Plant Ecophysiology in a Restoration Context

- Objectives:
  – How can the foundations of and theory in plant ecophysiological ↔ restoration ecology ↔ ecological restoration?
    - Light and energy relations
      – Photosynthesis
      – Microclimate
    - Belowground resource availability and acquisition
      – Nutrients
      – Water

Plant Ecophysiology in a Restoration Context

- Chapter authors

Jim (Father of Plant Ecophysiology)

Darren (My postdoc advisor)

Plant Ecophysiology in a Restoration Context

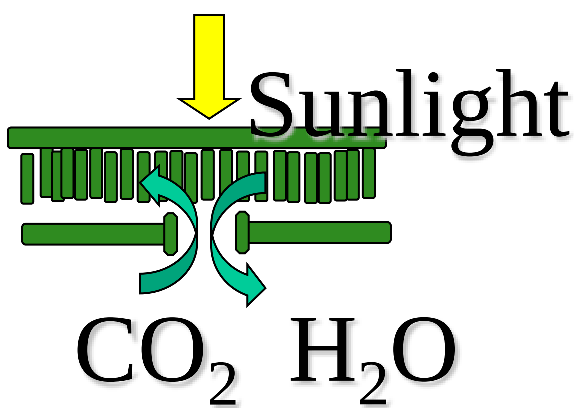
- Ecophysiology
  - The science of the interrelationships between the **physiology** of organisms and their **environment**
    - Or: Physiological adaptations to the environment (tolerance)
    - *Physiology*: study of the physical and biochemical functions of living organisms
  - Where are we in the ecological hierarchy?
  - How can restoration benefit from ecophys. info?
    - Understanding ecophysiological mechanisms for survival, performance, and adaptation can:
      - Describe potential for a plant to persist in a given habitat
      - Allow for assessment of the impact of an altered environment on plant performance and restoration outcomes

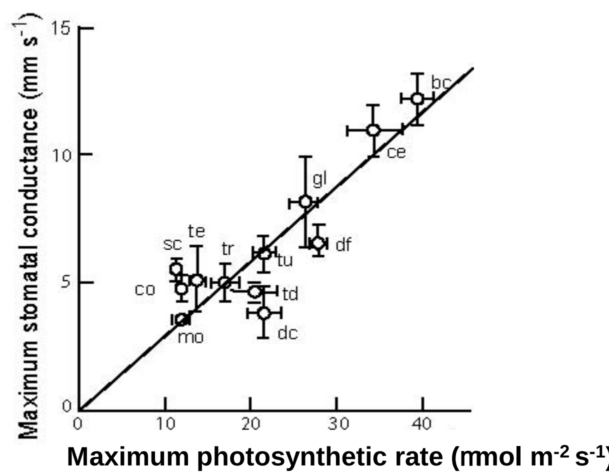
Plant Ecophysiology in a Restoration Context

- Ecophysiology
  - In a restoration context ≈ tolerance to abiotic & biotic stresses in an altered environment
    - I.e., Competitive capacity
  - Intensive modification of the physical environment → establishment of target species may not be possible
    - Use other, better adapted species matched to environment
    - Restore the physical environment 1st, & then target species
  - Two basic ecophysiological themes related to the capacity for plants to establish & tolerate abiotic environment in a restoration context
    1) Light & energy relations
    2) H_2O & nutrient relations

