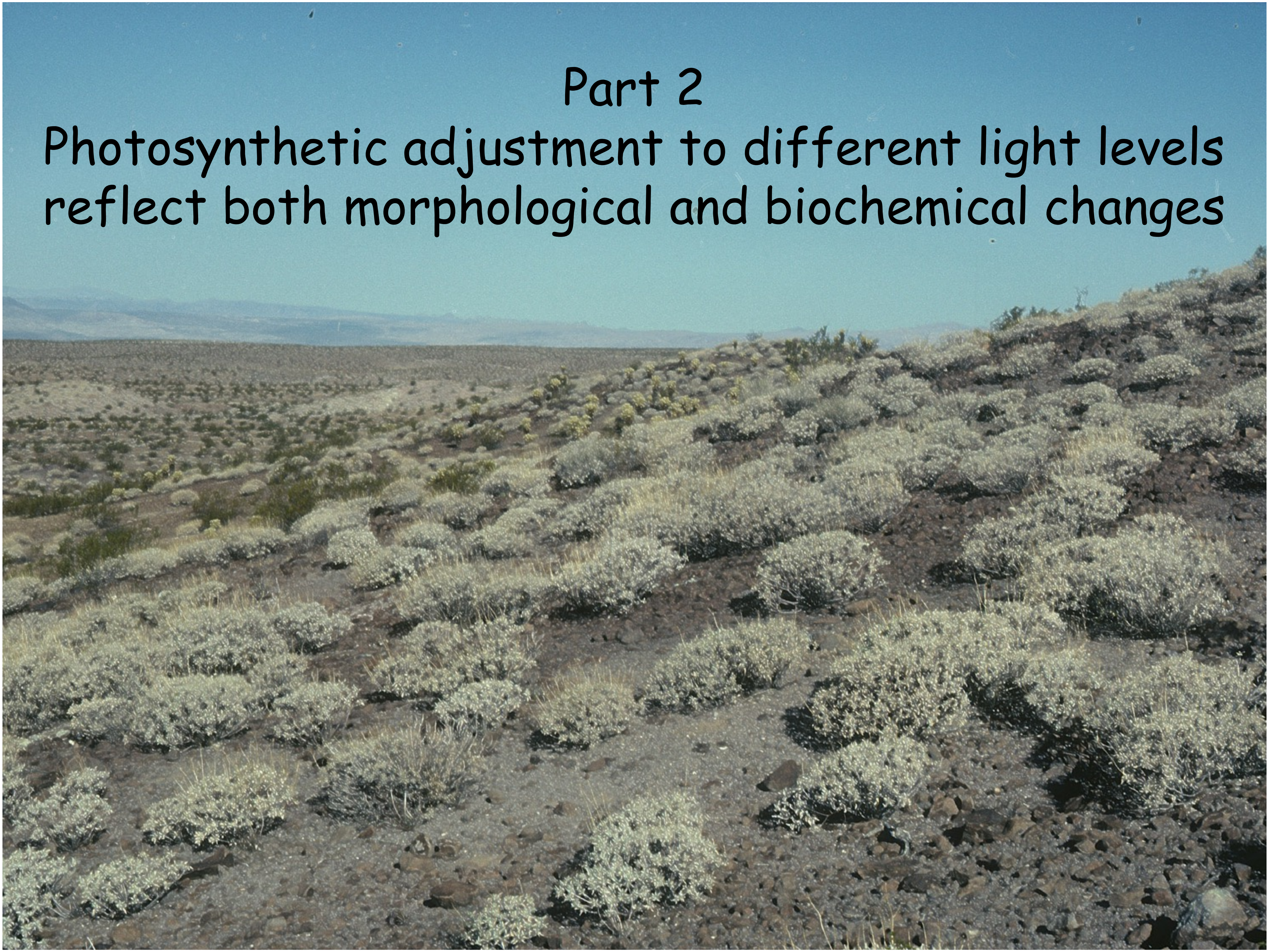
Phenotypic variation can appear as biochemical, morphological, and phenological changes

Responses within a plant population or species

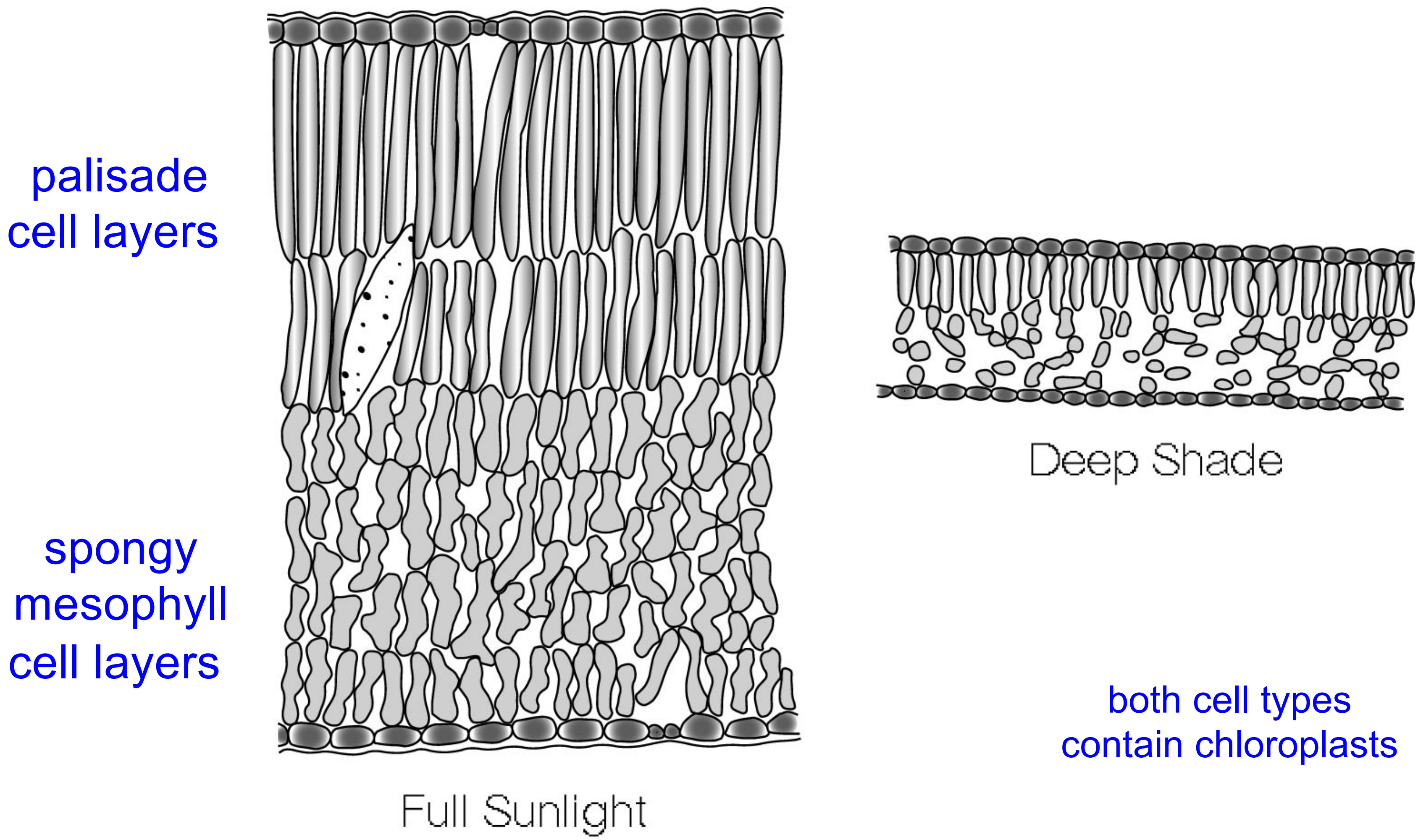
- **evolution** (e.g., generational changes in gene frequencies)

Plasticity – a measure describing the extent to which a given a given *genotype* can express multiple *phenotypes*

A plant population may contain many genotypes


Part 2
Photosynthetic adjustment to different light levels reflect both morphological and biochemical changes

Leaf morphology exhibits tremendous plasticity and this morphological acclimation benefits photosynthesis



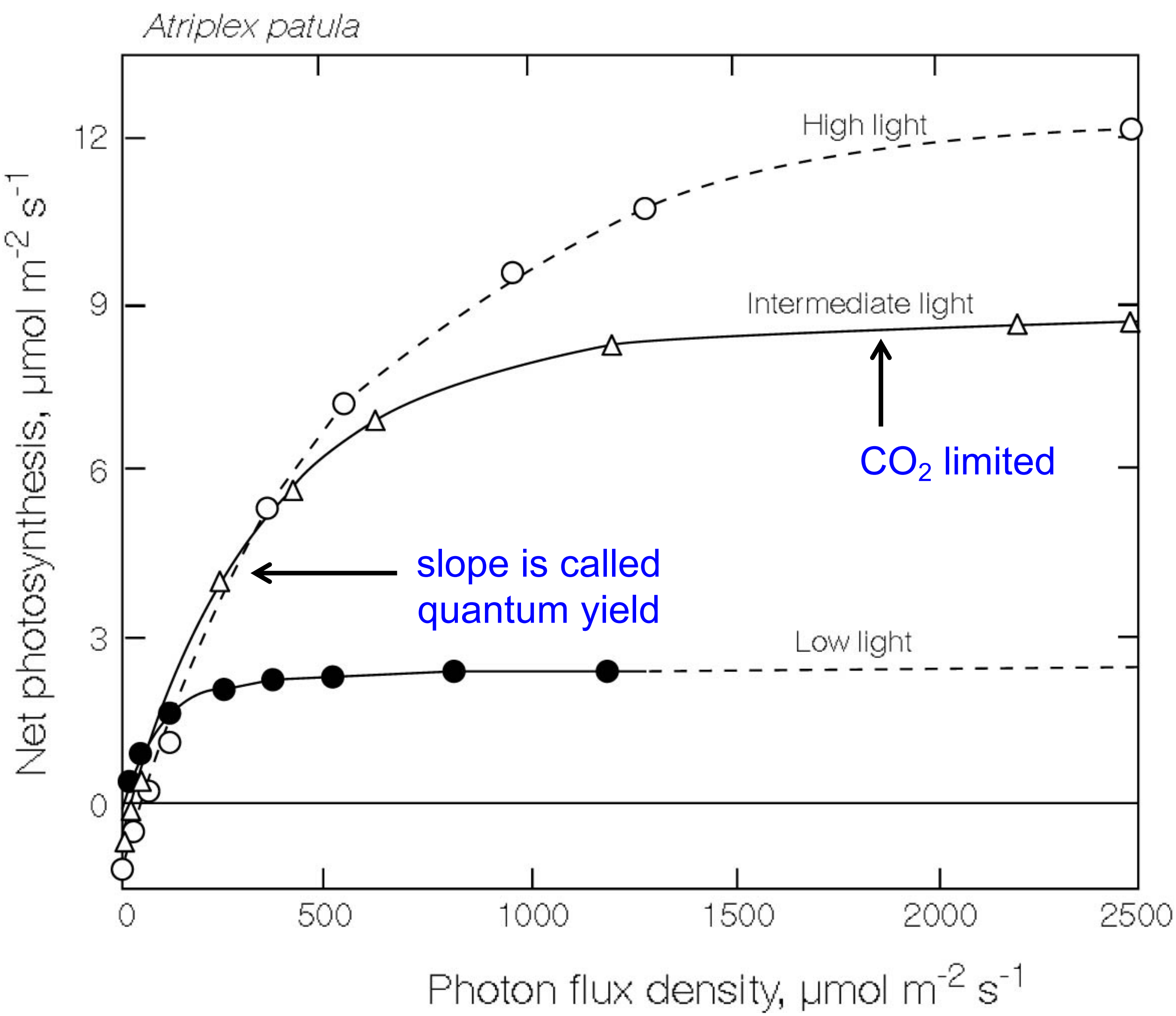
a light pipe is created by stacking **palisade cells** upon each other

Both biochemical and morphological changes occur as leaves acclimate to differences in the PFD levels of a habitat

