Plant Water Relations: The Connection Between Water Stress and Plant Productivity

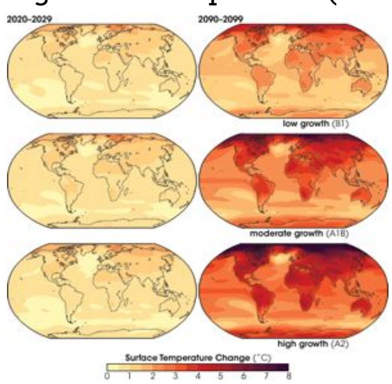
Michael Tyree
Assistant Professor
Homer T. Rogers Endowed Prof.
School of Forestry
mtyree@latech.edu
http://www2.latech.edu/~mtyree/

Source: Dead trees in Houston's Memorial Park, January 2012 (Photo courtesy Texas Forest Service)

Question 1: Climate scientists predict ____ by the end of this century?

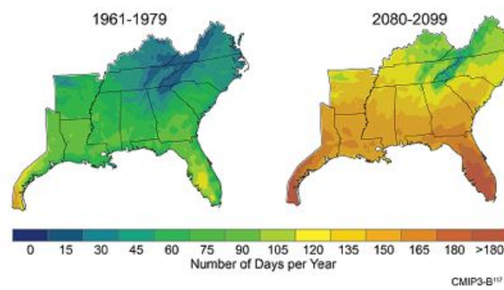
- **a. Temperature will increase**
- **b. Precipitation will decrease**
- **c. Both a & b**
- **d. No change**

Rising surface temperature (2-6°C)

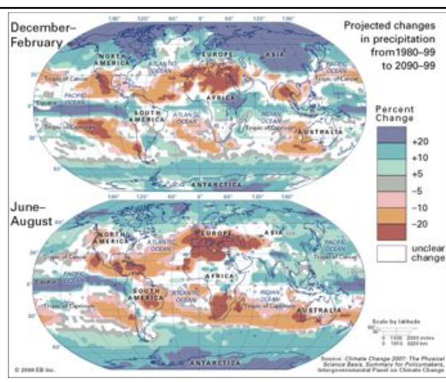


Source: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC.*

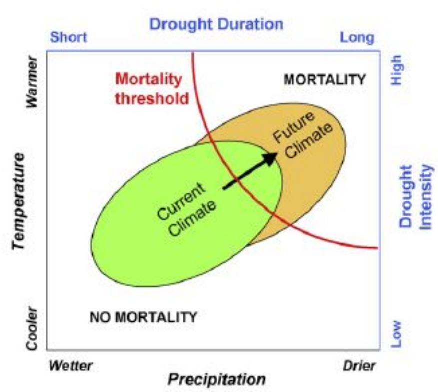
Number of days above 90°F is expected to increase



Source: *Support of this dataset is provided by the Office of Science, U.S. Department of Energy. For an overview and documentation of the CMIP3 modelling activity, see Meehl, G.A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor, 2007: The WCRP CMIP3 multi-model dataset: a new era in climate change research. Bulletin of the American Meteorological Society, 88(9), 1383-1394.*



Source: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Accessed September 4, 2008: http://www.ipcc.ch/ipccreports/ar4-wg1.htm*



Source: *Allen, C.D. et al. 2010. Forest Ecology and Management.*

Outline

- What is productivity?
- Plant-water relations
- Drought stress & plant responses
- Managing for water stress

Productivity begins with carbon capture

Productivity begins with carbon capture

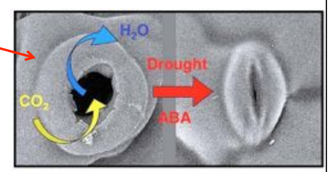
Source: http://www.discoverlife.org;
Photo by: Joshua Wimberly 2012

Source: Zoheb Jiwan; *Accessed on 2.04.14 at: http://www.studyblue.com/notes/note/n/zjiwani1/deck/2095192*

Gross Photosynthesis (leaf level)

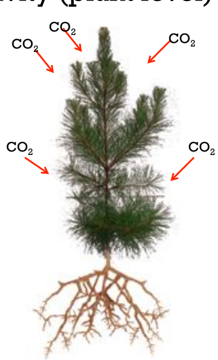
Source: *http://www.vcbio.science.ru.nl/en/image-gallery/show/PL0256/*

Infra-red gas analyzer can be used to measure both carbon uptake and water loss in the field.

