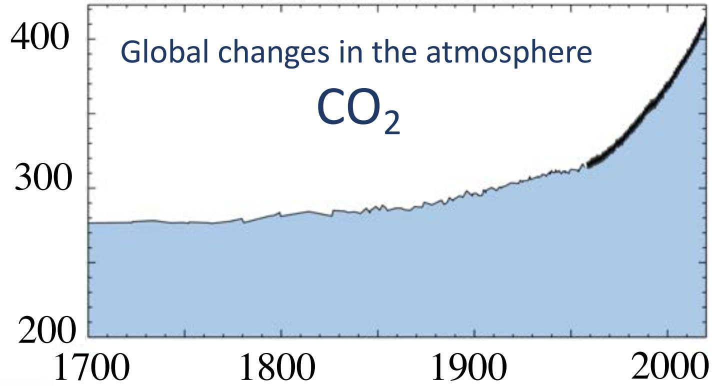


Topic 11

Photosynthesis

(5 parts)

Plant Ecology in a Changing World

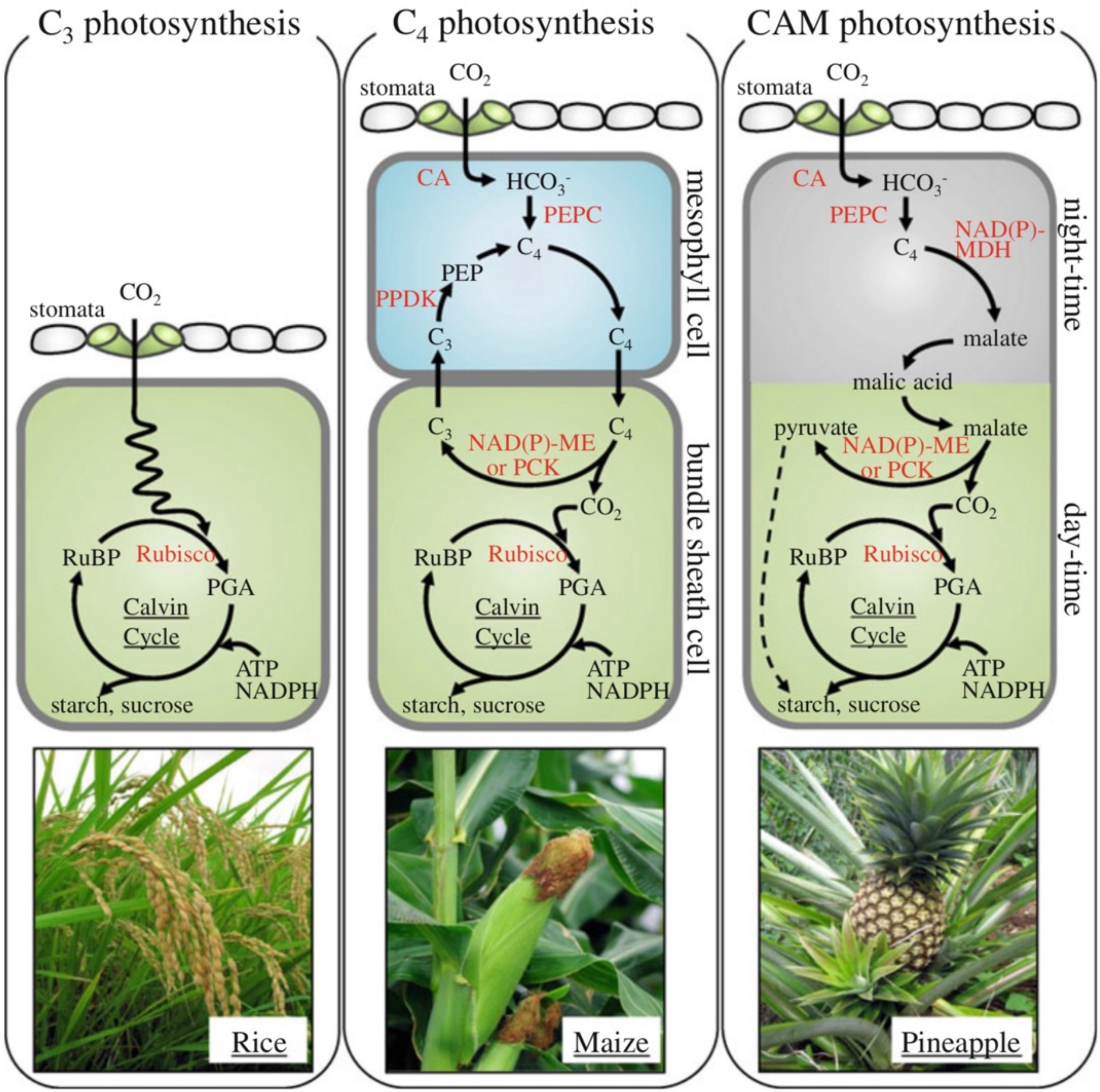
Jim Ehleringer, University of Utah
http://plantecology.net

First an overview
of different dark reaction pathways

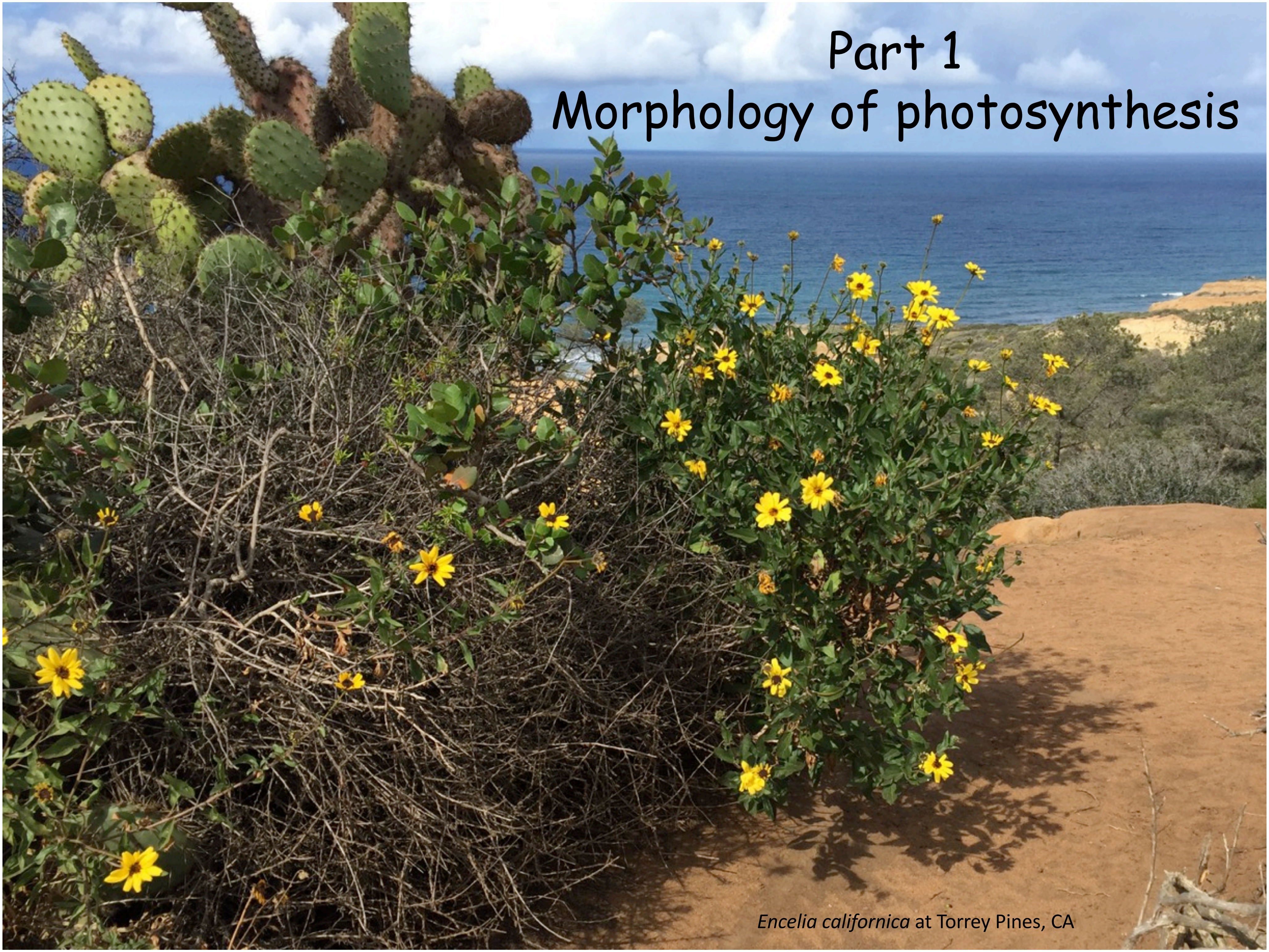
C_3 ancestral

C_4 derived
more in topic 25

CAM (derived)
more in topic 15



Part 1
Morphology of photosynthesis



Encelia californica at Torrey Pines, CA

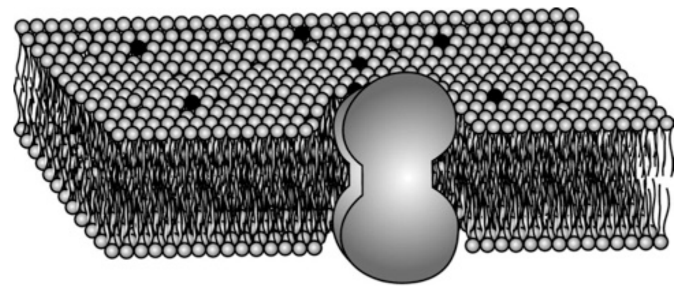
Photosynthesis is a process
distinguishing plants from animals

Another is mobility.

Given the autotrophic dependence and general immobility, a number of adaptation in plants that allow them to persist through rather large changes in the quality of the physical environment.

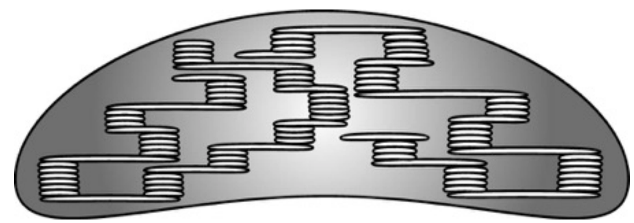
Here we will
- review fundamentals of leaf-level photosynthesis
- identify general photosynthetic relationships at the whole leaf level
- identify photosynthetic features responsive to natural selection

C_3 and C_4 photosynthesis requires the near-simultaneous capture of two resources and coordinated structure-function relationships:



photons

- depends on time, orientation, canopy position
- efficiency of light capture apparatus (absorptance, chlorophyll content)



once captured plants cannot move photons to different parts of the plant parts once captured

CO_2

- atmospheric CO_2 concentration
- CO_2 diffusion gradient (atmosphere to chloroplast)

plants don't breathe – no tidal volume changes
rely instead on diffusion through air
no significant long distance CO_2 transport

N.B., we will talk later about CAM photosynthesis, an exception, where CO_2 and photons are not taken up simultaneously

CO_2 diffusion barriers

medium dependent

maximize diffusion through air

minimize diffusion through water

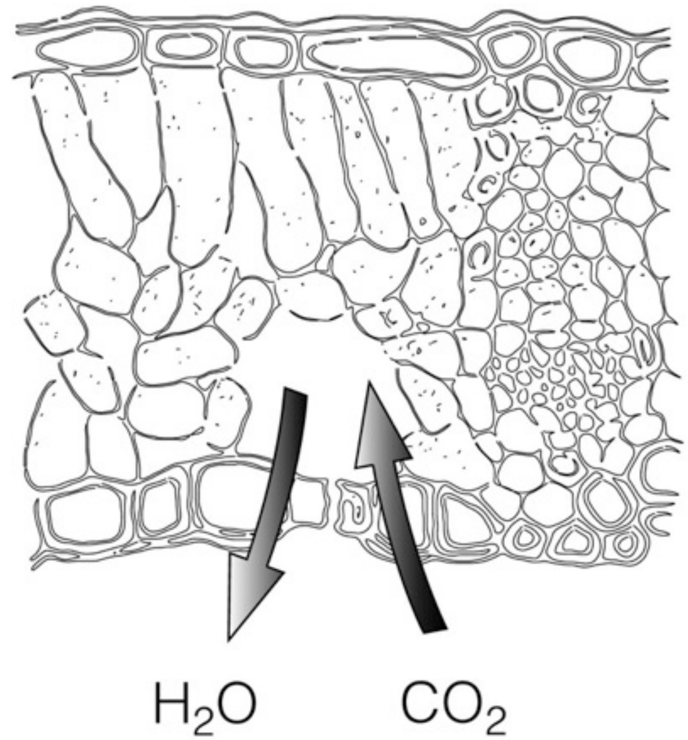
(diffusion constant @ 25 °C, $mm^2\ s^{-1}$)

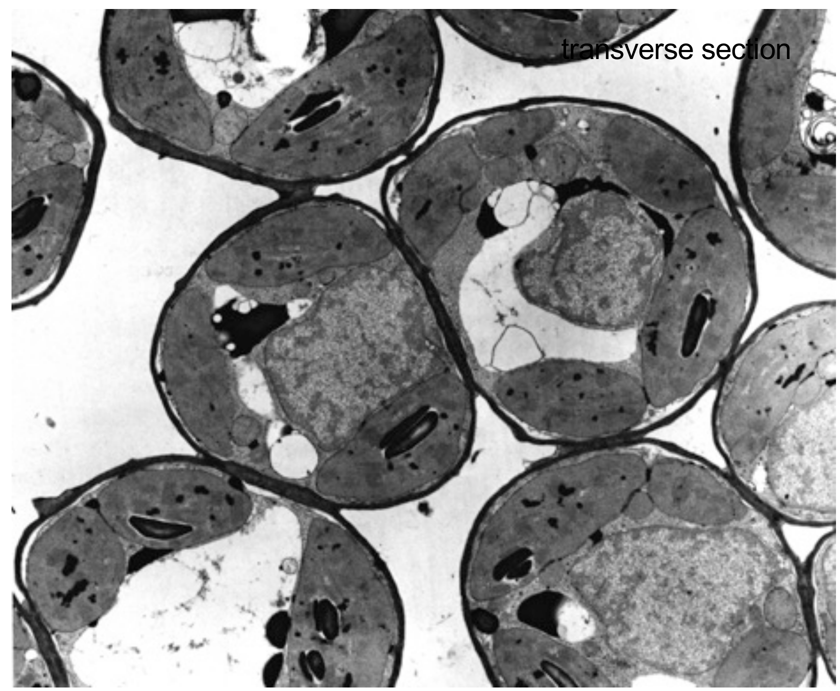
CO_2 in air	15.1
CO_2 in water	0.0016
HCO_3^- in water	0.0014
H_2O in air	24.9
H_2O in H_2O	0.0025

CO_2 solubility ($mm^3\ m^{-3}$) in water is low

10 °C	1.194
20 °C	0.878
30 °C	0.665

cross section

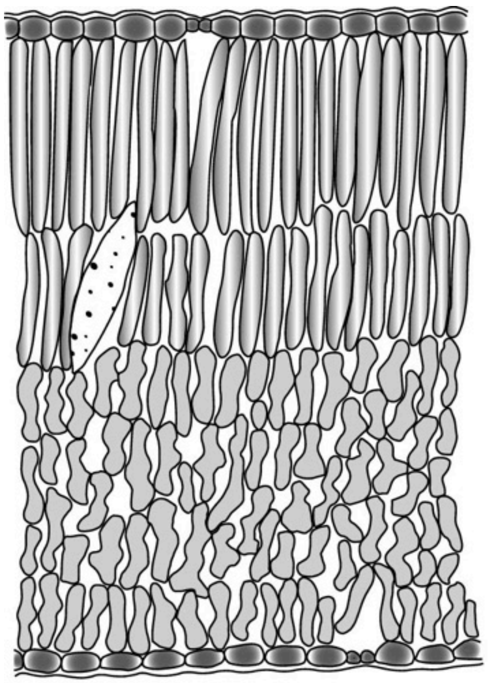




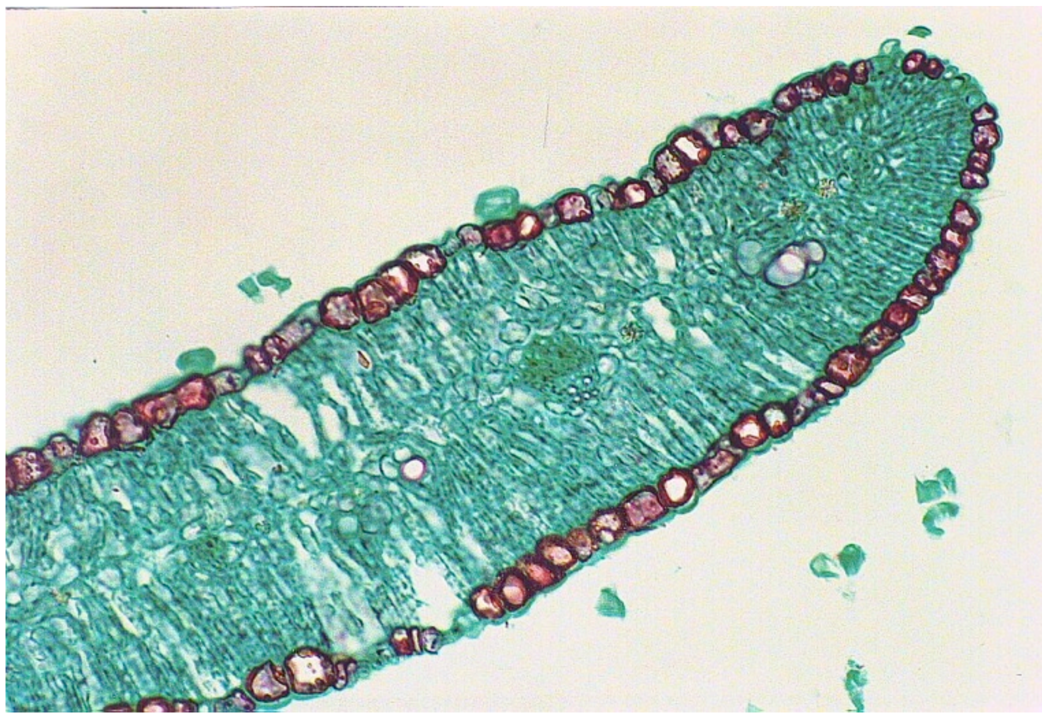
Although palisade cells on the top of leaf, there are variations to consider