- morphological adjustments include changes in
  - palisade layer thickness
  - leaf thickness
  - stomatal density
  - cuticle thickness
  - chloroplast size

- biochemical adjustments include changes in
  - photosynthetic enzymes, especially Rubisco
  - mitochondrial respiration rate
  - Light harvesting complex (LHC) size
  - chlorophyll a/b ratio

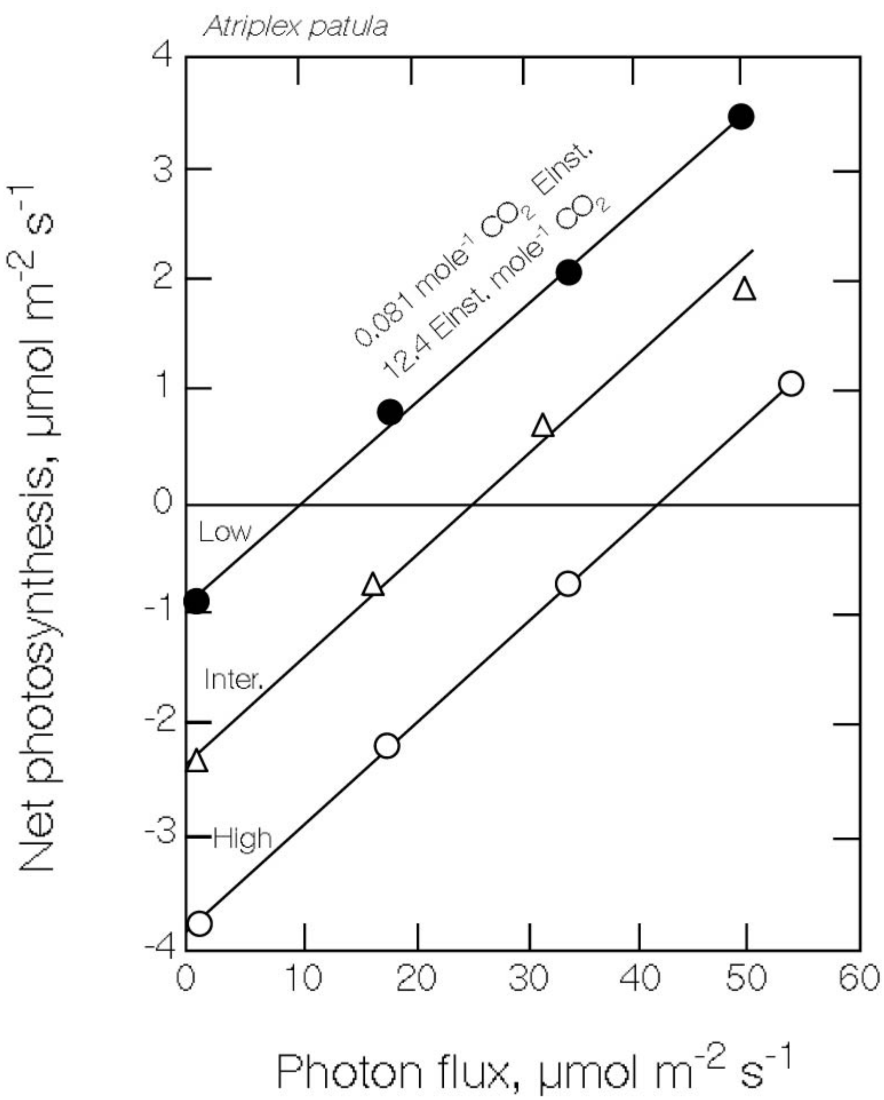
Leaf photosynthesis responses to PFD depend on a leaf's environmental history (sun – shade environments)



quantum yield is ~ 0.05

At PFD = 0, flux is mitochondrial respiration

The light-use efficiency of photosynthesis (quantum yield) is not sensitive to the growth environment.



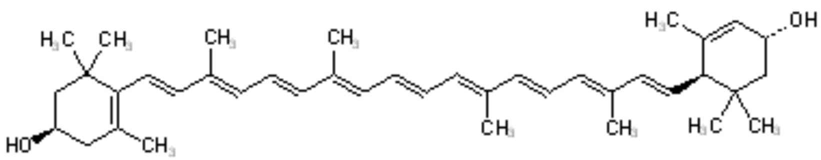
A_{max}/R_d ~ 8-12

Note: the brighter the growth environment, the higher is the mitochondrial respiration.

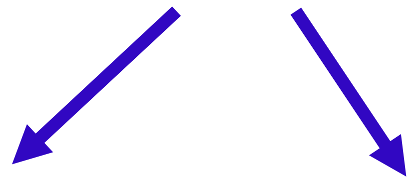
How do leaves respond to high-light, which could be a stressor?

