Why Hydrology Is So Important, With Case Study in Bottomland Hardwood Forests

Bottomland hardwood forest in Tensas Parish, LA; photo by Virginia Velez-Thaxton

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Plant's Eye-View of Wetlands

Photo by Loretta Battaglia

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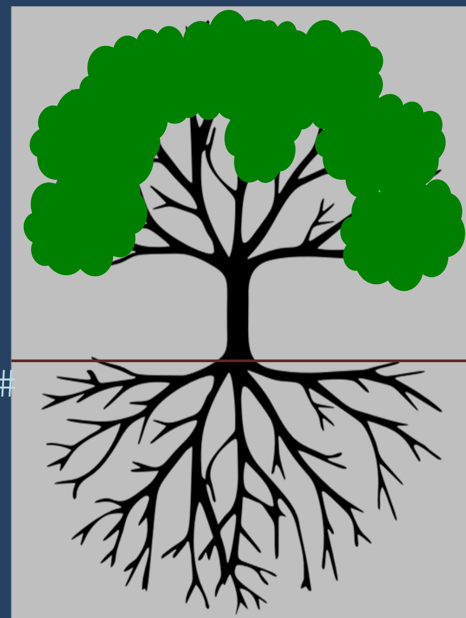
What on Earth is That Plant Doing?

Photosynthesis:

CO_2#-#H_2O#-#E → Sugar#-# O_2#

Aerobic Respiration:

Sugar#-#O_2 → CO_2#-#H_2O#-# E



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Wetland Biogeochemistry

- interrelated physical, chemical, biological processes
- soil is where these interactions occur

Photo by Loretta Battaglia

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Hydric Soils

"Soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part."

- Form when oxygen is cut off by saturation
- Reducing conditions dominate
- Are the medium in which chemical transformations take place

http://www.epa.gov/reg3esd1/wetlands/hydric.htm

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Soil Saturation

- Wetland soils are hydric (saturated) by definition
- Saturation initiates a series of biogeochemical reactions that only reverse once saturation (anoxia) ends
- As water rises, it displaces air in pore spaces
- O_2 diffusion is greatly diminished
- Microbial activity quickly consumes any dissolved O_2 and O_2 left as air within soil pores
- Anaerobic autotrophs reduce Fe and Mn and employ these electrons in ATP (cellular energy) production
- Anaerobic heterotrophs oxidize OM and use Fe and Mn as electron acceptors during respiration

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Oxidized Layer During Flooding

Thickness depends on:

- Temperature
- Population of aerobic autotrophs & heterotrophs
- Surface mixing

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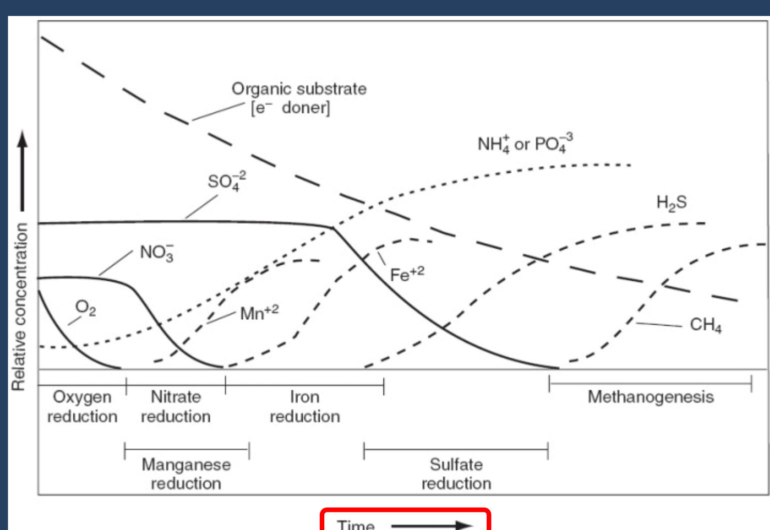
Sequence of Reactions After Soil Flooding



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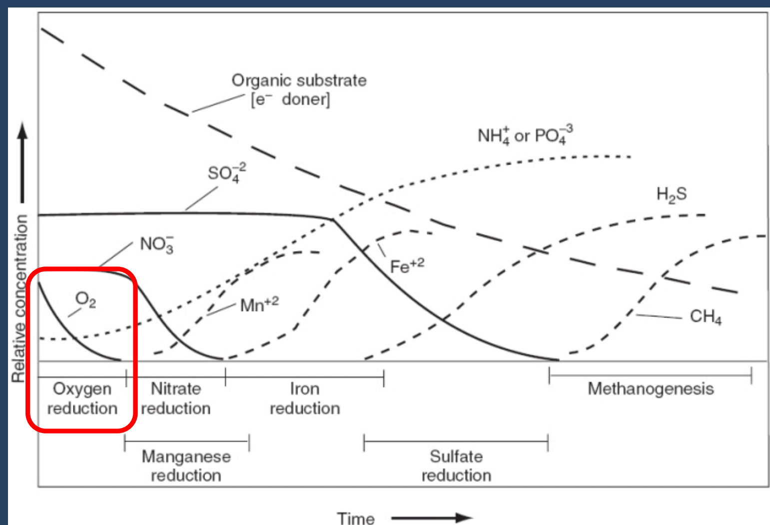

