Wetland Ecology, Functions, and Management

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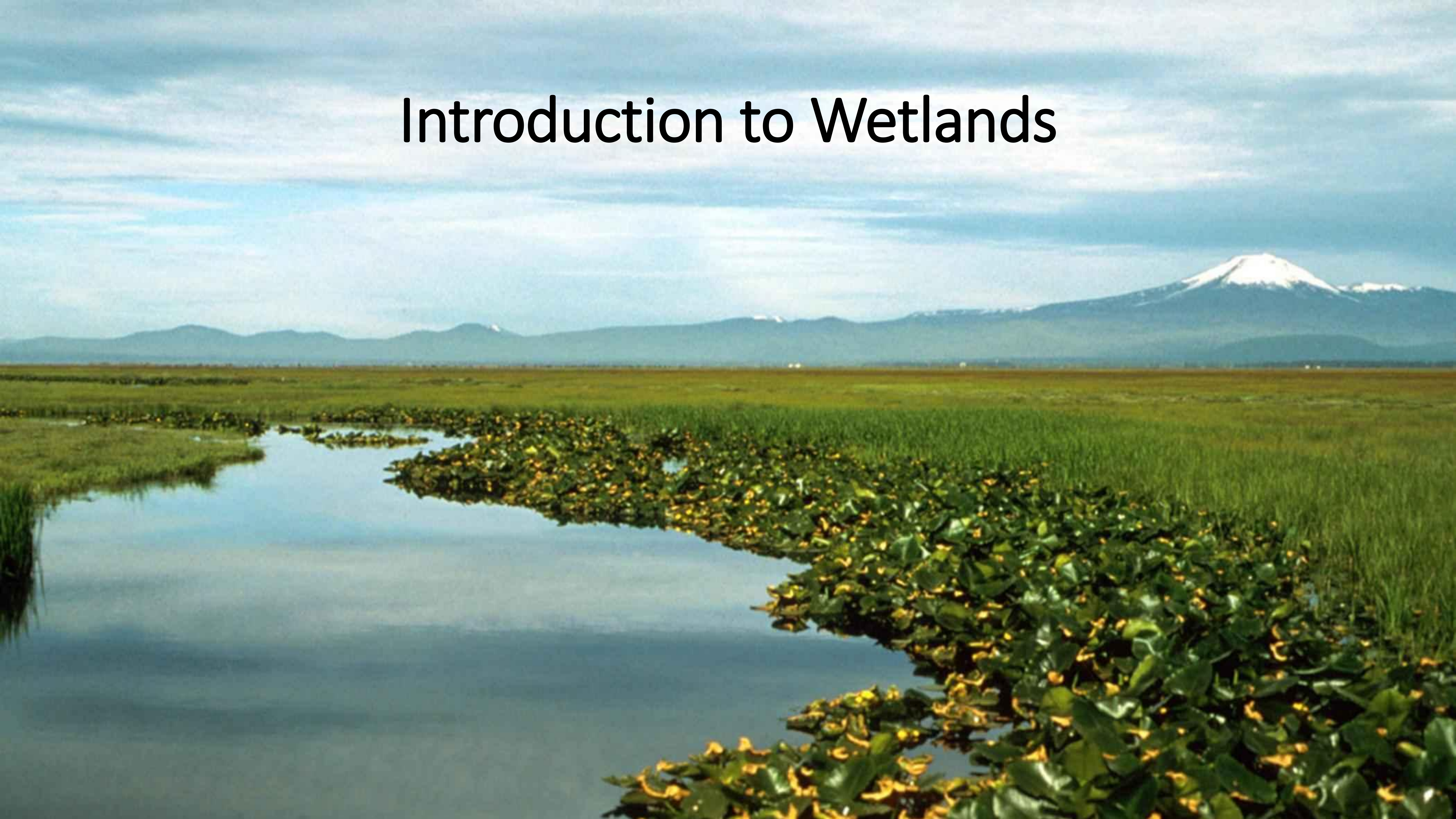
Introduction to Wetlands

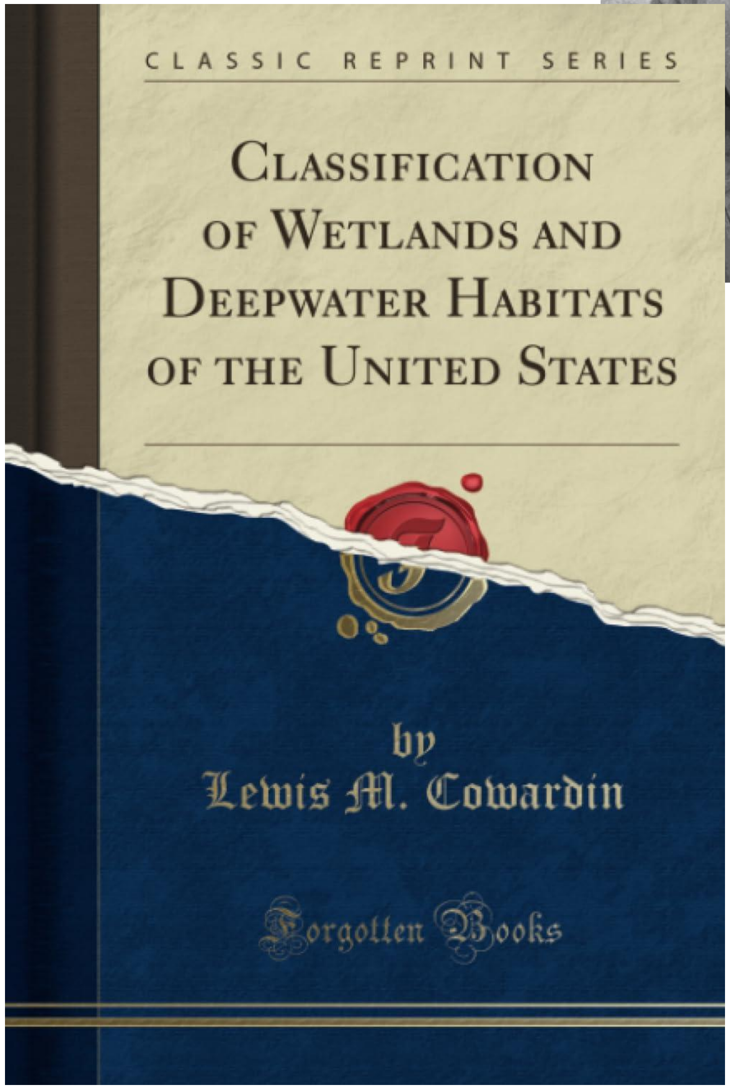


What is a Wetland?

- Wetlands are transitional ecosystems situated between terrestrial and aquatic biomes.
- **The Three Pillars:** Definition is legally and scientifically bound by Hydrology (inundation), Hydric Soils (anaerobic), and Hydrophytic Vegetation (adapted plants).
- They arise when inundation by water produces soils dominated by anaerobic (reducing) processes.
- Once dismissed as "wastelands," they are now recognised as critical "watershed infrastructure".

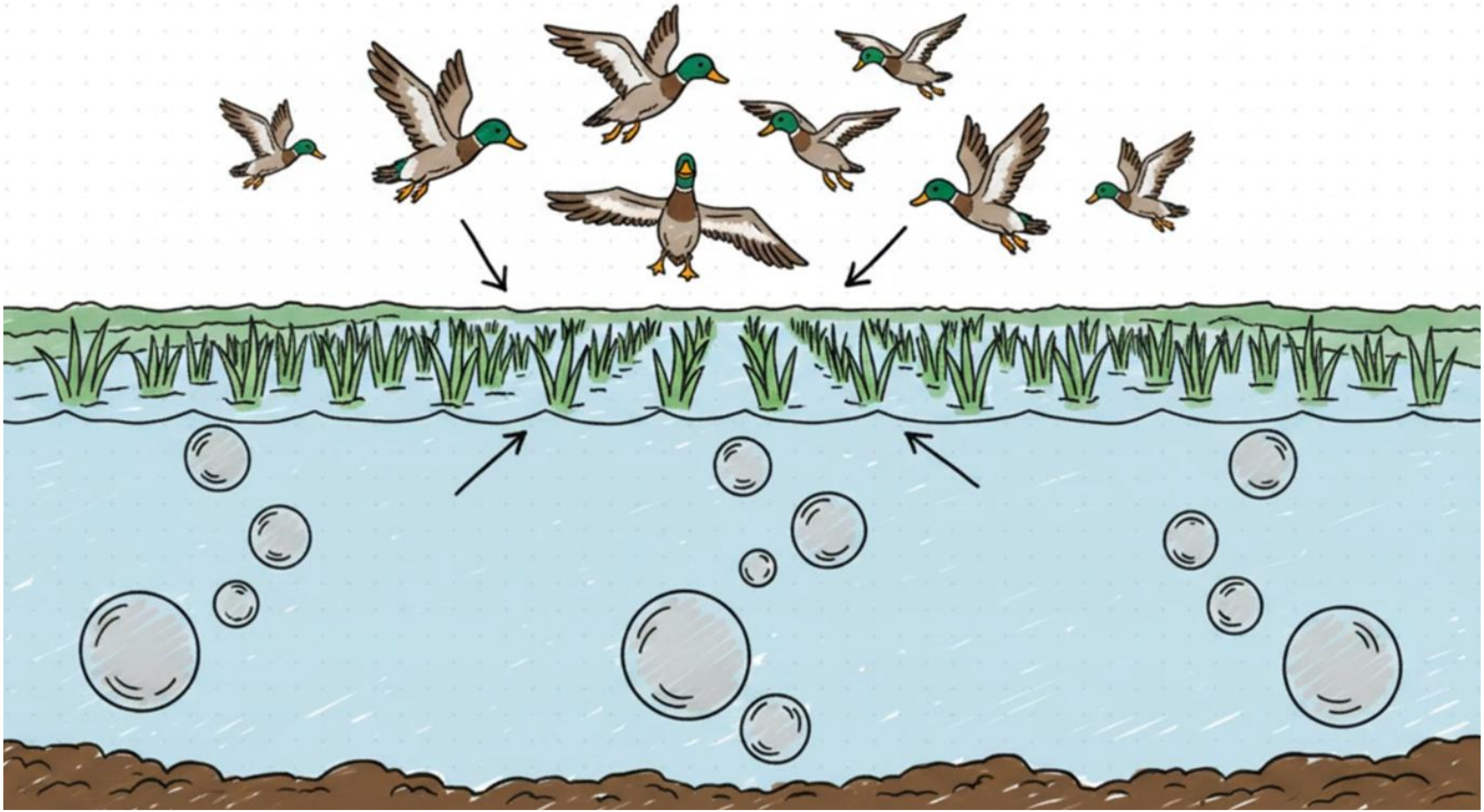
Classification Systems (The Cowardin Framework)

- Developed for the U.S. Fish and Wildlife Service; uses a hierarchical approach based on ecological and hydrological traits.
- **Marine:** Open ocean and exposed coastlines.
- **Estuarine:** Semi-enclosed coastal waters where ocean water meets freshwater.
- **Riverine, Lacustrine, and Palustrine:** Channels, lakes (>2m deep), and inland marshes/bogs respectively.