Plant Ecophysiology in a Restoration Context

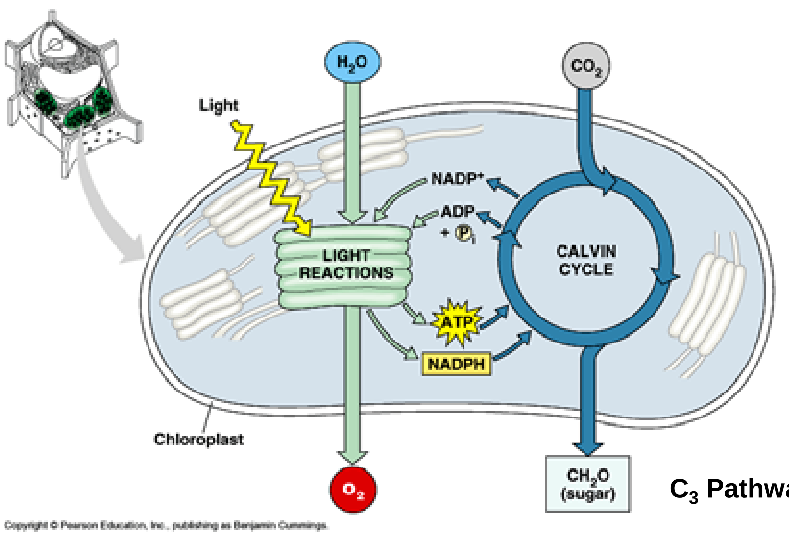
- Photosynthesis
  - Base of almost all food chains (photoautotrophs)
  - CO_2 + Sunlight = Organic matter (C = stored energy)
  - Controlled at the leaf/plant level by availability of **H_2O, nutrients, light,** temperature, CO_2, etc.
  - Compromise/tradeoff between CO_2 uptake & H_2O loss
    - ~400 moles of H_2O lost for every mole of CO_2 taken up





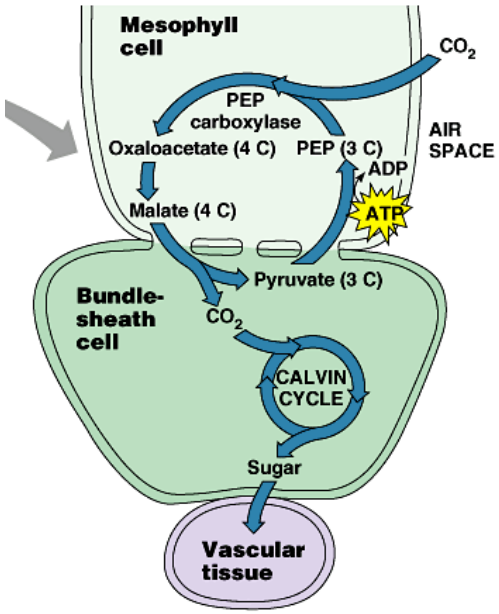
Plant Ecophysiology in a Restoration Context

- Photosynthesis
  - C_3 vs. C_4 (vs. CAM)
    - Different pathways have different adaptations to the env.
      - C_3 most typically found in cool and moist environments
      - C_4 most typically found in warm and dry environments



C_3 Pathway

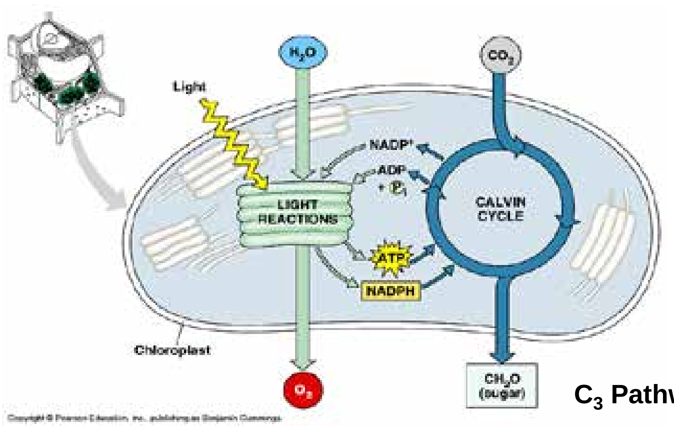
vs.



The C_4 pathway

Plant Ecophysiology in a Restoration Context

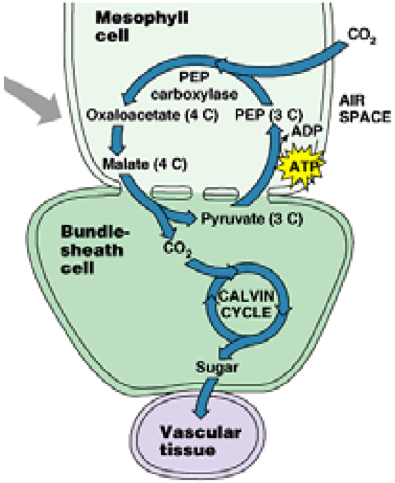
- C_3 Photosynthesis
  - Ancestral pathway; most plants; 80-90% of global NPP
  - ~35% inefficiency due to 'photorespiration'
    - Rubisco can also react with O_2 to convert sugars to CO_2
    - Safety valve
      - Keeps light harvesting reaction going when CO_2 is low
      - Limits presence of O_2 radicals
    - Photorespiration ↑ as temperature ↑