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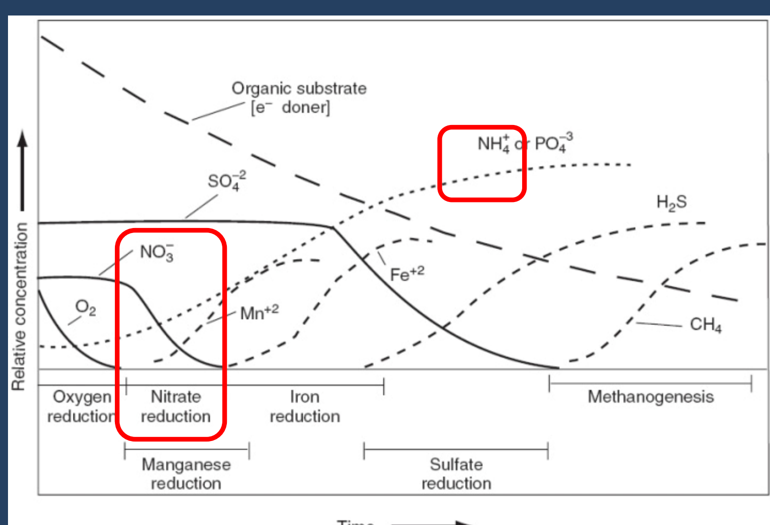

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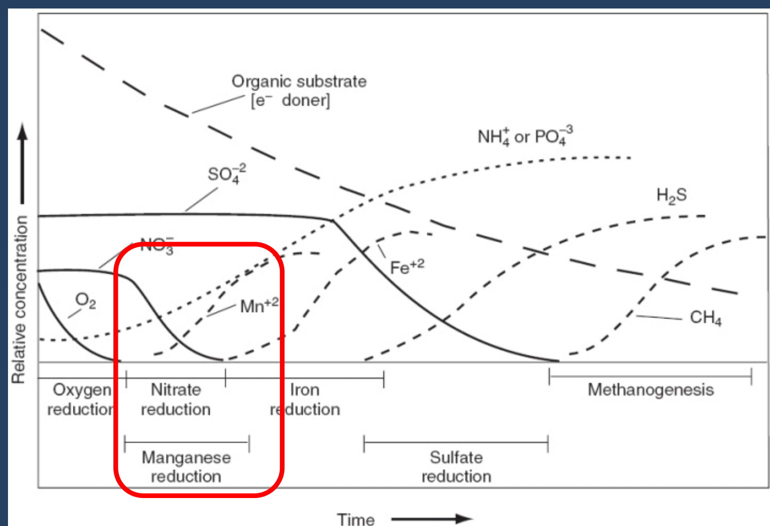

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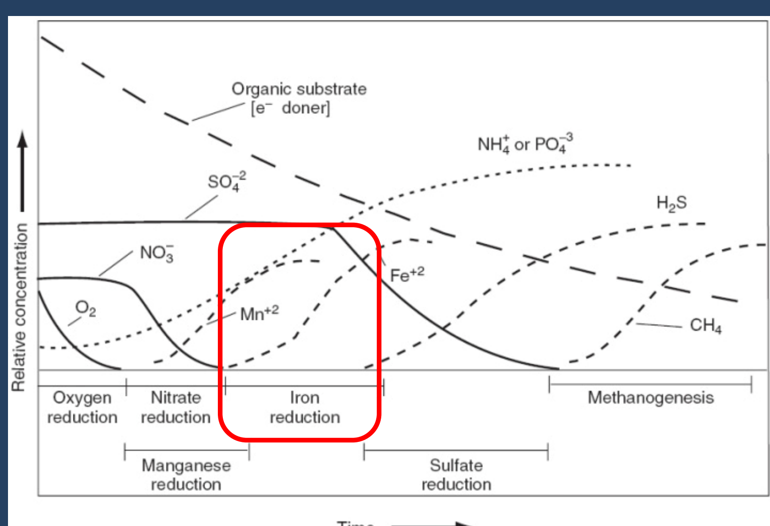

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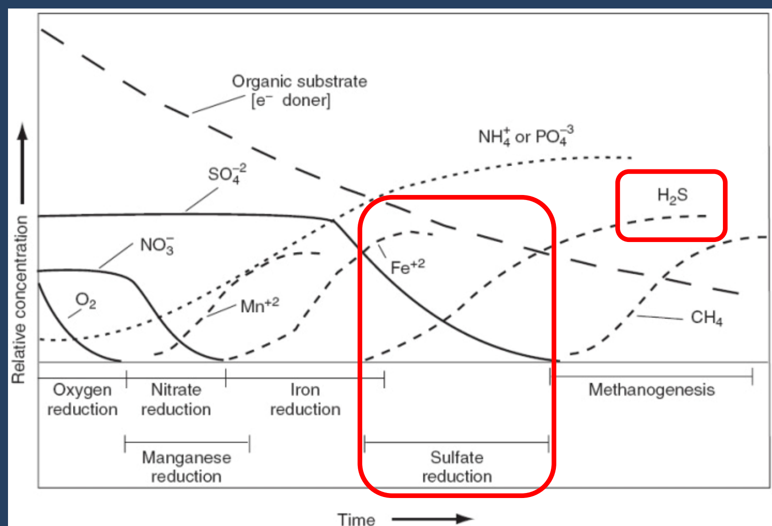
Sequence of Reactions After Soil Flooding



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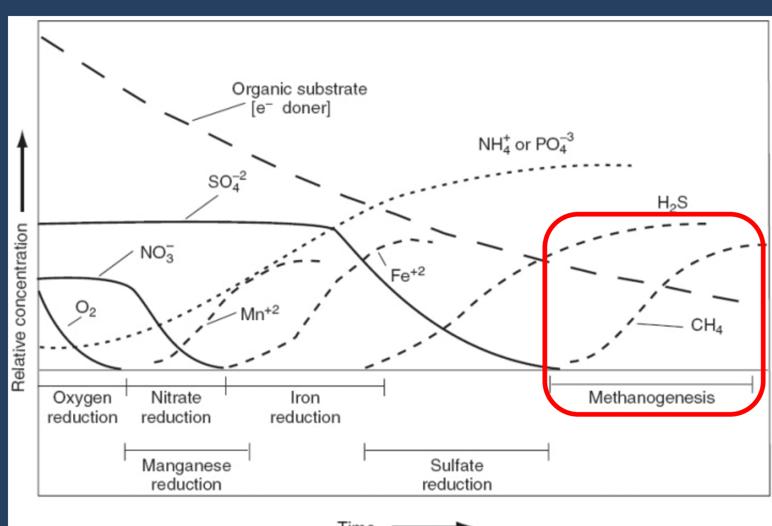
Sequence of Reactions After Soil Flooding



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Rate of O_2 Depletion Depends On:

- Ambient temperature
- Availability of organic substrates for microbial respiration
- Chemical demand from reducing Fe and Mn,

Resulting lack of O_2

- Alters nutrient availability
- Precludes normal aerobic root respiration
- Increases soil toxins
- Demands specialized plant adaptations

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The Wetland Environment – STRESS!!