Classification Systems (The Ramsar Framework)

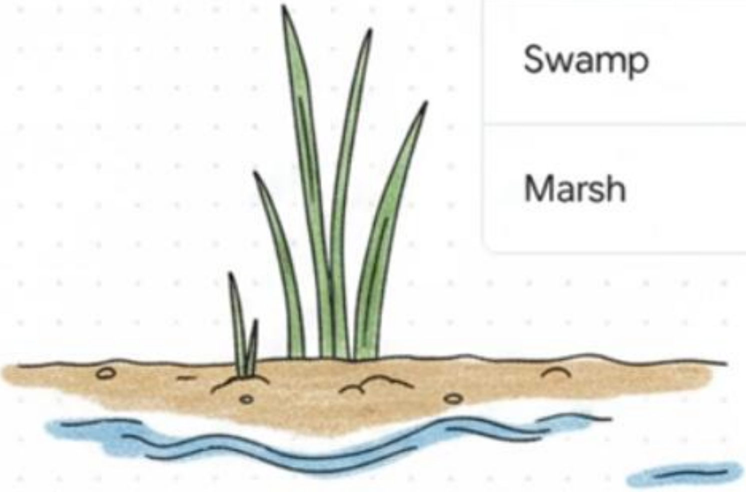
- Recognises 42 wetland types grouped into three broad categories: Marine/Coastal, Inland, and Human-made.
- **Human-made wetlands:** Includes rice paddies, aquaculture ponds, and wastewater treatment wetlands.
- Significance: Acknowledges that anthropogenic systems can provide vital ecosystem services, such as habitat for migratory birds.

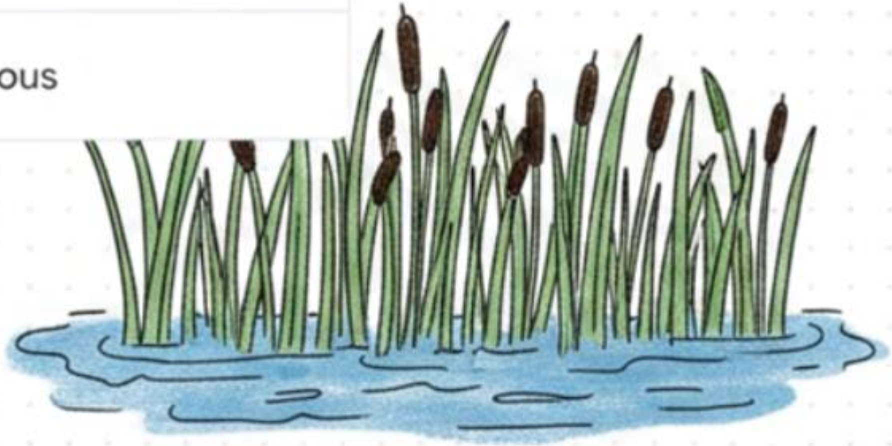


Human-made wetlands

Major Wetland Types and Characteristics

Type	Soil	Plant Life
Bog	Acidic Peat	Sphagnum Moss
Fen	Shallow Peat	Sedges & Grasses
Swamp	Hydric (Not Peat)	Trees
Marsh	Hydric (Not Peat)	Herbaceous





Major Wetland Types and Characteristics

- **Marshes and Swamps:** Dominated by herbaceous plants and trees respectively, rooted in mineral hydric soils.
- **Bogs and Fens:** Peat-accumulating wetlands; bogs are acidic and ombrotrophic (rain-fed), while fens are minero-trophic (groundwater-fed).
- **Shallow Water:** Littoral zones of lakes or prairie potholes covered by at least 25 cm of water.

Global Distribution and Major Wetlands

Hudson Bay Lowlands

- ***Located:*** Canada
- ***Size:*** The largest wetland in Canada and one of the largest in the world, the Hudson Bay Lowlands is approximately 80 million acres in size.
- ***Species:*** The wetlands provide important habitat for migratory birds and large mammals such as polar bears and wolverines!

West Siberian Lowlands

- ***Located:*** Russia
- ***Size:*** The Lowlands are made up of more than 640 million acres (this is almost 7 times the size of Germany).
- ***Species:*** In the Lowlands, winter can last 5-7 months out of the year. These wetlands are home to brown bear, waterfowl, otter, muskrat, elk and more.

Llanos de Moxos

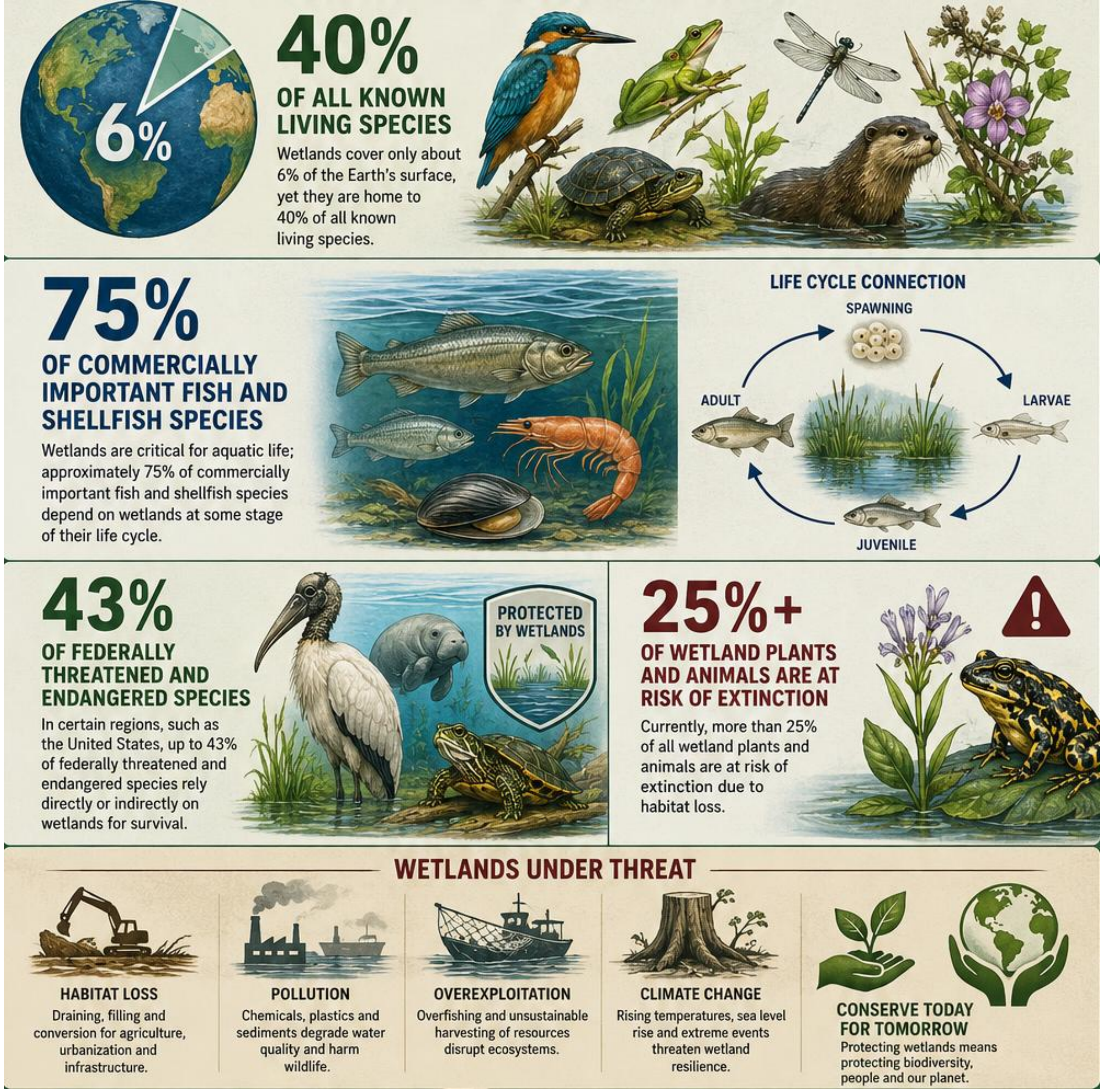
- ***Location:*** Bolivia.
- ***Size:*** Llanos de Moxos is more than 17 million acres—roughly equal in size of North Dakota.
- ***Species:*** This biologically diverse wetland is home to at least 565 different birds, 625 fish, 100 reptiles, 60 amphibians, and 1,000 plant species