C_3 Pathway

Plant Ecophysiology in a Restoration Context

- C_4 Photosynthesis
  - Evolved multiple times; most common in grasses
    - Advantageous in low CO_2 environments (i.e., stomata closed with H_2O stress), and warm & dry conditions
  - 1 additional set of reactions + C_3 photosynthesis
    - **Spatial segregation** of light and dark reactions
  - Advantages:
    - Increases CO_2 conc. in bundle sheath cells
      - Essentially eliminates photorespiration
    - Reduces H_2O loss
  - Why don't all plants do it?
    - PEP Carboxylase is 30% more expensive to regenerate than Rubisco



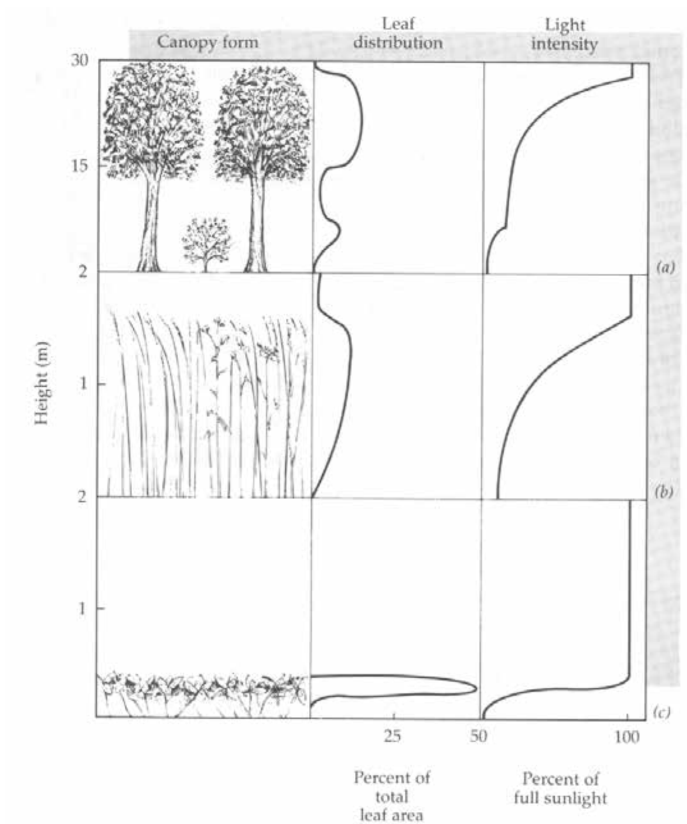
The C_4 pathway

Plant Ecophysiology in a Restoration Context

- C_3 vs. C_4 Photosynthesis
  - ↑ photosynthetic rates in C_4 plants
    - Particularly in warm microclimates of open, disturbed sites
      - ↑ photorespiration in C_3 species
      - Lots of aggressive invasive species are C_4
  - C_4 is currently advantageous in low CO_2 and/or warm and dry environments
    - Increased H_2O stress with global climate change?
    - Rising atmospheric CO_2 levels?
  - PEP Carboxylase is 30% more expensive to regenerate than Rubisco (must “pay off” to invest)
  - C_3 vs. C_4 distribution / presence is ultimately a function of competitive ability within a given env.

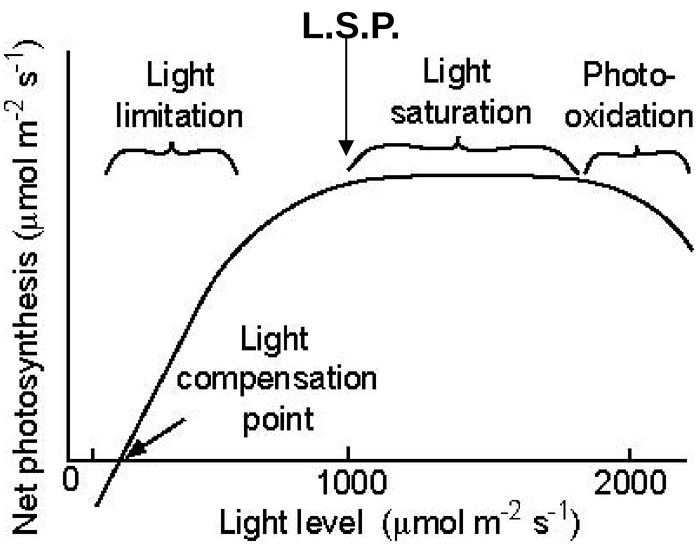
Plant Ecophysiology in a Restoration Context

