Lecture 4: Physical challenges for terrestrial plants, emphasis on tradeoffs and alternative lifestyles

Main themes in plant physiological ecology

- Stresses on plants are especially challenging because plants can't evade stress by moving
- Plants solve problems by growth & development, not behaviour, so carbon balance is central
- Tradeoffs on photosynthesis: compromises involving 3 necessities: light, temperature, water
- Adaptations to an extreme habitat: deserts
- Adaptations to an extreme lifestyle: epiphytes
- Sclerophylly: resolving a multi-part paradox

Plant ecophysiology of carbon balance: tradeoffs & constraints abound

- Autotrophs: depend on net photosynthesis (= gross Ps minus respiration); conversion of CO_2 to fixed carbon:

- $CO_2 + H_2O$ ⇌ (Photosynthesis / Respiration) Carbohydrate + O_2

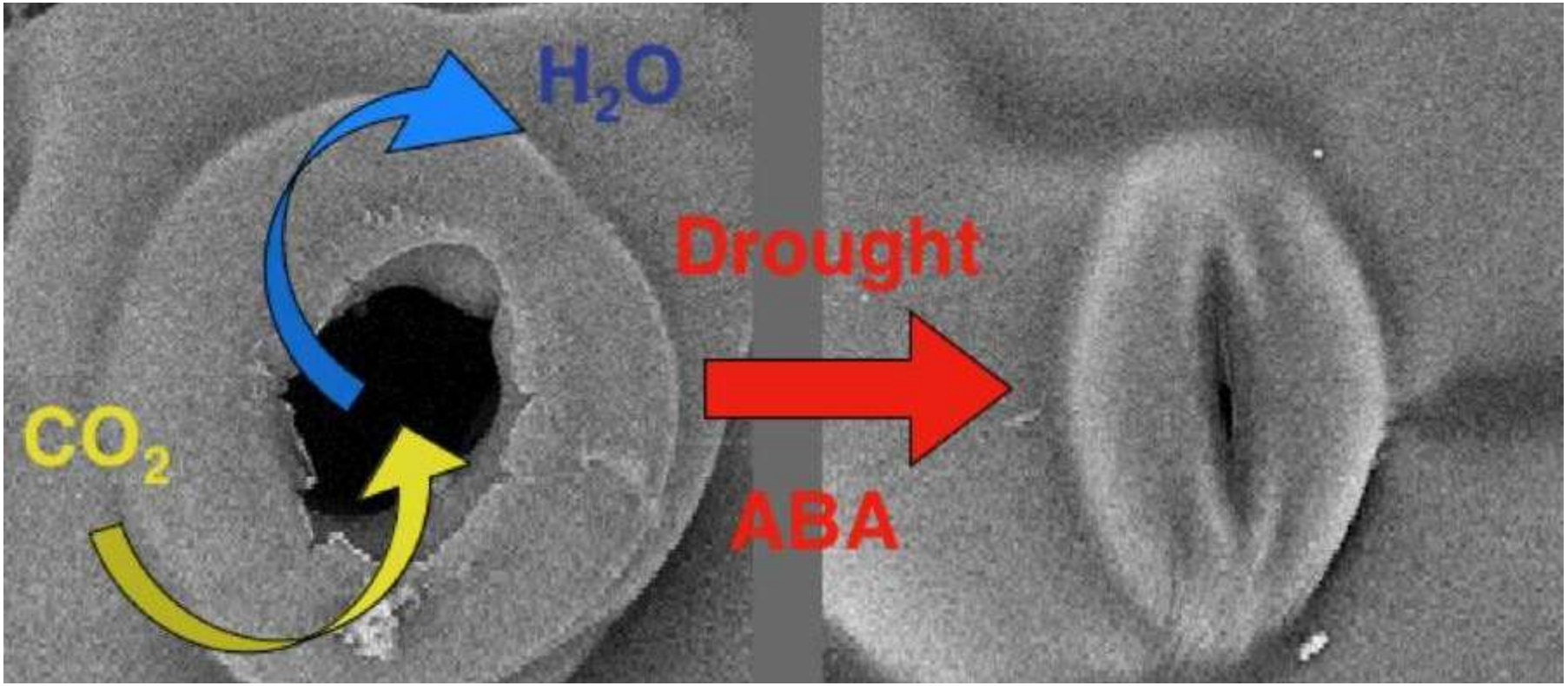
- Must bring together light, gases, & water in functioning photosynthetic tissue
- Functioning requires OK temperature, osmotic balance, enzymes, dissolved nutrients from soil, etc.
- Any of these components can limit fitness
- Anatomy & physiology reflect constraints

Photosynthetic structures embody adaptation to environmental stresses

- Photosynthetic (green) structures are usually leaves (but can be stems)
- Leaf size and shape: SA:V ratios important again, as for animals
  - Benefits of large leaf surface area: good for harvesting light, CO_2
  - Costs of large leaf surface area: bad for overheating, water loss by evapotranspiration through stomata