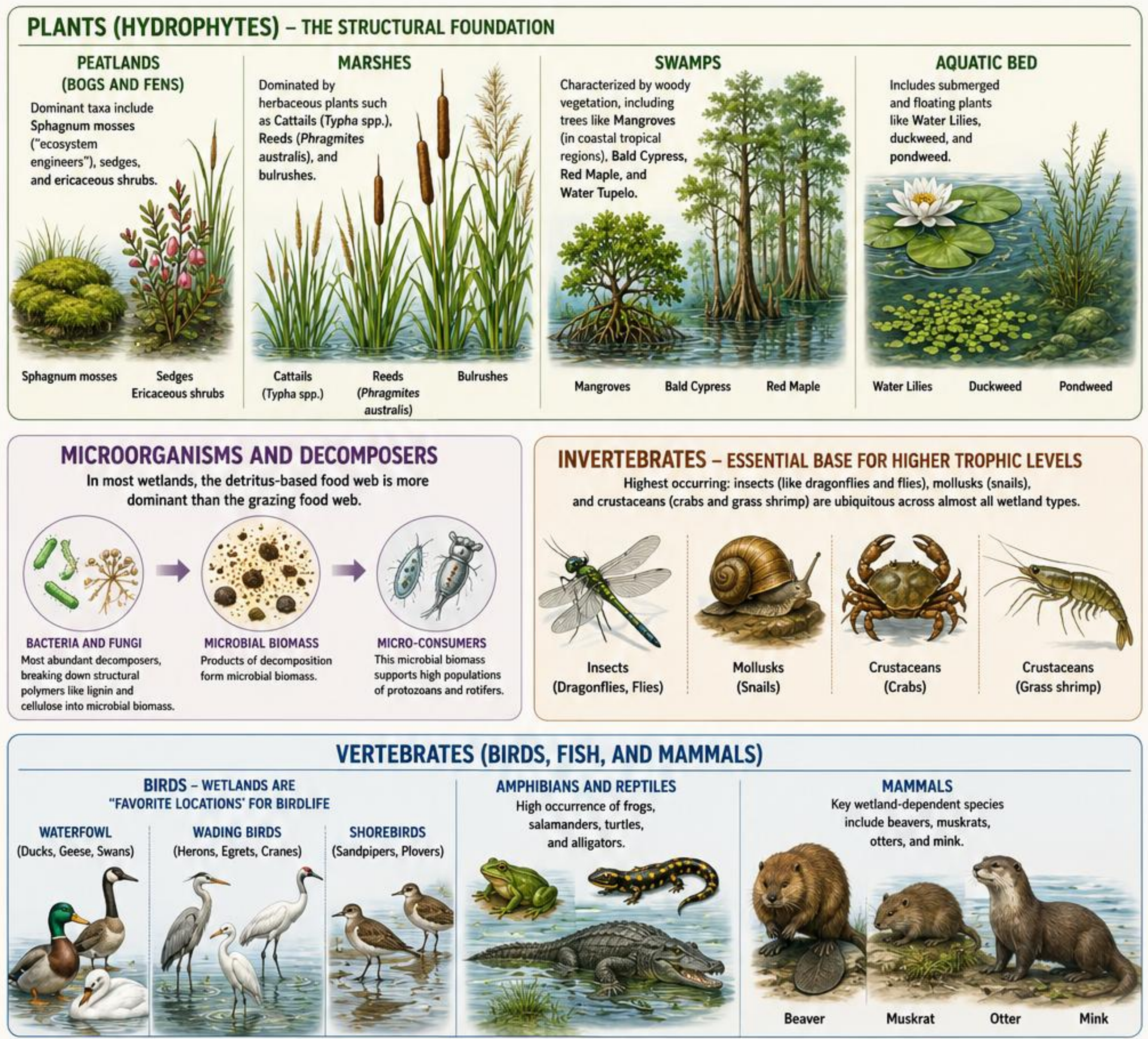
Everglades National Park

- ***Location:*** Florida, U.S.A.
- ***Size:*** 1.5 million acres
- ***Species:***This vast subtropical wilderness of cypress swamps, mangrove forests, pineland and hardwood hammocks is home to many endangered species, including West Indian manatees, American crocodiles and Florida panthers.

Wetland Ecology

Global Taxonomic Dominance and Richness



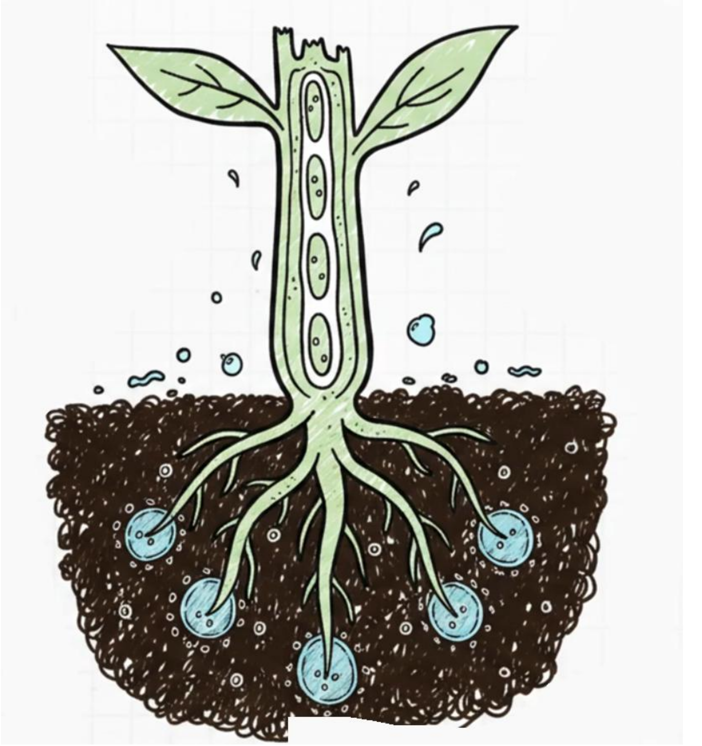

PLANTS (HYDROPHYTES) – THE STRUCTURAL FOUNDATION
PEATLANDS (BOGS AND FENS)
Dominant taxa include Sphagnum mosses ("ecosystem engineers"), sedges, and ericaceous shrubs.
Sphagnum mosses
Sedges
Ericaceous shrubs
MARSHES
Dominated by herbaceous plants such as Cattails (Typha spp.), Reeds (Phragmites australis), and bulrushes.
Cattails (Typha spp.)
Reeds (Phragmites australis)
Bulrushes
SWAMPS
Characterized by woody vegetation, including trees like Mangroves (in coastal tropical regions), Bald Cypress, Red Maple, and Water Tupelo.
Mangroves
Bald Cypress
Red Maple
AQUATIC BED
Includes submerged and floating plants like Water Lilies, duckweed, and pondweed.
Water Lilies
Duckweed
Pondweed
MICROORGANISMS AND DECOMPOSERS
In most wetlands, the detritus-based food web is more dominant than the grazing food web.
BACTERIA AND FUNGI
Most abundant decomposers, breaking down structural polymers like lignin and cellulose into microbial biomass.
MICROBIAL BIOMASS
Products of decomposition form microbial biomass.
MICRO-CONSUMERS
This microbial biomass supports high populations of protozoans and rotifers.
INVERTEBRATES – ESSENTIAL BASE FOR HIGHER TROPHIC LEVELS
Highest occurring: insects (like dragonflies and flies), mollusks (snails), and crustaceans (crabs and grass shrimp) are ubiquitous across almost all wetland types.
Insects (Dragonflies, Flies)
Mollusks (Snails)
Crustaceans (Crabs)
Crustaceans (Grass shrimp)
VERTEBRATES (BIRDS, FISH, AND MAMMALS)
BIRDS – WETLANDS ARE "FAVORITE LOCATIONS" FOR BIRDLIFE
WATERFOWL
(Ducks, Geese, Swans)
WADING BIRDS
(Herons, Egrets, Cranes)
SHOREBIRDS
(Sandpipers, Plovers)
AMPHIBIANS AND REPTILES
High occurrence of frogs, salamanders, turtles, and alligators.
MAMMALS
Key wetland-dependent species include beavers, muskrats, otters, and mink.
Beaver
Muskrat
Otter
Mink

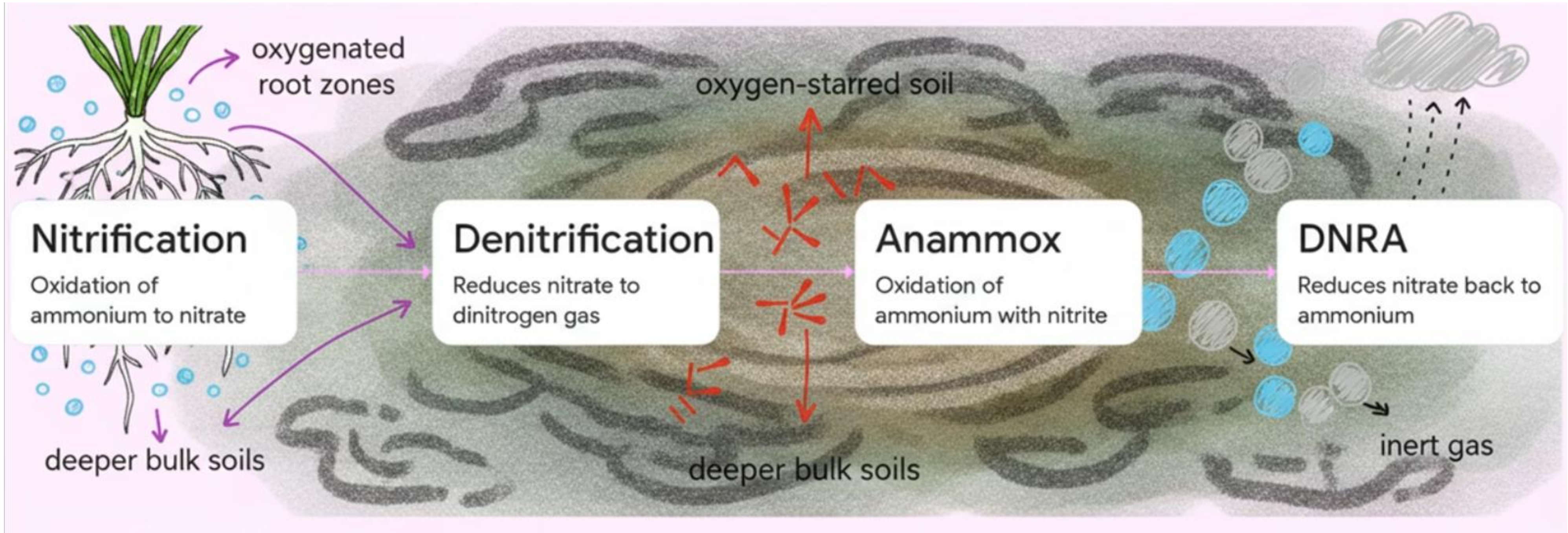
Hydrology – The Master Variable

- Hydrology acts as the primary constraint, determining soil saturation and nutrient availability.
- **Hydroperiod:** The seasonal pattern of water table depth and surface inundation over time.
- **Hydropattern:** The unique water-level time series that sets the template for soil development and vegetation.
- Minor fluctuations in the water table can shift soils between anaerobic and aerobic states, driving rapid biochemical transitions.