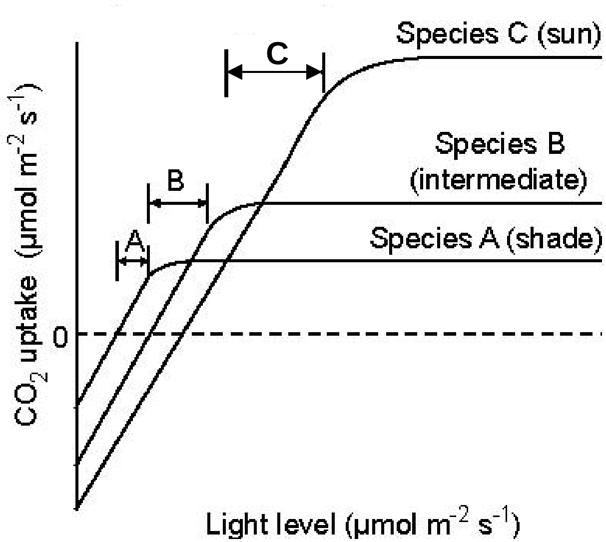
- Light as a necessity and a stressor
  - Species vary greatly in need for & tolerance to light
    - Strong light profile exists in most ecological systems
      - Species-specific adaptations to light levels



Plant Ecophysiology in a Restoration Context

- Light as a necessity and a stressor
  - Photosynthesis ↑ as light increases to a certain point
    - Light Saturation Point (L.S.P.) determined primarily by:
      - Stomatal conductance & leaf protein content
    - Light Compensation Point (L.C.P.) determines balance between C source vs. C sink
    - Different adaptations across plants leads to coexistence





Plant Ecophysiology in a Restoration Context

- Photosynthesis requires 3 basic things:
  - 1) Sufficient supply of light
    - Not too little and not too much → ecological adaptations of individual species
      - At low light levels, light compensation and/or light saturation points not met
      - At high light levels
        - » Photoinhibition: excess energy from light reactions oxidizes cellular components & ↓ photosynthetic capacity
        - » ↑ temperature and photorespiration (for C_3 plants)
        - » ↑ moisture stress by ↑ evapotranspiration → ↓ photosynthetic capacity as stomata close and/or leaves curl/wilt/die

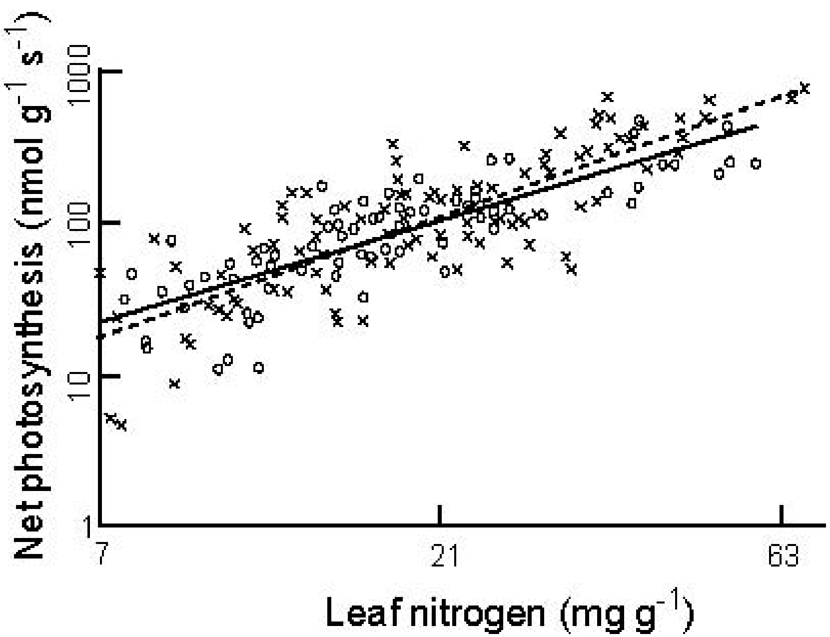
Plant Ecophysiology in a Restoration Context