Plants with large leaves combat overheating by:

- Growing in shady habitats
- Evaporative cooling by opening stomata



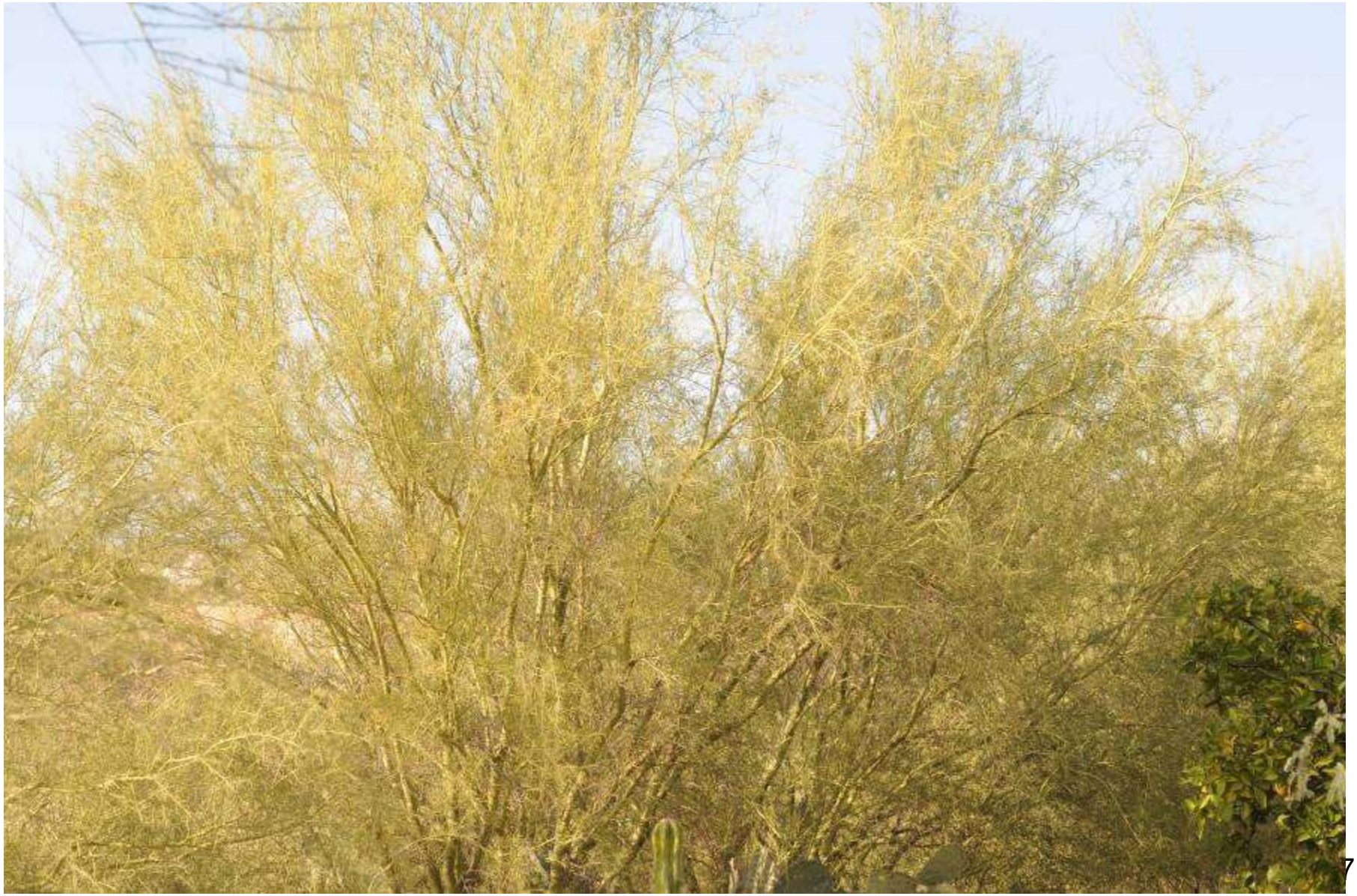
www.isv.cnrs-gif.fr/jg/images/stomata.jpg

Evaporative cooling needs plentiful water—not always available. Plants with large leaves combat water loss by:

- Closing stomata…
- …but that shuts off all gas exchange, including CO_2 input, so photosynthesis shuts down. Plant stops growing…
- …and risks overheating & tissue damage.
- Theefore, fundamental tradeoff between water conservation and rapid growth
- Consequences most obvious in desert plants

Keeping cool *while conserving water*: Sonoran Desert, Arizona

Palo Verde (*Parkinsonia* sp.)



Palo Verde = “green stick”

Photosynthetic bark on trunks & branches; can grow without incurring heat load & water loss through leaves

Microphylly in Palo Verde

Microphylly in mesquite (*Prosopis* sp.)