Palisade cells on top of leaf only

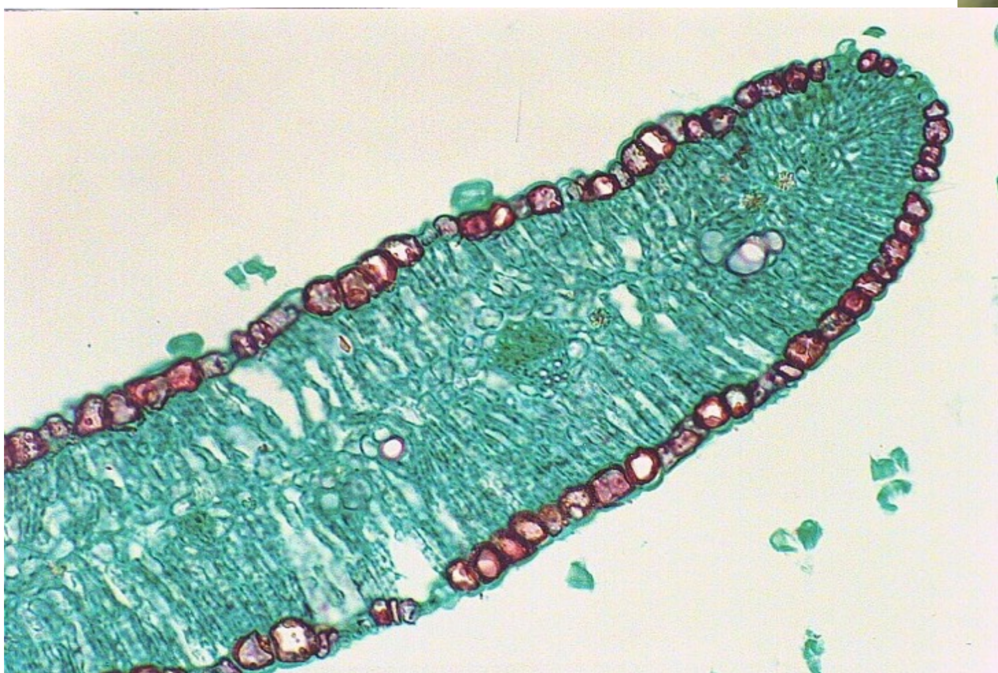
Palisade cells on both top and bottom of leaf



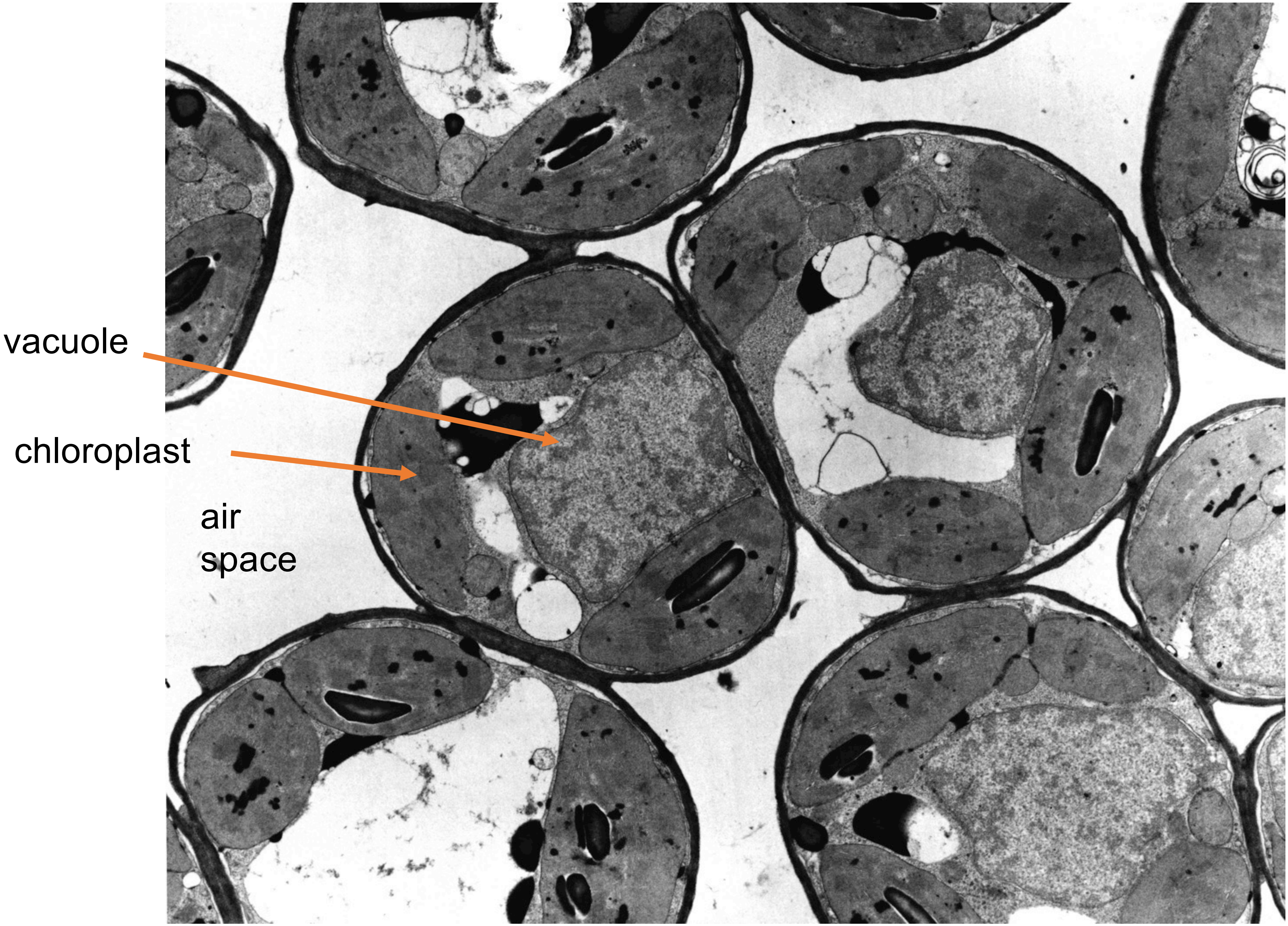
Full Sunlight

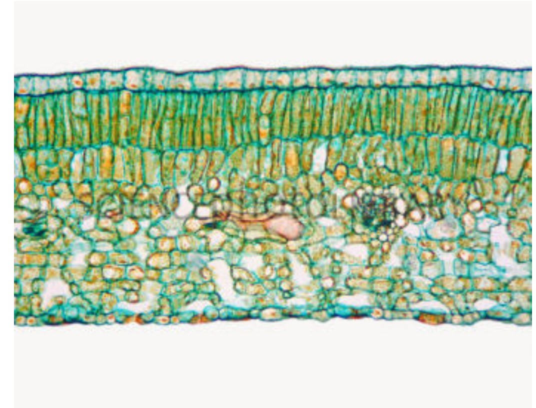


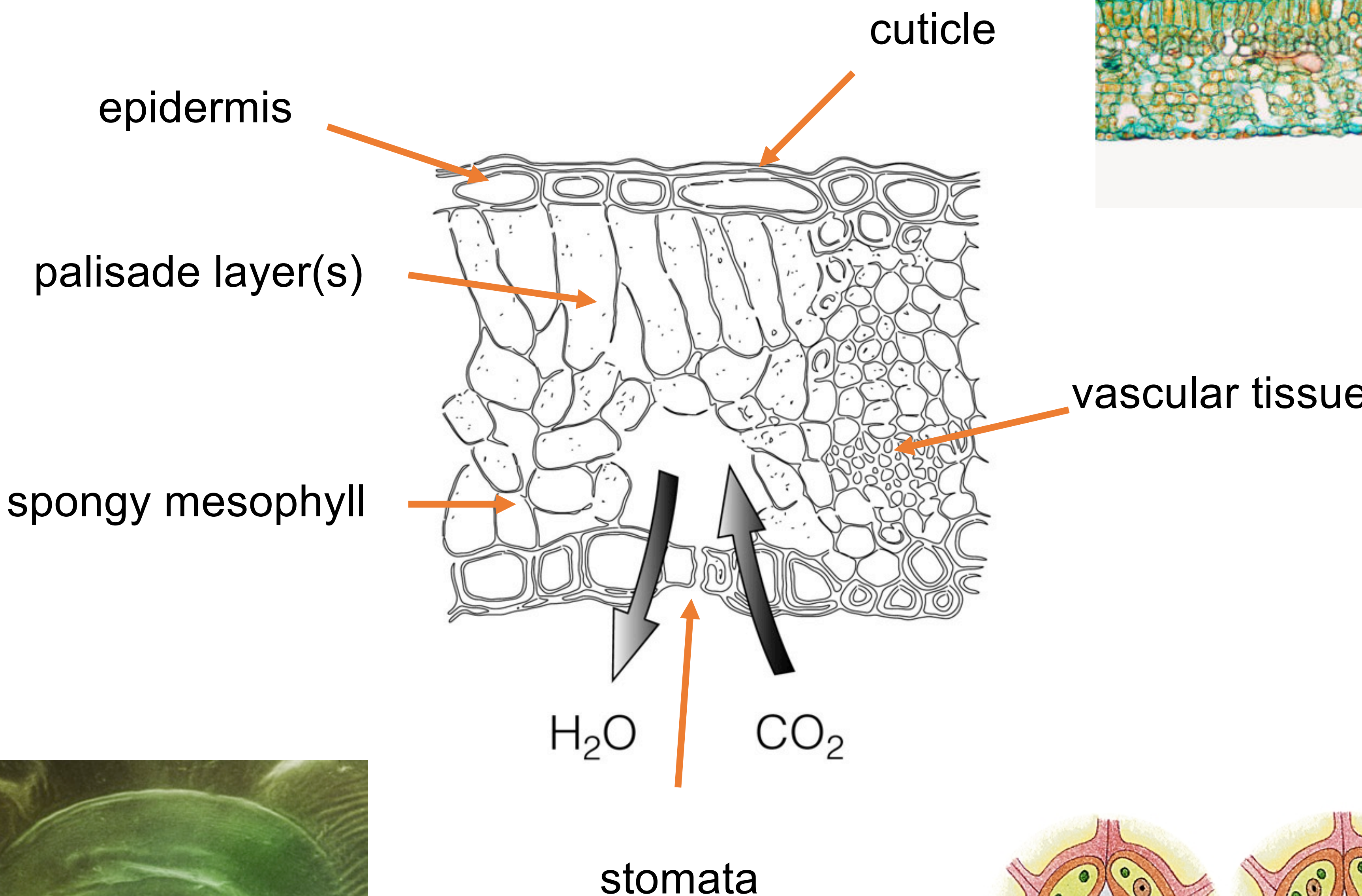
Larrea tridentata,
creosote bush

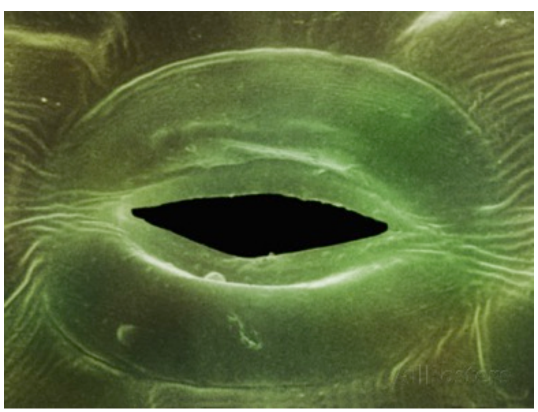


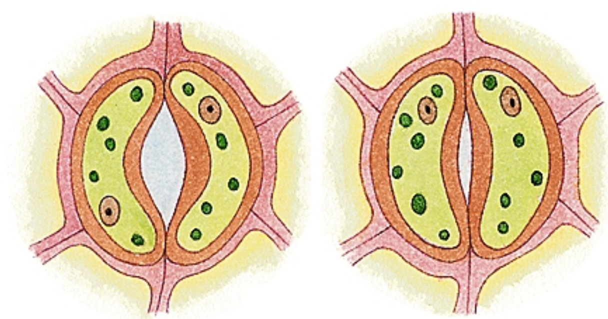
Transverse section through a leaf; note chloroplast position relative to air spaces