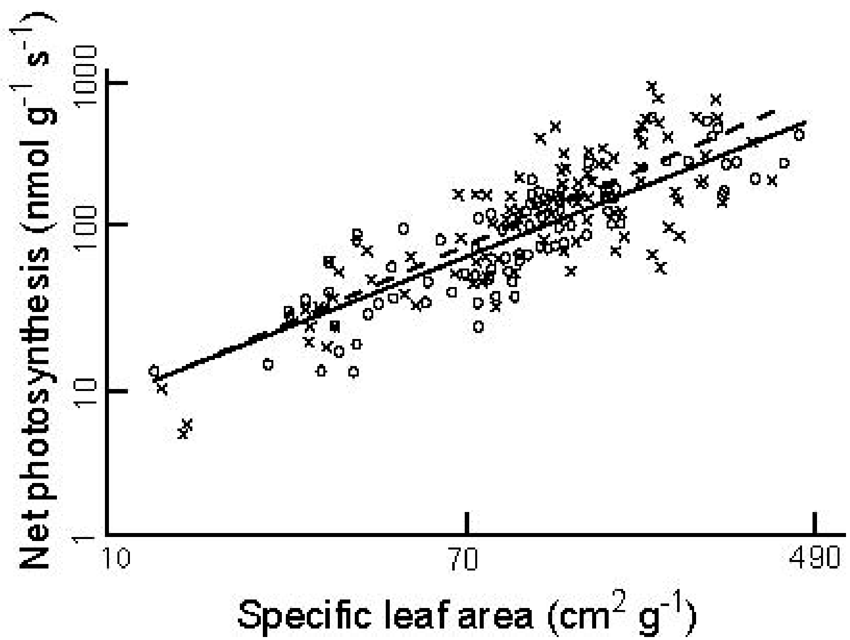
- Photosynthesis requires 3 basic things:
  - 2) Sufficient supply of nutrients
    - To build proteins (e.g., enzymes) associated with the photosynthetic system
      - Rubisco, PEP Carboxylase, etc.
      - Photosynthetic enzymes account for ~50% of foliar N
  - 3) Sufficient supply of H_2O
    - Keeps stomata open → CO_2 diffusion into the leaf
    - Needed in light reaction, but minor compared to H_2O loss via evapotranspiration (ET)

  - Also need adequate CO_2 and appropriate temperature

Plant Ecophysiology in a Restoration Context

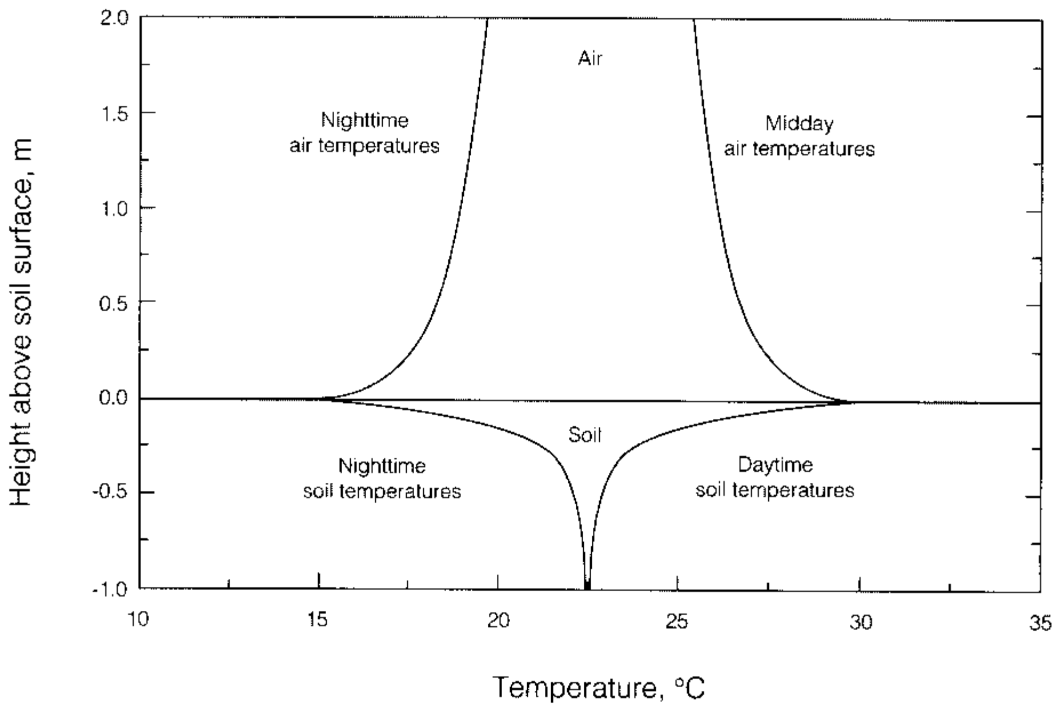
- Measuring photosynthetic rates
  - Expensive and technologically challenging
    - Modern-day Infra-Red Gas Analyzers (IRGAs)
  - Proxies for photosynthetic rates
    - Foliar N, SLA, leaf longevity, etc.