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The Wetland Environment – STRESS!!

- Wetlands characterized by unique stresses
- Periodic drying difficult for aquatic species
- Temperature extremes in shallow water
- Often prolonged flooding difficult for terrestrial species
- Anoxia – the single most severe stress for many species
  - Resulting nutrient supply altered
  - Increased concentrations of particular toxins
- In coastal systems – salt stress

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Stress of Inundation

- Following flooding of a typical non-flood-tolerant plant:
  - O_2 supply to roots rapidly diminishes
  - Aerobic metabolism of root shuts down
    - Impairs energy status of the cells
    - Plant reduces all metabolic functions: cell extension, cell division, nutrient absorption, etc.
- When cell metabolism shifts to glycolysis, ATP function is greatly reduced
- Toxic end products of fermentation accumulate in cells
- Anoxia causes pathological changes to mitochondrial structures; complete destruction of mitochondria occurs within 24 hours
- Reduced conditions drive build-up of soil toxins (e.g., H_2S)

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How Do They Do It?

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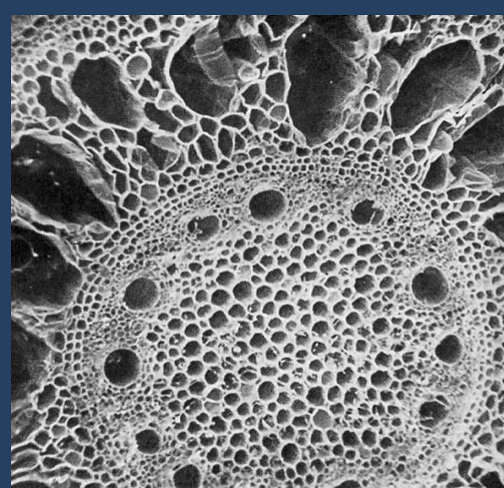
One of Many Wetland Plant Adaptations: Aerenchyma Tissue

- air spaces evolved for passive diffusion of O_2 from leaf tissue to petiole, stem, and down to buried rhizome or root
- as roots elongate they can oxidize their surroundings (**oxidized rhizophere**), which may benefit neighboring plants too
- very well-developed in emergent marsh and aquatic plants (e.g., in *Spartina*)



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Another Wetland Plant Adaptation

- pressurized bulk flow of O_2 from leaves to roots
- Common in water lilies (*Nymphaea*) and other floating emergents, but also *Typha*, *Phragmites*…
- O_2 goes in through young leaves, petiole, rhizome
- CO_2 passes up and out through older petioles and leaves
- ~22 L of air can enter a leaf and flow to rhizome in one day!

Nymphaea odorata; wikimedia commons, SanctuaryX

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A Recap

Photo by Loretta Battaglia

- Wetlands are stressful places for plants because of anoxic root zones and other cascading effects.
- Plants have evolved myriad adaptations to deal with these stresses.
- Different kinds of wetlands present different sorts of stresses and unique plant assemblages that can handle those stresses
- Small differences in hydrology can mean big differences in the sorts of stresses plants experience.
- Thus, small differences in hydrology can affect species occurrence in big ways.

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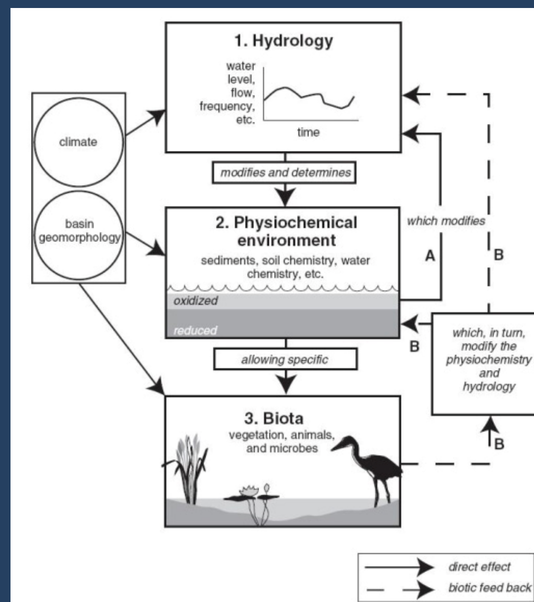
Hydrology Drives Wetland Chemistry

- Hydrology determines physiochemical environ
- Oxygen availability
- Nutrient availability
- pH
- Toxicity (H_2S)
- Transport of sediment
- Transport of nutrients
- Transport of DOC, salinity, toxins, etc.