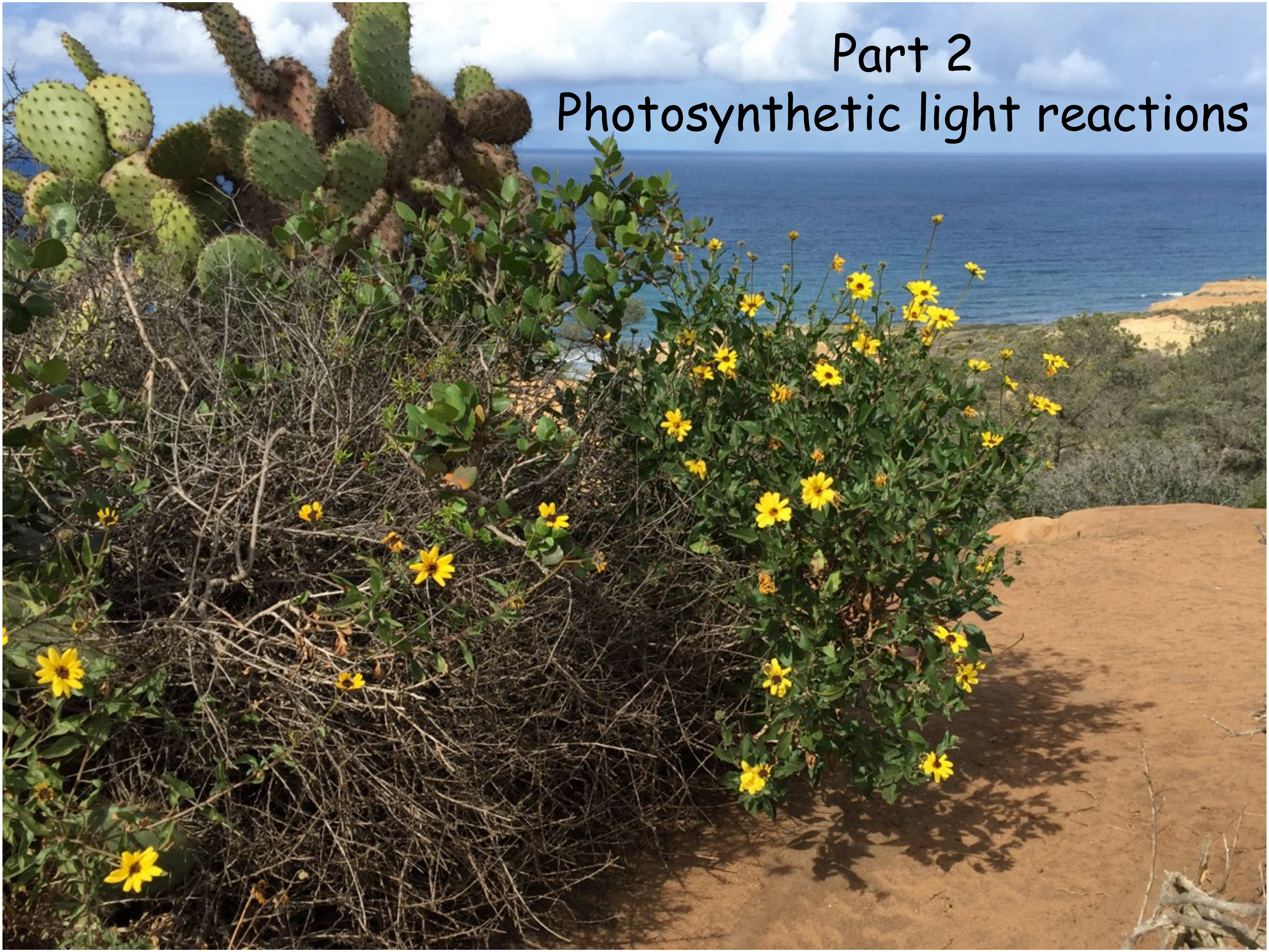


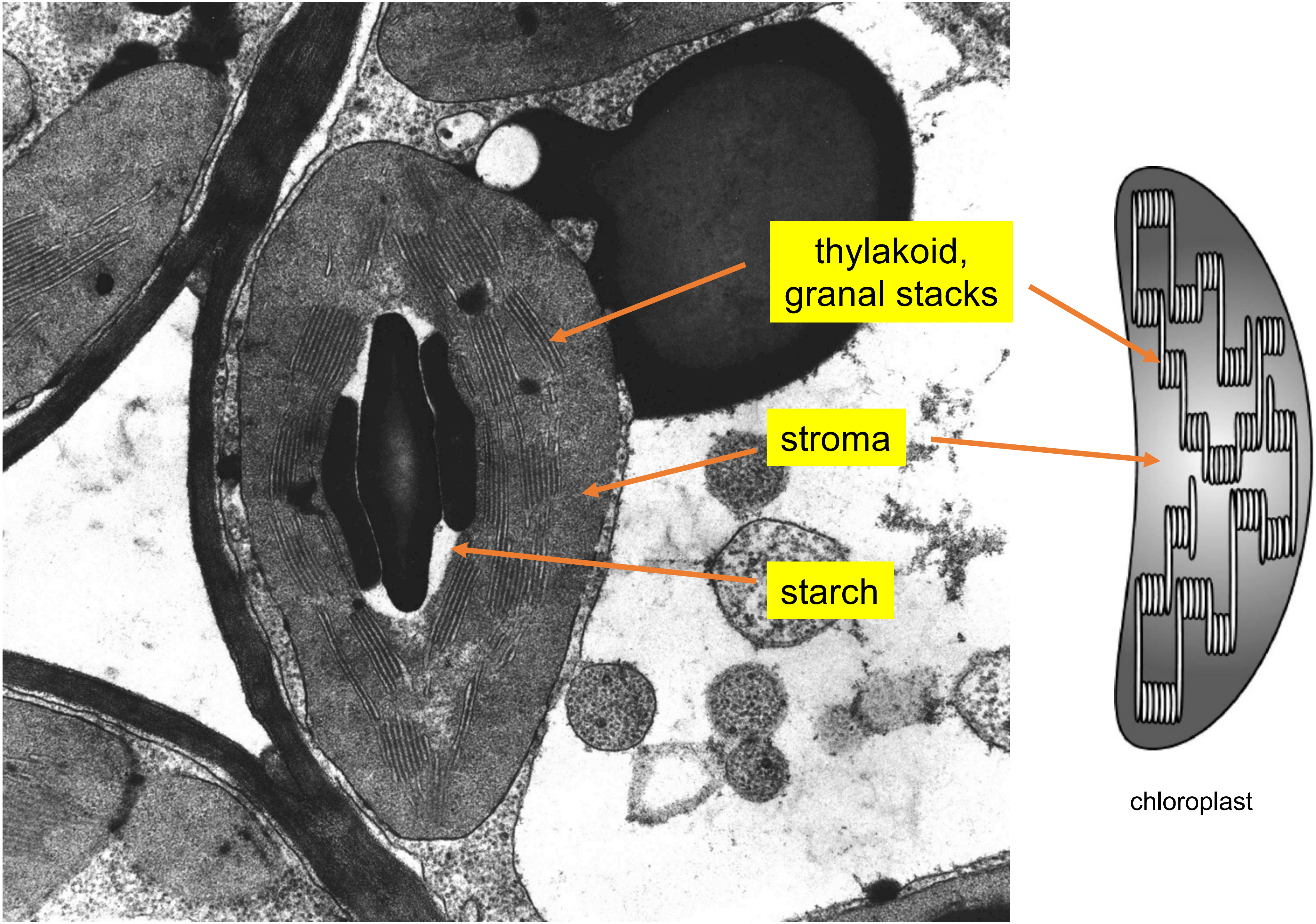



cuticle
epidermis
palisade layer(s)
vascular tissue
spongy mesophyll
H_2O
CO_2
stomata