Plant Ecophysiology in a Restoration Context

- Microclimate stressors
  - Variation in microclimate → leads to small scale heterogeneity characteristic of all ecological systems
    - Soil surface & adjacent atmosphere hotter in day and cooler at night than the overlying atmosphere



Plant Ecophysiology in a Restoration Context

- Microclimate stressors
  - Adaptations to ↑ light/temperature at leaf level
    - Net energy balance for a leaf
      - Solar + infrared radiation = infrared reradiation + convection + transpiration
        - » Absorbed radiation: small leaves, pubescence (light reflection), solar tracking, etc.
        - » Increase transpiration rates
      - Restoration Context: Shading
        - » Natural or artificial
  - Stressors when they result in tissue desiccation, protein degradation, increased respiration, etc.
  - Particularly important for small, establishing plants
    - Establishment is the most important barrier to presence

Plant Ecophysiology in a Restoration Context

- H_2O and Nutrients (Belowground resources)
  - Many restoration activities challenged by significant alterations to soil conditions
    - No soil (e.g., mining)
    - Sand:Silt:Clay ratios (soil texture)
    - Bulk density (typically ↑; e.g., compaction)
    - Organic Matter content (typically ↓)
    - Symbiotic microbes
      - Mycorrhizae, N-fixing bacteria, etc. present?
    - Contaminants (e.g., heavy metals and toxic compounds)

Plant Ecophysiology in a Restoration Context

- H_2O and Nutrients (Belowground resources)
  - Many restoration activities challenged by significant alterations to soil conditions
    - In isolation or together, these things impact availability and distribution of belowground resources
      - I.e., impacts ability of plants to acquire essential resources
    - Subtle to drastic changes in soils and belowground resources challenge restoration at many sites, & can preclude restoration at some sites

Plant Ecophysiology in a Restoration Context

- Minerals / Nutrients
  - Taken up via roots and mycorrhizae
    - An active, energy dependent process
    - Lots of activity in rhizosphere
  - Restoration → supplemental nutrient additions
    - **N, P, K,** Ca, Fe, Mg, S
    - N and P commonly the most limiting nutrients
      - Depends on substrate, disturbance, etc.
  - Uptake is facilitated by solubility
    - Unfortunately, this also increases leaching losses
  - Mycorrhizae can be very important
    - Greatly expand volume of soil exploited for H_2O and nutrients
    - Many plants will not grow without proper mycorrhizal symbionts