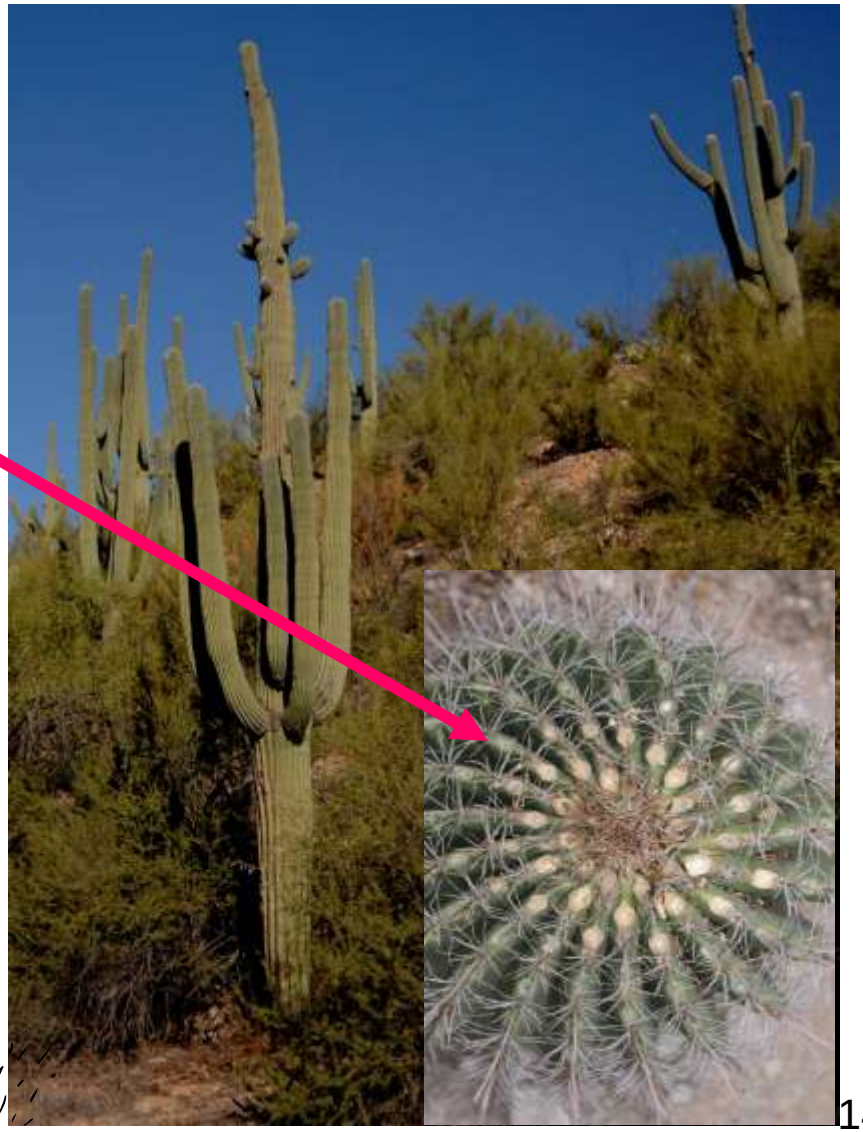
Microphylly taken to extremes: no leaves!
Santa Rita prickly pear (*Opuntia santa-rita*)

Cacti: extensive but shallow roots

Episodic patterns of H_2O availability in Sonoran desert: Rillito River, Tucson, Arizona

Saguaro cactus (*Carnegiea gigantea*)
Restricted to Sonoran desert, adapted to episodic rains

- Grows to 15 m, 200 yr, 5+ tonnes
- Extensive, shallow roots
- Accordion-pleated trunk allows expansion
- Can absorb 800 L of water from one storm, use it gradually for growth
- Mnemonic digression for water storage: David Grundman (d. 1982)



Animals can evade stress through behaviour: what about plants?

- Deciduous habit: dropping leaves during dry or cold seasons can reduce water stress and tissue damage

Tropical deciduous forest, Guancaste Province, Costa Rica

Dry season

Rainy season

Terminological clarification: "evergreen"

- The most important groups of land plants are angiosperms and conifers. Loosely, "evergreen" is used as a synonym for "conifer,"…
- …but some conifers are **not** evergreen…
- …and many evergreens are **not** conifers (especially in wet tropics)!