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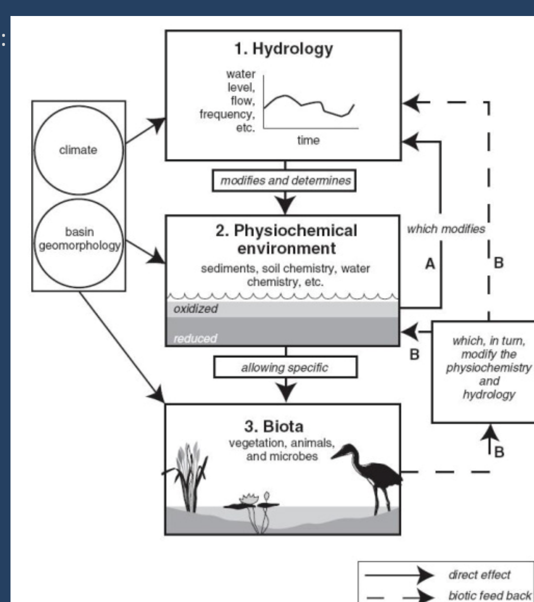
Hydrology Influences Wetland Biota

- Anoxia is strong biotic filter: anoxia ← hydrology
- Productivity ← nutrients nutrients ← hydrology
- Disturbance regime ← hydrology
- Determinants of communities ← biotic filters, nutrient availability, disturbance regime



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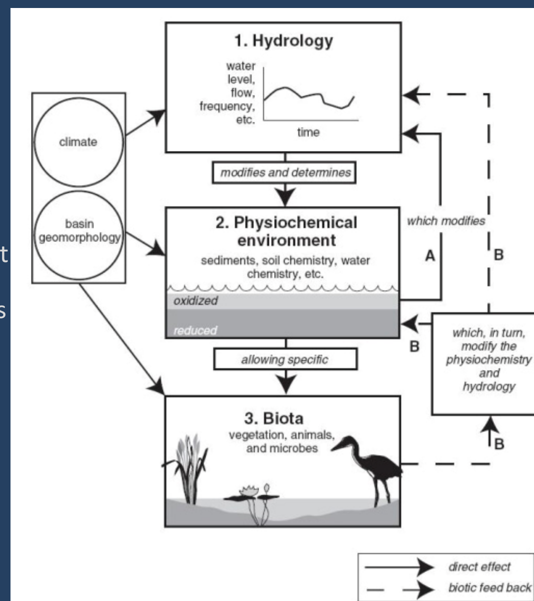
Biotic Feedbacks on Hydrology: Ecosystem Engineers

PLANTS

- Plants trap sediment
- Plants reduce surface flow
- Plants reduced erosion
- Plants die and build-up peat
- Plants break-up water flows

ANIMALS

- Beavers dam streams
- Muskrats burrow and alter water flows
- Hogs wallow



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Flood Pulses Are Super Important

Floods:

- cause inundation and anoxia,
- wash-in nutrients and sediment,
- wash away nutrients and sediment,
- cause shifts in biota.

Fluctuations range widely:

- Year to year
- Seasonally (within year)
- Monthly or semimonthly
- Daily or semidaily
- Unpredictable

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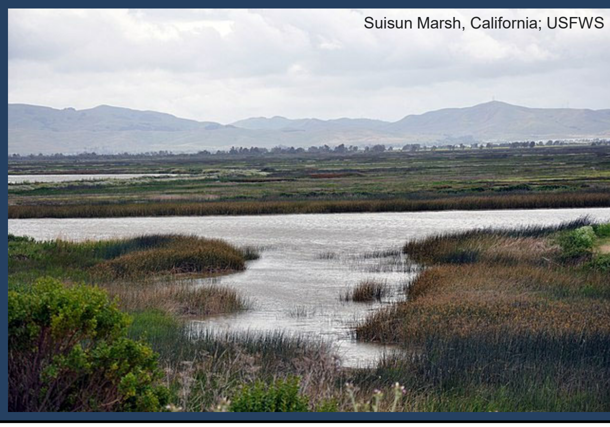
A Recap

- Hydrology is the primary driver of both biogeochemistry and of biotic assemblages.
- Biota feed-back on hydrology: plants trap sediment and beavers build dams.
- Flood pulses dump sediment and nutrients in unique ways depending on the system.



Suisun Marsh, California; USFWS

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Case Study: Bottomland Hardwood Forests

Bottomland hardwood forest in Tensas Parish, LA; photo by Virginia Velez-Thaxton

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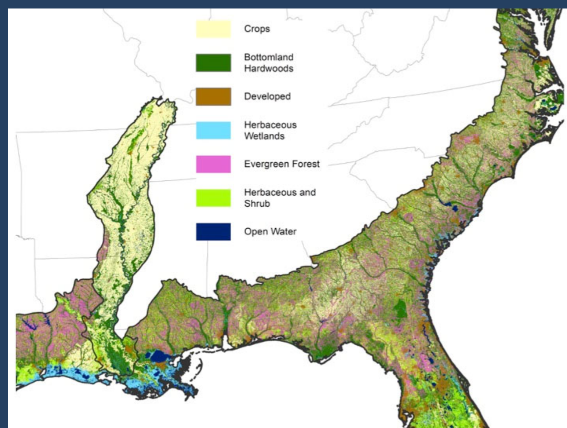
Bottomland Hardwood Forest – Definition

- Riparian forests of the southeastern USA
- Occur in floodplains periodically inundated by adjoining rivers



Gagnon, P. R., Battaglia, L. L., Hanberry, B. B., Conner, W. H., & King, S. L. (2021). Fire in Floodplain Forests of the Southeastern USA. In *Fire Ecology and Management: Past, Present, and Future of US Forested Ecosystems* (pp. 201-242). Springer, Cham.