Xanthophyll cycle

auxiliary pigments



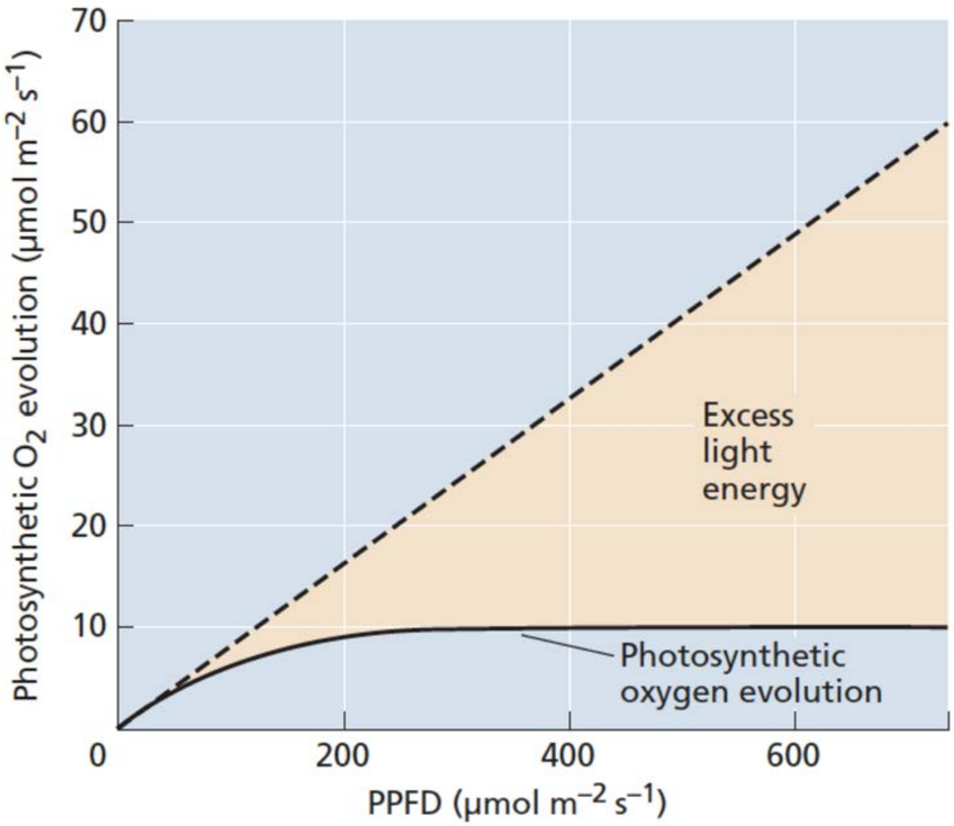
Avoidance



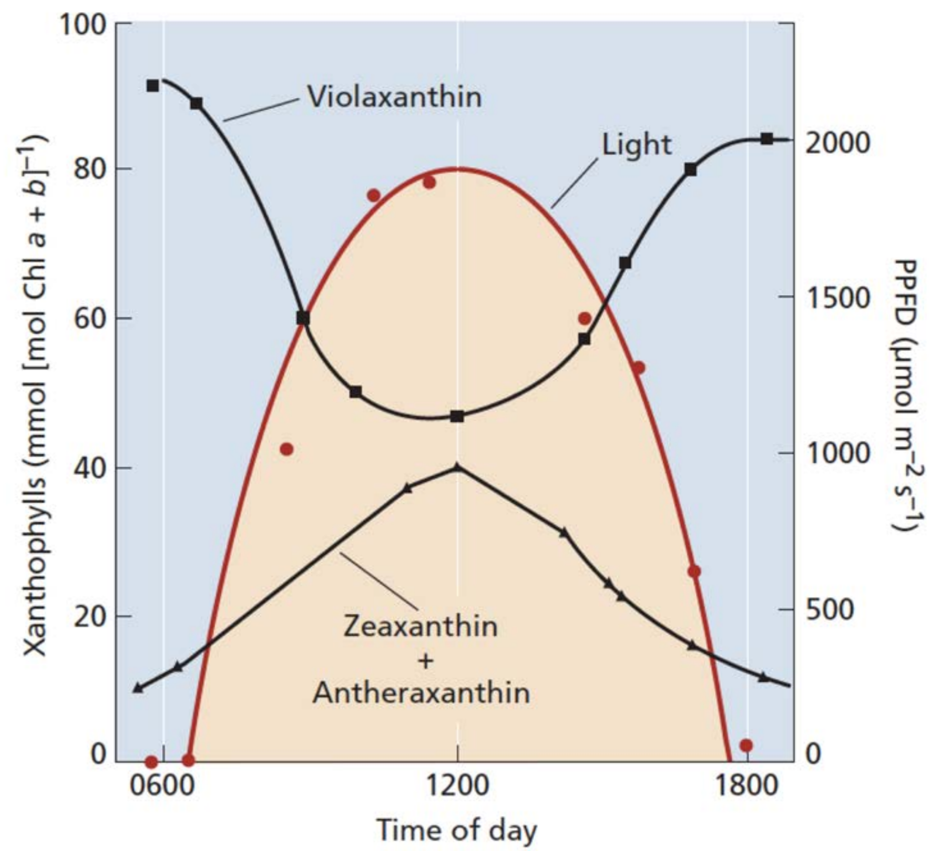
leaf movements

chloroplast movements

Plant responses to excessive sunlight

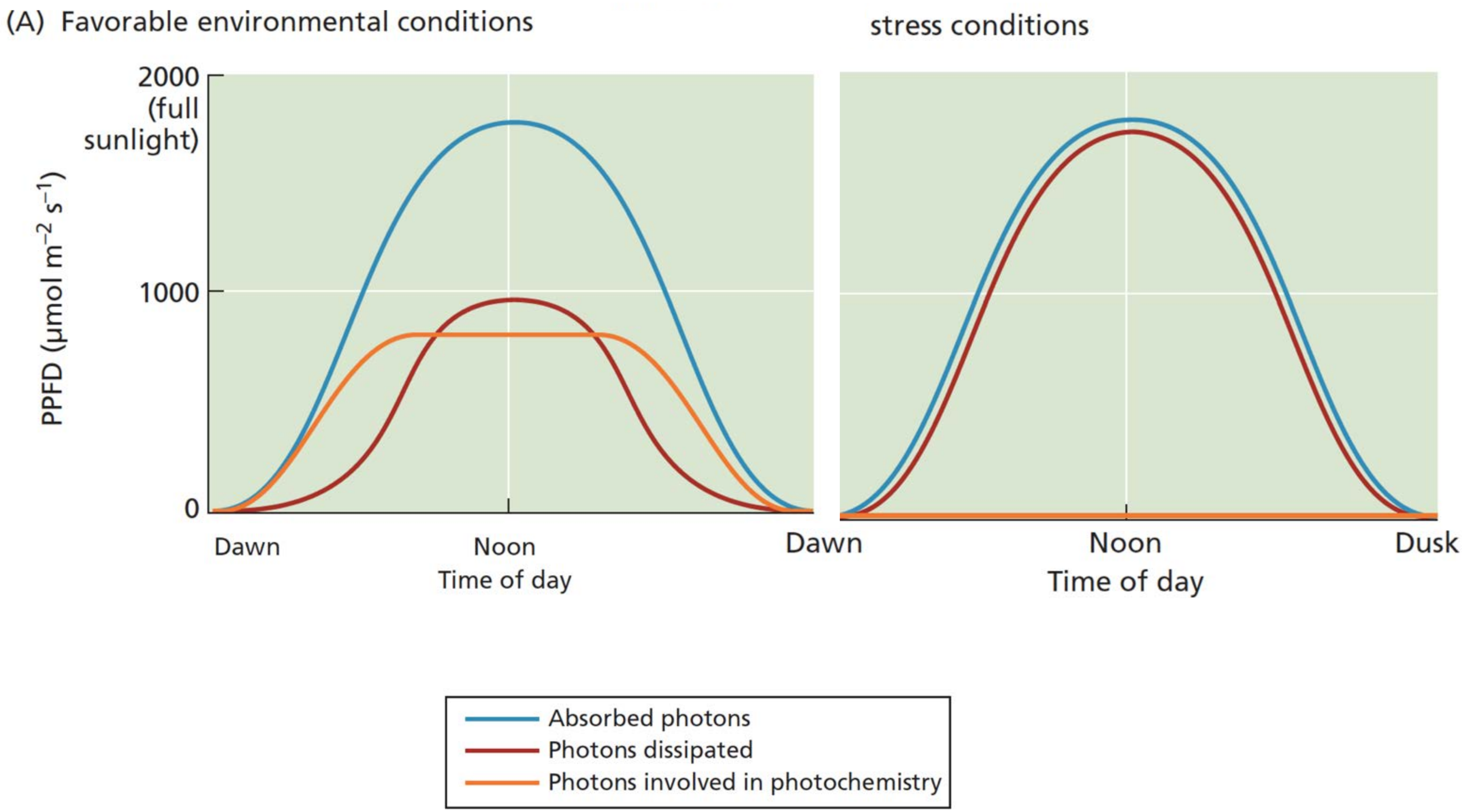


Tolerance - xanthophyll cycle



Alternative is photoinhibition – a photochemical response to excessive sunlight

- production of photo-oxidants associated with ATP and NADPH
- degradation of photosystems results in bleaching of chlorophyll

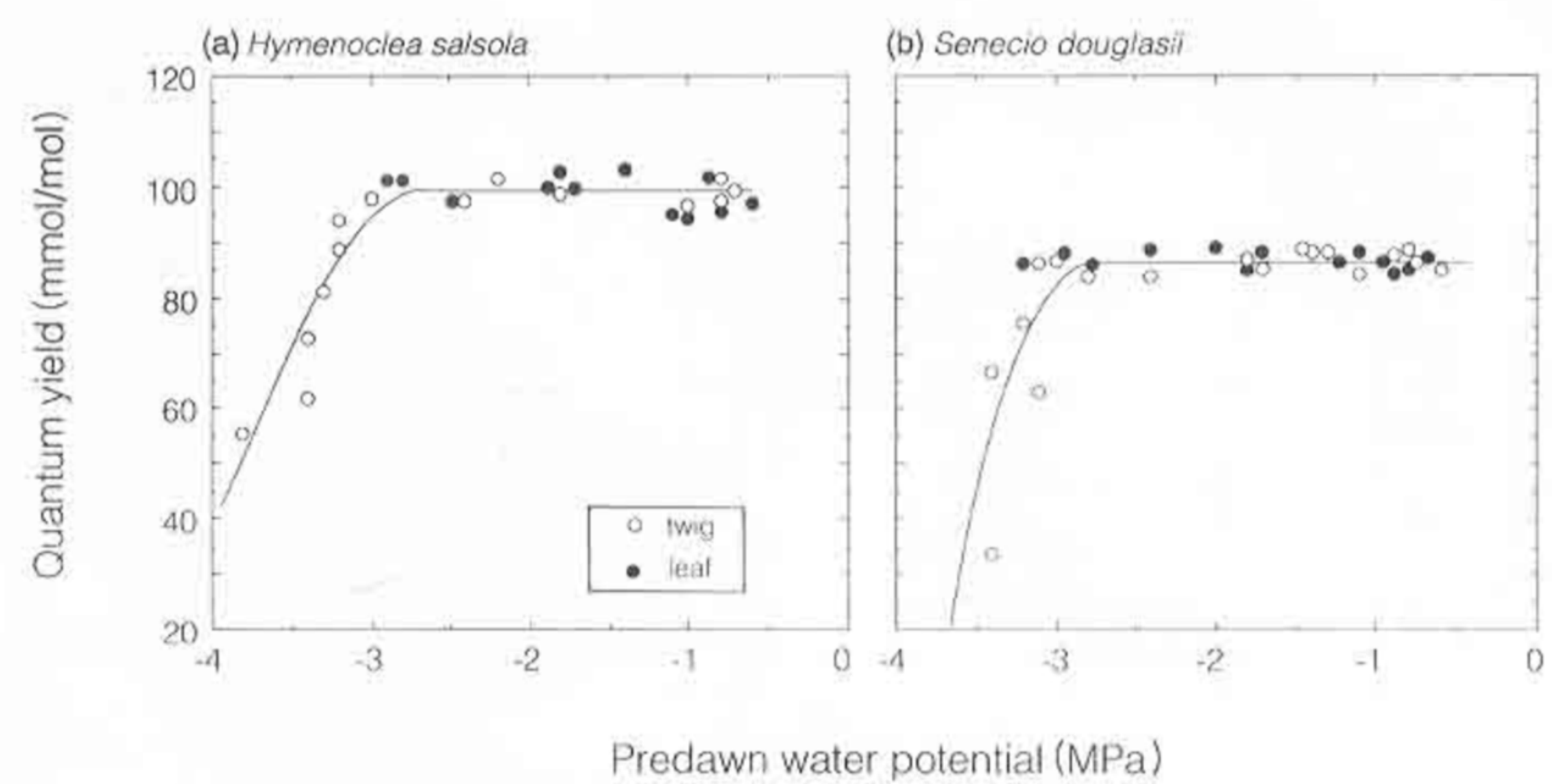


(A) Favorable environmental conditions
stress conditions
2000 (full sunlight)
1000
0
PPFD (μmol m⁻² s⁻¹)
Dawn
Noon
Time of day
Dawn
Noon
Dusk
Time of day
Absorbed photons
Photons dissipated
Photons involved in photochemistry

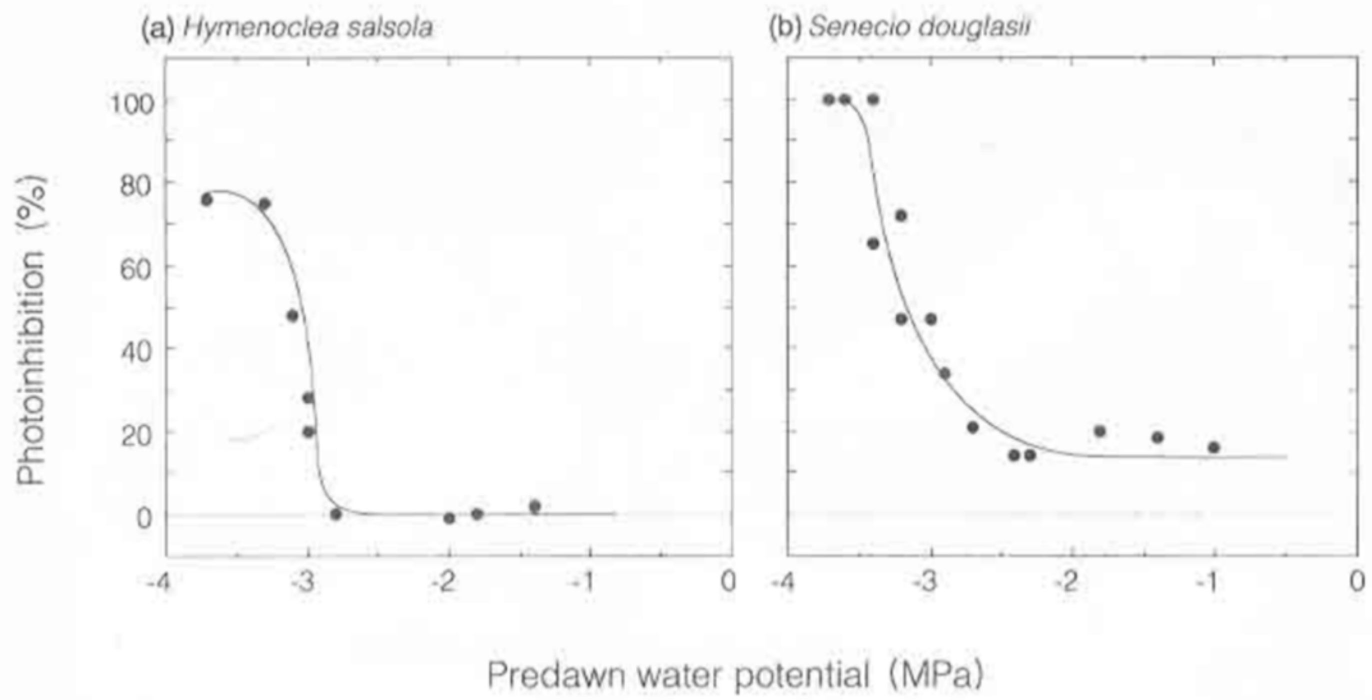
… but what happens when photosynthetic tissues are exposed to high light with limited water (stomata fully or partially closed)?