Red pine, *Pinus resinosa,* evergreen conifer

Tamarack, *Larix laricina,* deciduous conifer

Rosemary, *Rosmarinus officinalis,* evergreen angiosperm

A more useful terminology for leaf structure and persistence: mesophyll to sclerophyll

Mesophyll, sugar maple, *Acer saccharum*

Sclerophyll, red pine*, Pinus resinosa* Joker's Hill

Mesophyll

- Leaves large
- Thin, papery, flexible

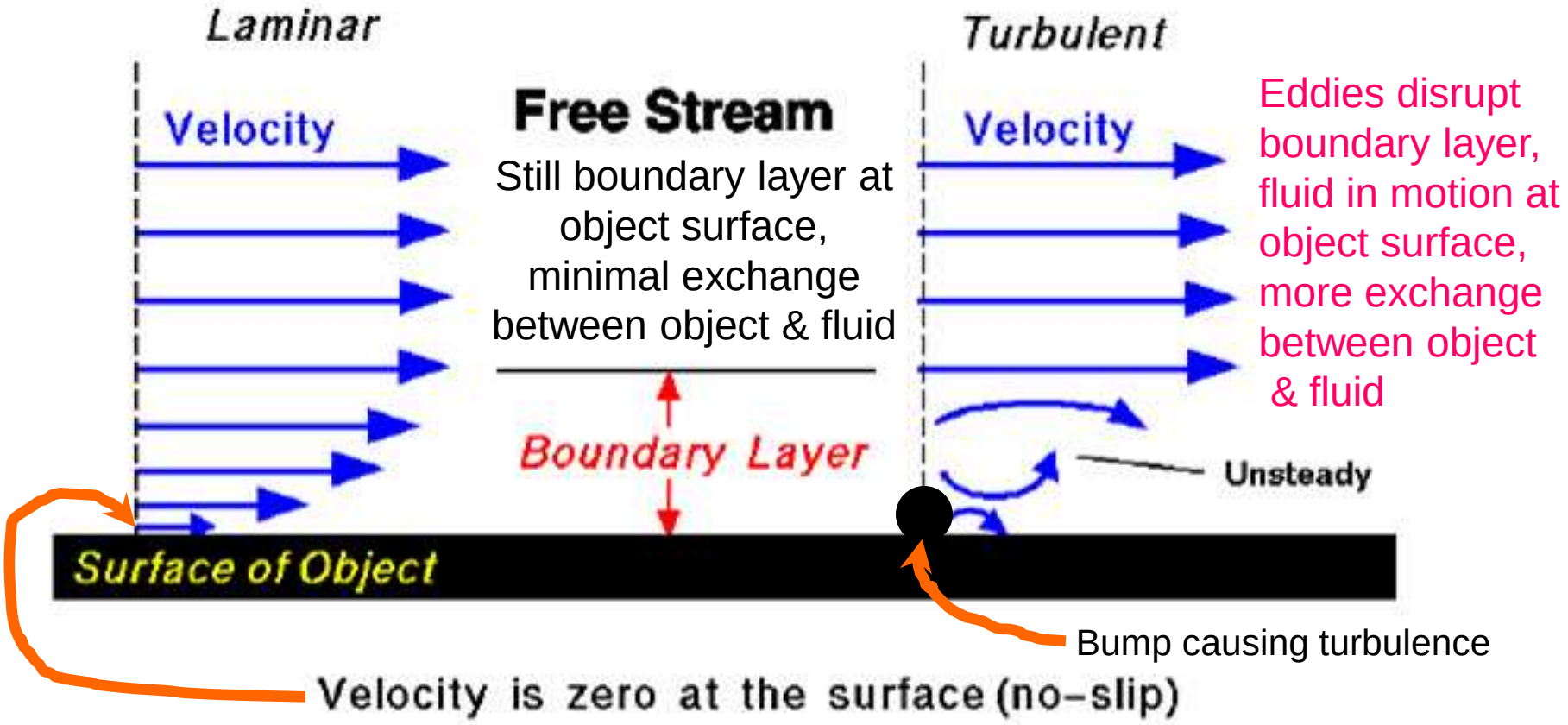
- High SA:V
- Flimsy, fragile
- Frequently deciduous, last only 1 season
- Prominent local examples: hardwood trees such as maples, oaks

Sclerophyll

- Leaves small
- Thick, needles or scales
- Low SA:V
- Tough, leathery
- Frequently evergreen, last several seasons
- Prominent local examples: coniferous trees such as pines, firs, spruces

Leaf shape also influences gas exchange through laminar vs. turbulent flow of fluids over surfaces

Blue arrows show fluid flow vectors across 2 objects, one smooth, one bumpy



Smooth, streamlined surfaces produce laminar flow; rough edges & irregularities produce turbulent flow, drag

In vehicle design, try to minimize turbulence,

Vehicle frontal area (A): 2:12 m
Drag coefficient (cw): 00:28
Air resistance index (cw × A): 00:59