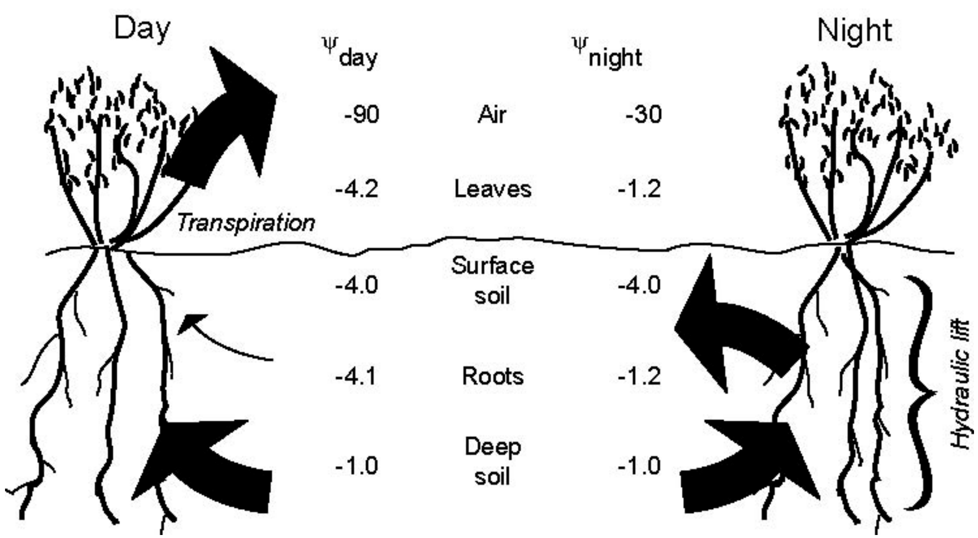
Plant Ecophysiology in a Restoration Context

- Minerals / Nutrients
  - Toxic soils
    - High saline concentrations
    - Altered pH
      - Excess H^+ or OH^- impacts membrane integrity and ion uptake
      - Changes solubility of nutrients, and toxic metals
    - High metal toxicity
      - Needed in small amounts, but toxic in large amounts
      - Reduces growth and alters metabolism
  - Some plants adapted to these situations
    - Can be targeted for restoration/remediation
      - Accumulators (bioremediation)
      - Excluders

Plant Ecophysiology in a Restoration Context

- H_2O Availability and Acquisition
  - Partially an active process
    - Plant roots grow to exploit resources; hydraulic architecture
  - Primarily a passive process
    - Driven by leaf transpiration (which is driven by VPD)
      - But stomatal conductance & hydraulic architecture set limits
    - H_2O movement driven by gradients in water potential / energy across SPAC