Biogeochemical Adaptations

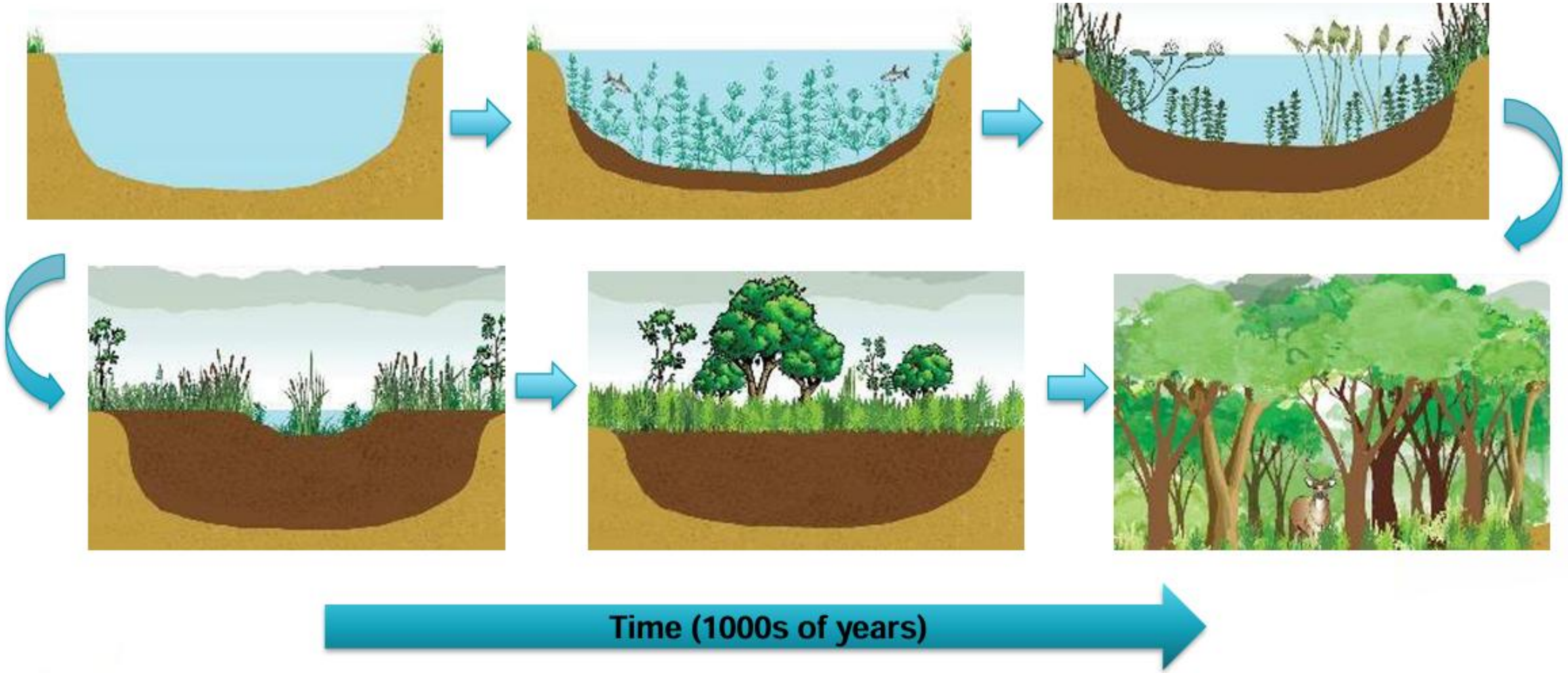
- Waterlogged soils inhibit oxygen diffusion, creating a reducing environment.
- Biota must adapt: Hydrophytic plants develop aerenchyma (air-filled tissue) to transport oxygen to roots.
- Microbial communities facilitate essential transformations like denitrification and methanogenesis.



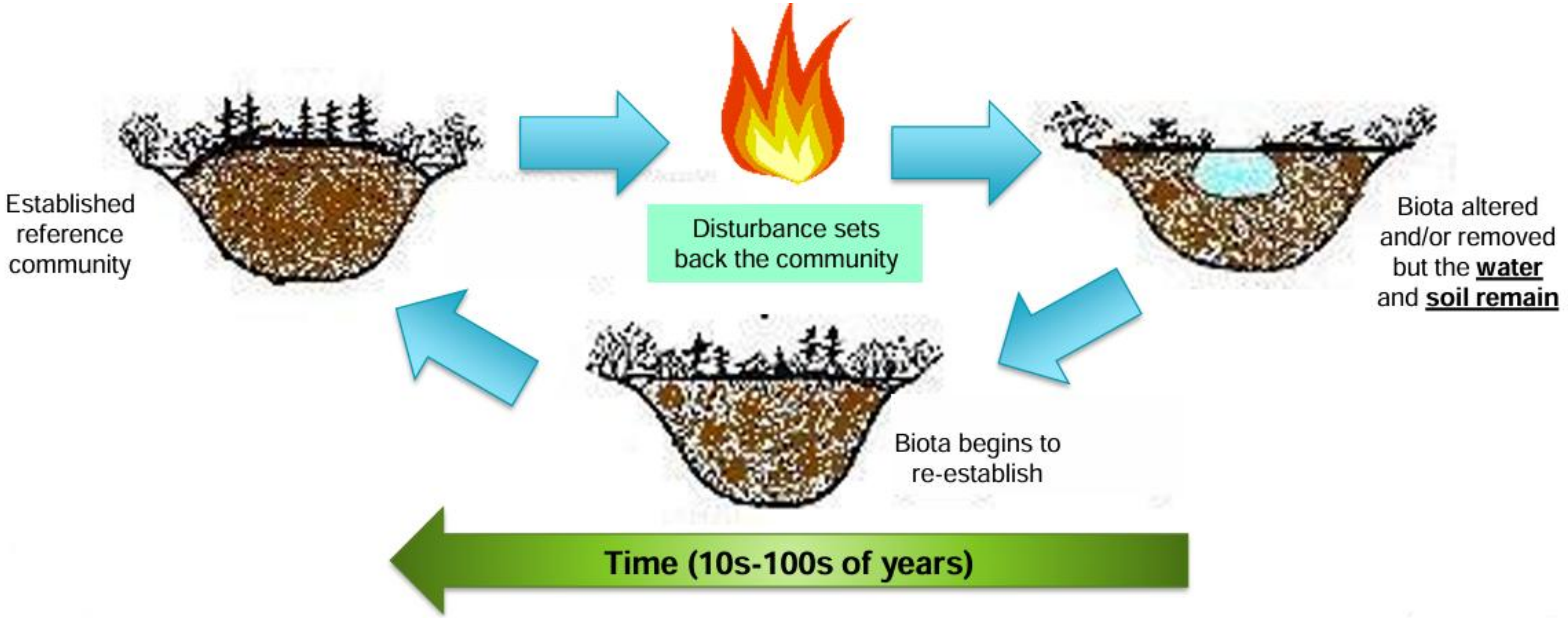


Ecological Dynamics – Succession and Equilibrium

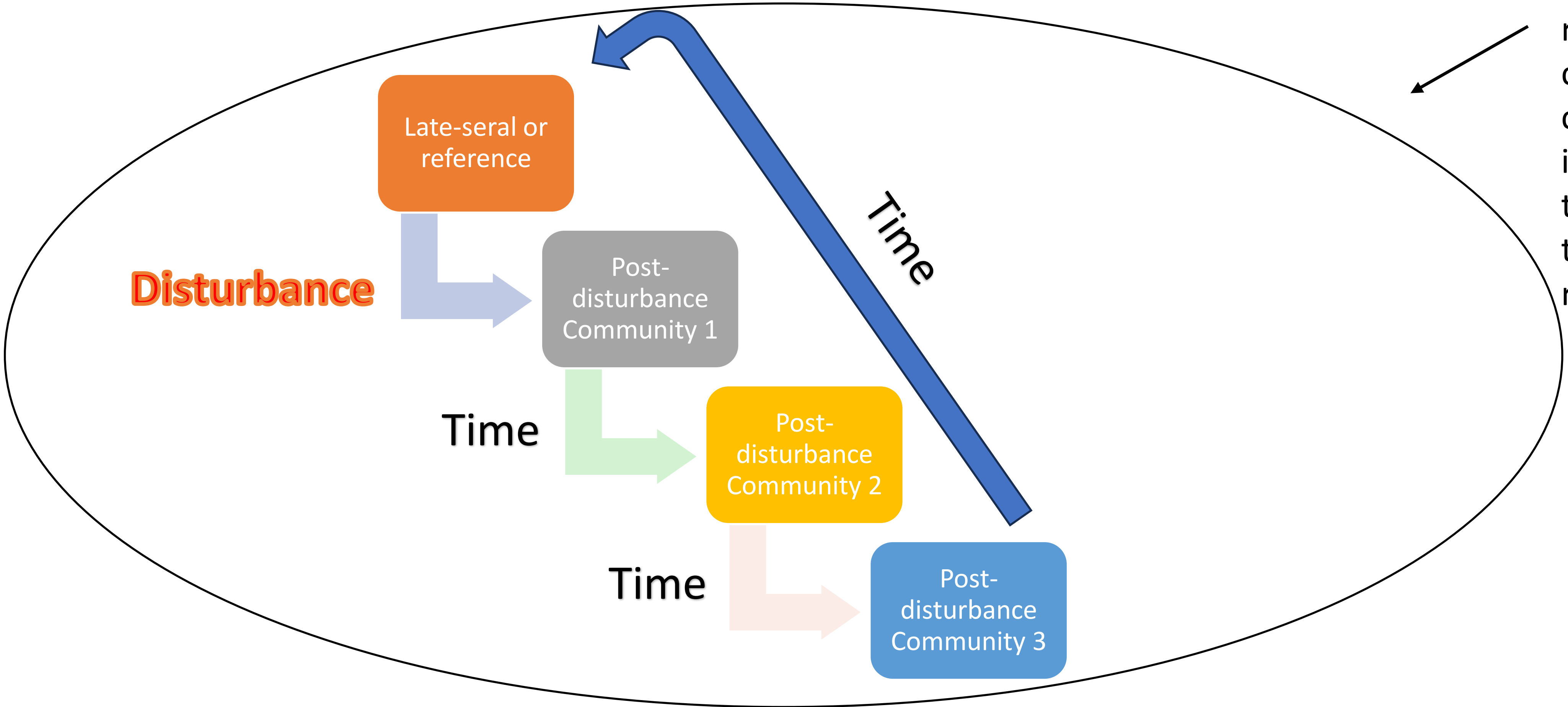
- **Primary Succession:** Starts in open water and can take thousands of years to reach a stable "reference community".