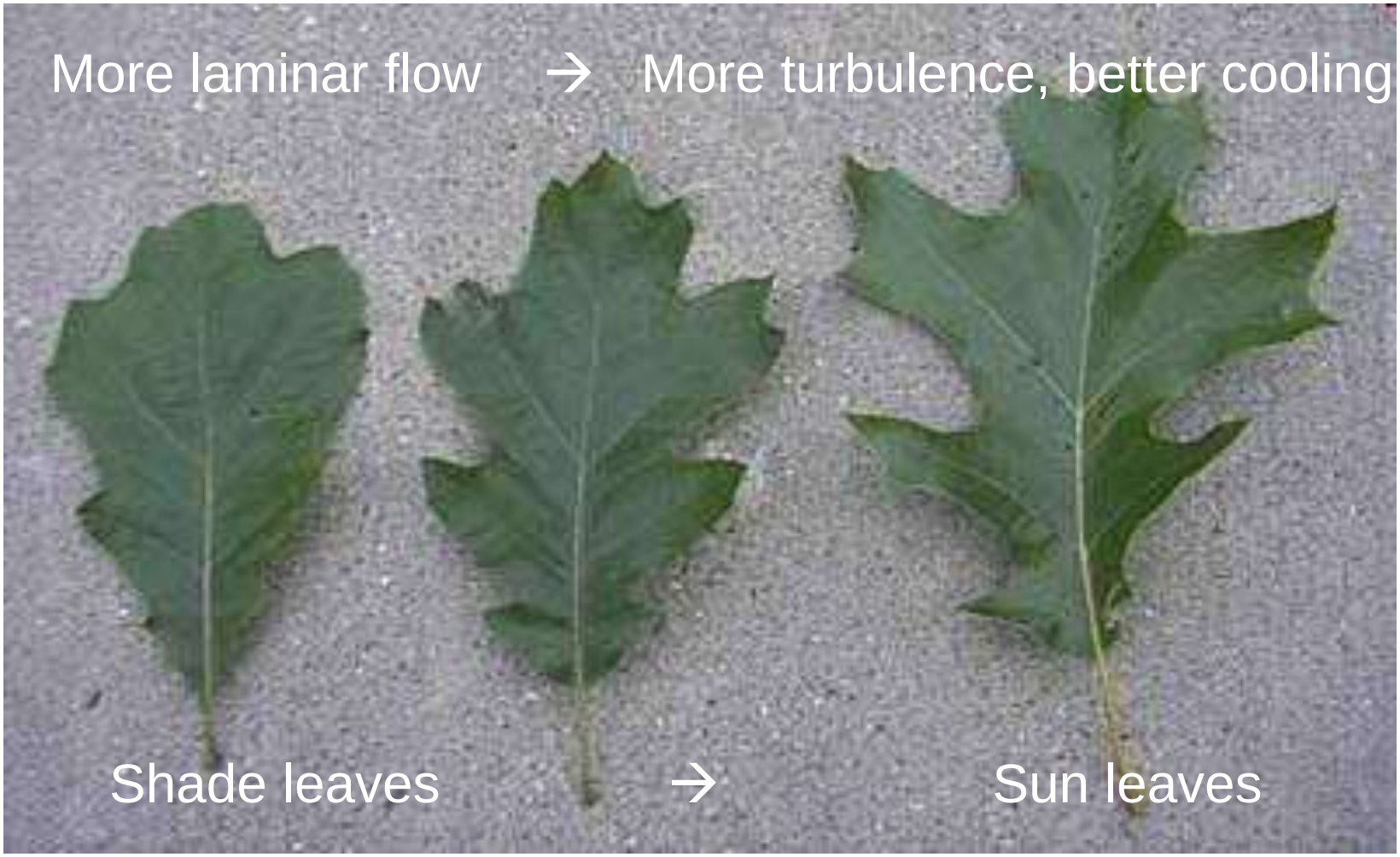
Front: 42 kg buoyancy
Rear: 28 kg buoyancy

Vehicle frontal area (A): 2:17 m
Drag coefficient (cw): 00:33
Air resistance index (cw × A): 0.71