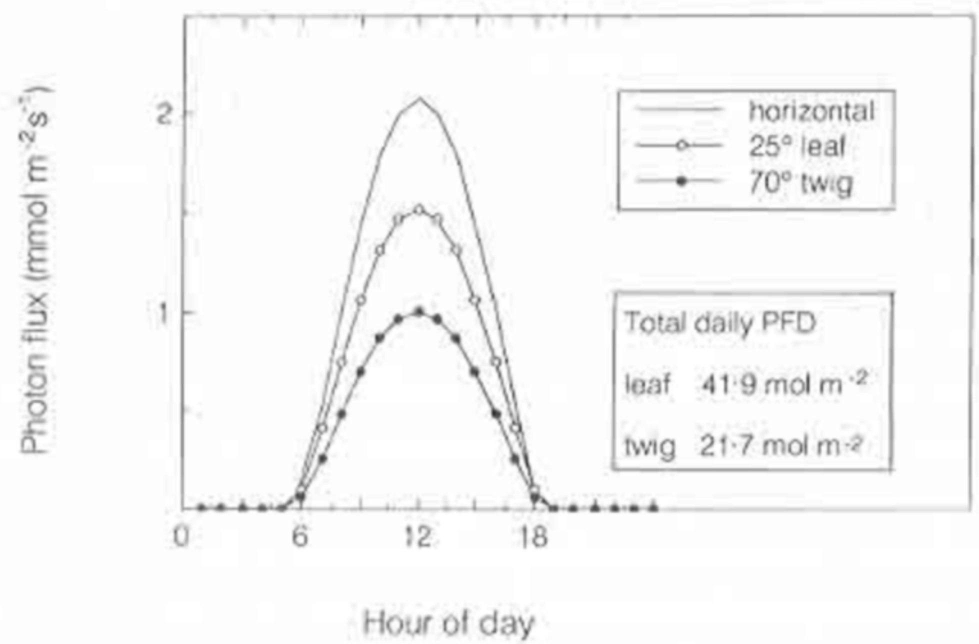




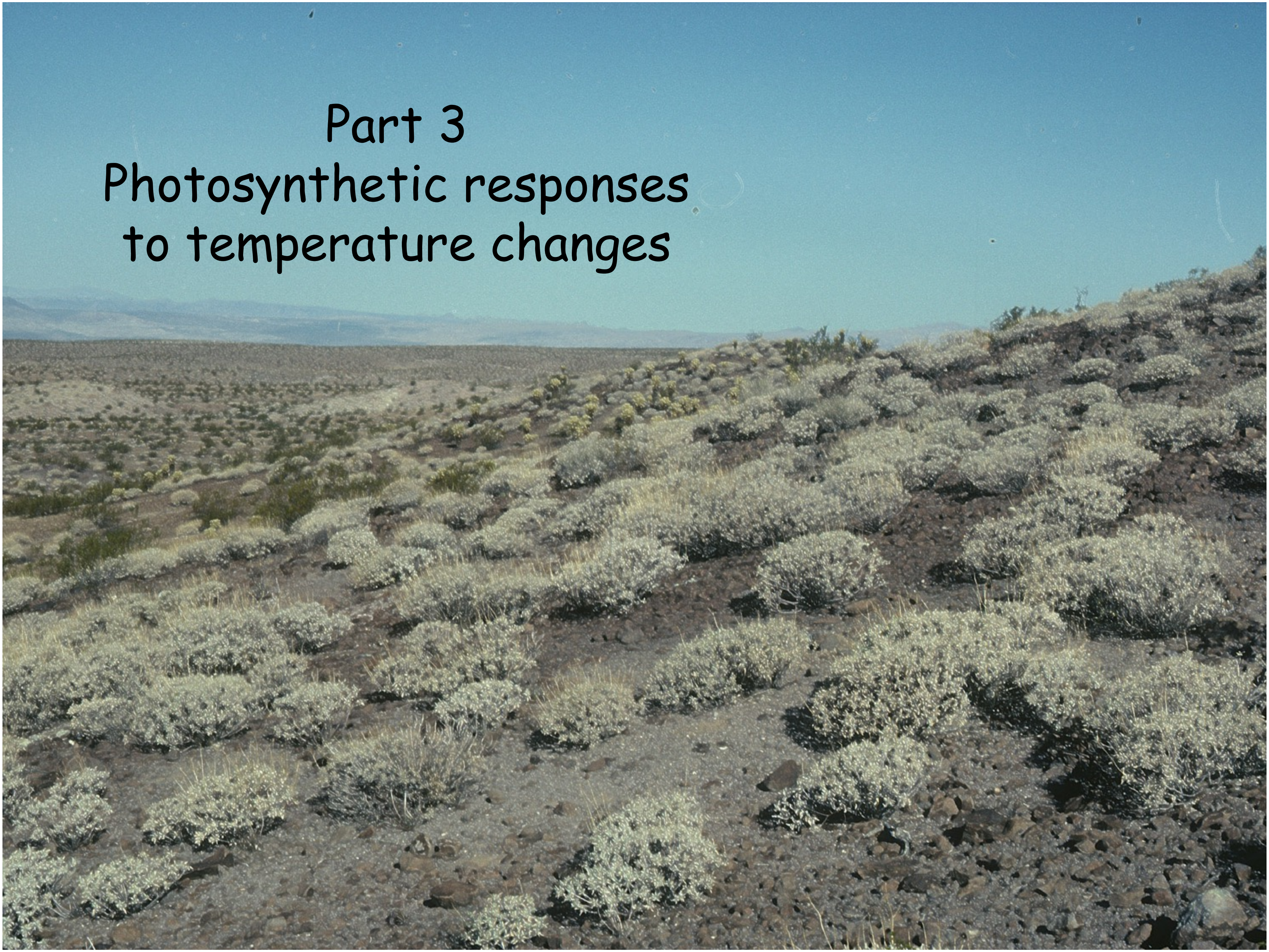


Photoinhibition occurs as plants become water stressed

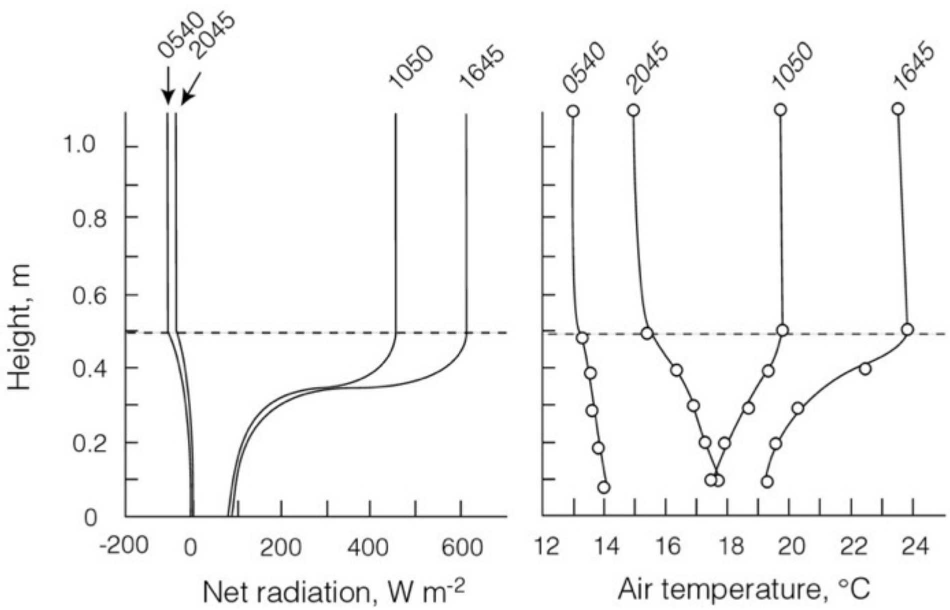




To reduce photoinhibition impacts, low-angle leaves are dropped in favor of steep-angles stems

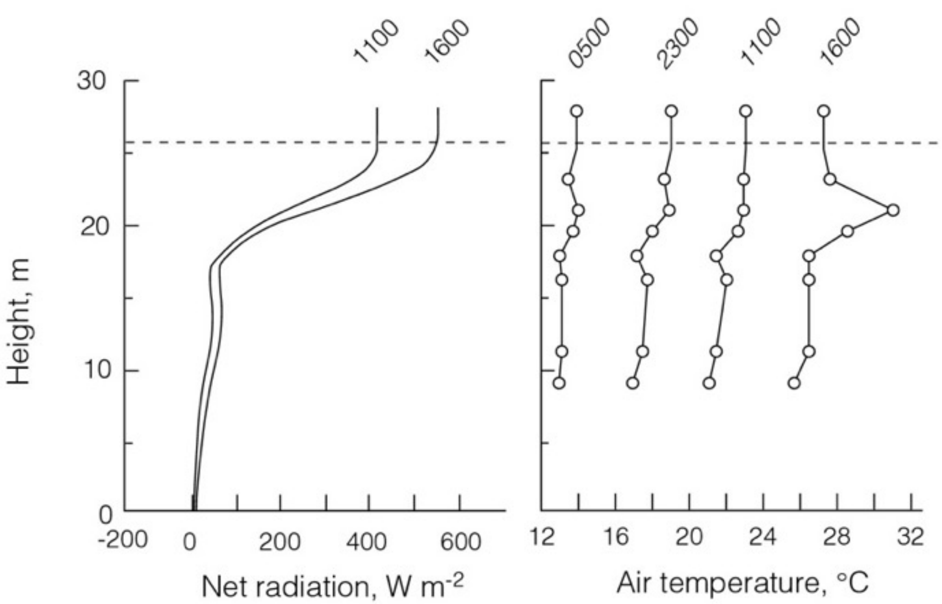

Part 3
Photosynthetic responses
to temperature changes

While changes in PFD throughout a canopy are large, variations in leaf temperature within a canopy tend to be low.

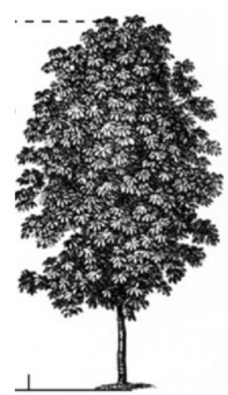


pasture

Thus, there are far greater intra-canopy adjustments to changes in light than to temperature.



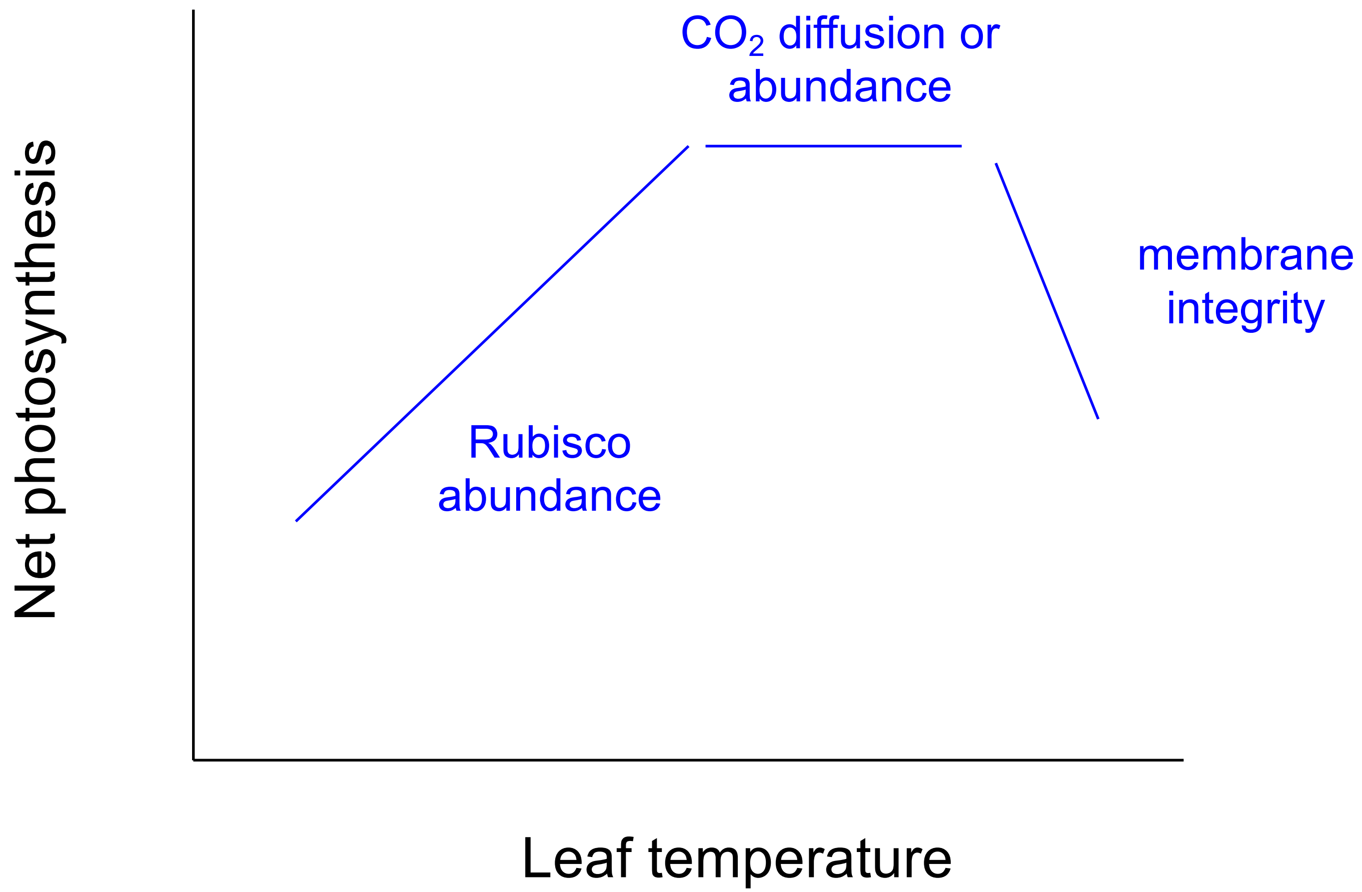
forest



However, position within the micro-climate profile can be an important factor.

Leaf temperature adjustments are largely a response to either season or microclimate.