- **Secondary Succession:** A series of changes that occur to an already existing ecosystem after a disturbance.



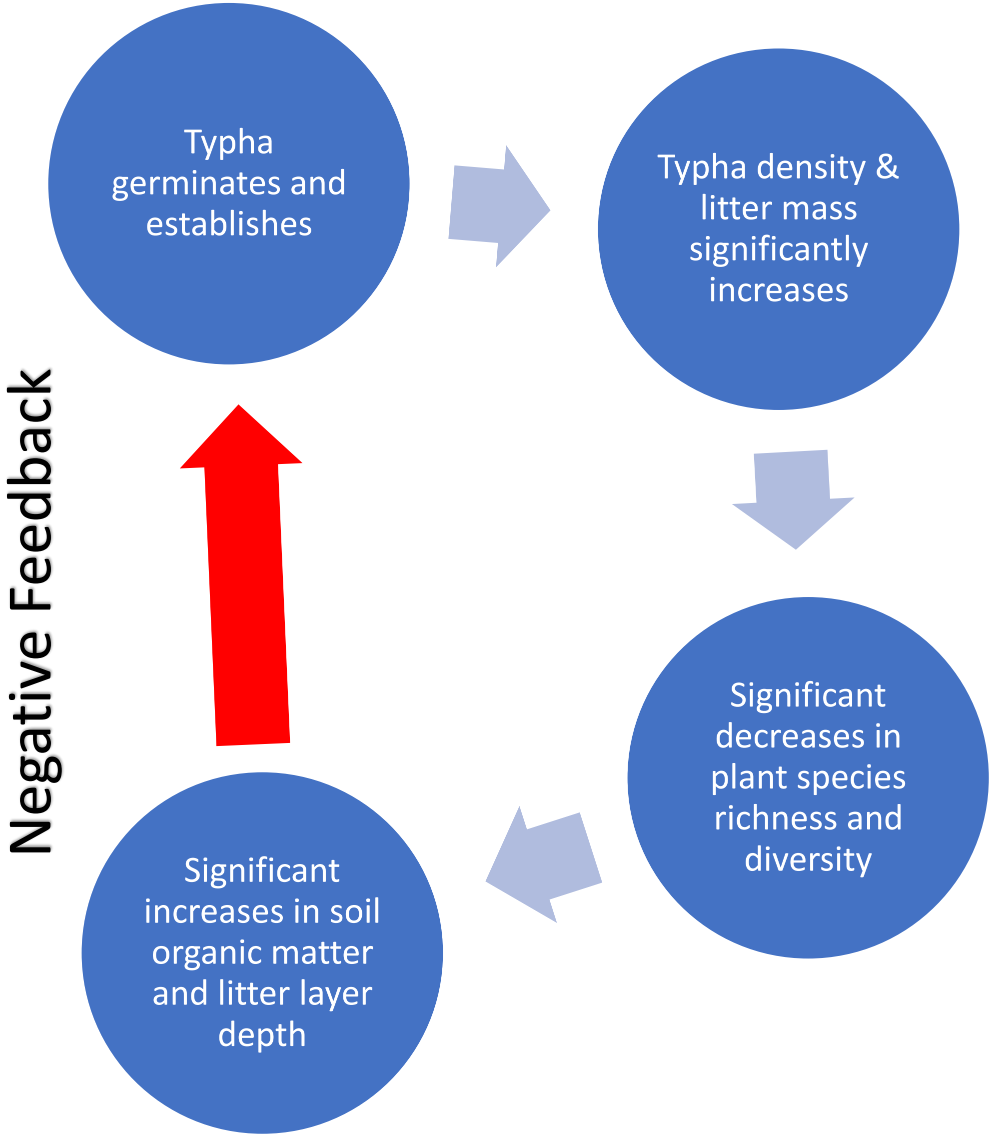
- **Ecological Equilibrium:** A state where ecosystem components interact to maintain structure and function despite pressure.
- Wetlands are dynamic; they are constantly being destroyed and created by river dynamics, sea-level rise, and climate change.



State: a recognizable, resistant, and resilient complex of ecosystem components that interact to determine the functional status of the site and its inherent resistance to change.

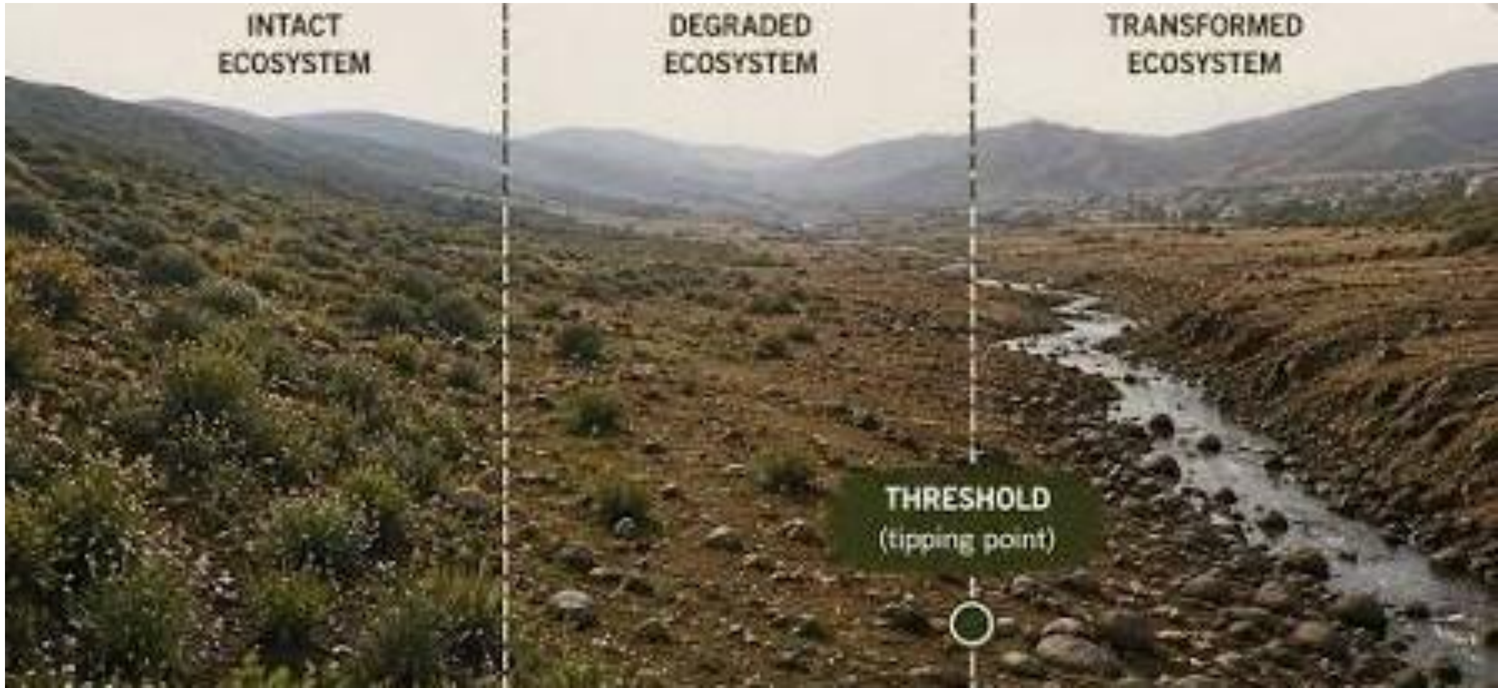
Negative feedbacks maintain the state in a self-sustaining pattern of predictable changes/vegetation expressions due to disturbance over time

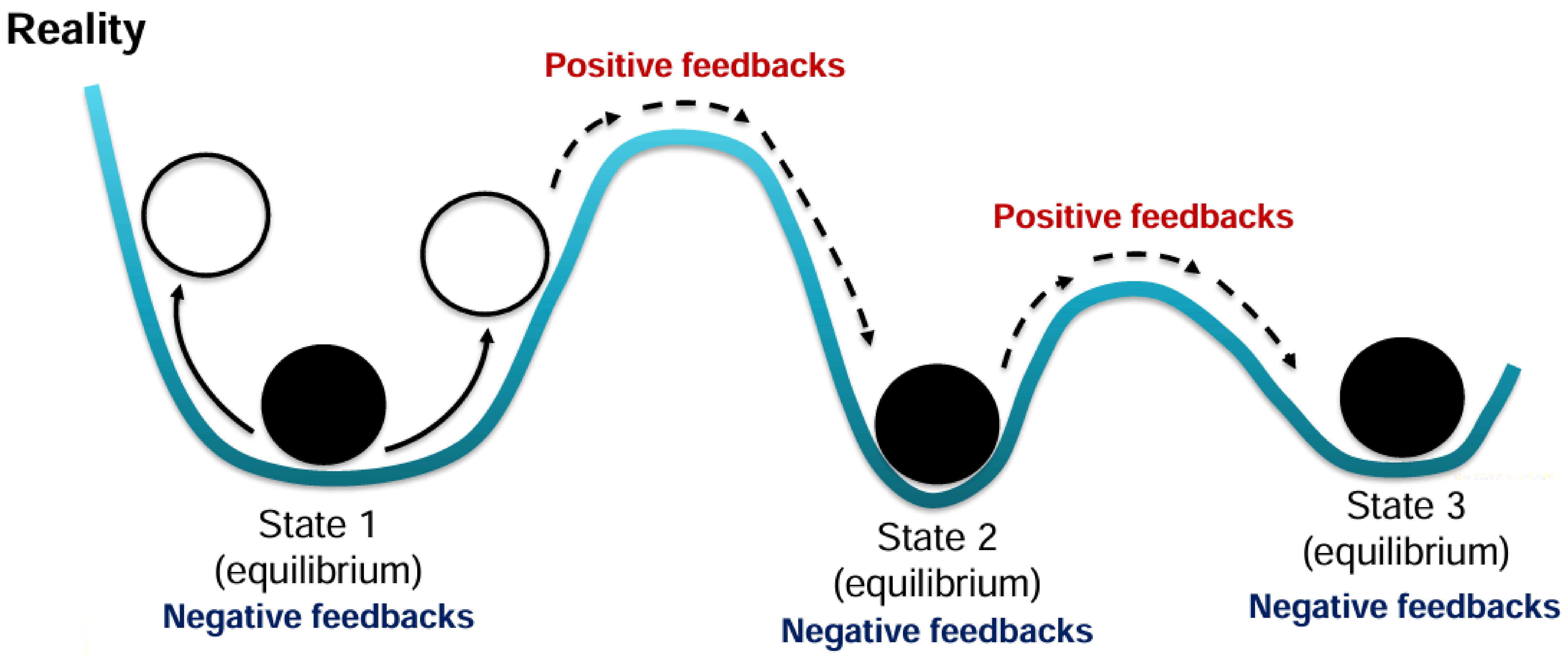
Negative Feedback Loop (*Typha x glauca* invasion – North America)



The Concept of Ecological Thresholds

- **Thresholds:** Boundaries in space and time between two ecological "states".
- Crossing a threshold (e.g., via excessive nutrient loading) causes positive feedbacks to take over, making degradation difficult to reverse.
- Systems may shift between **alternative stable states**, requiring significant human intervention to restore.