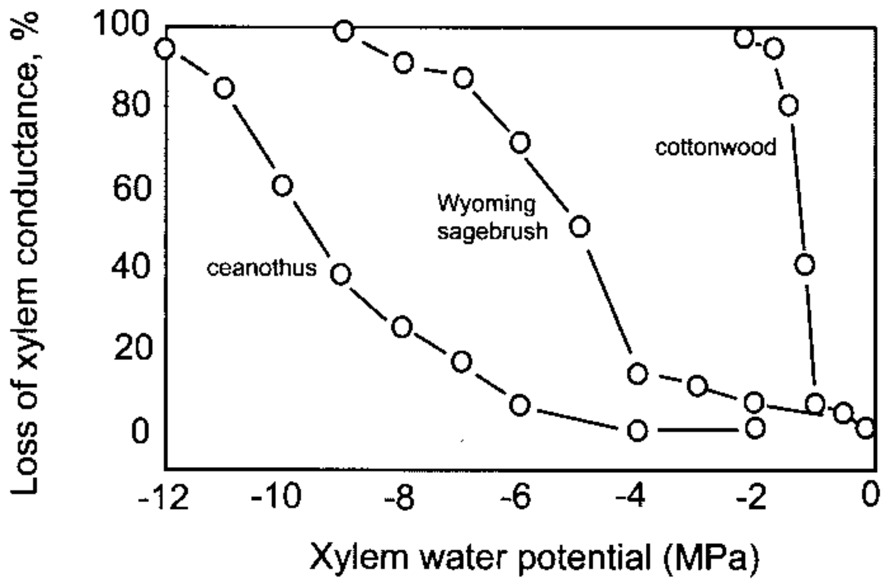
Typical



Hydraulic Redistribution

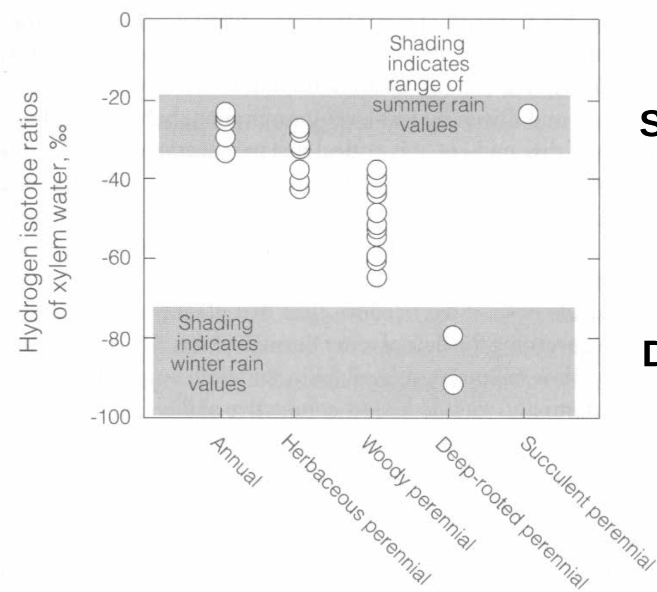
Plant Ecophysiology in a Restoration Context

- H_2O Availability and Acquisition
  - Similar process across species
    - Different species have vastly different sensitivities to H_2O limitation / excess
      - <u>Natural setting</u>: results in species distributions along environmental gradients of H_2O availability
      - <u>Restoration</u>: H_2O often critical determinant of species survival
        - » Supplemental H_2O, particularly during establishment
        - » Choose appropriate species for site conditions



Plant Ecophysiology in a Restoration Context

- H_2O Availability and Acquisition
  - Basic rooting zones differ by species, and within a species by life stage
    - For restoration, critical to know:
      - Actual rooting depth (and how it changes with age)
      - Depth from which plants extract H_2O (and nutrients), and their availability at those depths



Surface H_2O

Deep H_2O

Plant Ecophysiology in a Restoration Context

- H_2O Availability and Acquisition - Restoration
  - – H_2O commonly one of the most limiting resources
  - – Reduction of light / temperature stressors can alleviate H_2O loss and/or photoinhibition
    - Shade cloth
    - Facilitator plants
      - – Challenging due to competition, but knowing rooting depths and potential resource partitioning can inform use of facilitation
  - – Requires knowledge of factors governing H_2O acquisition and transport for a given system
    - Mean Annual Precipitation, and seasonal distribution
    - Fog interception and drip
    - Hydraulic redistribution
    - Canopy architecture

Plant Ecophysiology in a Restoration Context

- Ecophysiology - Restoration perspective
  - Ecophysiological characteristics in a restoration can:
    - Identify candidate restoration species
    - Identify performance expectations
    - Provide means of monitoring restoration
    - Help attain restoration goals
  - Field-based comparative studies are needed
    - Expensive and time consuming; technologically challenging
    - New, less expensive, and easier techniques gradually becoming available
  - Need to carefully select which variables to measure
    - Based on stresses expected to have greatest impact in a restoration setting
    - Identify candidate species for restoration that match site characteristics

Week 7 Readings/Lecture Slide Highlights

1. Plants differ in their ability to tolerate abiotic (and biotic) stress, and understanding species tolerance to abiotic (and biotic) stress informs the selection of species to match a given physical environment in a restoration context.

Week 7 Readings/Lecture Slide Highlights

2. Varied tolerance to abiotic (and biotic) variables across species is largely what allows them to coexist in a restoration site (e.g., resource partitioning).

Week 7 Readings/Lecture Slide Highlights

3. Microclimate is often more important that the prevailing overall site climate in determining a species ability to establish and survive, particularly for small plants (e.g., seedlings). In a restoration context, microclimate can often be manipulated to increase survival and growth of target species (e.g., shading, irrigation).

Week 7 Readings/Lecture Slide Highlights

4. In a restoration setting, the ecophysiological variables selected for monitoring should be based on the abiotic stressors that have the most impact on survival and growth of the target species for that restoration site. These ecophysiological variables can then be used to both inform initial species selection, and to monitor restoration success over time.

Week 7 Readings/Lecture Slide Highlights

5. While ecophysiology is largely about species tolerance to the physical/abiotic environment, these tolerances can only be fully understood, appreciated and managed within the context of biotic interactions (e.g., competition).