There are three fundamental constraints (limits) to the response curve of leaf photosynthesis to temperature (assuming adequate PFD and CO_2)



And therefore, there are three solutions to increase photosynthesis

Tidestromia oblongifolia

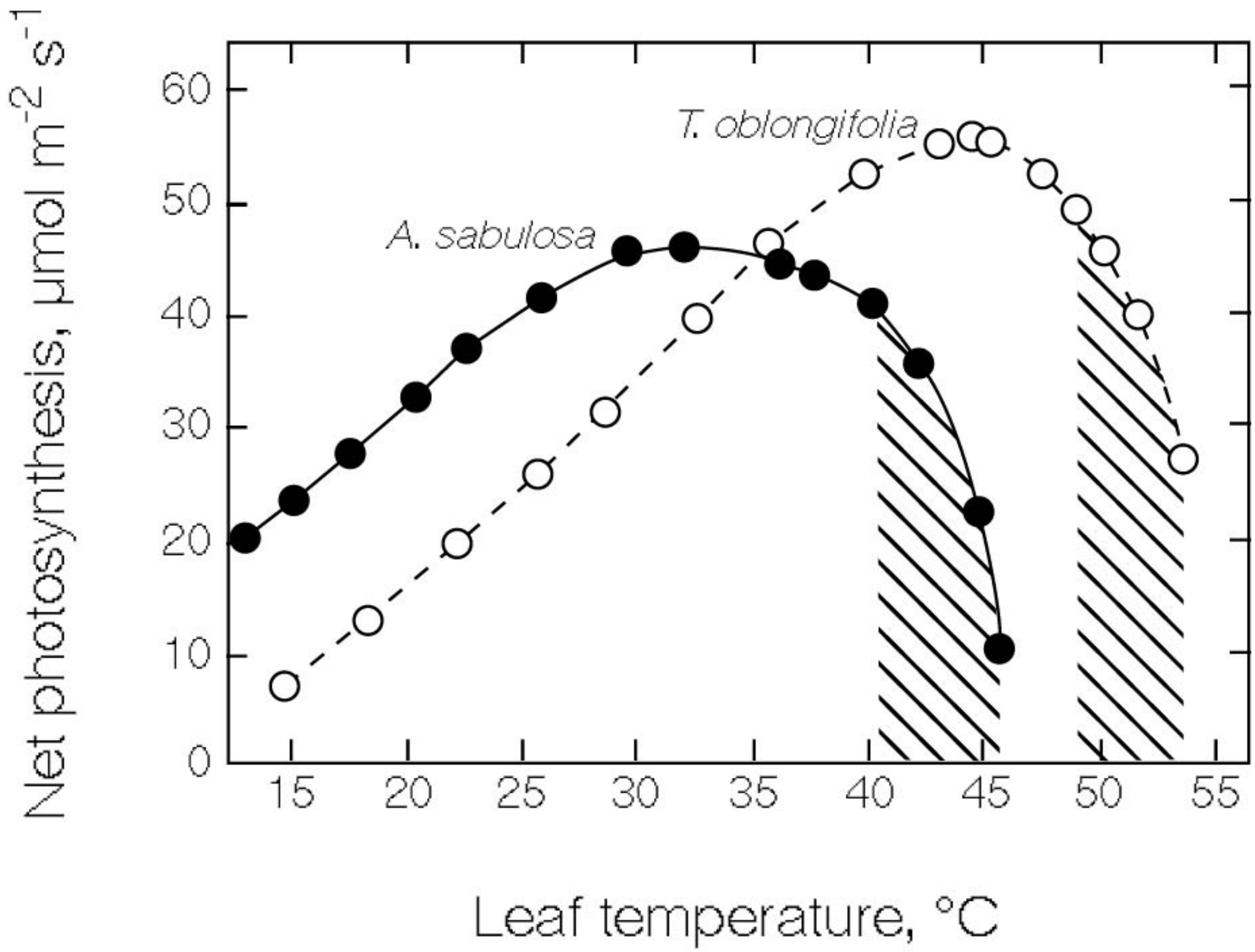
857. Atriplex sabulosa Rouy.
A. rosea L.
Frosted Orache.

Tidestromia oblongifolia = desert

Atriplex sabulosa = coastal

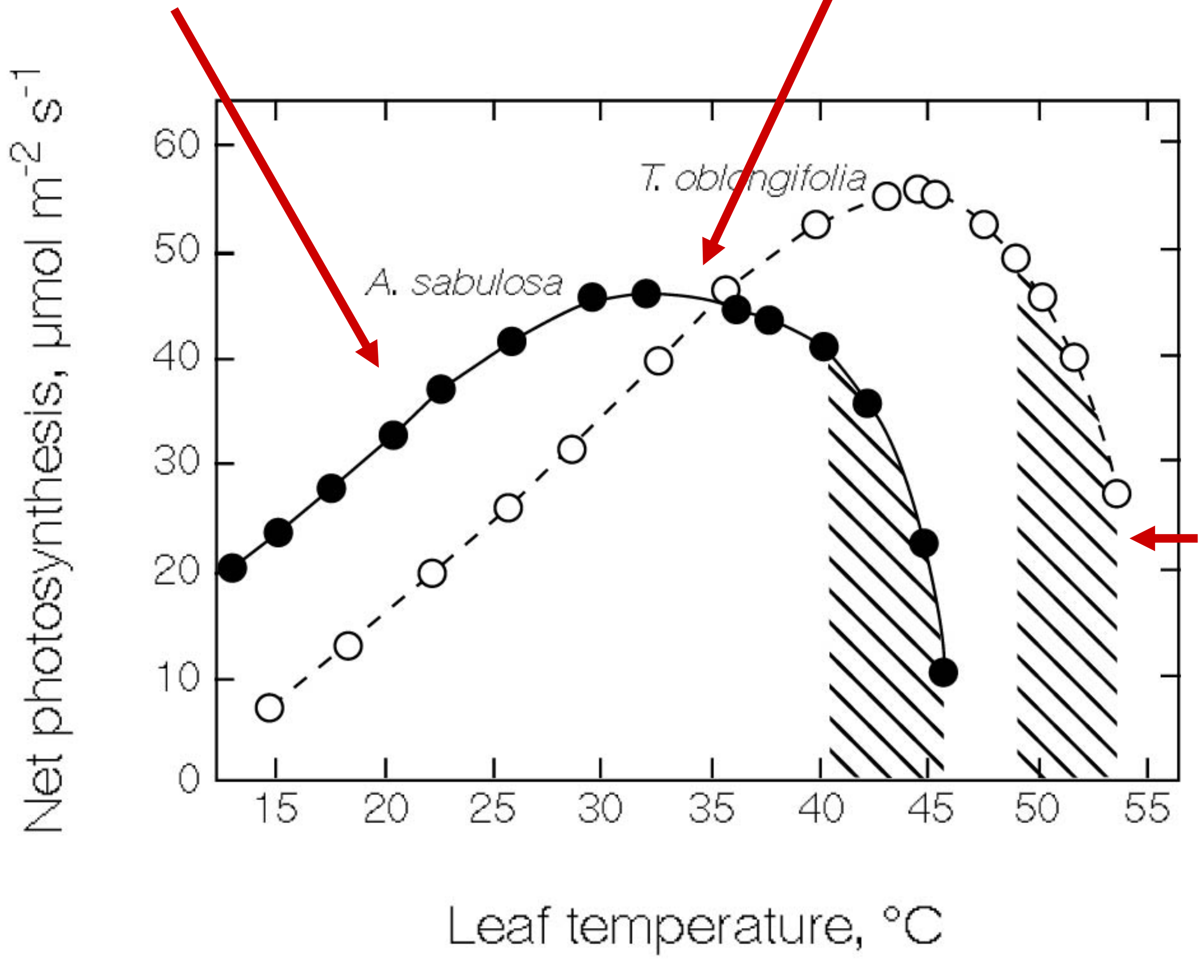
both are C_4-photosynthesis plants

In a high PFD environment, photosynthesis is often very temperature sensitive

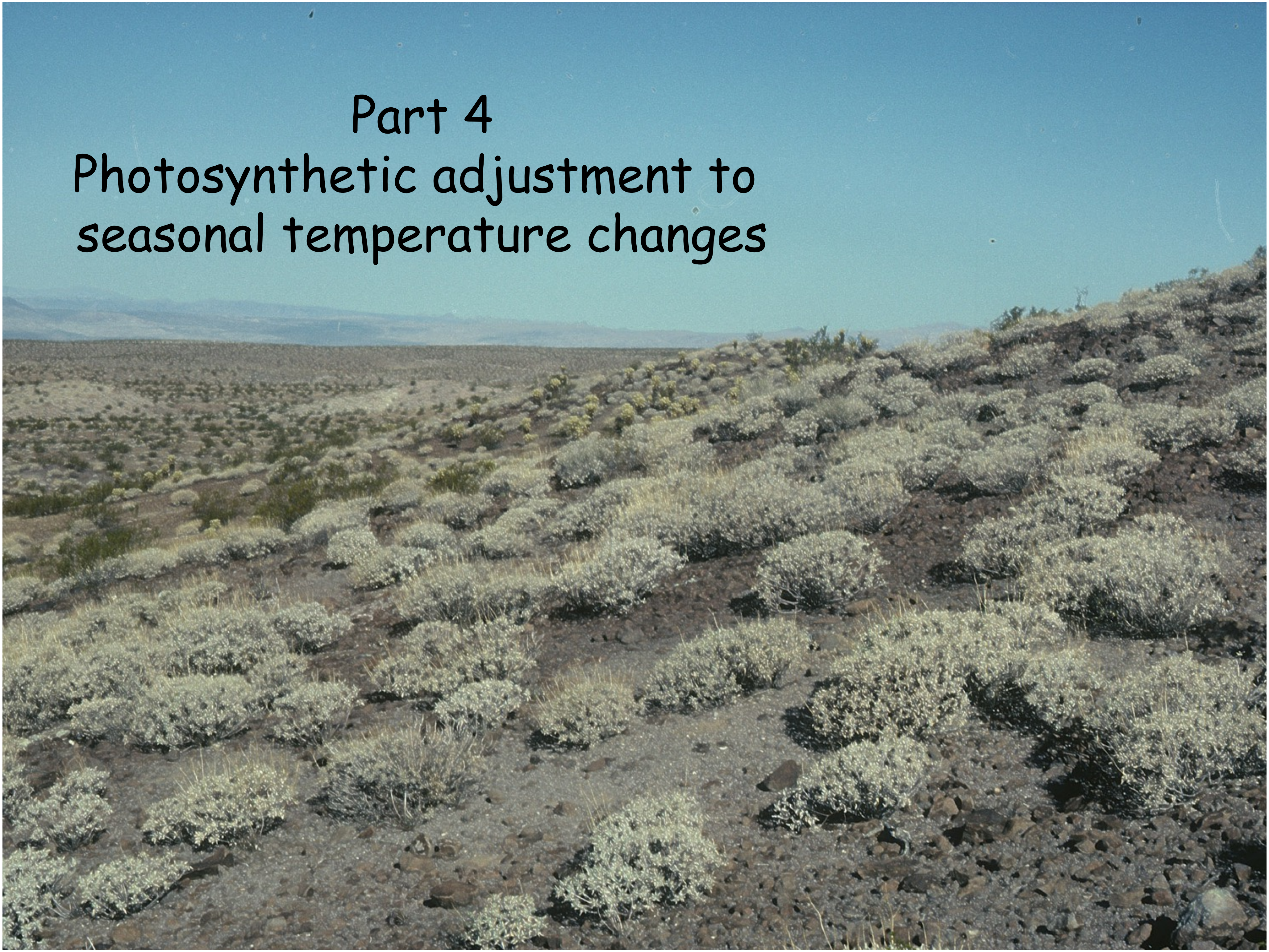


At low temperatures, photosynthesis is limited by enzyme concentration.

At temperatures in-between, photosynthesis is limited by CO_2 diffusion.