Reality
Positive feedbacks
Positive feedbacks
State 1
(equilibrium)
Negative feedbacks
State 2
(equilibrium)
Negative feedbacks
State 3
(equilibrium)
Negative feedbacks

Global Ecological Examples

- **Boreal Peatlands:** Characterised by *Sphagnum* mosses acting as "ecosystem engineers" to acidify the environment.

- **Inland Arid Playas:** Ephemeral systems that provide critical stopover habitat for migratory species.

- **Inland Arid Playas:** Ephemeral systems that provide critical stopover habitat for migratory species.

Case Study – The Everglades, USA

- **Ecological Context:** An oligotrophic (low-nutrient) fresh-water marshland defined by limited phosphorus and decadal fire cycles.
- **Ecological Mosaic:** Historical self-regulation resulted in a complex mosaic of open water, wet peatlands, and sawgrass marshes.
- **Tipping Points:** Altered hydrology (canals) and nutrient inputs have pushed the system across thresholds, leading to the spread of invasive trees (*Melaleuca*).
- **Lesson:** Successional trajectories are dictated by the balance of flooding, fire, and fertility.

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DOI 10.1007/s11273-009-9156-4

ORIGINAL PAPER

The Everglades: North America's subtropical wetland

Curtis J. Richardson

Received: 21 August 2008 / Accepted: 4 August 2009 / Published online: 27 August 2009

Abstract The Everglades is the largest subtropical wetland in the United States. Because of its size, floral and faunal diversity, geological history and hydrological functions on the Florida landscape, the remaining Everglades are considered to be the crown jewel of U.S. wetlands. It is also called a "sentinel wetland" to test our society's resolve for ecosystem restoration. Originally called Pa-hay-okee ("grassy lake") by the American Indians, it was later popularized as the "river of grass" by Marjory Stoneman Douglas. This metaphor unfortunately has led to a

succession patterns, and provides a new peatland classification of the Everglades system, which may help in the development of a more appropriate restoration management framework.

Keywords Peatland · Wetland · Classification · Hydrology · Phosphorus · Biogeochemistry · Fire · Plant communities · Ecosystem management

Source: http://doi.org/10.1007/s11273-009-9156-4

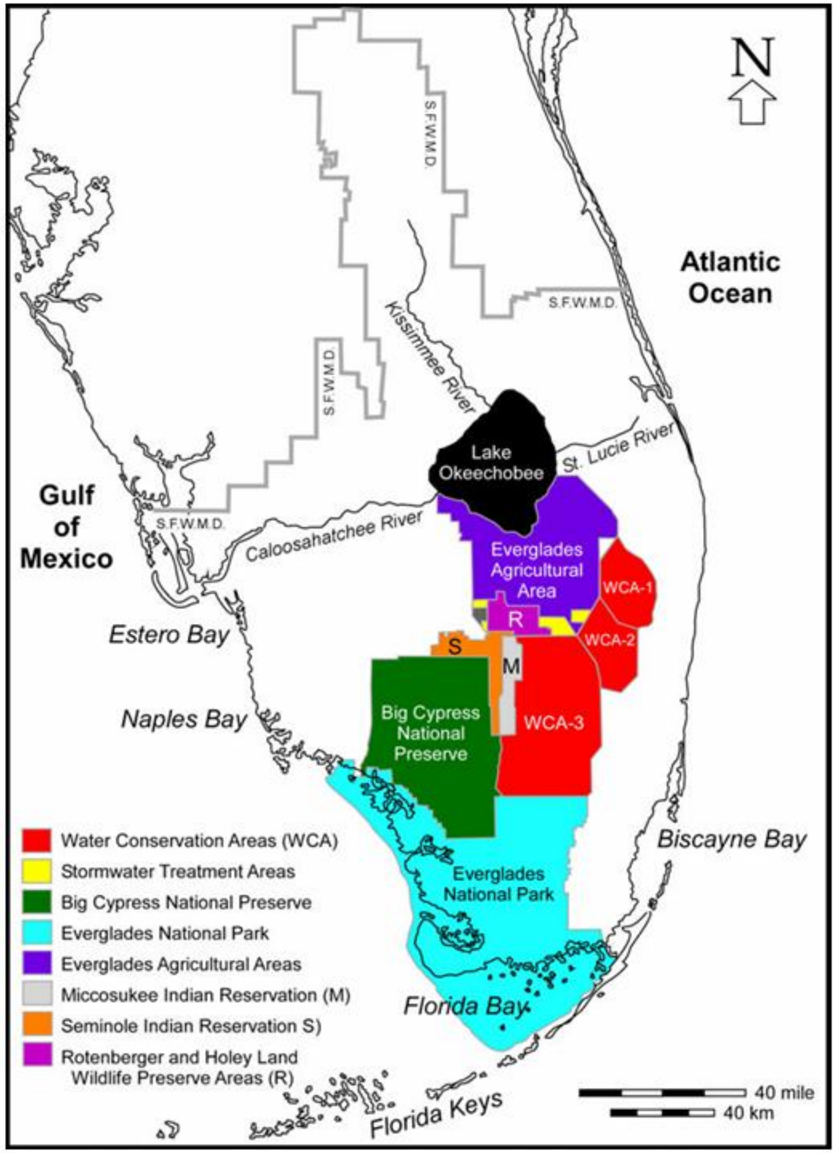


Fig. 1 A Map of the current boundaries of the South Florida Water Management District (SFWMD) that shows the Kissimmee River, Lake Okeechobee and Everglades land use complex. The Everglades is now divided into the state owned water conservation areas (WCAs), Stormwater treatment areas (STAs), the Everglades National Park and Everglades Agricultural Area (EAA). The surrounding areas are the Big Cypress National Preserve, Florida Bay and the developed crop and urban land, a large part of which was former Everglades. Two Indian Reservations are shown to be part of the current Everglades

The Everglades ecosystem

Geology and soils

YBP, blockage of drainage from the Everglades due to rising sea level, a change to a subtropical climate, and the concurrent increase in rainfall allowed for the development of the Everglades as we know it. Three

Source: http://doi.org/10.1007/s11273-009-9156-4

is mostly marine and freshwater marls, limestone, and sandstone (Enos and Perkins 1977).

A geological study of the bedrock that underlies the Everglades shows a differentiation in permeability from north to south. Low-permeability limestone underlies the northern portion of the Everglades basin around Lake Okeechobee and extends into the northern half of WCA-3A and into the western portions of WCA-2A (Gleason 1974; Perkins 1977). In the southern section of WCA-3A and the southeastern section of WCA-2B, there is an abrupt shift to highly permeable limestone (Perkins 1977; Harvey and McCormick 2009). This has important ramifications for the movement and storage of water, peat development, and the establishment of plant communities. According to Gleason (1974), bedrock configuration established the drainage directions prior to peat deposition in the Everglades. For example, Lake Okeechobee flowed through a channel eastward to the area now known as WCA-1, and a deep depression bisected the lower Everglades and created a southwest flow gradient toward Florida Bay (Fig. 2). Gleason (1974) also noted that tree island orientation is correlated with drainage directions expected from bedrock topography. Wu et al. (2006) further suggest it is impossible to understand the spatial complexity or patterns of the tree islands or the ridge and slough