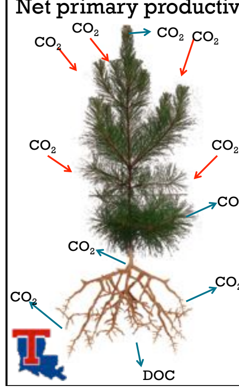


Source: *http://plantcellbiology.masters.grkraj.org.*

Gross Primary Productivity (plant level)



Sources of C loss (plant level)
Net primary productivity



Carbon allocation

Why do we see such early reductions in productivity (growth)?

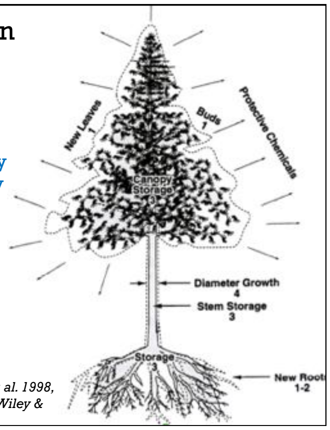


Figure 18.6: *Barnes, B.V. et al. 1998, Forest Ecology 4th ed. John Wiley & Sons, Inc.*

Outline

- ✓ What is productivity?
- Plant-water relations
- Drought stress & plant responses
- Managing for water stress

Question 2: How does water move through a plant?

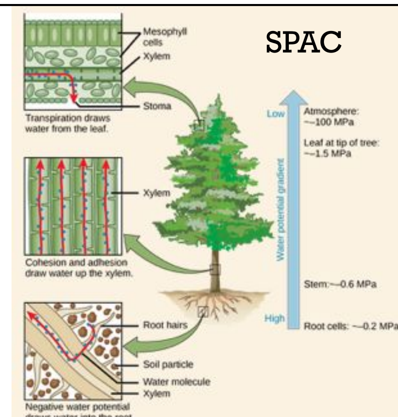
a. Pumped by the roots

b. Suction generated by foliage

c. No water movement

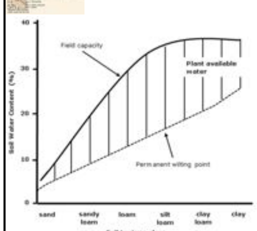
d. Absorbed through the foliage

Soil Plant Atmosphere Cont. (SPAC) model

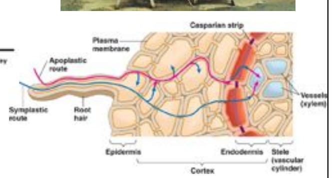


Source: *http://cnx.org/content/ m44708/ latest/?collection=col11516/latest*

SPAC model: Soil water

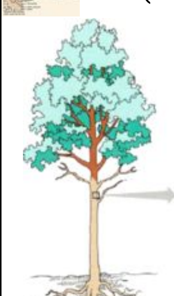


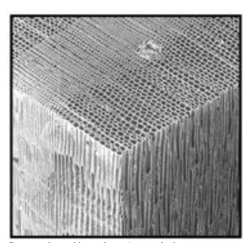
Source: *2012 Nature Education*



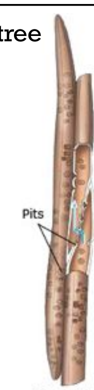
Source: *2008 Pearson Education Inc.*

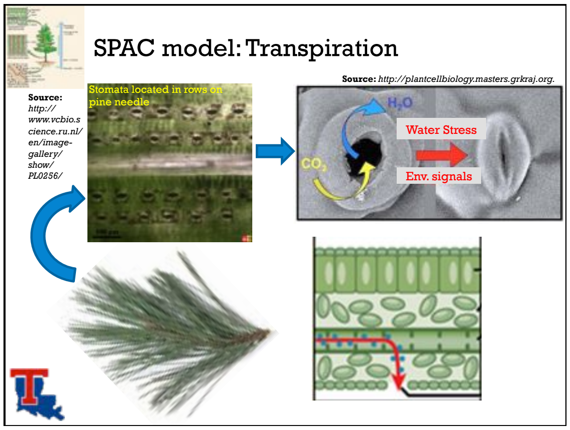
SPAC model: bulk flow up the tree (cohesion-tension theory)