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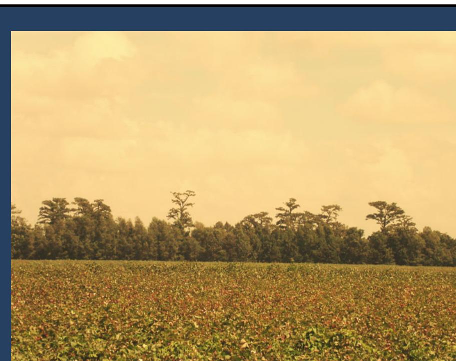
Bottomland Hardwood Forests

Modern BLHF:
- Agriculture
- Levies
- Roads
- Gas lines, development, industry
- Reservoirs upriver alter flood seasonality



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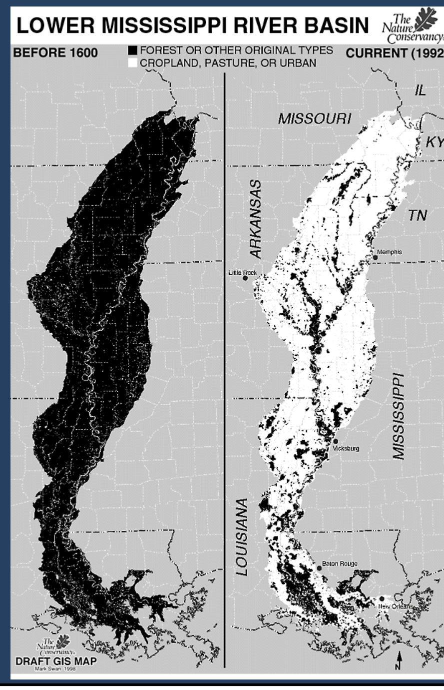
Today's riparian forests are VERY different

- Decadent old growth forests with numerous small gaps are gone
- Replaced by dense, single aged second growth forests with closed canopies
- Cut off from rivers that once fed the floodplains
- Or if inside levies, flooding now deeper and longer than historically
- Beavers controlled everywhere
- Passenger pigeons eliminated
- Fire excluded from the landscape



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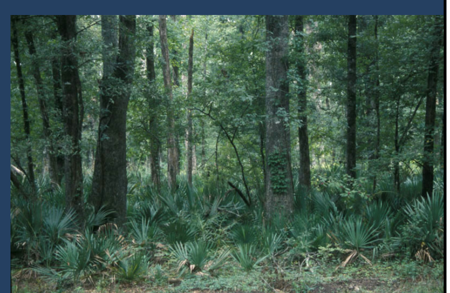
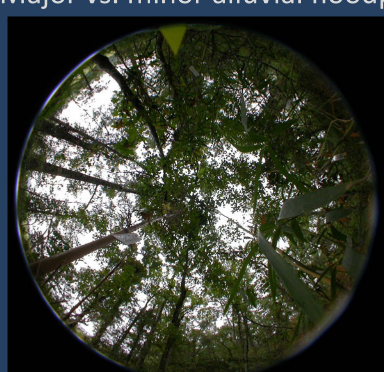
Bottomland Hardwood Forests

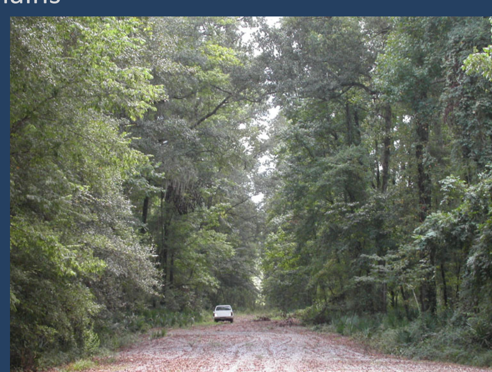
Most are highly productive

Red vs. black river systems

Major vs. minor alluvial floodplains







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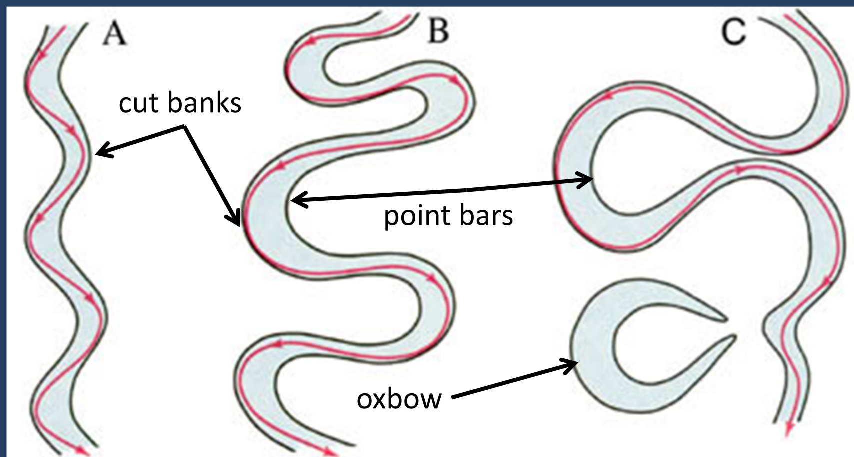
River Meanders



http://www.indiana.edu/~g105lab/images/gaia_chapter_12/meander_formation.htm

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River Meanders

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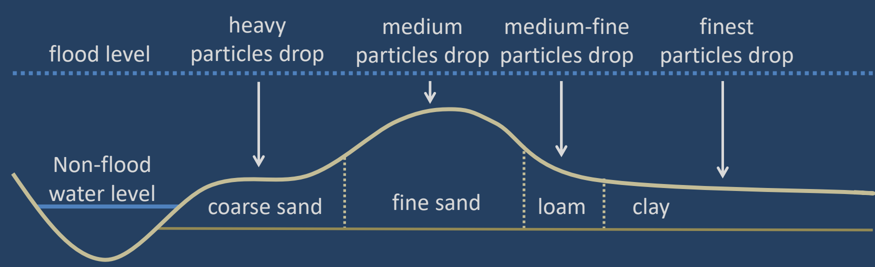
Microtopography and Soil Texture

- As river water slows down, sediment it carries begins to drop.
- The heaviest, coarsest particles drop first.
- The smallest (clay) particles drop last in still water.