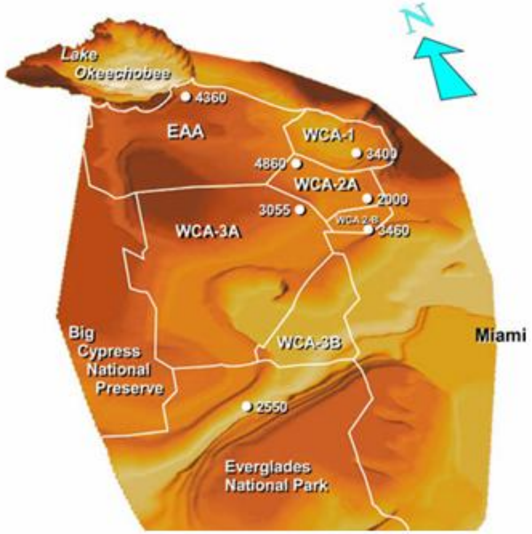
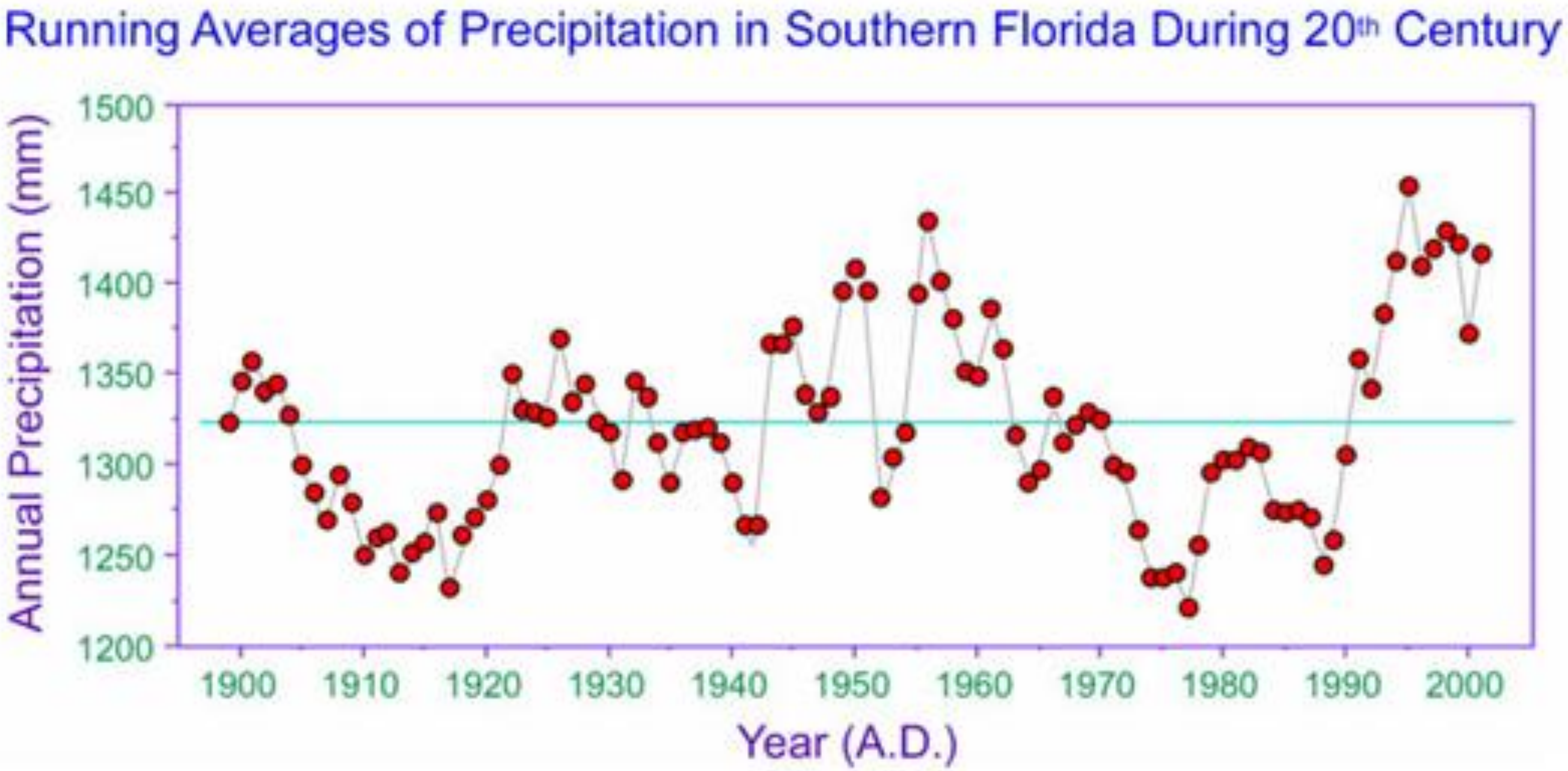


Fig. 2 Bedrock map of the Everglades prior to peat development based on kriging of USGS depth measurements and isopleths maps (Parker et al. 1955; Parker and Cooke 1944). *Darker shades* represent higher regions (bedrock plateau south of Lake Okeechobee, etc.) and *lighter shades* represent depressions or troughs in the bedrock (e.g., in WCA-1 and in lower WCA-3A, WCA-3B, and in the northern portion of the ENP where Taylor slough is now found). Also shown are basal dates of peat from ^{14}C measurements (McDowell et al. 1969; Gleason 1974; Craft and Richardson 1998)

Source: http://doi.org/10.1007/s11273-009-9156-4

Fig. 3 Annual precipitation (9 point smoothing was used to better show trends) in the Florida Everglades based on data from 1895 to 2005. The average rainfall from 1895 to 2005 is shown with a horizontal line. Data source used was from NOAA for the Florida Everglades and SW Division at (http://www.ncdc.noaa.gov/onlineprod/drought/xmgr.html)



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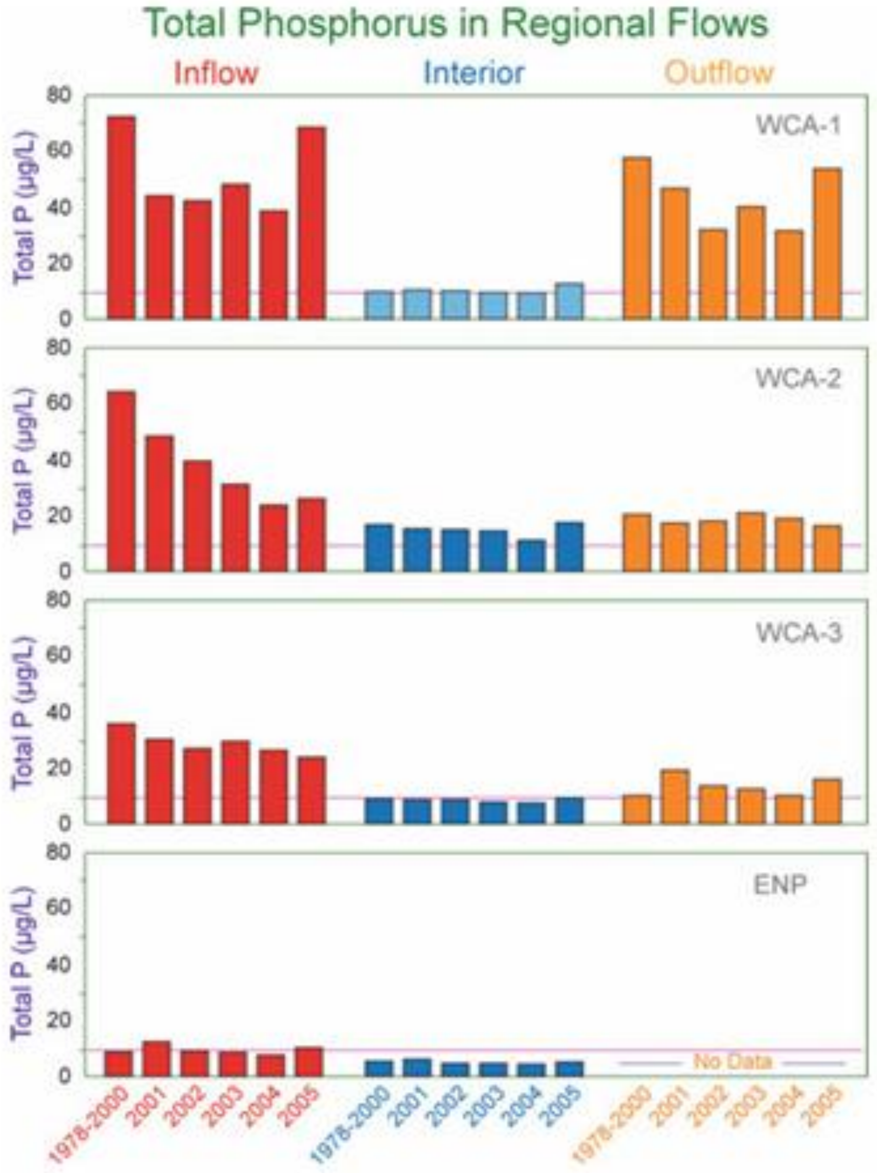

Fig. 5 A comparison of phosphorus input, interior and outflow concentrations from 1978 to 2005 for WCA-1A, WCA-2A, WCA-3A, and the ENP. All values are the annual geometric mean of total phosphorus. Data are from the South Florida Water Management District (2003, 2004, 2005, 2006)

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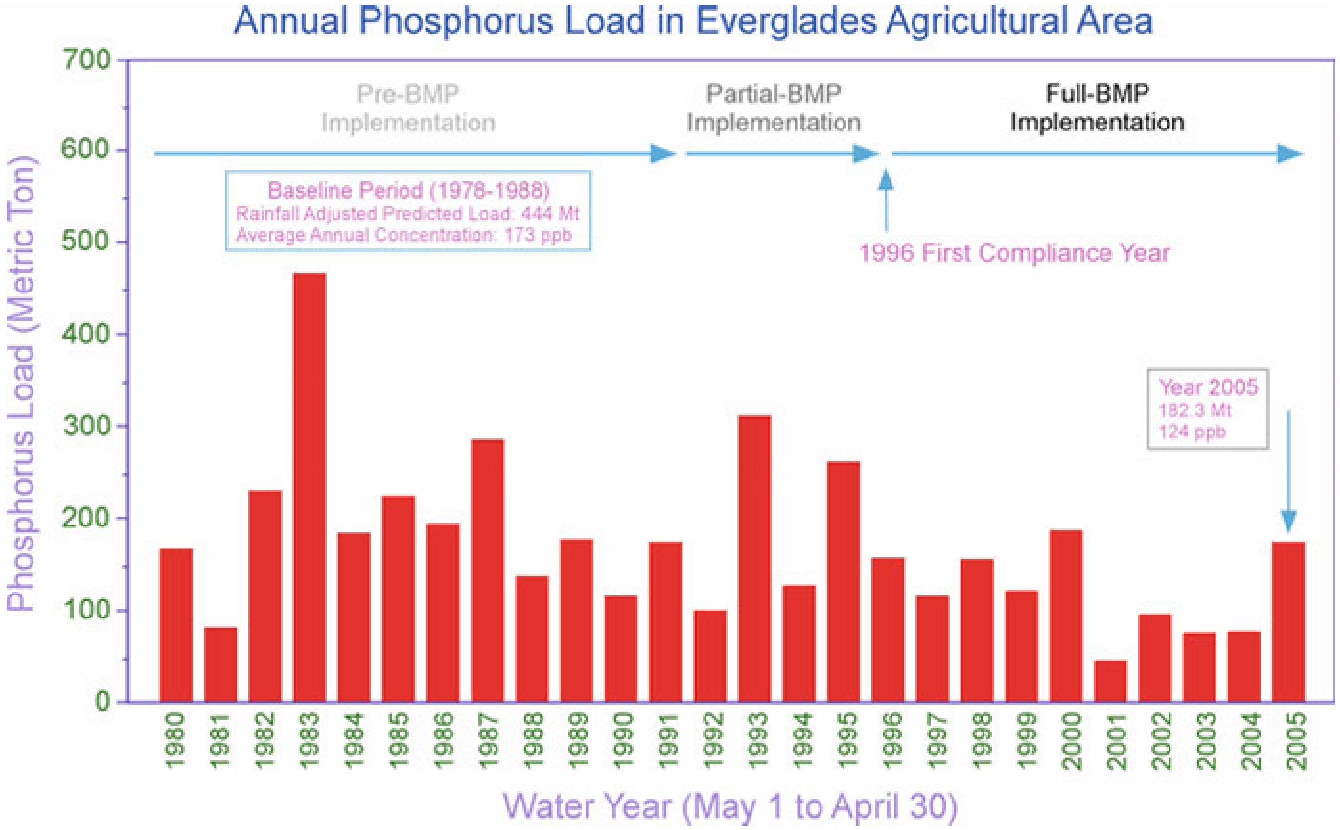

Fig. 6 Total phosphorus loads from the Everglades Agricultural Area (EAA) to the Everglades Protection Area (EPA) from 1980 until 2005. Best management practices (BMP) are denoted as well as the first compliance year. Data from South Florida Water Management District (2006)

operation have greatly exceeded their design loading criteria by more than a factor of two, and outflow P concentrations have also greatly exceeded desired levels (Richardson and Huvane 2008). In fact, in 2005 and 2006 four of the STAs exceeded 50 μg l^{-1} P, and several had output values over 100 μg l^{-1} P.