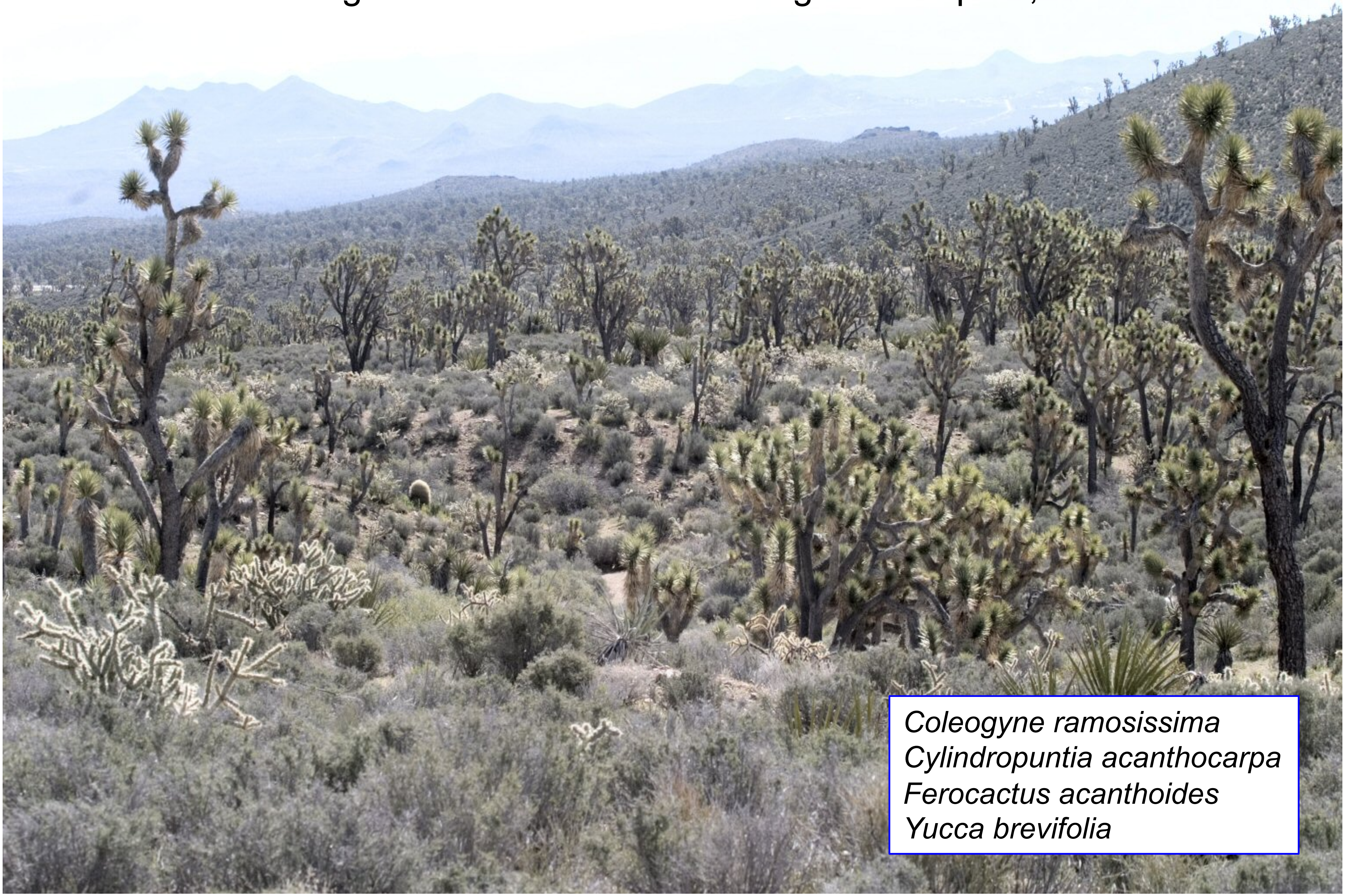


At high temperatures, photosynthesis is limited by membrane integrity.


Part 4
Photosynthetic adjustment to
seasonal temperature changes

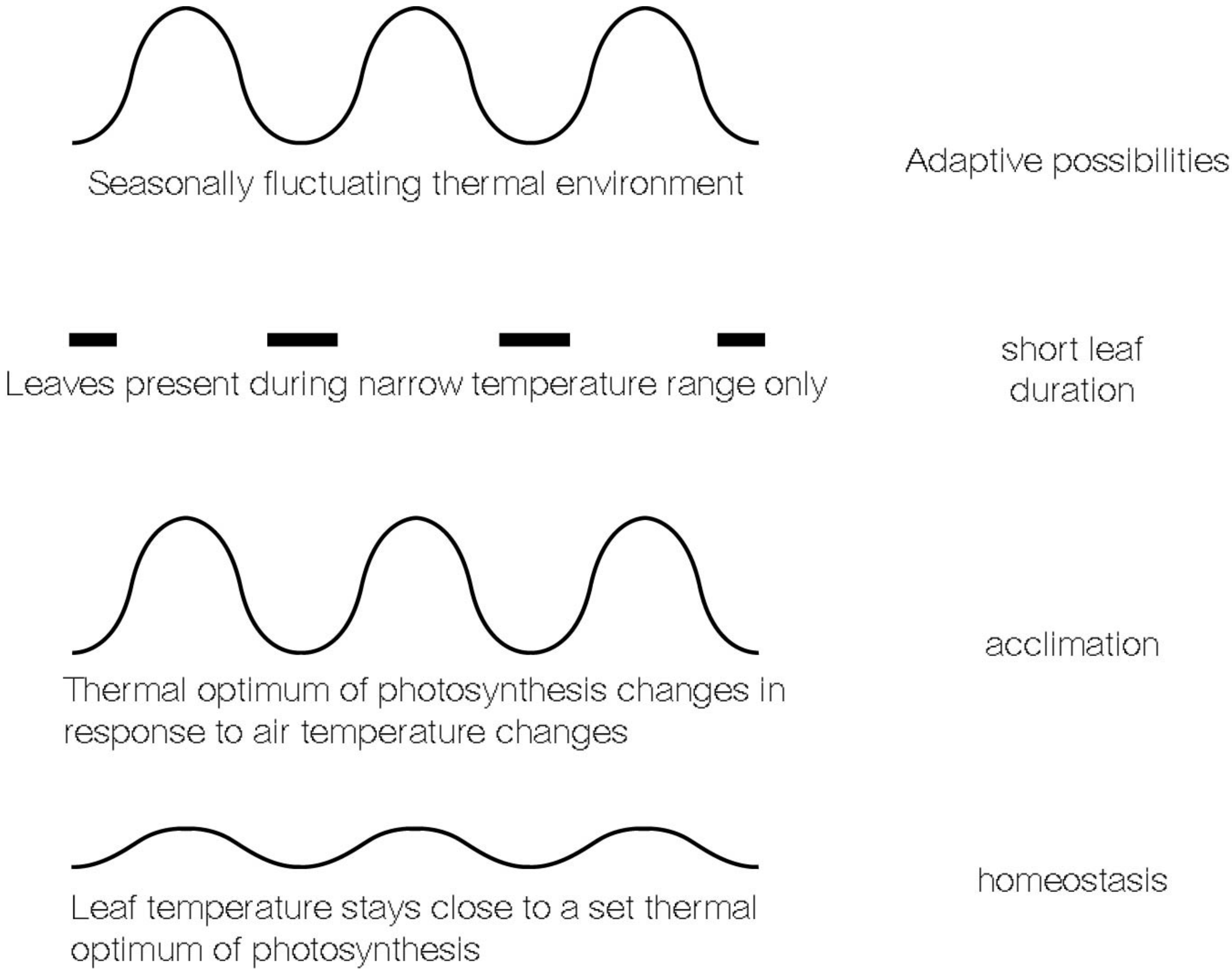
Many environments experience extremes in **cold** temperatures, such as here in the Wasatch Mountains near Alta

Many environments experience extremes in **hot** temperatures, such as here in the high desert between Searchlight and Tipton, Nevada



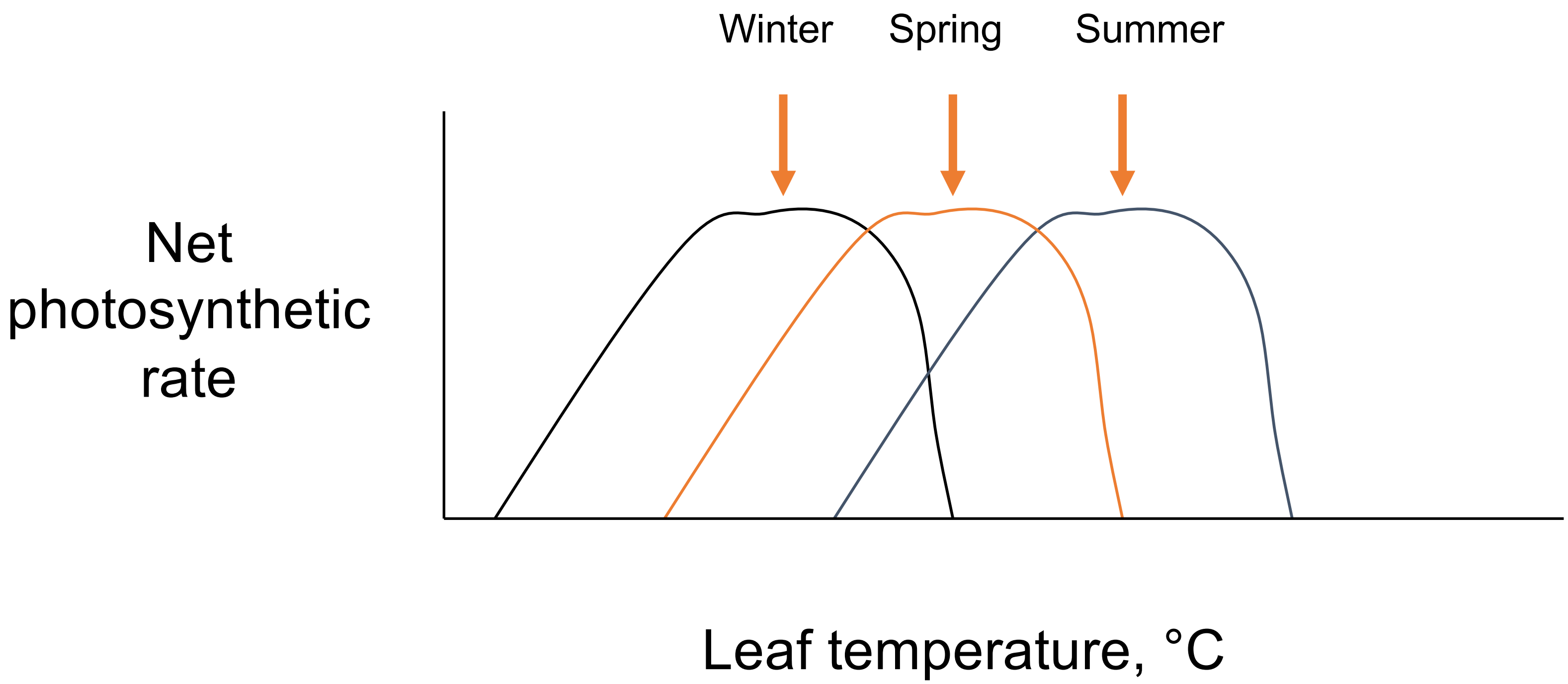
Coleogyne ramosissima
Cylindropuntia acanthocarpa
Ferocactus acanthoides
Yucca brevifolia

Both biochemical and morphological changes occur as leaves acclimate to seasonal temperature changes in a habitat