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Bottomland Hardwood Forests

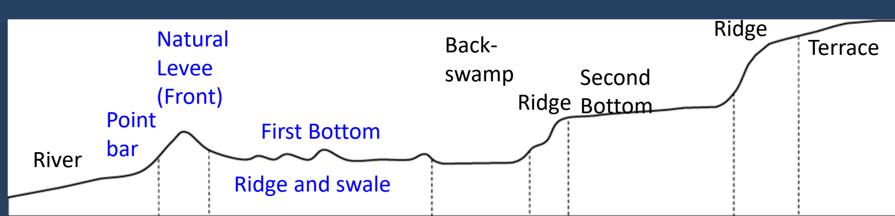
Point bar – sediment deposits in river channel from erosion upstream

Natural levee or Front – high, well-drained ridges that form from repeated floods that overflow the front lands

First bottom – current or recent floodplain containing newer deposits of alluvium and less mature soils (entisols)

Low ridges – banks of older, smaller or less permanent watercourses

Swales – narrow, poorly drained low areas that parallel low ridges



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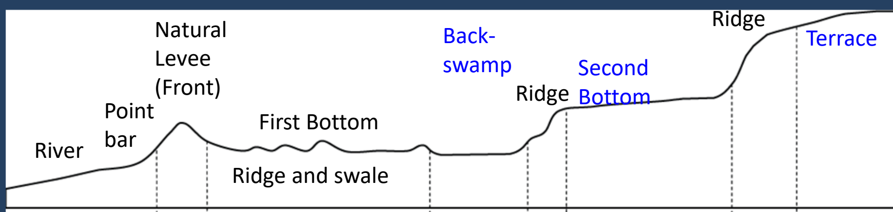
Bottomland Hardwood Forests

Flats – areas between ridges which are typically wide, with poor surface drainage.
Sloughs – channels from former water courses that typically still hold water during some seasons.
Swamp – abandoned section of channel becomes oxbow lake and with sedimentation, a swamp.
Second bottom – remnants from former floodplains, left behind after riverbed erode to new lower elevation.
Low terrace – shallow valley walls of slow-moving river systems.



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Bottomland Hardwood Forest – Hydrology

- BLHF are most often flooded during late winter and spring.
- Most often dry (or driest) during summer and fall.
- Hydrology varies greatly by microtopography.
- Elevational differences of a few inches have outsized effects.
- Flooding from local weather events
- Flooding from snowmelt and major weather events upstream
- Inflows and outflows from/to both groundwater and overland into river

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Bottomland Hardwood Trees

Obligate wetland species
Bald cypress (*Taxodium distichum*) OBL
Water tupelo (*Nyssa aquatica*) OBL
Swamp tupelo (*Nyssa biflora*) OBL
Overcup oak (*Quercus lyrata*) OBL
Black willow (*Salix nigra*) OBL
Water hickory (*Carya aquatica*) OBL
Bitter pecan (*C. illinoiensis* x *lecontei*) OBL

Black gum (*Nyssa sylvatica*) FAC
Red maple (*Acer rubrum*) FAC
***Silver maple (*Acer saccharinum*) FAC/W
Bitternut hickory (*Carya cordiformis*) FAC
Water oak (*Quercus nigra*) FAC
Shumard oak (*Quercus pagoda*) FAC
Sweetgum (*Liquidambar styraciflua*) FAC
E. cottonwood (*Populus deltoides*) FAC

Facultative wetland species
Box elder (*Acer negundo*) FACW
Shellbark hickory (*Carya laciniosa*) FACW
Swamp chestnut oak (*Q. michauxii*) FACW
Willow oak (*Quercus phellos*) FACW
Pin oak (*Quercus palustris*) FACW
Cherrybark oak (*Quercus pagoda*) FACW
Swamp white oak (*Quercus bicolor*) FACW
River birch (*Betula nigra*) FACW
Sycamore (*Platanus occidentalis*) FACW
Green ash (*Fraxinus pennsylvanica*) FACW
Sugar berry (*Celtis laevigita*) FACW

Facultative upland species
Sugar maple (*Acer saccharum*) FACU
Pecan (*Carya illinoisensis*) FACU
Shagbark hickory (*Carya ovata*) FACU
Tulip tree (*Liriodendron tulipifera*) FACU
Bur oak (*Quercus macrocarpa*) FACU
Northern red oak (*Quercus rubra*) FACU
Southern red oak (*Quercus falcata*) FACU
Northern white oak (*Quercus alba*) FACU
Winged elm (*Ulmus alata*) FACU

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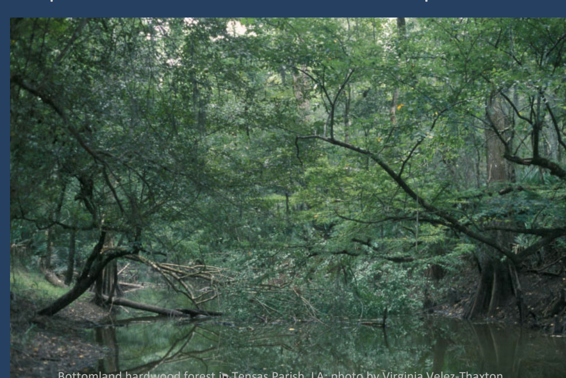
A Recap

- BLHF are species rich riverine forests in the SE USA
- Adapted for conditions in dynamic river floodplains
- Drastically altered by habitat fragmentation & hydrological modifications
- Annual river flooding created many distinct zones in the floodplains
- Eroding rivers and sedimentation patterns determined ecological zones
- Zones determined which tree species lived on which sites in floodplain

THE END

Questions?