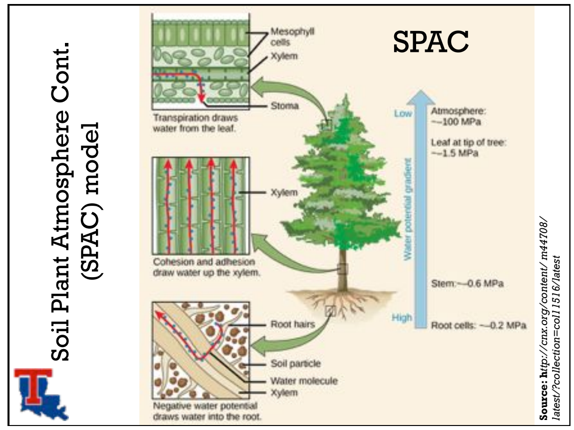


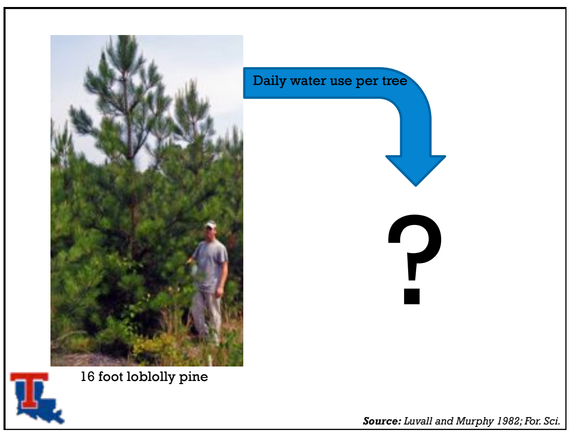


Source: *http://woodmagic.vt.edu/*









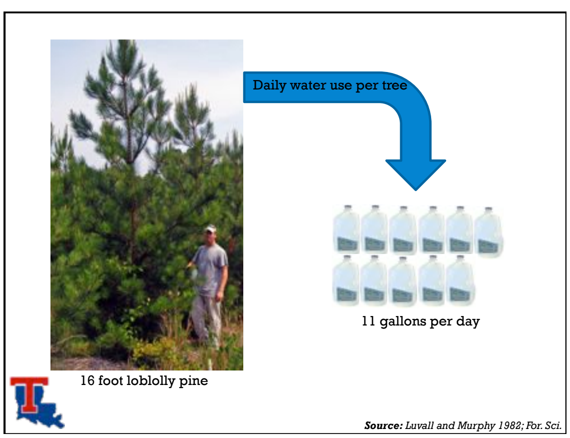
Question 3: How much water does a young loblolly pine use in a single day?

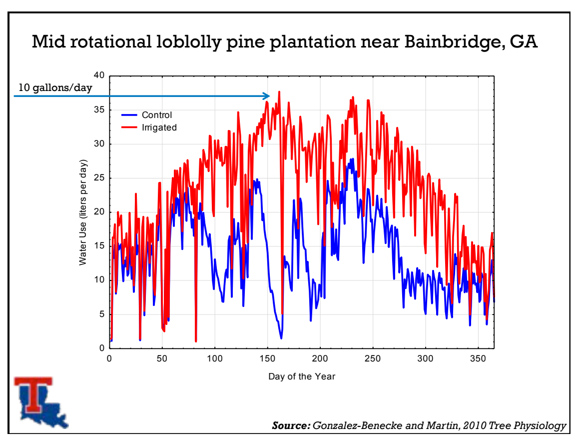
a. 1/2 gallon

b. 2 gallons

c. 5 gallons

d. > 10 gallons





How about fully grown conifers?