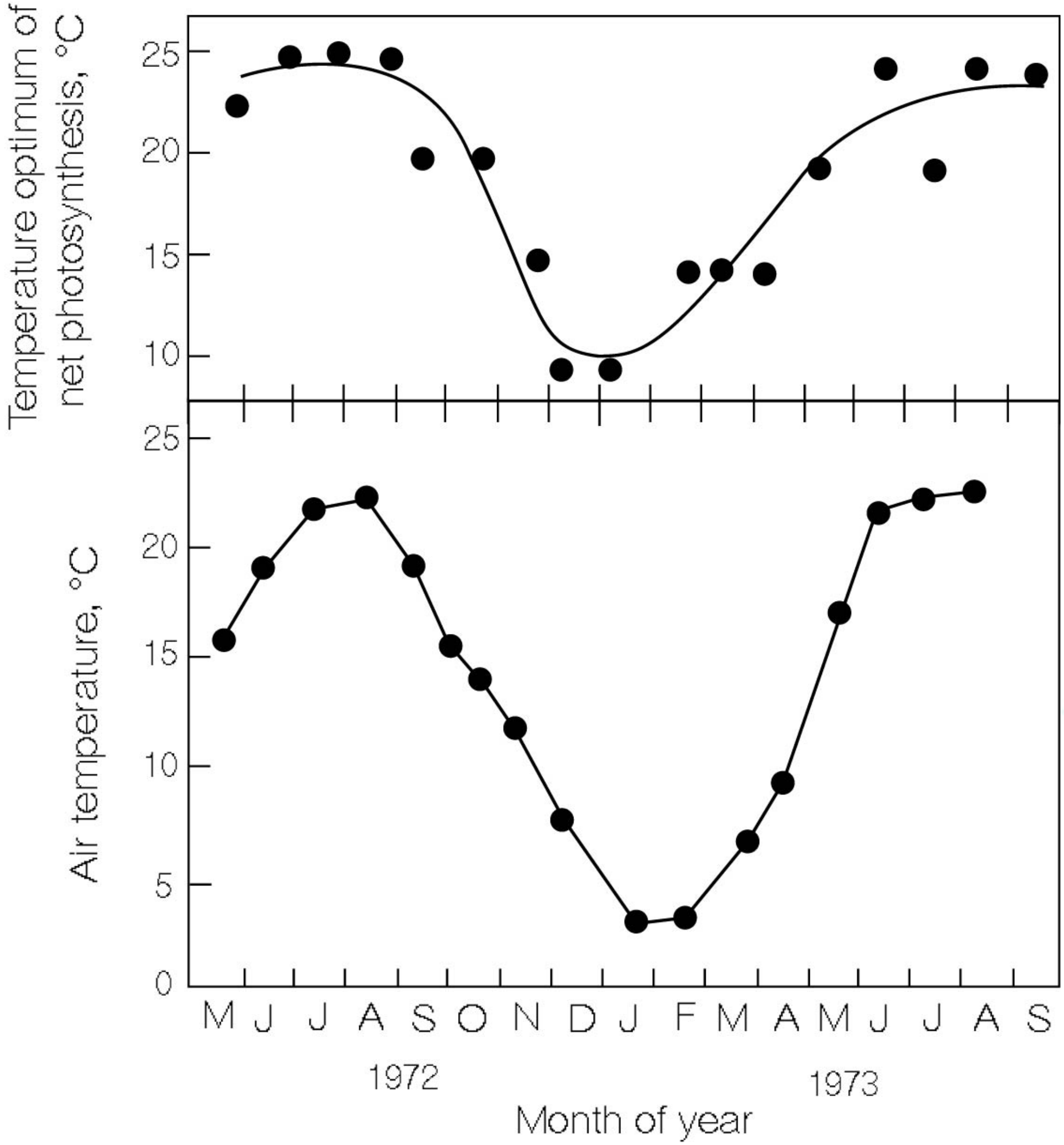


Larrea tridentata

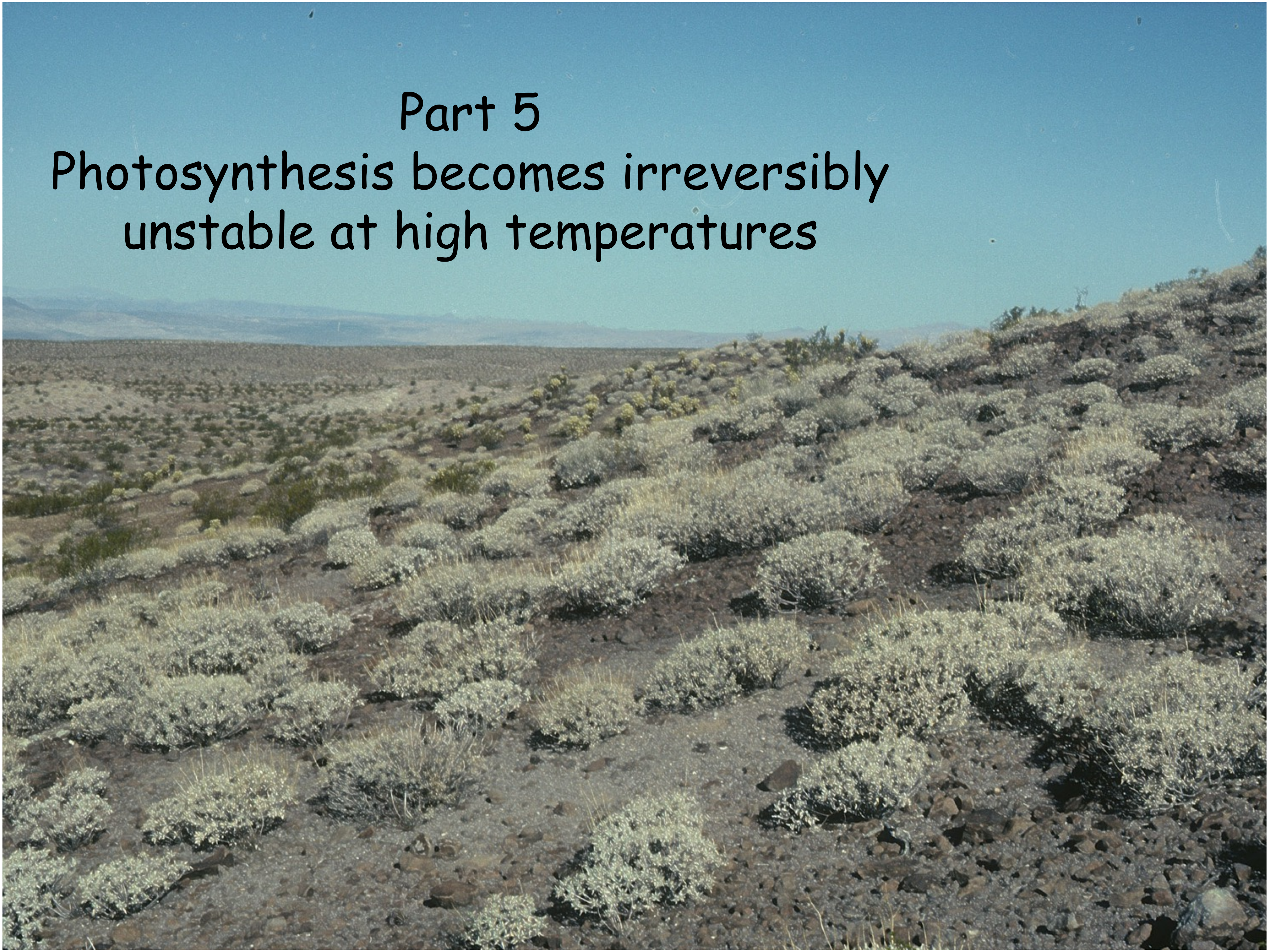
Larrea leaves are long-lived and exhibit a photosynthetic temperature acclimation



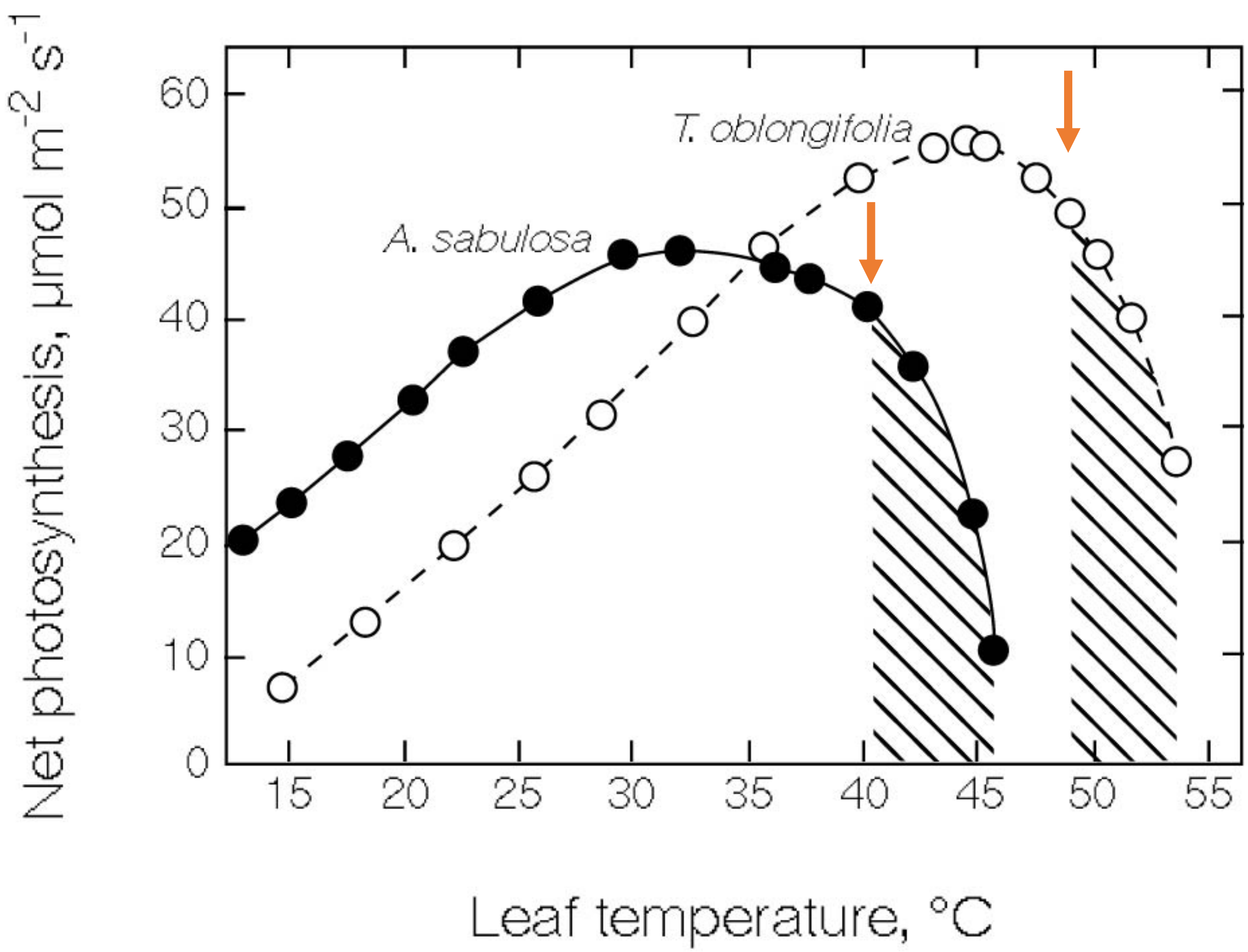
Many evergreen species exhibit biochemical adjustments to temperature