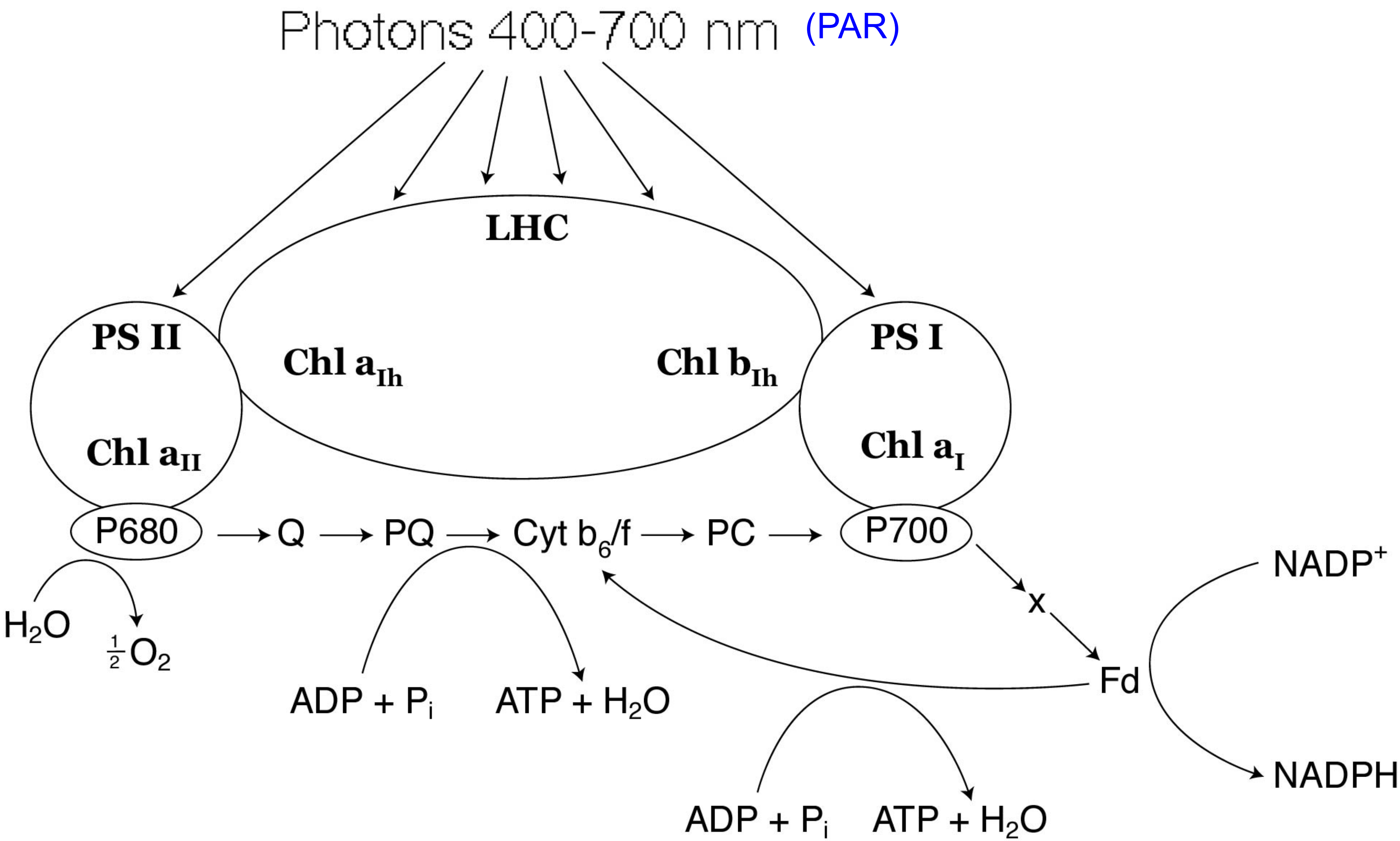



Part 2
Photosynthetic light reactions

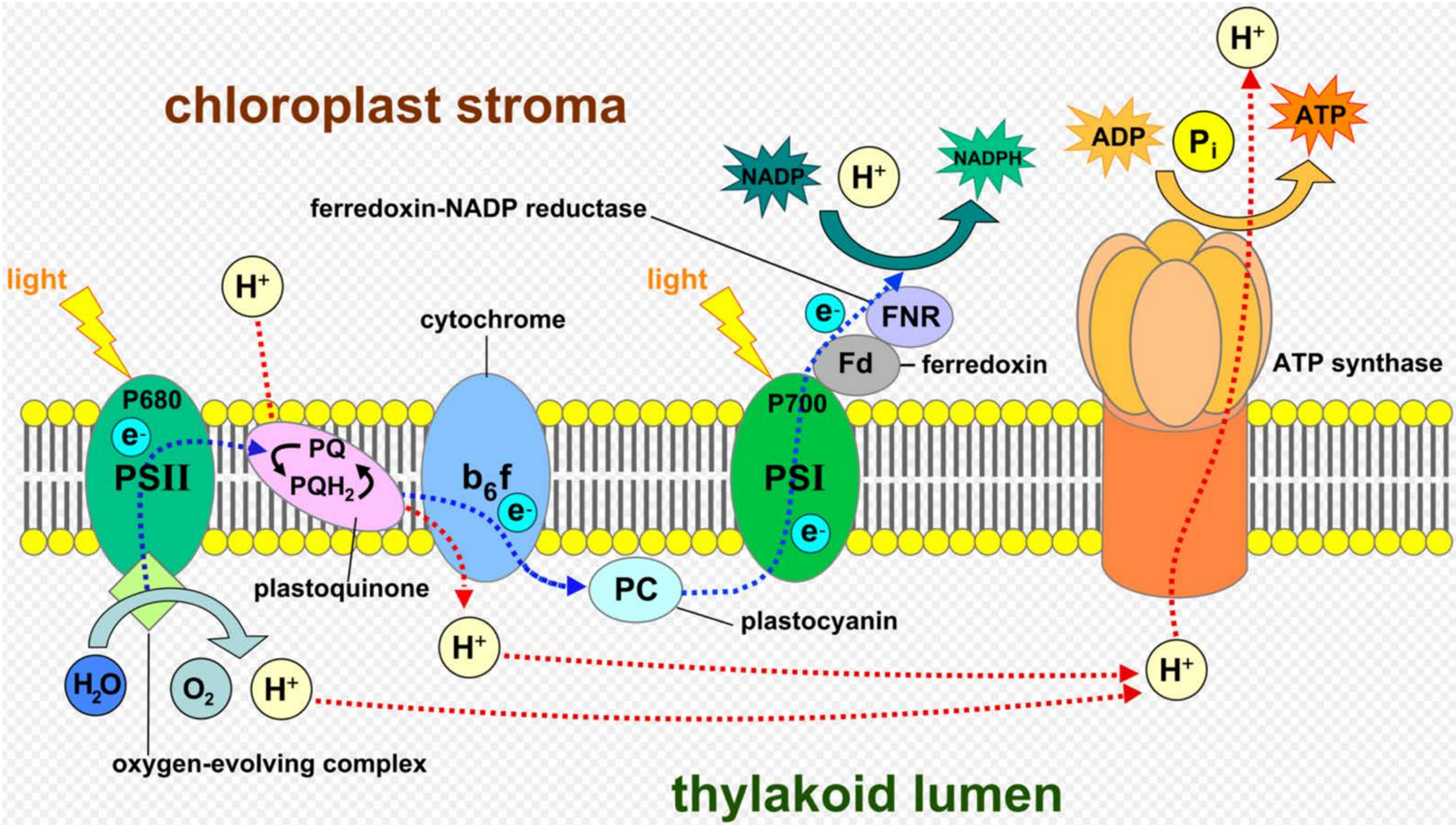


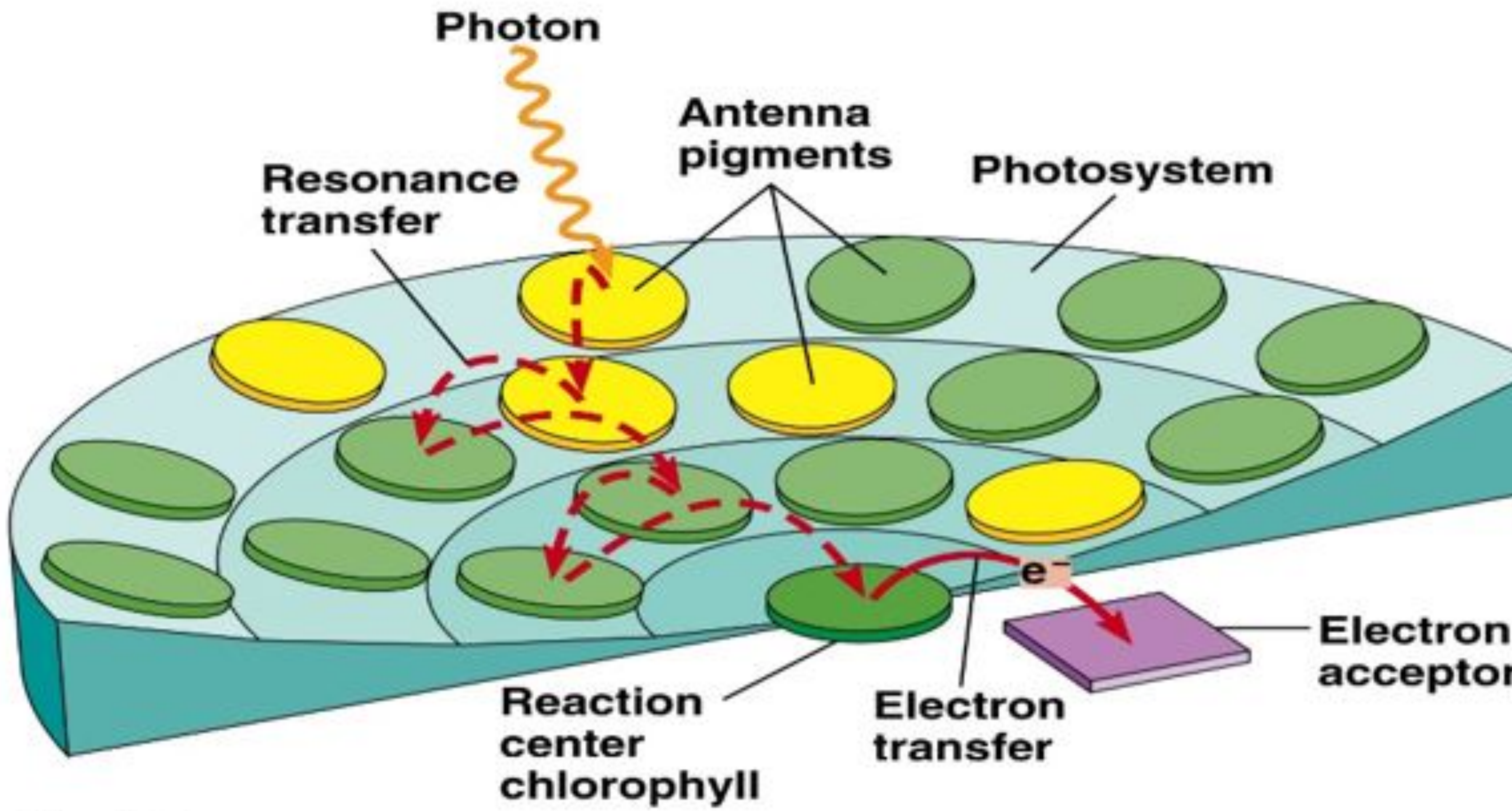
chloroplast

Light reactions of photosynthesis



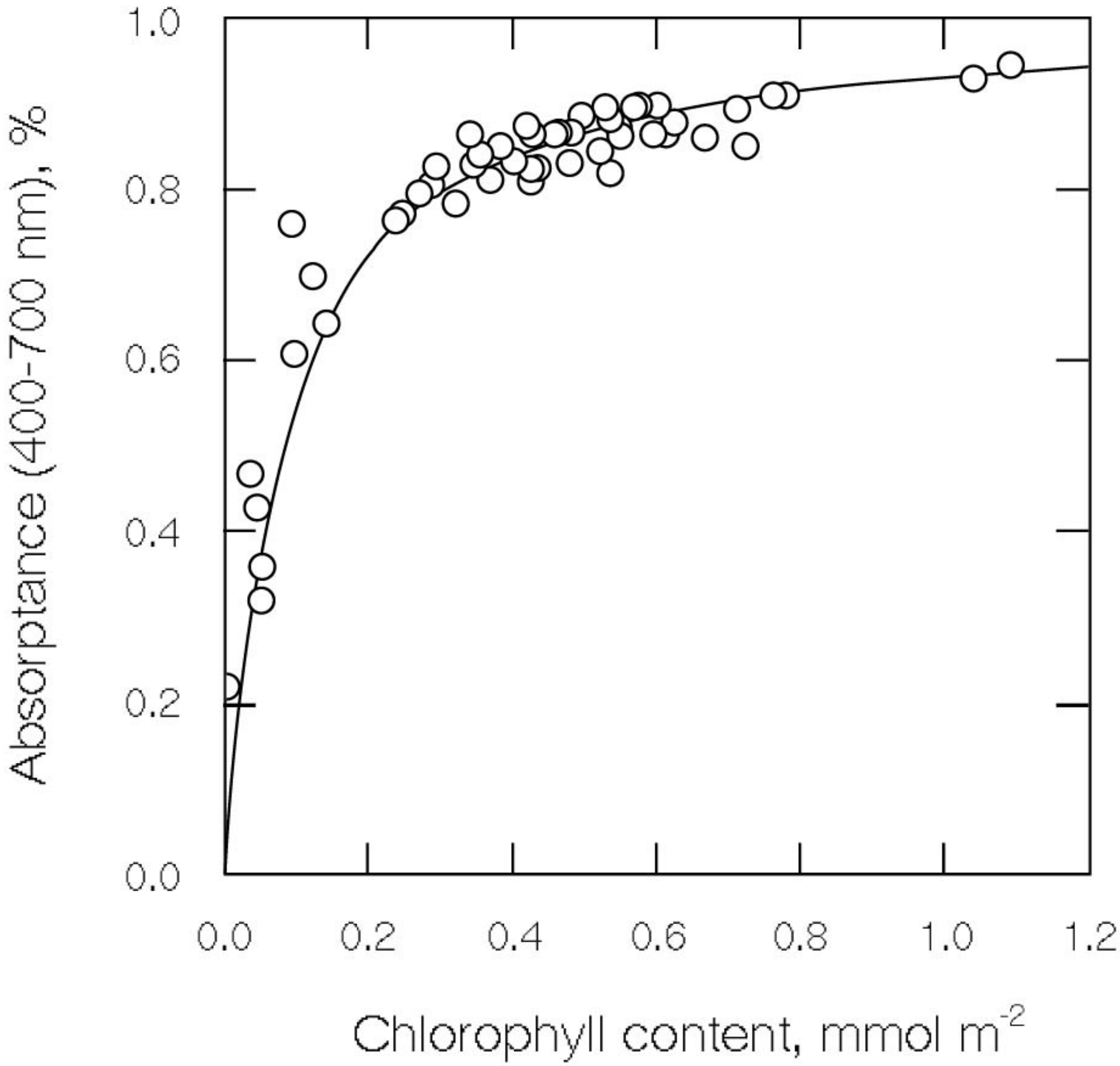
Light reactions of photosynthesis



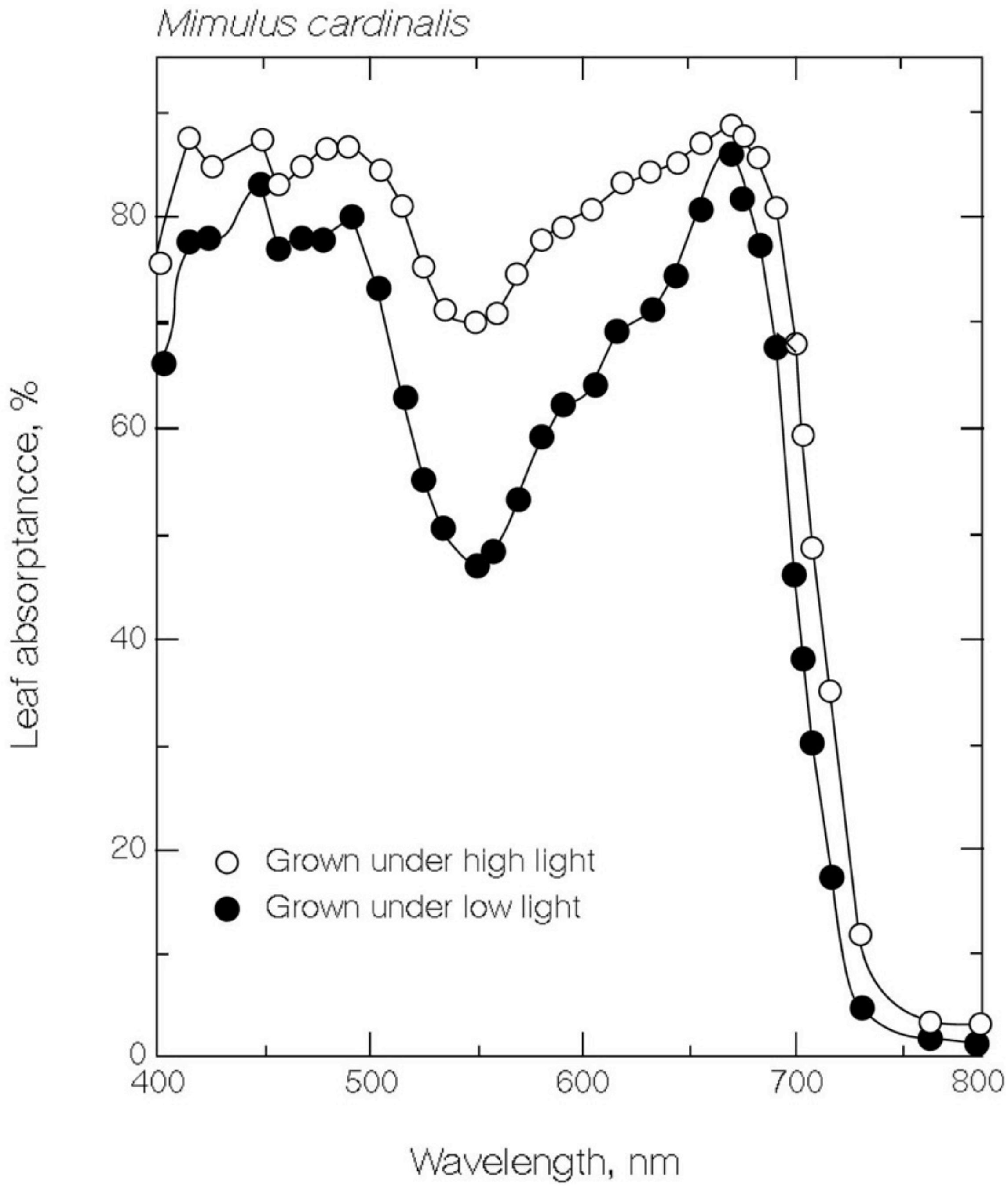

Photon
Antenna pigments
Resonance transfer
Photosystem
e⁻
Electron acceptor
Reaction center chlorophyll
Electron transfer

Leaves absorb 85% of all PAR, even at low chlorophyll concentrations

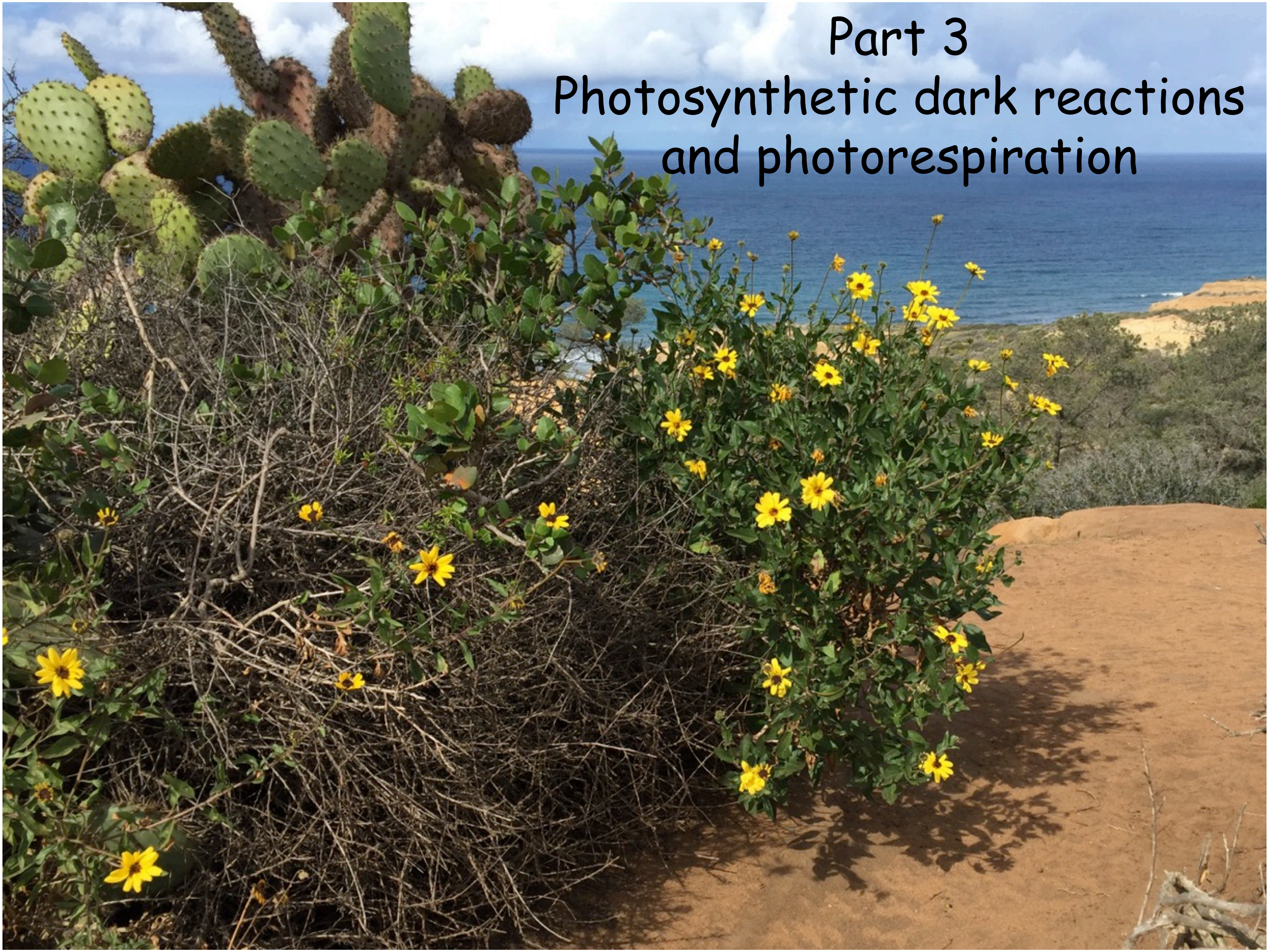
So why should there be variations in leaf chlorophyll content?



Leaf absorption spectrum mimics chlorophyll absorption spectrum



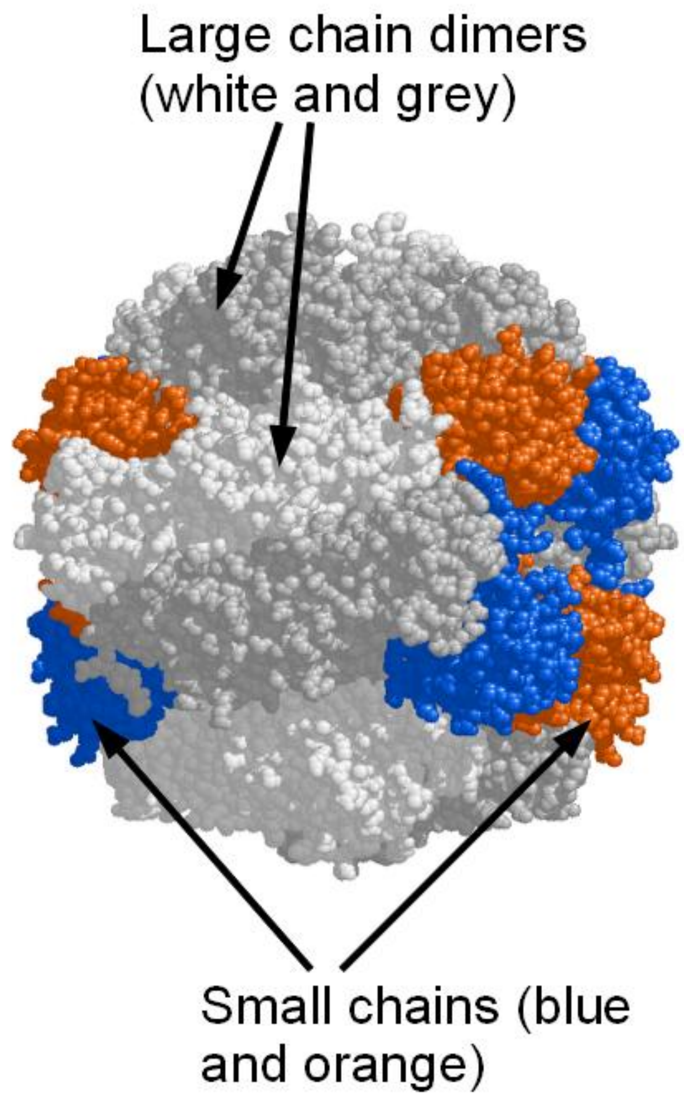
Part 3
Photosynthetic dark reactions and photorespiration



RuBisCO

(Ribulose-1,5-bisphosphate carboxylase oxygenase)

- Most abundant protein on earth
- Crucial for carbon fixation
- Source of energy for all heterotrophs
- Large chains synthesised by cDNA, small chains by nDNA



RuBP carboxylase (Rubisco)

$RuBP + CO_2 \text{ ---> } 2\ PGA$

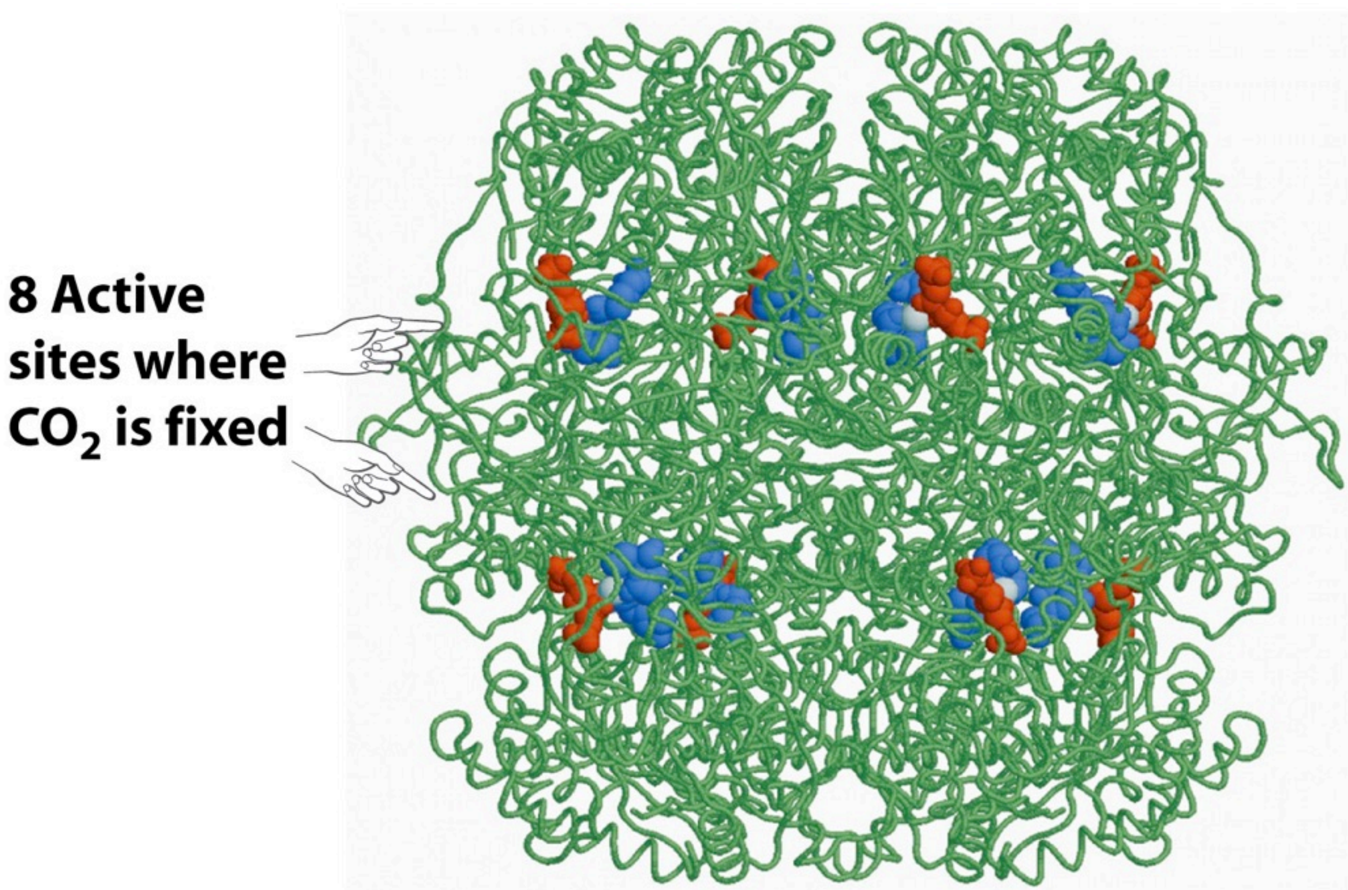
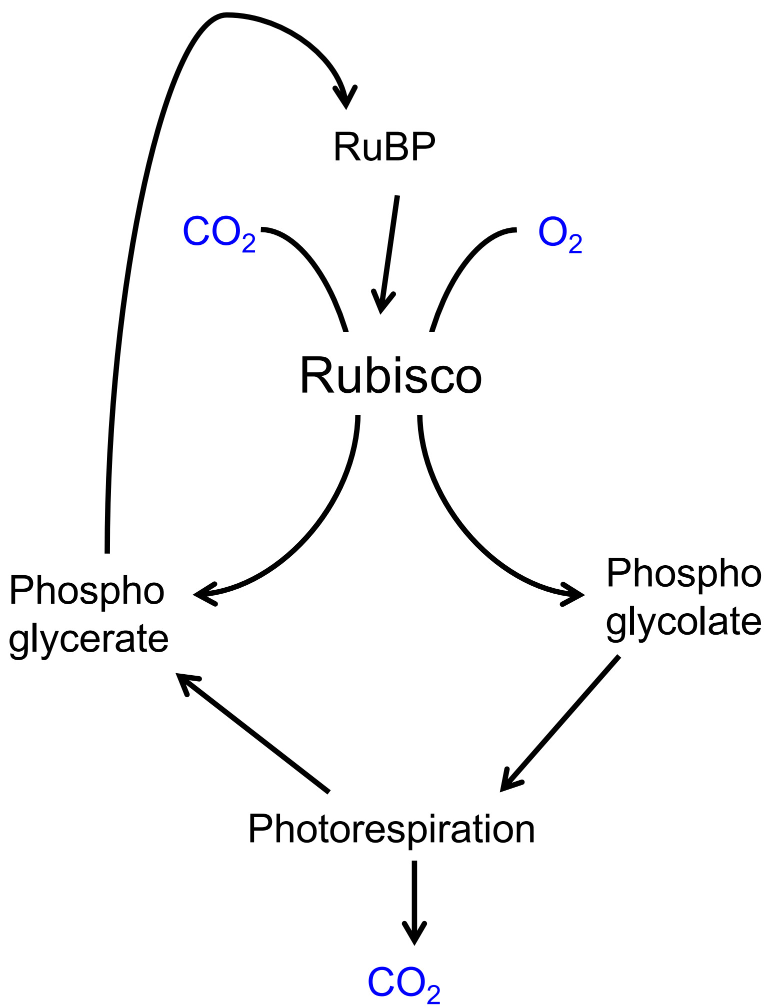
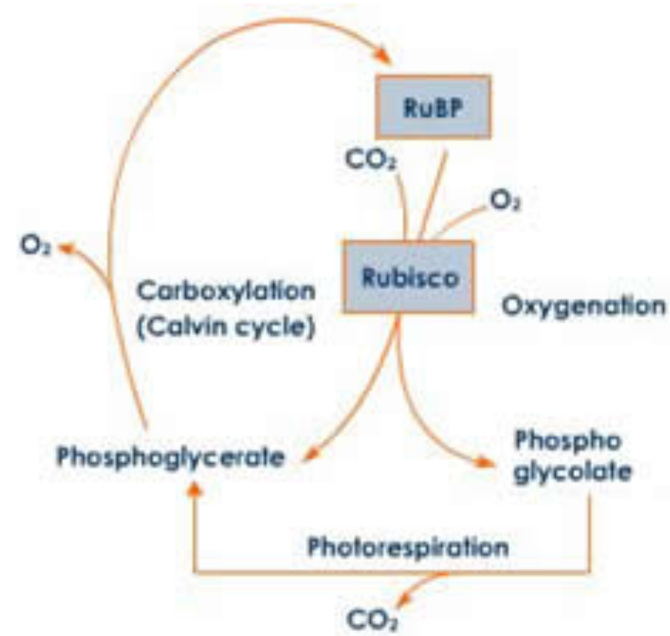