Bottomland hardwood forest in Tensas Parish, LA, photo by Virginia Velez-Thaxton

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GRAVEYARD

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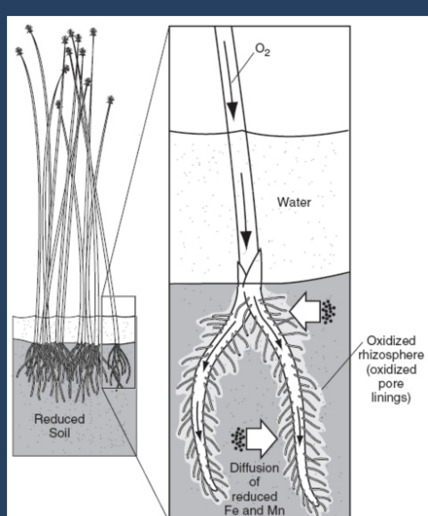
Oxidized Rhizosphere

- Some hydrophytes pump O_2 down their roots
- Leaves evidence of ferric & manganic oxides even after plant dies



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What Determines Wetland Type?

Swamp – Woody vegetation rooted in hydric soil

Marsh – Herbaceous vegetation rooted in hydric soil

Bog – Sphagnum moss/sedges/ericaceous shrubs, or trees rooted in deep peat; low pH (< 5.0); nutrient poor

Fen – Graminoids rooted in shallow peat; higher pH (6.0 or more); higher productivity than bog

2 sets of environmental factors are the primary determinants of wetland type:

Hydrological regime

Nutrient supply (N-P-K)

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Definition of Wetland

US Army Corps of Engineers is the primary permitting agency for the US:

The term "wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

- Hydrology
- Hydrophytes (water-adapted plants)
- Saturated soils

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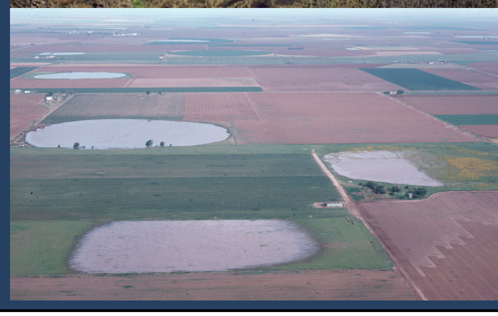
Cooler, Wetter Climates

- Less evapotranspiration
- Long dormant season
- More snow that soaks rather than runs off
- Bog & fen complex in Manitoba, Canada
- Playas in the Great Plains



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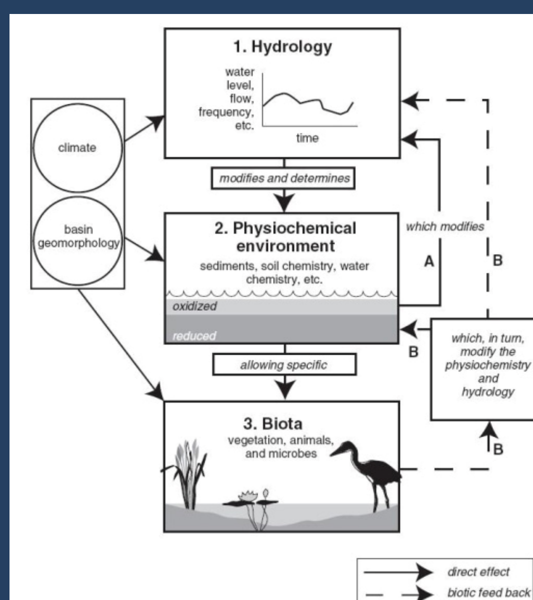
Determinants of Hydrology

- Climate & geomorphology determine hydrology
- Wetlands more common in cool & wet than in hot & dry climates
- Cool climates have less evapotranspiration
- Wet climates have excess water
- Wetlands more common in flat or gently sloped terrain
- Steep terrain does not collect and hold water



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Plant Adaptations: Pneumatophores

- woody species typically do not have these morphological adaptations
- exceptions that have aboveground extensions of roots (**pneumatophores**) give roots access to atmospheric gases
- ***Avicennia* (black mangroves)**

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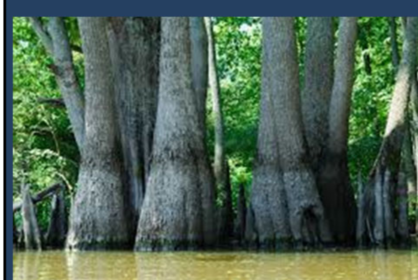
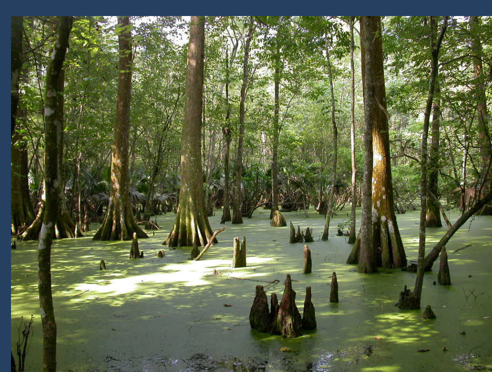
Plant Adaptations: Knees & Butt Swells

- **Butt swells** – large diameter trunks at or below high water levels, possibly related to gas exchange:
- ***Nyssa* (water tupelo)**