92 gallons per day (349 kg day^{-1})
Source: *Teskey and Sheriff 1996; Tree Physiol*

Pinus radiata (Monterey Pine)
82 feet (25 m)

140 gallons per day (530 kg day^{-1})
Source: *Kline et al. 1976; J. Appl. Eco*

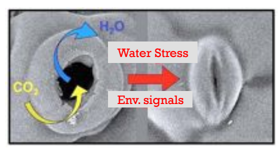
Pseudotsuga menziesii L. (Douglas-fir)
250 feet (76 m)

Outline

- ✓ What is productivity?
- ✓ Plant-water relations
- Drought stress & plant responses
- Managing for water stress

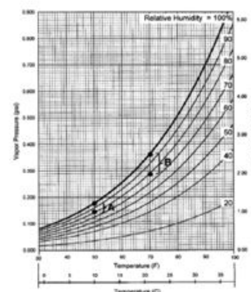
Temperature increases water demand?

Vapor Pressure Deficit drives this exchange



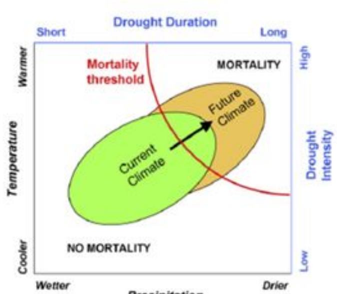
Remember the coupling of water and carbon dioxide movement across the leaf!!

CO_2 / H_2O = WUE

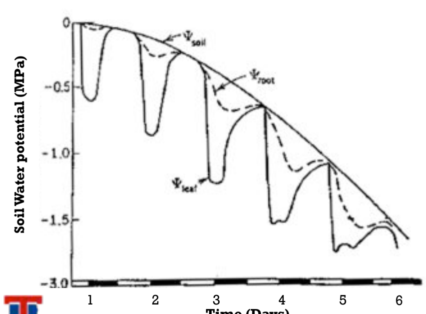


Source: *http://ohioonline.osu.edu/aex-fact/0804.html*

Compounded by drier growing conditions



Water stress falls along a continuum



Pessarakli 1994, Figure 11

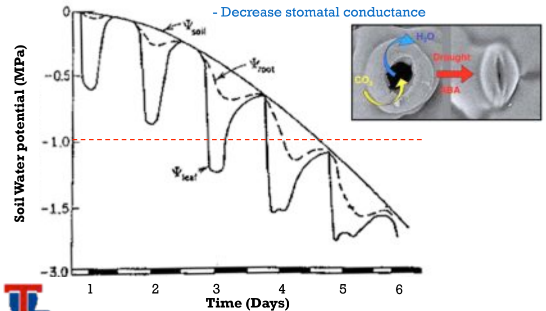
Wilting

Not a sign in pines or most conifers

Photo: Wilted leaves of American Beautyberry in Wolf Pen Creek Park. College Station, Texas, August 25, 2011. Accessed on 12.06.13 at http://www.asergeev.com/pictures/archives/compress/2011/979/16x.htm

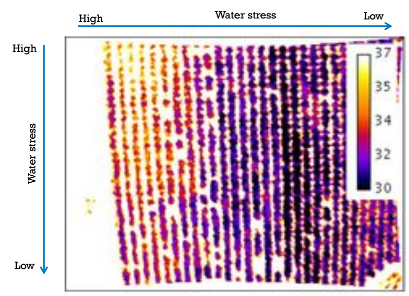
Mild stress (about -1.0 MPa)

- Decrease stomatal conductance



Pessarakli 1994, Figure 11

Thermal image (degrees C) of water-stressed peach orchard

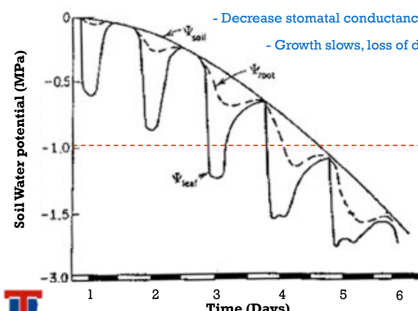


Source: *Zarco-Tejada et al. New era in remote sensing of crops with unmanned robots. SPIE 2008 http://spie.org/X32288.xml, accessed on 02.14.14*