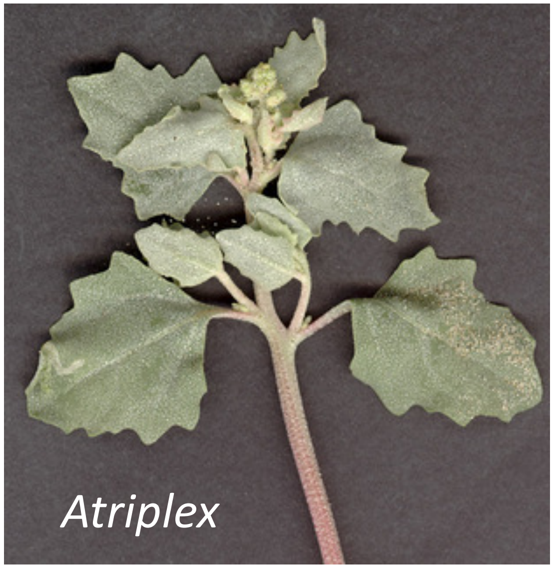


Pinus taeda, loblolly pine

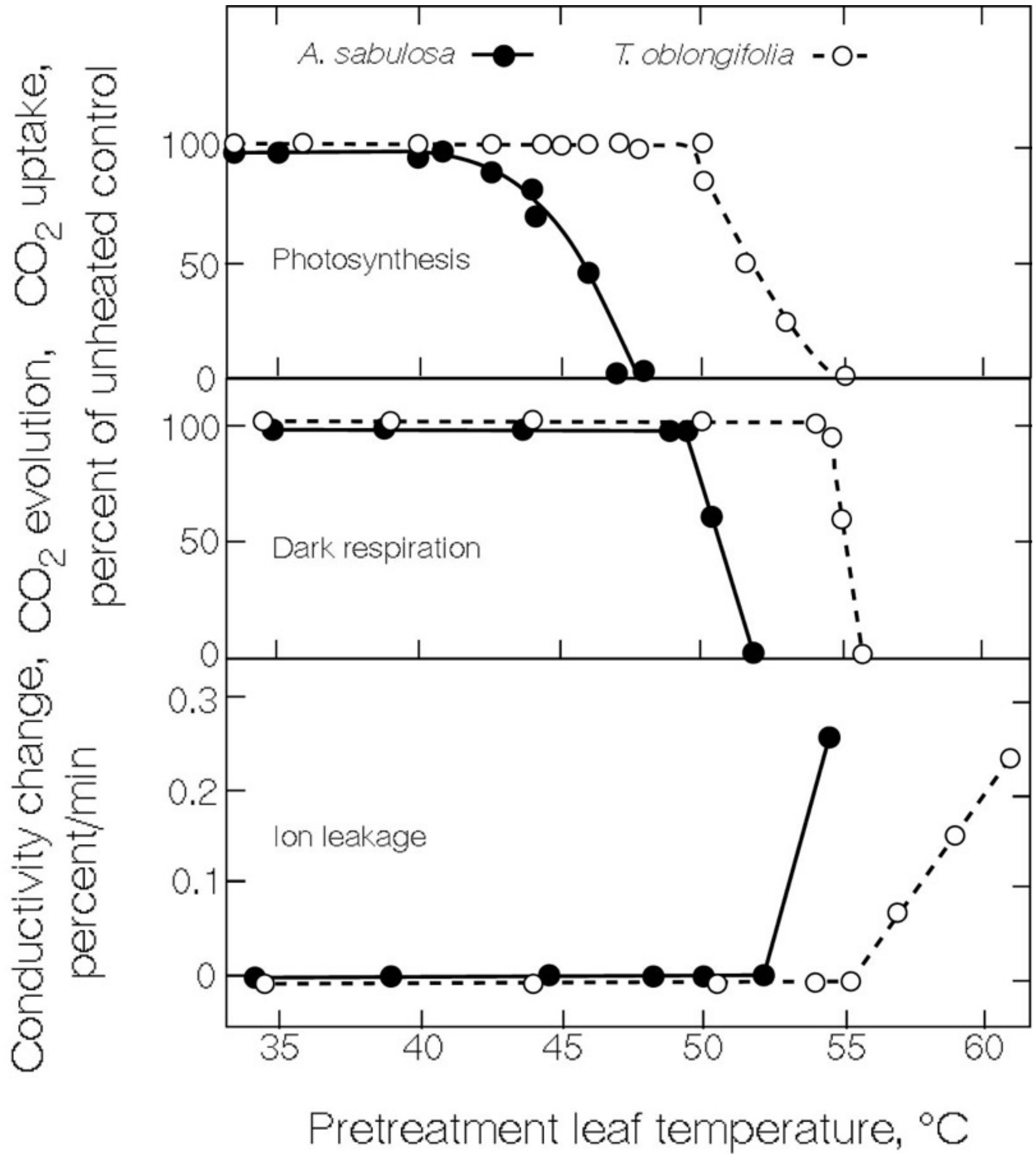

Part 5
Photosynthesis becomes irreversibly
unstable at high temperatures

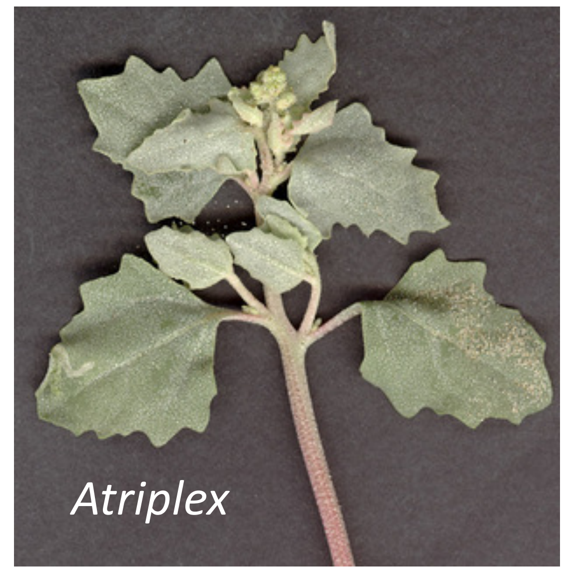
Why does photosynthesis become unstable at high leaf temperatures?





Neither changes in respiration rate nor ion leakage contribute to photosynthetic decline



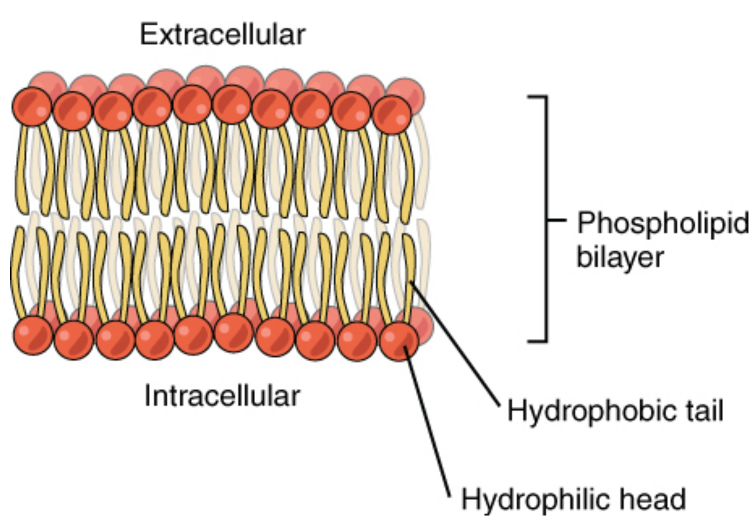


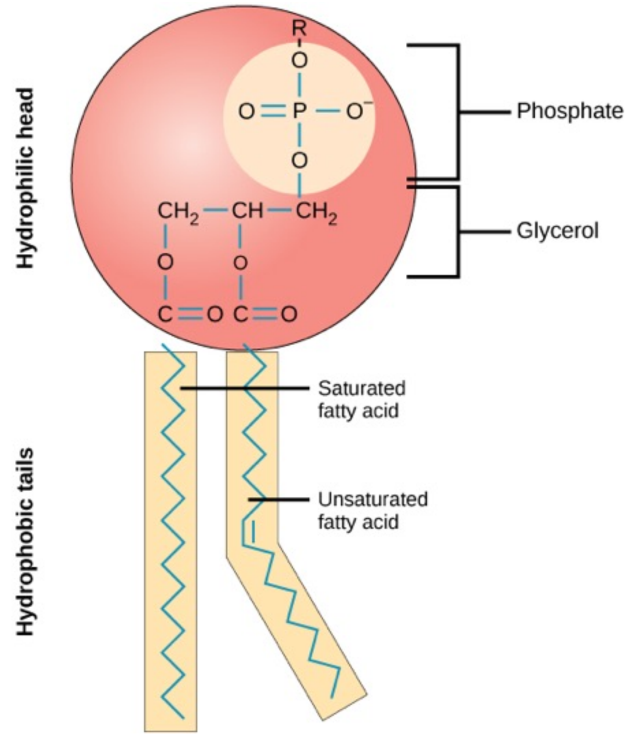
And there are changes in the polar lipid composition when plants are grown at different temperatures

Table I. *Fatty Acid Composition of Total Polar Lipids From Leaves of Nerium oleander Grown at 20/15°C or 45/32°C*

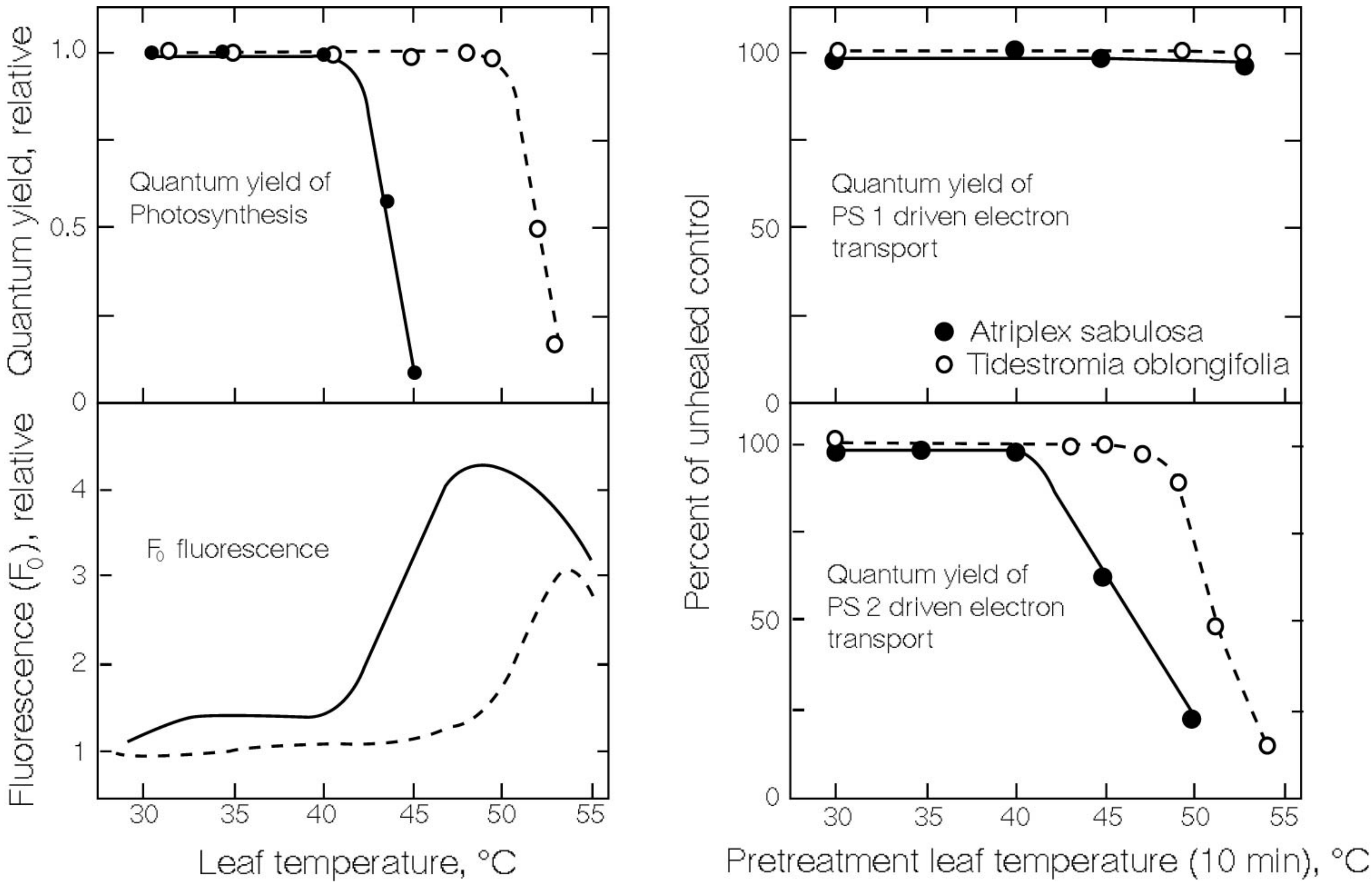
All data are the mean of three determinations on single polar lipid samples; $\sigma \simeq \pm 0.05 \times$ mol %.

Growth Temperature	Fatty Acid					
	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$
°C	*mol %*					
20/15	16.0	0.8	2.2	3.7	13.7	63.2
45/32	19.0	1.0	4.7	11.2	16.3	47.8





The photosynthetic decline with temperature is associated with PS II instability



Encelia farinosa, near Vidal Junction, CA