Front: 10 kg buoyancy
Rear: 23 kg buoyancy

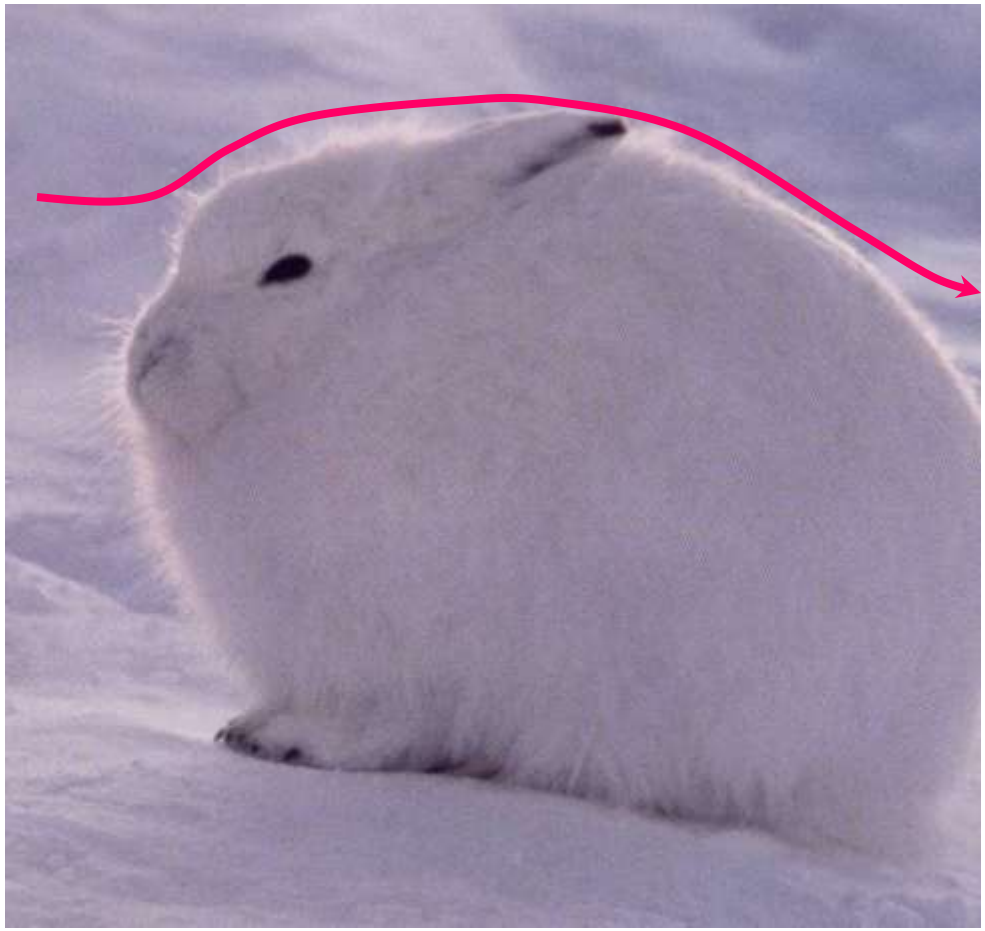
but for cooling leaves, more turbulence is better!

Morphological plasticity: sun and shade leaves from one red oak tree

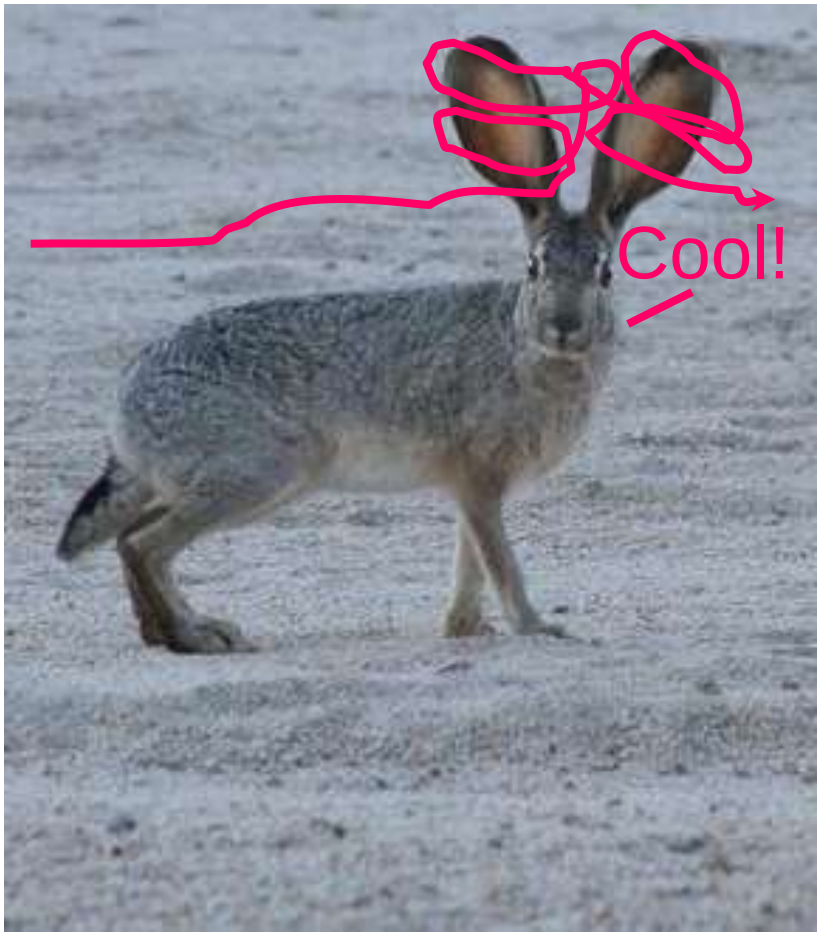


Monstera deliciosa, sun and shade leaves: dissected outlines cause turbulent airflow

Recursive digression: Convective cooling aided by turbulence



Lepus arcticus (Art Wolfe)



Lepus californicus (www.pestproducts.com)

Nurse tree effect: saguaro seedling sheltered by palo verde

Life form digression: the unrooted life of epiphytes

- Epiphytes grow on trees, so they aren't able to put their roots into the soil…
- …leading to water stress and nutrient shortages

travel.mongabay.com

Luquillo Forest, Puerto Rico

La Selva Biol. Station, Costa Rica

Plant water relations, special cases: demonstration

- Convergent evolution of unrelated lineages toward common life forms: cacti & euphorbias
- Water storage strategies by epiphytes (whose roots can't access soil water):
  - Sponge (many orchids, ferns, aroids)
  - Tank (many bromeliads)
  - Succulence (epiphytic cactus)