Mild stress (about -1.0 MPa)

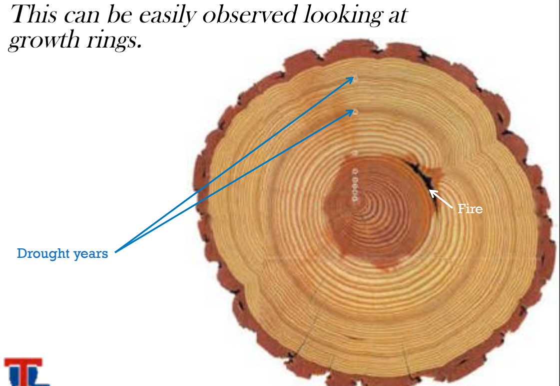
- Decrease stomatal conductance

- Growth slows, loss of diameter growth



Pessarakli 1994, Figure 11

This can be easily observed looking at growth rings.

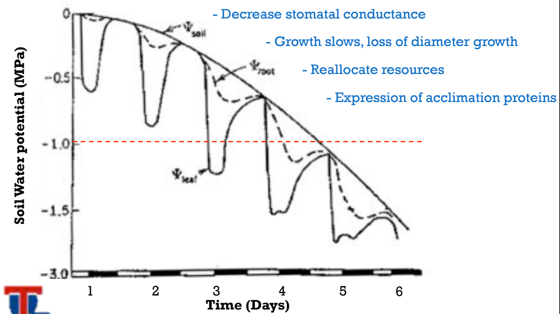


http://www.arborday.org/trees/RingsPix.cfm

Schedule of events

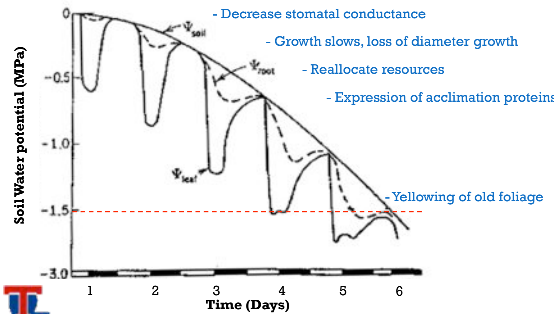
- Decrease stomatal conductance
- Growth slows – loss of cell expansion (turgor), less flushes per year, less diameter growth (remember where trees put their resources)
- Reallocate resources – younger trees
  - Changes in R:S (*Teskey 1987*)
  - Decreases in leaf area (*Bongarten et al. 1986*)
- Expression of acclimation proteins under mild stress (<1MPa; *Watkinson et al 2003, Plant Physiology*)
  - protective protiens (HSP, dehydrins)
  - water transport (aquaporins)
  - stomatal regulation (Abscisic acid)
  - Osmotic adjustment, photosynthetic acclimation
- Expression of senescence genes with severe stress (1.0 - 1.5MPa; *Watkinson et al 2003, Plant Physiology*)
  - Yellowing of old needles
- Xylem impediments to water flow (air embolisms)
- C starvation leading to mortality (*McDowell et al. 2008, New Phytologist*)

Mild stress (about -1.0 Mpa)



Pessarakli 1994, Figure 11

Increasing stress (< -1.5 MPa)