Figure 10-21 Biological Science, 2/e

RuBP oxygenase (Rubisco) … because Rubisco is also sensitive to O_2

$$RuBP + O_2 \dashrightarrow PGA + PG$$



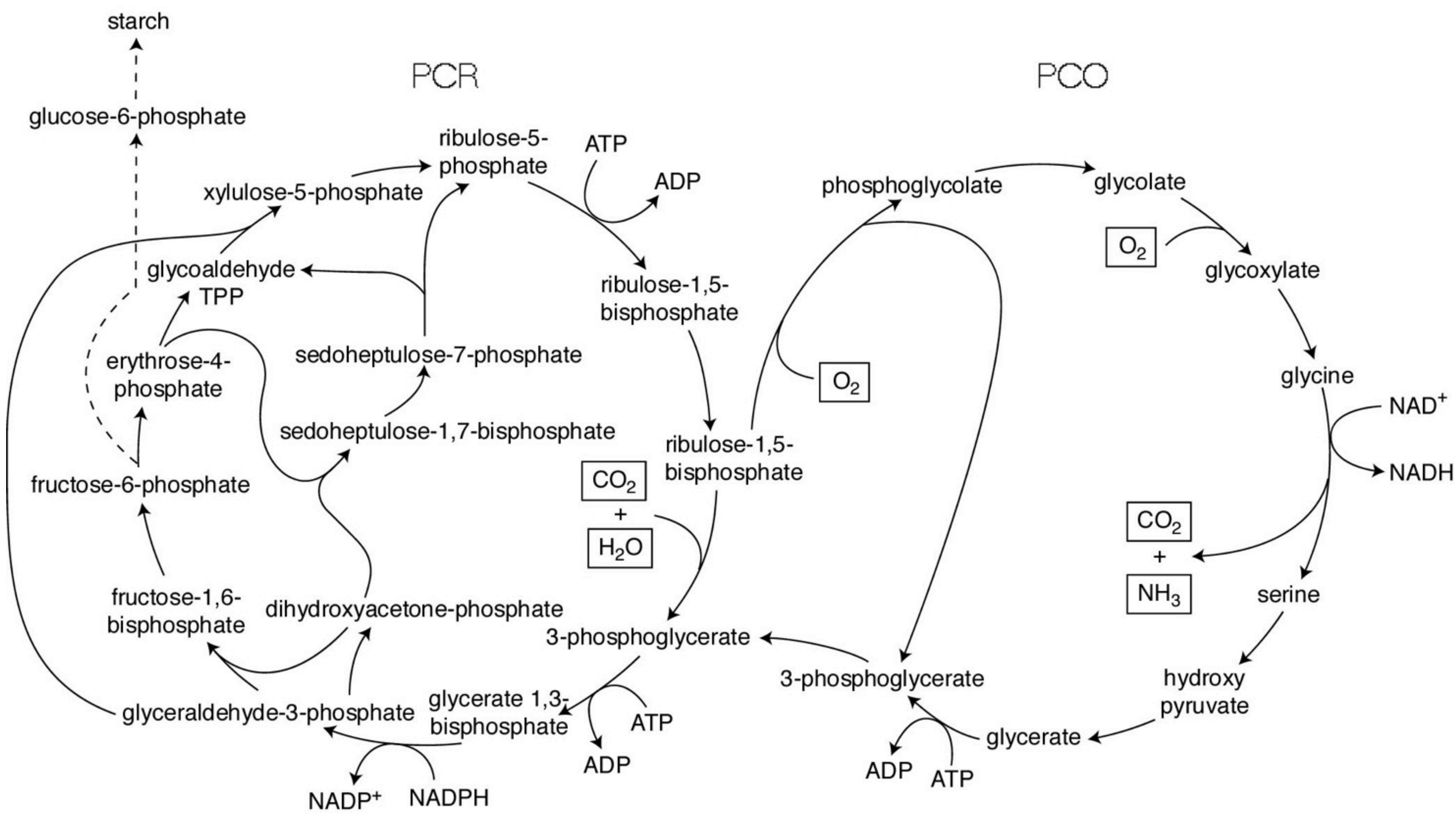


This oxygenase activity is also referred to as photorespiration

Recall the definition of respiration

Photosynthetic carbon **reduction**

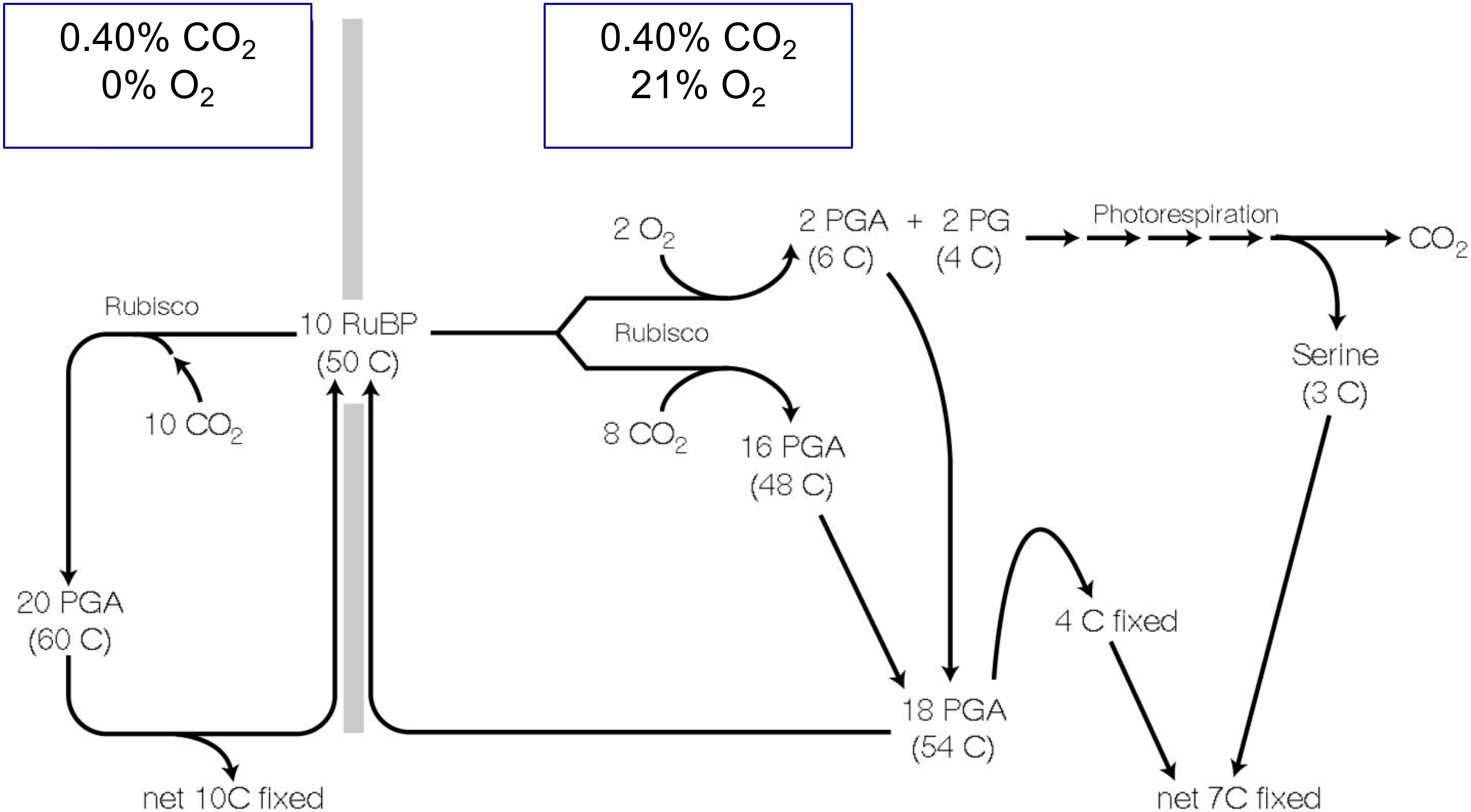
Photosynthetic carbon **oxidation**



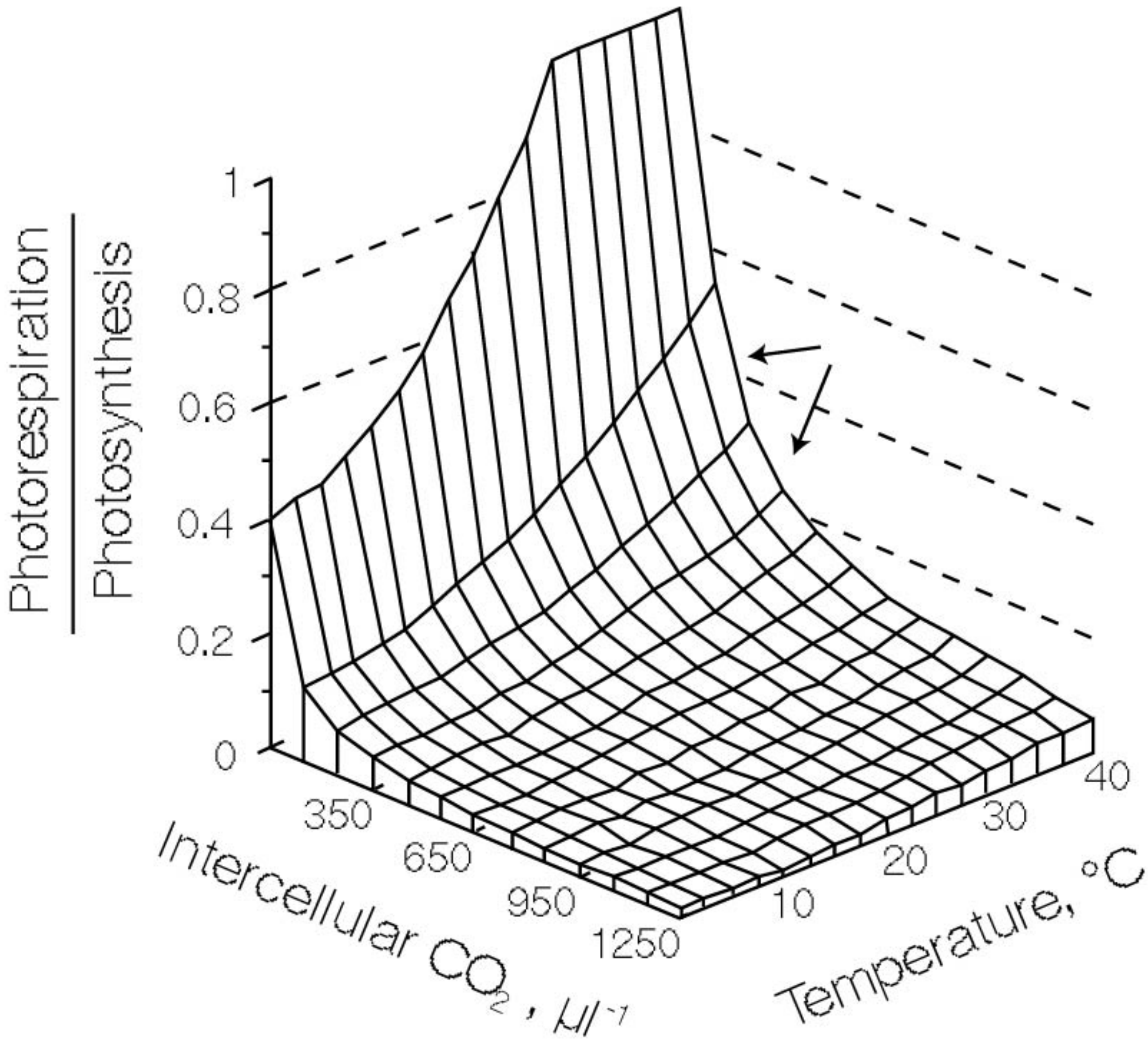
A change in the atmosphere CO_2 and O_2 influences the PCR-PCO balance