- **Knees** (precise function still unclear):
- ***Taxodium* (bald cypress)**





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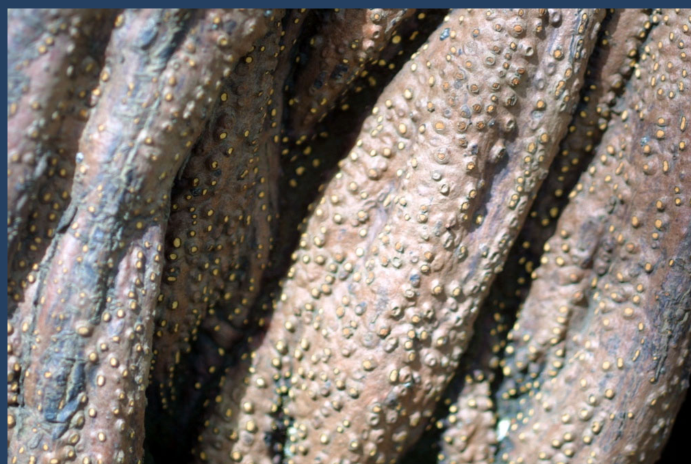
Plant Adaptations: Enlarged Lenticels

- **lenticels** – smalls pores where CO_2 and O_2 exchange occurs



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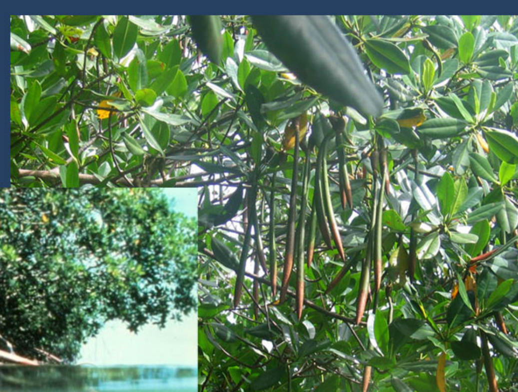
Plant Adaptations

- Viviparous seedlings
- *Rhizophora* stilt roots



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Plant Adaptations: Adventitious Roots

- adventitious roots develop above anaerobic layer

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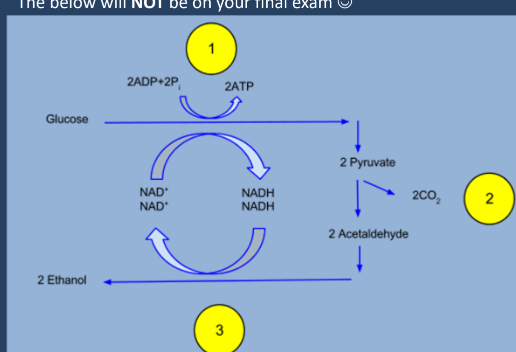
Plant Adaptations: Physiological Mods

Physiological adaptations that avoid producing ethanol or that diffuse ethanol more efficiently in anaerobic environment

The below will **NOT** be on your final exam ☺



Davidcarmack: Creative Commons Attribution-Share Alike 3.0 Unported

In ethanol fermentation. One glucose molecule breaks down into two pyruvates via glycolysis (1). The energy from these exothermic reactions is used to bind inorganic phosphates to ADP and convert NAD+ to NADH. The two pyruvates are then broken down into two Acetaldehyde and give off two CO2 as a waste product (2). The two Acetaldehydes are then reduced to two ethanol, and NADH is oxidized back into NAD+ (3).

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Plant Adaptations to Very Low Fertility

- Low fertility = more leathery evergreen species (**sclerophylly**) because deciduous foliage "too expensive"
- extremely infertile soils, dominance by carnivorous plants (e.g., pitcher plant bog)

Sarracenia (pitcher plants)

Drosera (sundews)

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Secondary Constraints – Marsh

- Exposed to atmosphere (herbivory and fire)
- Wave action and ice
- Heavy shade, intense competition
- In coastal settings, salinity
- Violent storms

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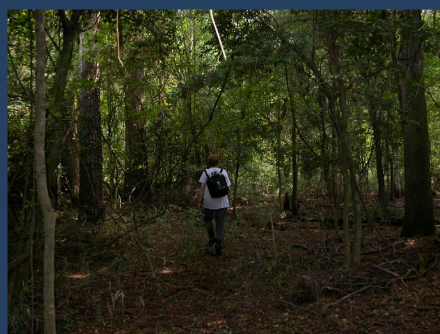
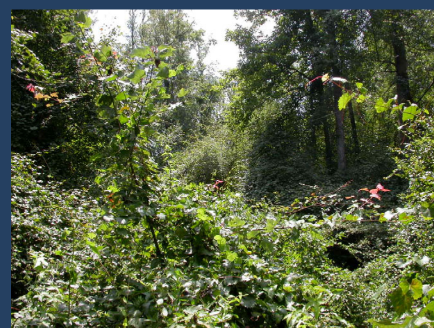
Secondary Constraints – Swamp

- Shade - often need canopy opening to regenerate





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Adaptations to Salinity Stress In Multicellular Plants

- If salt is allowed in, plant must be able to remove it
- Special secretory glands in leaves can excrete salt (crystallized on leaf surface of salt marsh grasses, e.g. *Spartina*)
- Selectively remove sodium relative to other ions such as potassium
- Salt removal costs plant

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Salt Marshes

Salt and brackish coastlines of temperate & high-latitudes

Tidal zones

Cordgrass (*Spartina* spp.)

Valuable estuaries

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Mangroves

Forested tropical/subtropical salt/brackish swamps

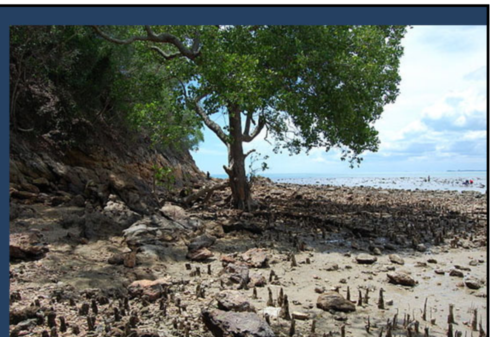
Several different genera of (unrelated) trees

Black mangroves (*Avicennia* spp.) have pneumatophores

Red mangroves (*Rhizophora* spp.) have stilt roots

Highly productive estuaries

In some locations, tall forests



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