Pessarakli 1994, Figure 11

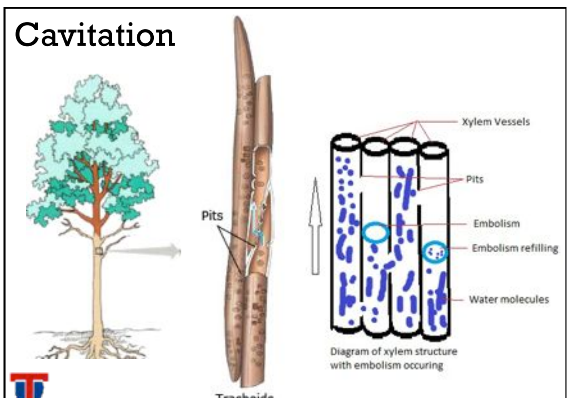
Early yellowing of old needles

Photo: http://www.tarleton.edu/Departments/range/ Woodlands %20and%20Forest/Loblolly%20Pine/loblolly_pine.htm

Schedule of events

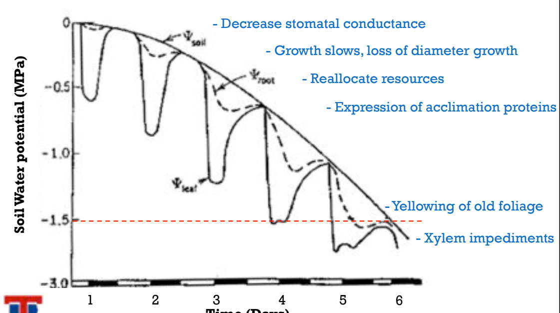
- Decrease stomatal conductance
- Growth slows – loss of cell expansion (turgor), less flushes per year, less diameter growth (remember where trees put their resources)
- Reallocate resources – younger trees
  - Changes in R:S (*Teskey 1987*)
  - Decreases in leaf area (*Bongarten et al. 1986*)
- Expression of acclimation proteins under mild stress (<1MPa; *Watkinson et al 2003, Plant Physiology*)
  - protective protiens (HSP, dehydrins)
  - water transport (aquaporins)
  - stomatal regulation (Abscisic acid)
  - Osmotic adjustment, photosynthetic acclimation
- Expression of senescence genes with severe stress (1.0 - 1.5MPa; *Watkinson et al 2003, Plant Physiology*)
  - Yellowing of old needles
- Xylem impediments to water flow (air embolisms)
- C starvation leading to mortality (*McDowell et al. 2008, New Phytologist*)

Cavitation



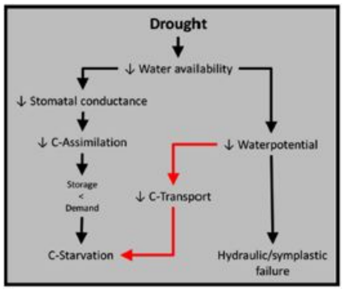
Source: *http://biofrontiers.wordpress.com/page/2/*

Increasing stress (< -1.5 MPa)



Pessarakli 1994, Figure 11

Carbon starvation hypothesis

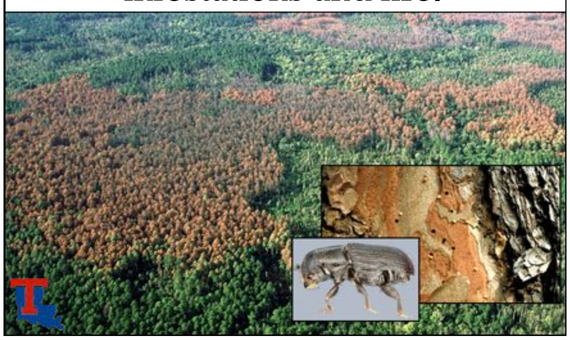


Source: *https://www.bgc-jena.mpg.de*

Schedule of events

- Decrease stomatal conductance
- Growth slows – loss of cell expansion (turgor), less flushes per year, less diameter growth (remember where trees put their resources)
- Reallocate resources – younger trees
  - Changes in R:S (*Teskey 1987*)
  - Decreases in leaf area (*Bongarten et al. 1986*)
- Expression of acclimation proteins under mild stress (<1MPa; *Watkinson et al 2003, Plant Physiology*)
  - protective protiens (HSP, dehydrins)
  - water transport (aquaporins)
  - stomatal regulation (Abscisic acid)
  - Osmotic adjustment, photosynthetic acclimation
- Expression of senescence genes with severe stress (1.0 - 1.5MPa; *Watkinson et al 2003, Plant Physiology*)
  - Yellowing of old needles
- Xylem impediments to water flow (air embolisms)
- C starvation leading to mortality (*McDowell et al. 2008, New Phytologist*)

Increased susceptibility to infestations and fire.