0.40% CO_2
0% O_2

0.40% CO_2
21% O_2

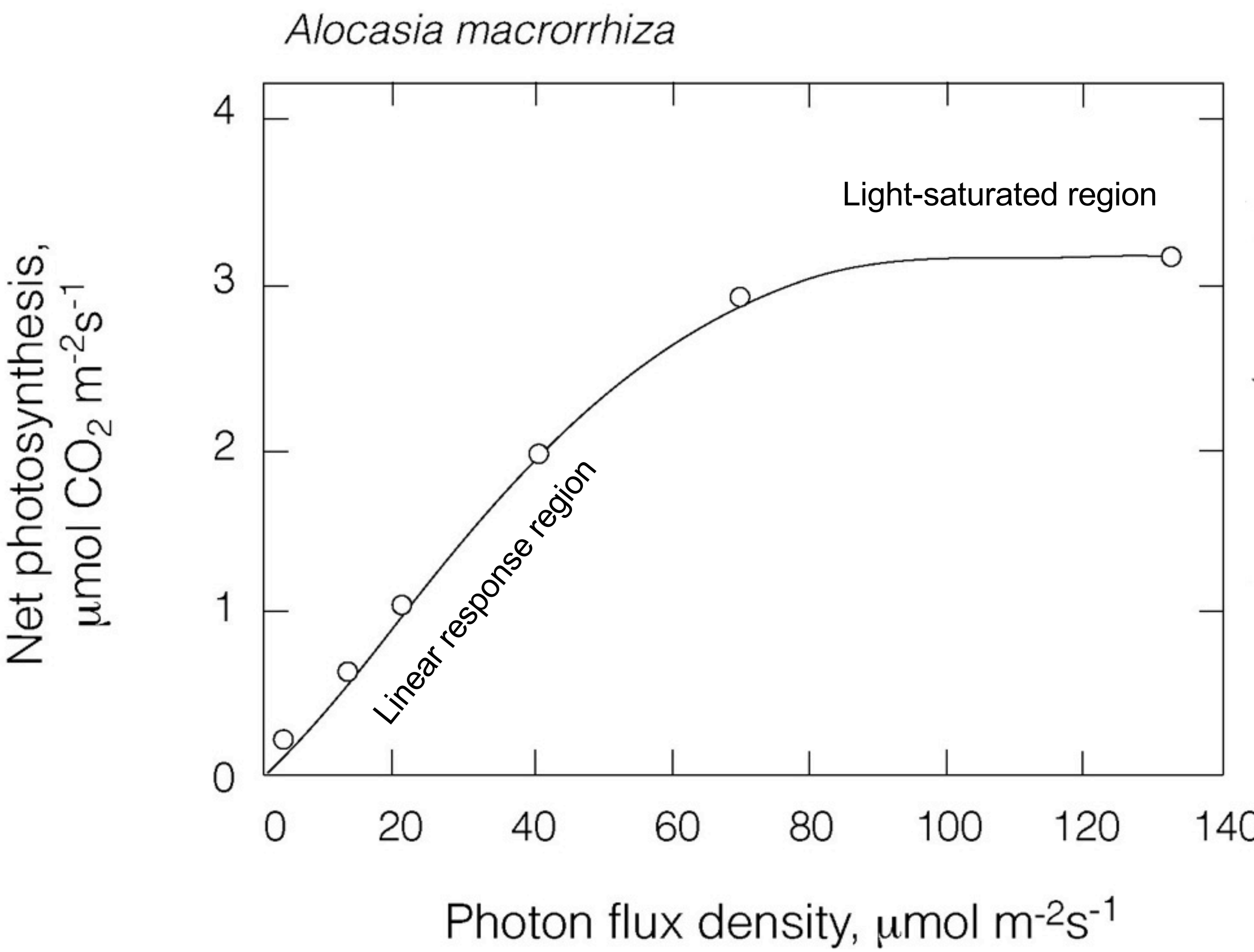


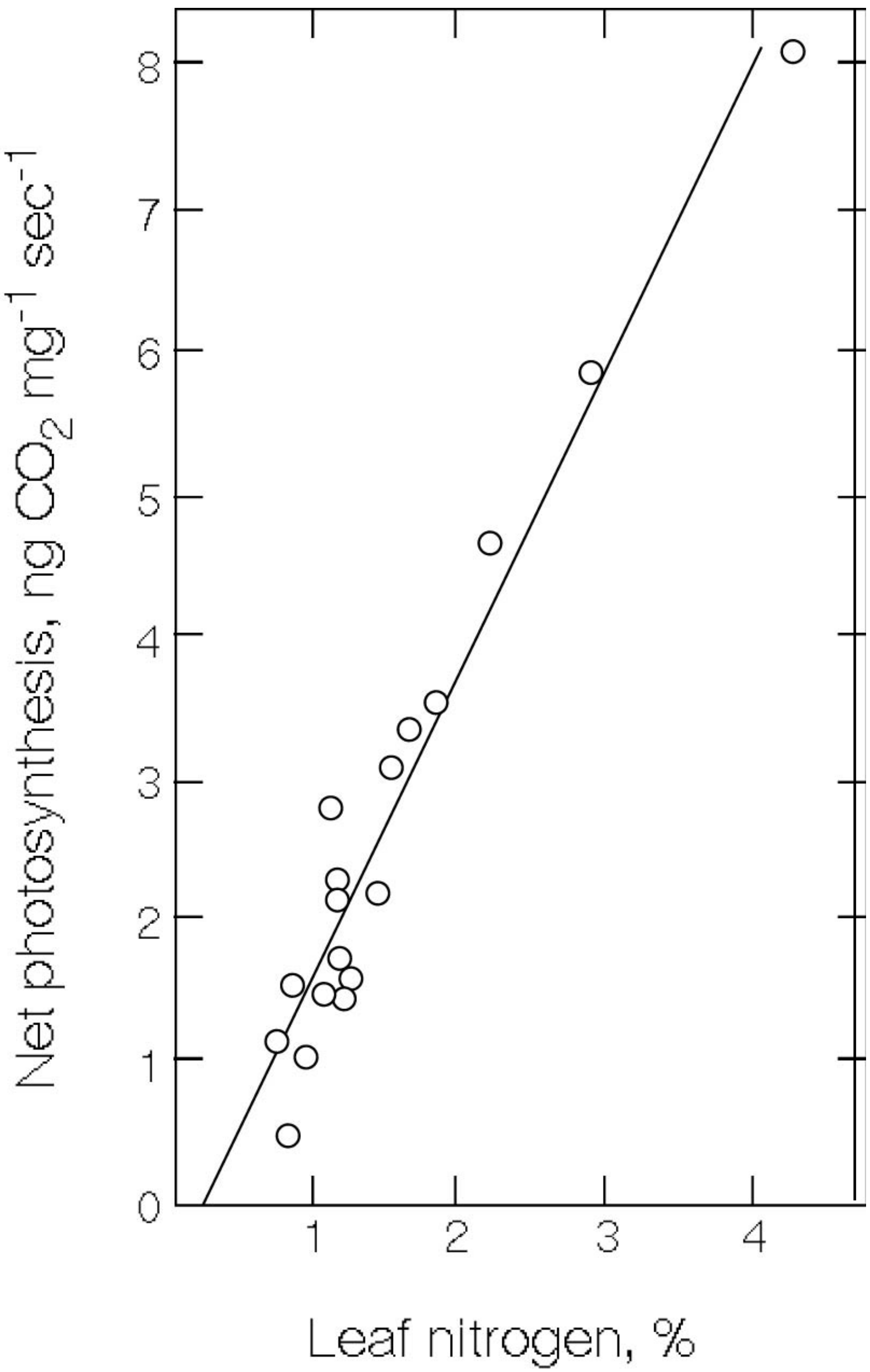
Photorespiration increases with increasing temperature and decreasing CO_2




Part 4
Bringing it together:
whole-leaf photosynthesis

Leaf-level net photosynthesis is measured at net CO_2 uptake



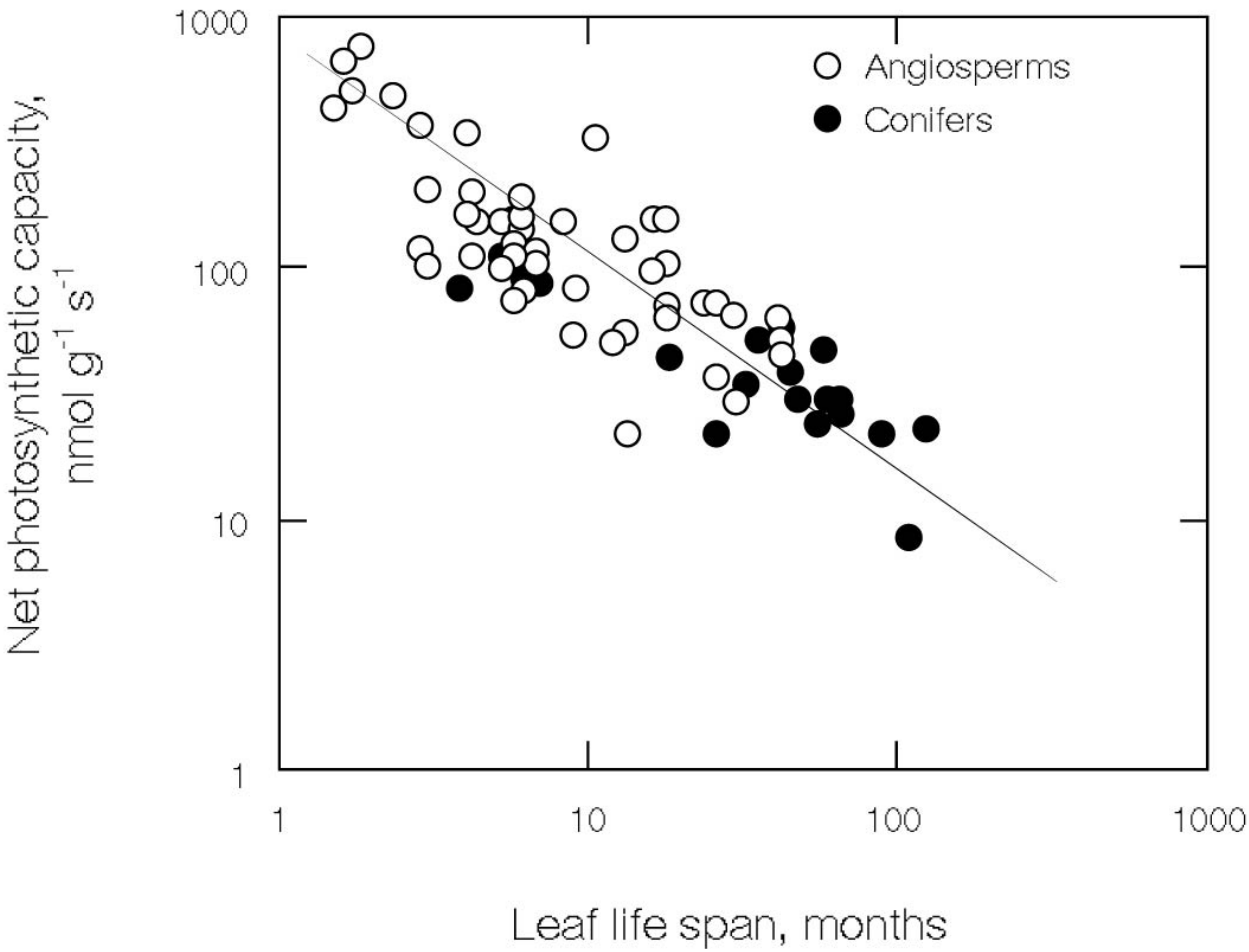


The PFD-saturated photosynthetic rate is often linearly proportional to the leaf nitrogen content (N, %)

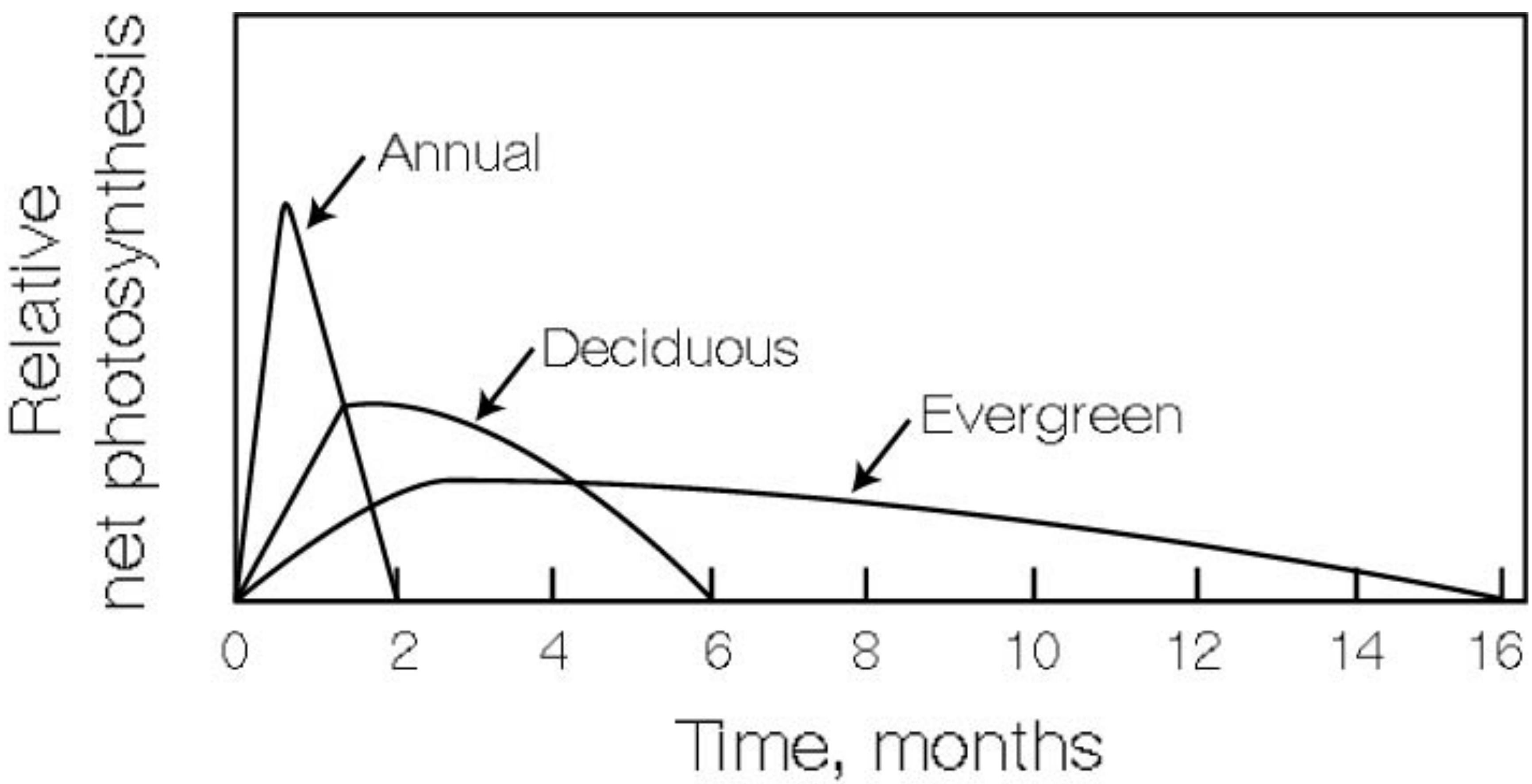
The changes in leaf nitrogen content reflect changes in protein content, particularly changes in the amount of Rubisco (~ 50% of leaf protein)

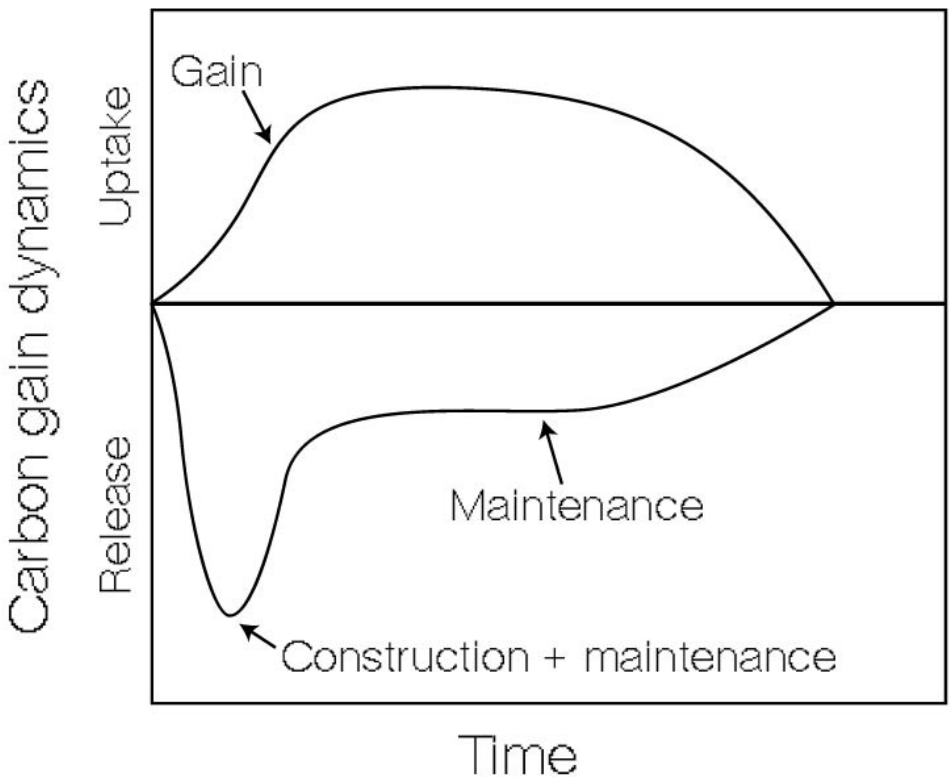
As a rule of thumb,
total % protein content = 6•N

Across a wide range of species, leaf life expectancy and flux rate appear to be negatively correlated



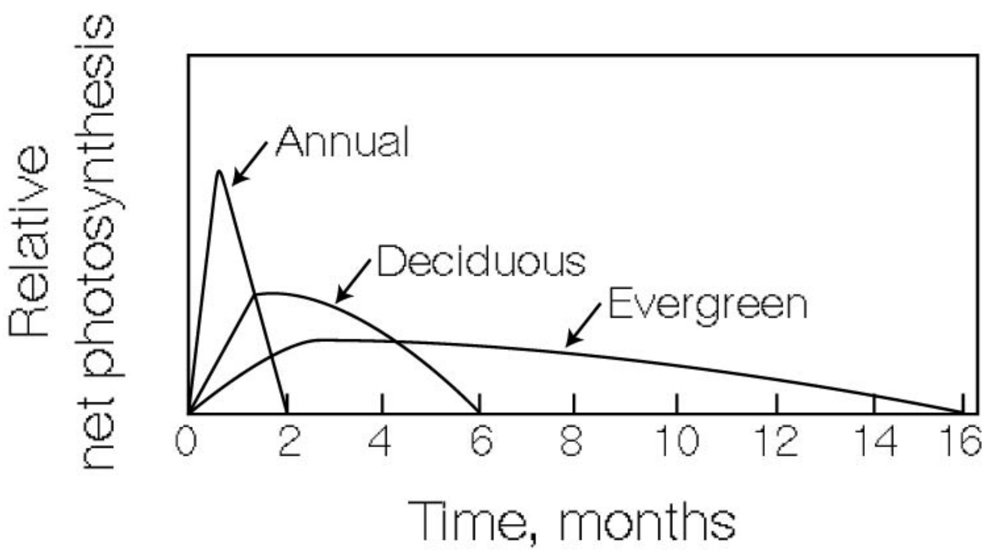
Across a wide range of life forms, leaf life expectancy and photosynthesis rate appear to be negatively correlated