Epiphytic *Rhipsalis* (Cactaceae), Brazil

Reconciling an apparent paradox 2:

Plants with sclerophyll leaves common in 4 situations

1. Boreal spruce-fir forests, high latitude/altitude, cool summers, severe winters, moist soils

2. Pine barrens, hot summers, mild winters, dry, sandy, acid soils

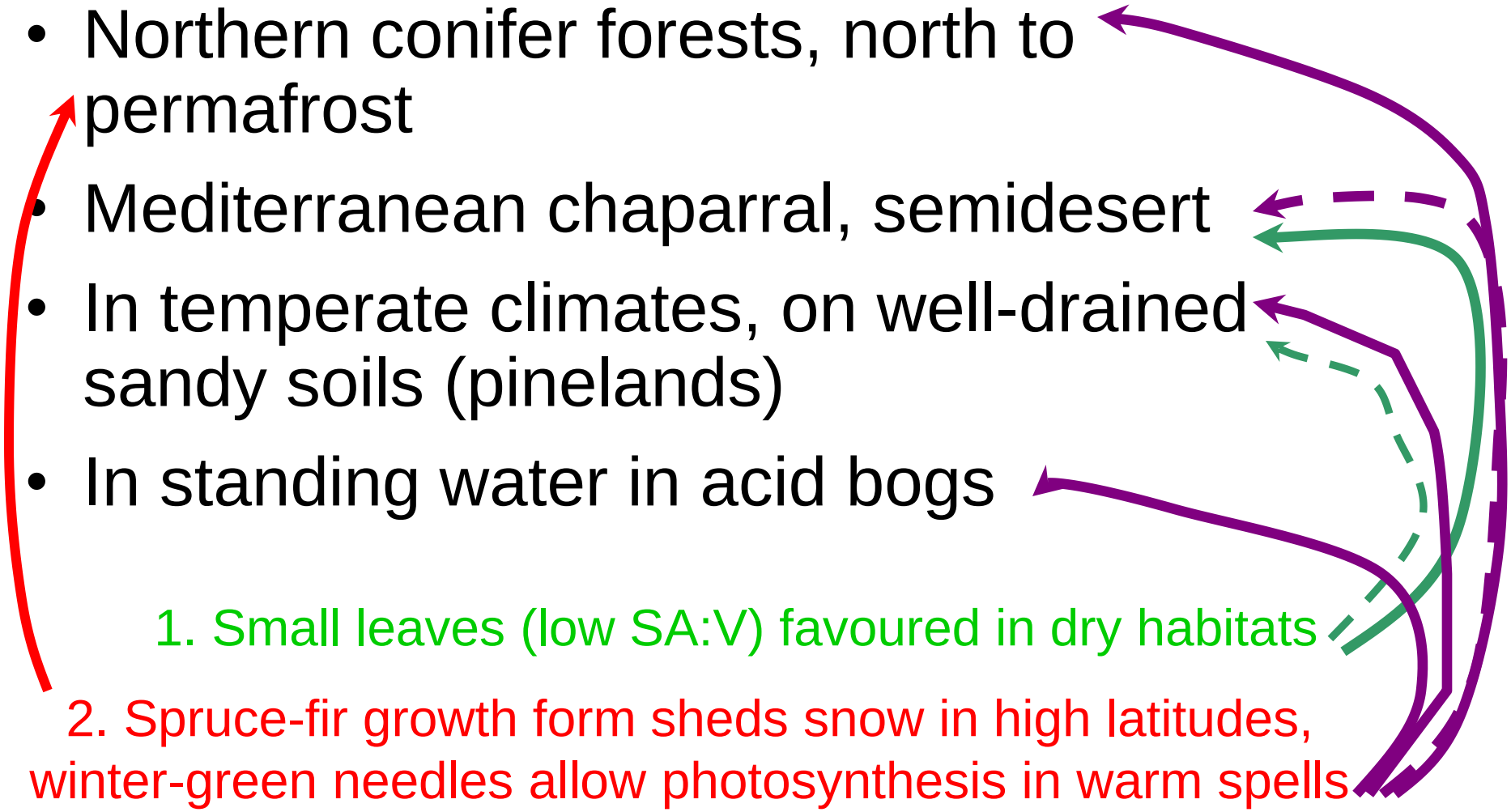
Paradoxical distribution of sclerophylls, cont.:

3. Maine bogs, cool summers, WET, acid

4. Mediterranean heaths, dry, HOT summers

Reconciling enigmatic distribution of sclerophyllous plants:

- Northern conifer forests, north to permafrost
- Mediterranean chaparral, semidesert
- In temperate climates, on well-drained sandy soils (pinelands)
- In standing water in acid bogs