Question 4: How do insects find drought stressed trees?

a. Heat signature from non-transpiring leaves

b. Hear embolisms occurring in xylem

c. Sense stress chemicals

d. All of the above

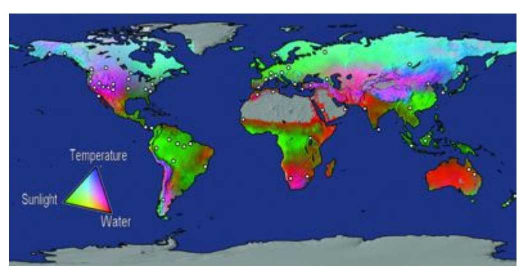
Increased susceptibility to infestations and fire.

Photo Credit: *Mike Ryon, Oak Ridge National Lab*

Photo Credit: *http://www.floridadisaster.org*

Citation: T.W. Coleman, Martin, A., et al. 2010. Disturbance from southern pine beetle, suppression, and wildfire affects vegetation composition in central Louisiana: A case study. General Technical Report SRS-129. USDA Forest Service, Southern Research Station, Asheville, NC.

Tree mortality



Caption: White dots indicate documented localities with forest mortality related to climatic stress from drought and high temperatures (Allen et al. For Ecol & Mgmt, 2010).

Outline

- ✓ What is productivity?
- ✓ Plant-water relations
- ✓ Drought stress & plant responses
- Managing for water stress

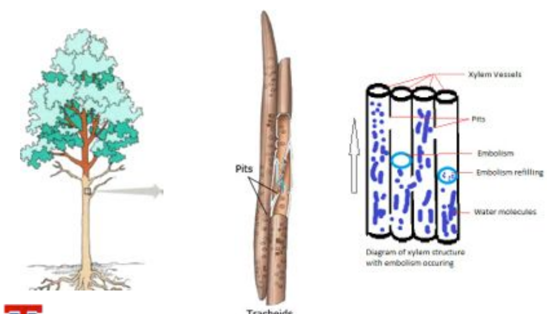
Major loblolly pine seed sources

Map: http://www.fao.org/docrep/006/e4209e/E4209E03.htm

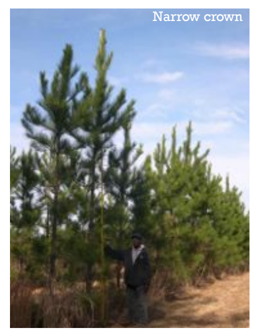
KEY TO SEED SOURCES
1-MARYLAND
2-DAIRE COUNTY, N.CAROLINA
3-ONSLOW COUNTY, N CAROLINA
4-GEORGETOWN COUNTY, S. CAROLINA
5-MARION COUNTY, FLORIDA
6-LIVINGSTON PARISH, LOUISIANA
7-"LOST PINES", TEXAS

Early work done mostly on seedlings and potted plants
- Western provenances decreased E (Bilan et al. 1977)
- Differences in R:S ratios (Ledig 1983, Bongarten & Teskey 1987)
- More fine-root ("Lost Pines"; van Buijtenen et al. 1976)

Genotypes with greater canopy conductance were less resistant to cavitation (*Aspinwall et al, 2011, Ecohydrology*)



Crown ideotypes (Broad vs Narrow)



Hill Farm, LA 2010

Actively Management & Intervene Early

Maintain healthy stands

- Maintain proper stand density
  - Thinning
  - Invasive
  - Competition control
- Protect against insects and disease
- Keep fuel loads low
  - Prescribed burning
  - Competition control
  - Stand density

Key Points

- Plants are going to be under more stress in the future.
- Loss of productivity can occur long before tree mortality
- Drought effects fall along a continuum
- We can manage at the plant and stand level