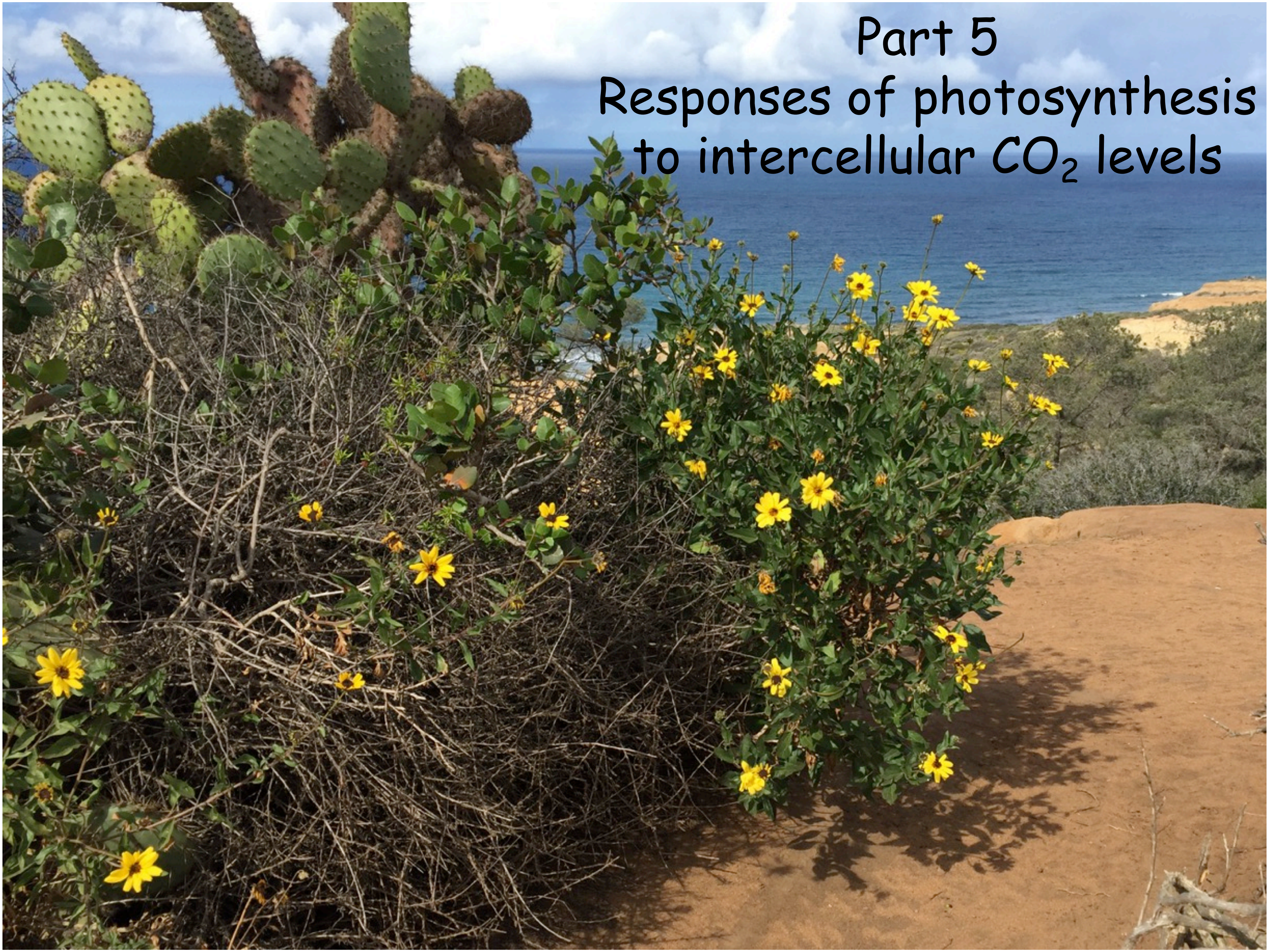


Anticipating a future lecture:

Carbon gain from photosynthesis is a function of both inputs and outputs over a leaf life time

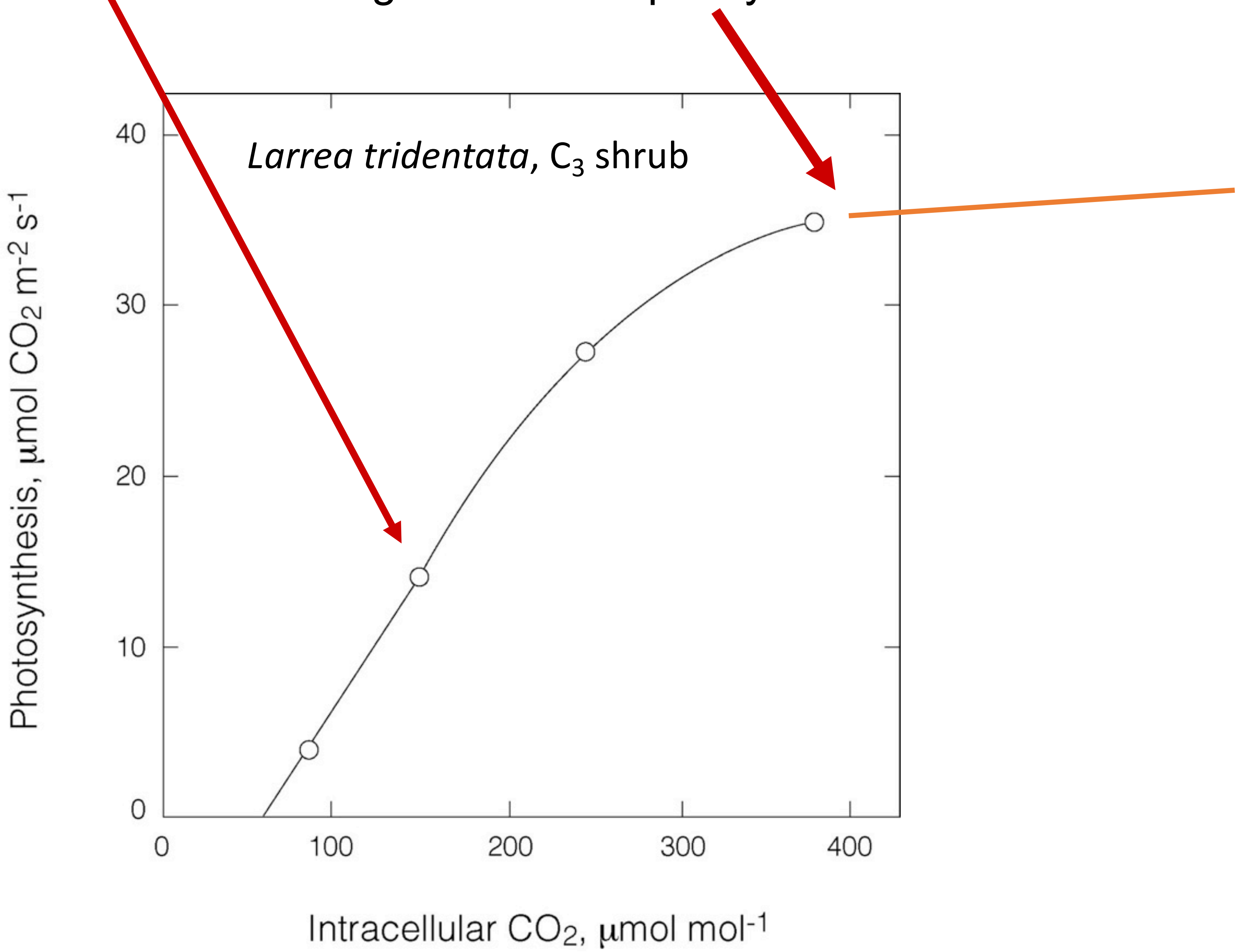


Carbon gain from photosynthesis
Changes over a leaf life time

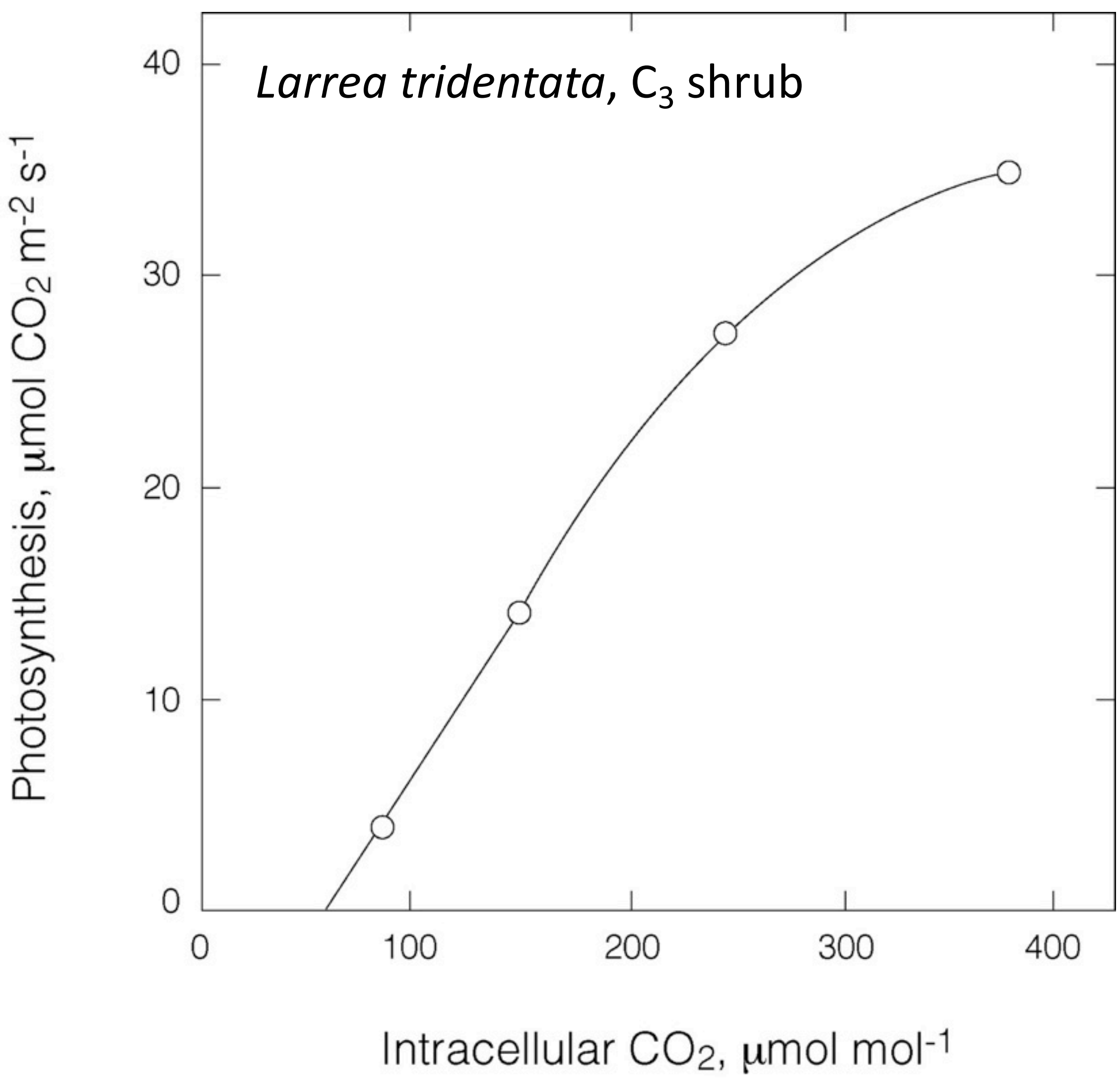

Part 5
Responses of photosynthesis
to intercellular CO_2 levels

At high light, a leaf's capacity to utilize CO_2 at highlight depends on

- RuBP carboxylase content
- RuBP regeneration capacity

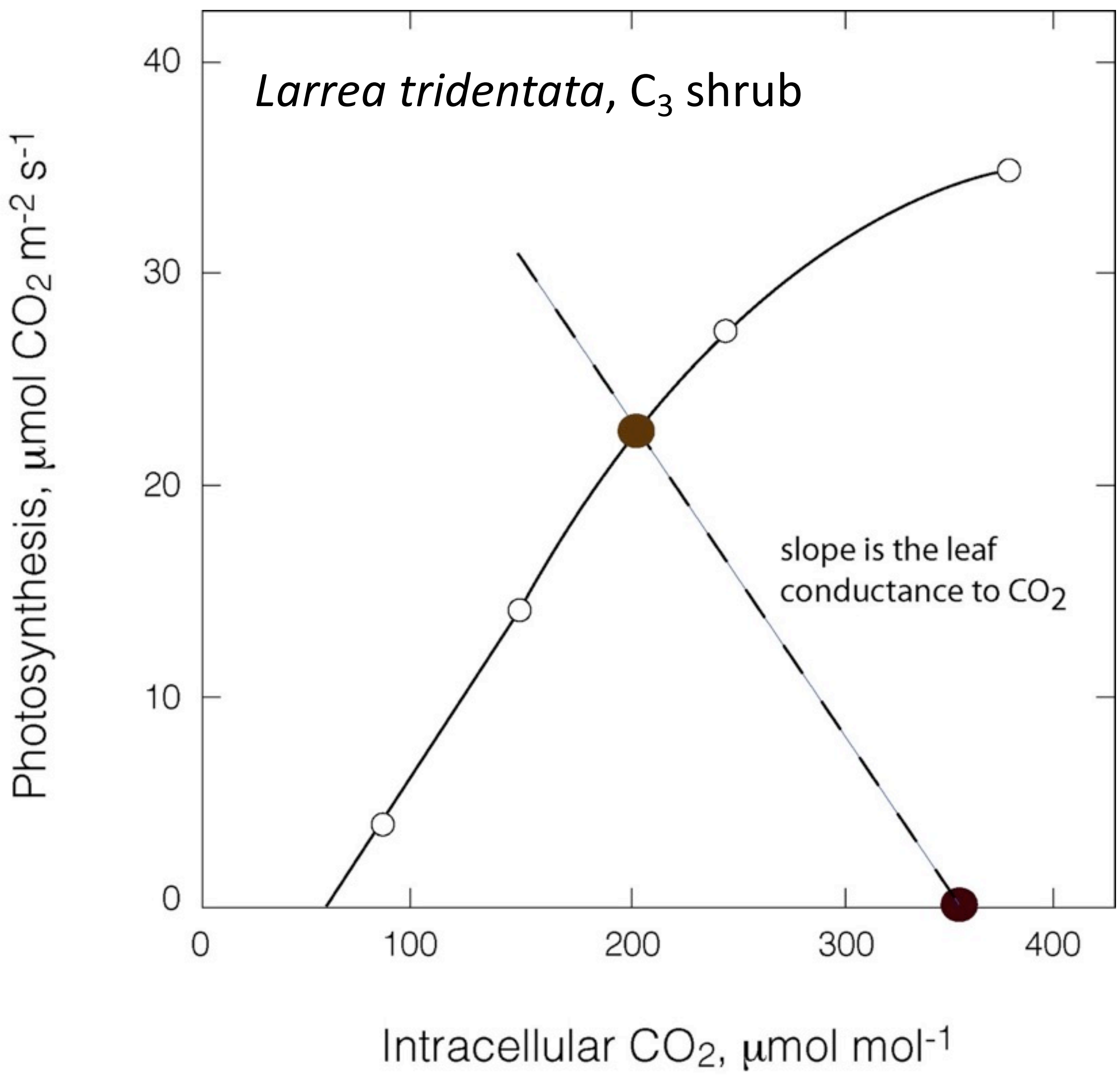


This response curve represents the leaf's potential capacity to photosynthesize. However, what is the actual photosynthetic rate under normal conditions?



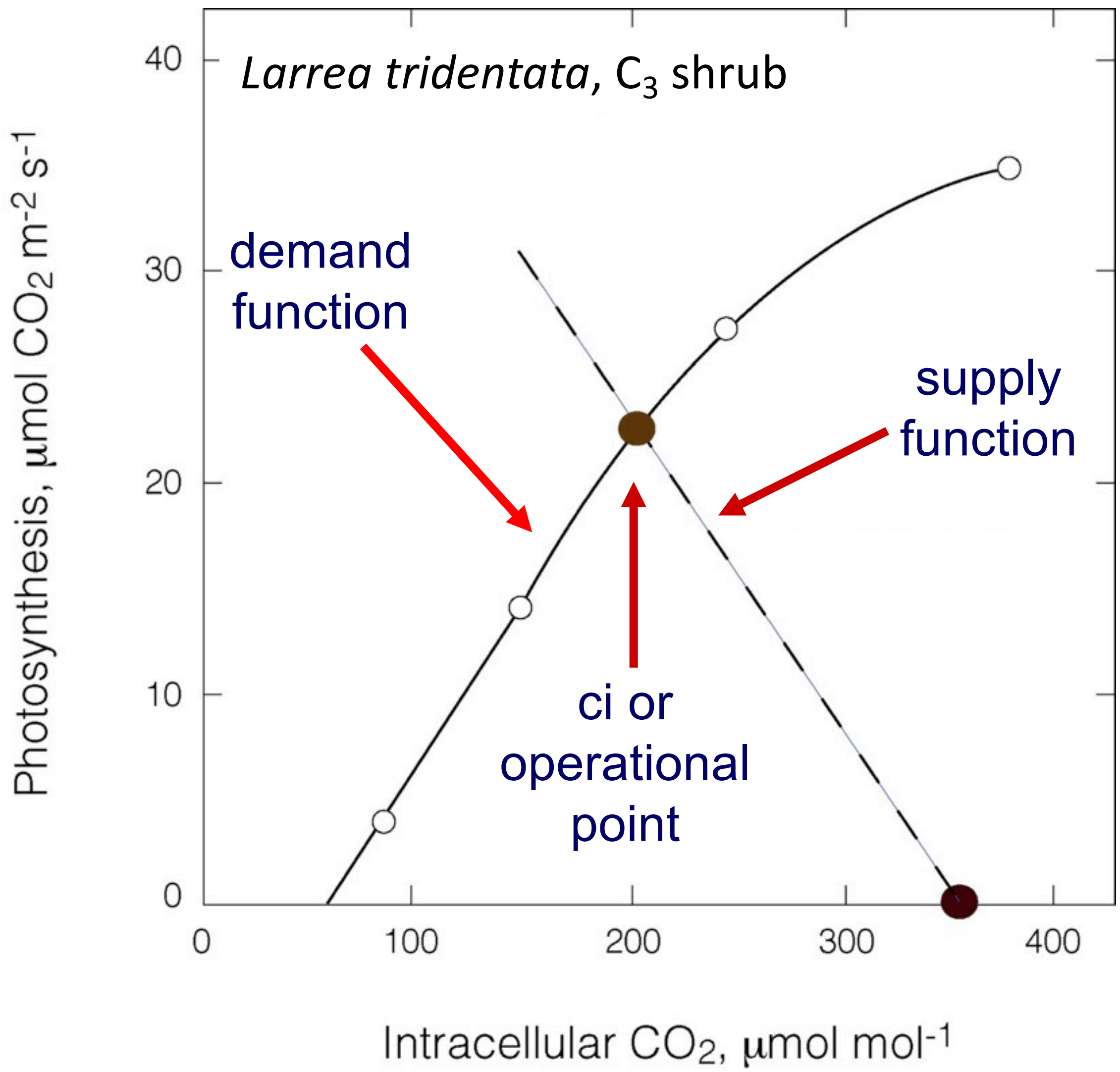
In economics, we would call this curve a **demand-response** curve.