1. Small leaves (low SA:V) favoured in dry habitats

2. Spruce-fir growth form sheds snow in high latitudes, winter-green needles allow photosynthesis in warm spells

3. Evergreen habit conserves nutrients in poor soils

Strangler figs

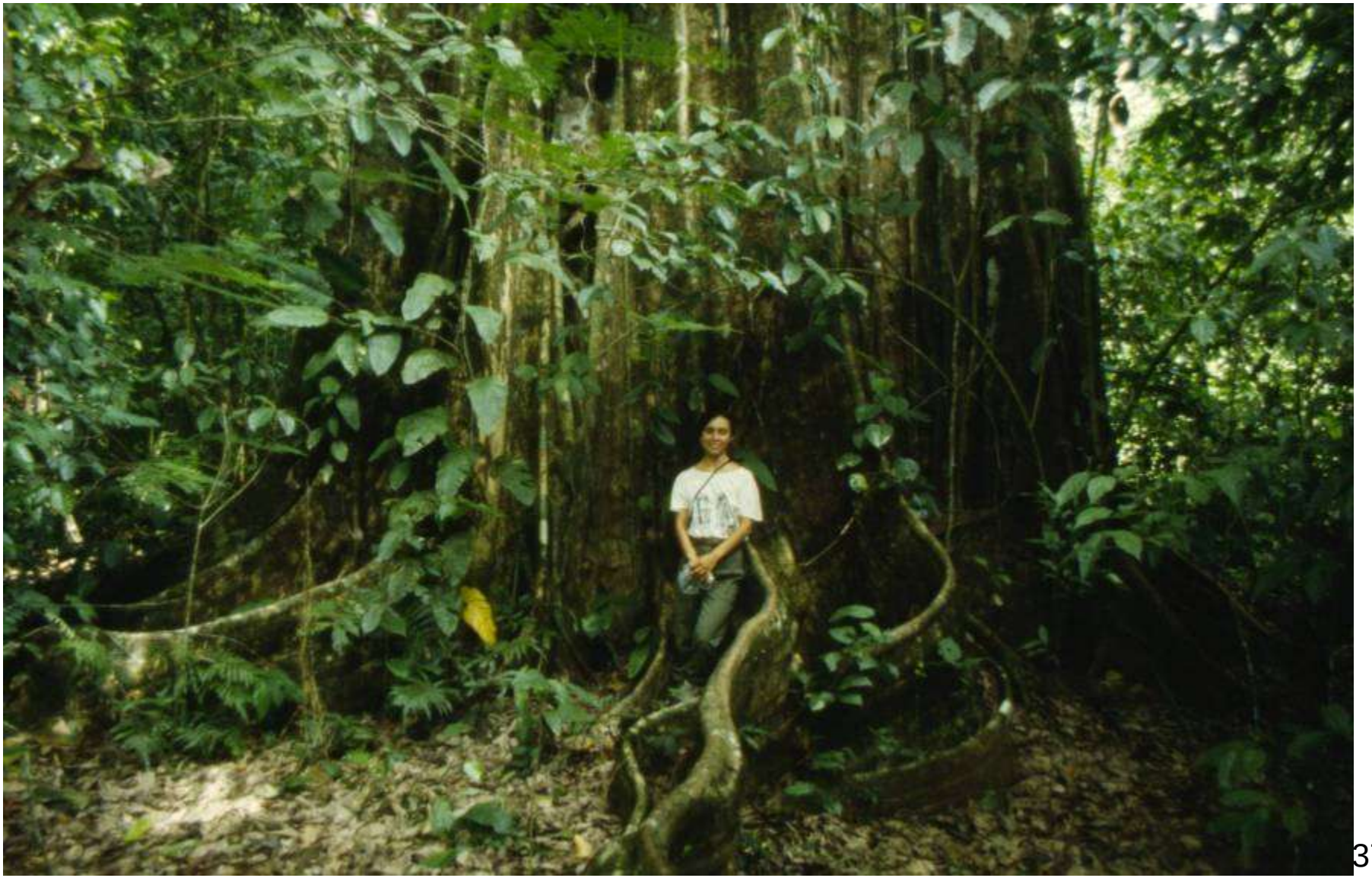
Pantropical hemiepiphytes: start life as unrooted epiphytic seedlings in the crown of a host tree;

aerial roots descend to earth, take root in the soil and start functioning as regular roots;

But aerial portions of roots also grow laterally around trunk of host tree, fuse with each other to create an interlinked,cylindrical sheath of wood

Strangler figs eventually kill host, become free-standing hollow trees (Vietnam)

Big fig trees, *Ficus insipida*, Corcovado, Costa Rica



Wrap-up questions (if time):

In what ways is the hemiepiphytic strangler habit an effective strategy for these habitats? What advantages do stranglers gain over (1) true epiphytes and (2) normal free-standing trees?

Next time: population ecology