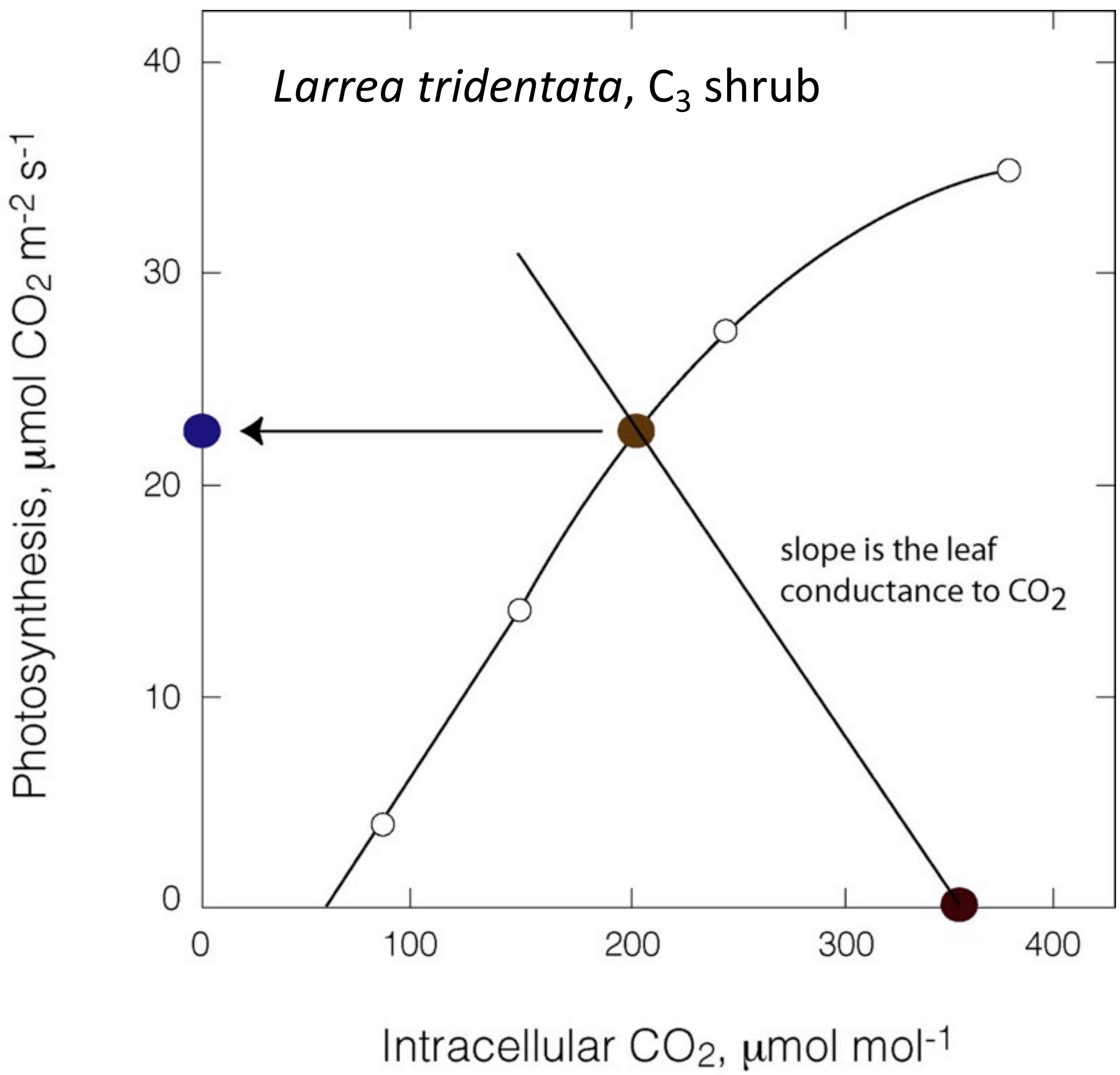
In economics, we would need a **supply** curve to determine actual photosynthesis.



If we draw a straight line from the atmospheric [CO_2] with a slope that is equal to the leaf conductance value, then we have a supply curve.

The intersection of the demand curve and the supply curve is the operational point, which is the actual photosynthetic rate of a leaf



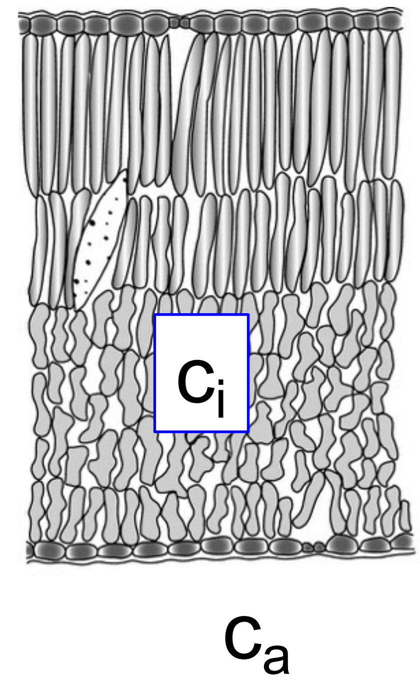


Larrea tridentata, C3 shrub
slope is the leaf conductance to CO2
Photosynthesis, µmol CO2 m-2 s-1
Intracellular CO2, µmol mol-1
0
10
20
30
40
0
100
200
300
400

In C_3 plants, leaves tend to operate at a point such that

intercellular CO_2 values are near the break point so that they are co-limited by RuBP carboxylase and RuBP regeneration capacities

then the ratio of intercellular-to-ambient CO_2 values are 0.65 – 0.75

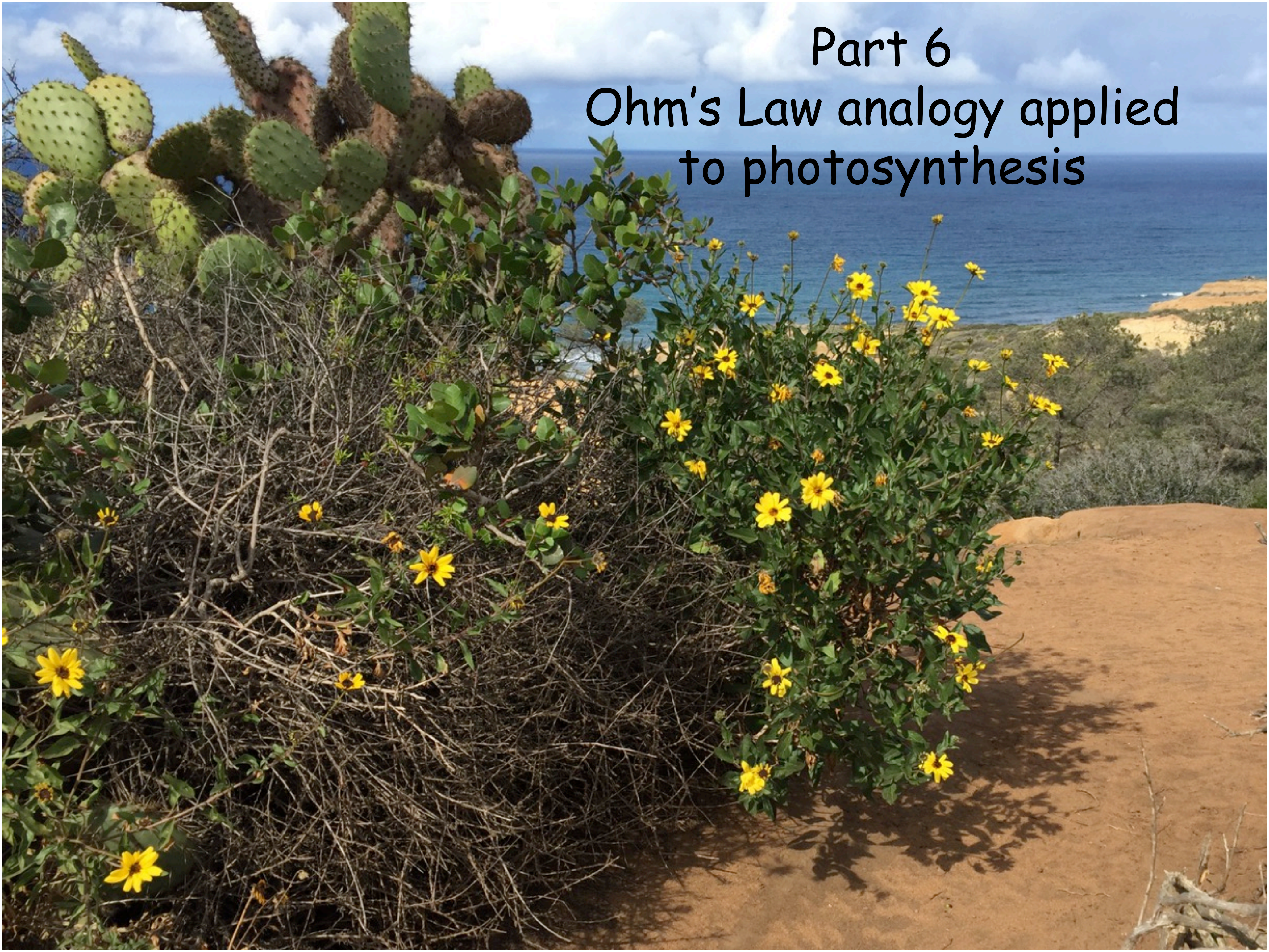


In a future lecture, we will learn that carbon isotope ratios provide a long-term estimate of ci/ca

Deviations from these central tendencies occur when plants are

under water stress, when ci/ca is lower

under low-light shade habitats, when ci/ca is higher


Part 6
Ohm’s Law analogy applied
to photosynthesis

Under steady state conditions,
transpiration and photosynthesis rates
can be described using Ohm's Law electrical analogies

$$E = [(e_i - e_a)/P] \cdot g$$

transpiration rate

intercellular and atmospheric vapor pressures

atmospheric pressure

leaf conductance to H_2O

$\boxed{g' = g/1.6}$

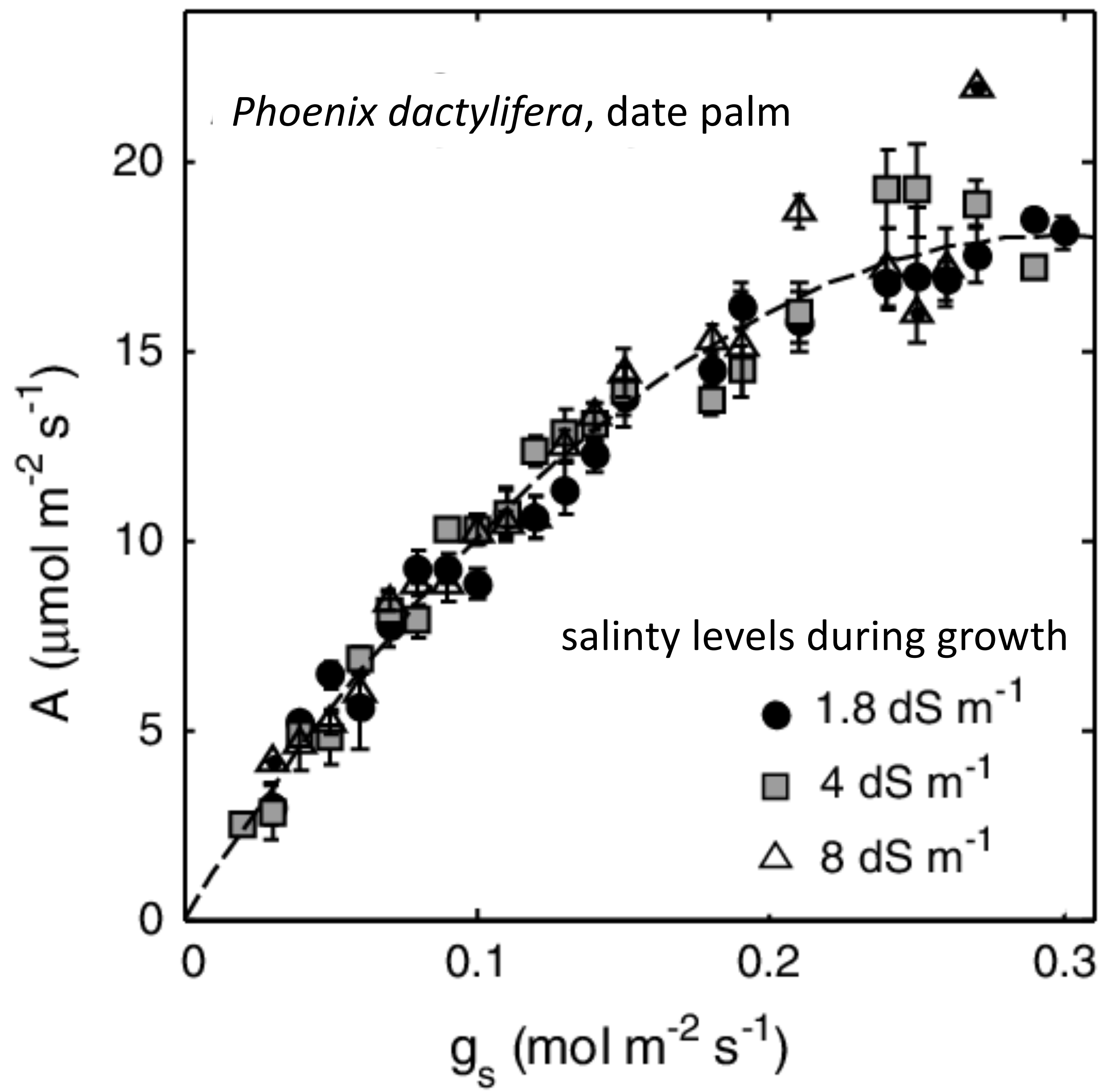
$$A = [(c_a - c_i)] \cdot g'$$

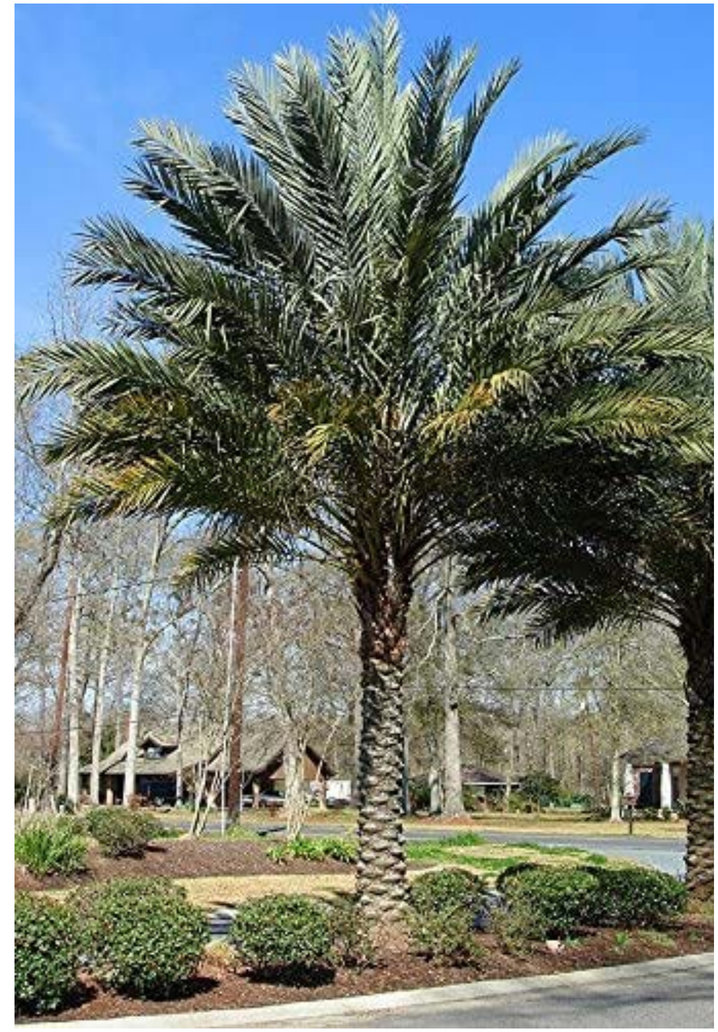
photosynthesis rate

atmospheric and intercellular carbon dioxide concentrations

leaf conductance to CO_2

Photosynthetic rate is proportional to stomatal conductance as predicted by Ohm's Law, but at high conductances other factor(s) becoming limiting





Sperling et al (2014)