USEPA criterion of 10 μg l^{-1} P for the Everglades by potentially creating a connecting natural water flow system south, expanding the size of the STAs and developing a series of reservoirs to help store water and remove pollutants (Stokstad 2008). This plan could have significant positive consequences for the

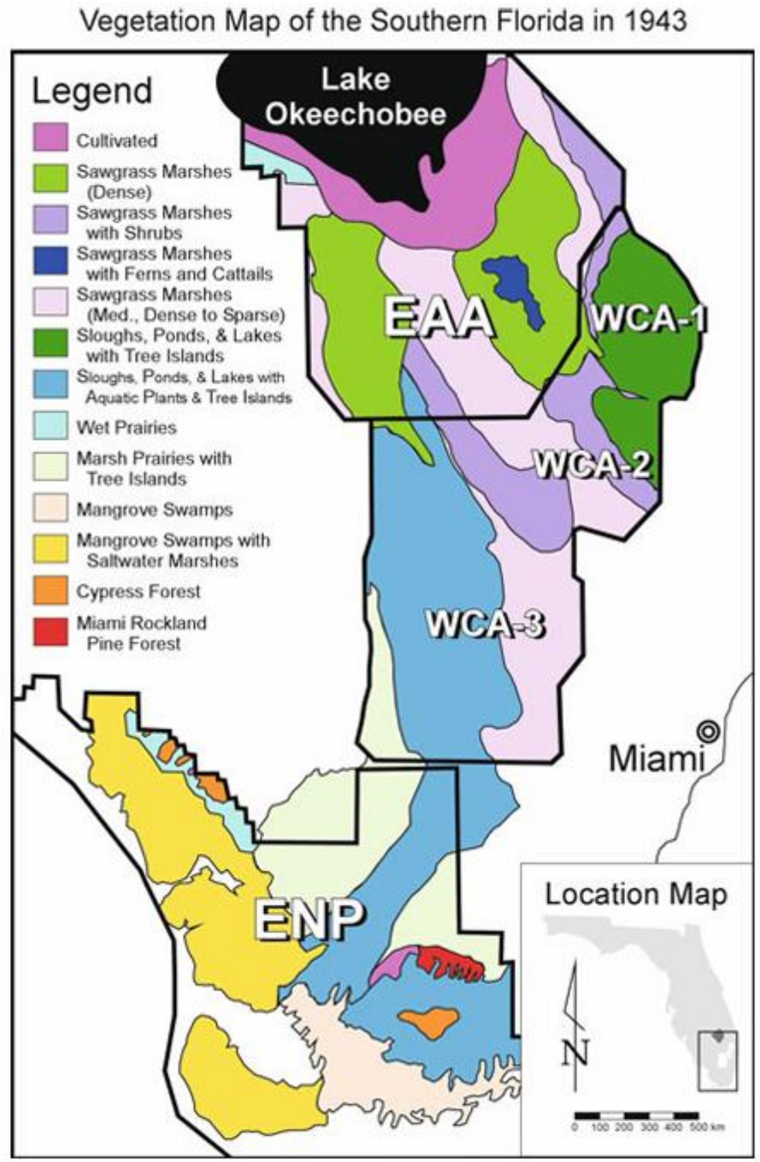

Fig. 7 Historic map of the vegetation communities in the Everglades based on the map of J.H. Davis (1943). The map has been redrawn and simplified from the original map, and the boundaries of the current water conservation areas (WCA-1, WCA-2, WCA-3), the Everglades National Park (ENP), and the Everglades Agricultural Areas have been added

elevated soil P concentrations and a possible source of fern spores for repopulation after a fire.

A complete listing of the plant species characteristic of each vegetation community in the Everglades is shown on Table 1. The dominant species for each community are noted, as well as their growth form. An abbreviated summary of the key ecological components of the major plant community types found in the Everglades fen is presented in the following sections. The common local names for the community types or habitats are used for comparative purposes. These habitats and their spatial distribution make the Everglades one of the more diverse peatland ecosystems in the world (Fig. 7). An aerial overview of tree islands and related communities in the southern Everglades is shown in Fig. 8.

Sawgrass

Sawgrass (*Cladium jamaicense*) is the dominant vegetation community found throughout the freshwater Everglades peatland (Fig. 7). Sawgrass is a sedge that grows to 2–3 m in height on deep peat but only 0.5 m on shallow peat. It was earlier thought that it prefers sites with a fairly constant water depth of 10–20 cm (Toth 1987; Gunderson 1990) but more recent studies show that it grows best in areas with low water to moderate levels and survives nicely under drought conditions (Lissner et al. 2003; Richardson 2008). Its presence in the Everglades is due to its ability to survive fire, low soil nutrient content and occasional freezing (Stewart and Ornes 1975). Saw-

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Fig. 8 Aerial view of tree islands in the southern Everglades. Note the surrounding sloughs and sawgrass stands with ponds (small circular deep water areas) scattered throughout and often created by fire and maintained by alligator activity. (Photo by Curtis J. Richardson)

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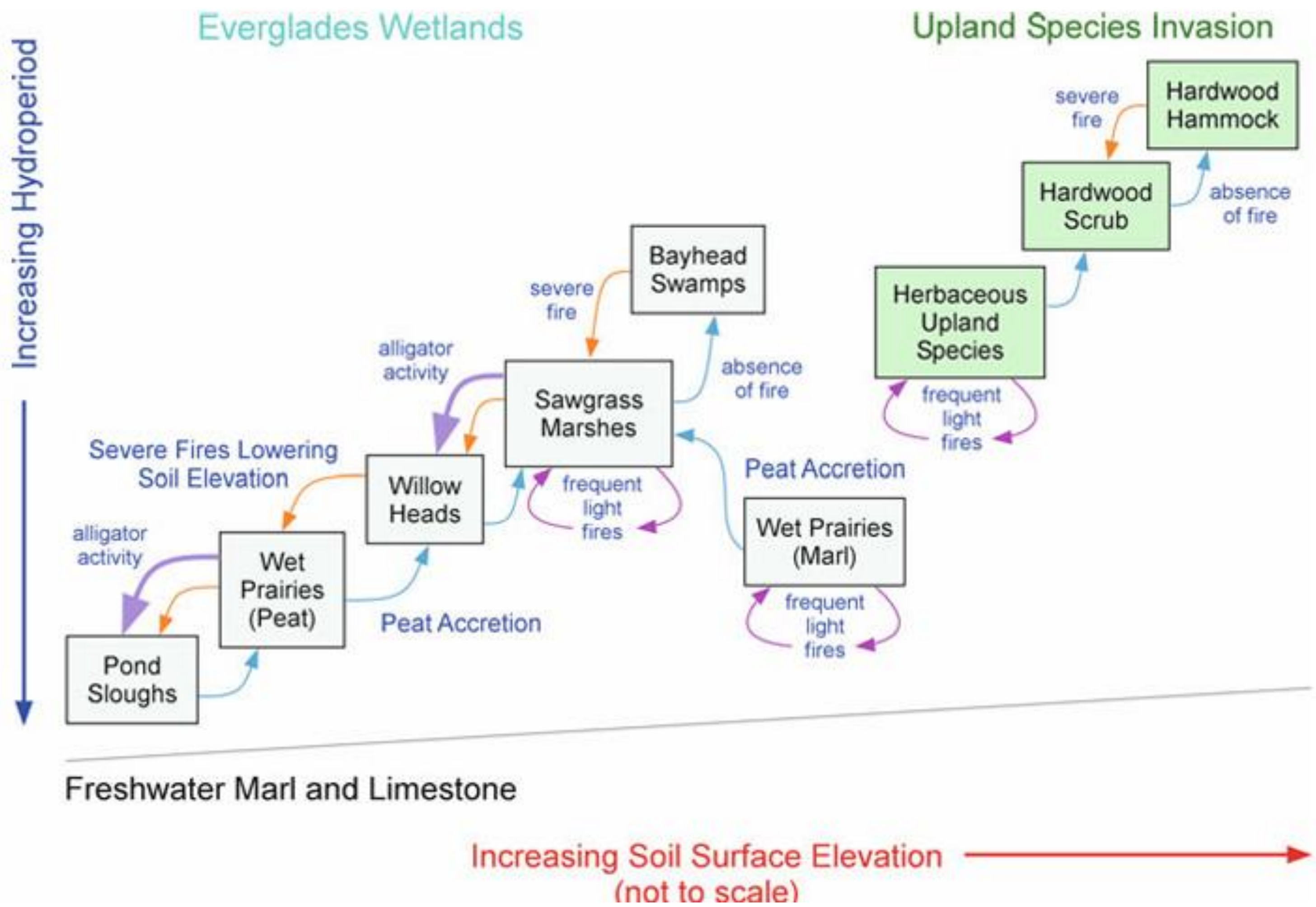
Fig. 9 Succession patterns related to fire and hydroperiod in the Everglades. Modified from Richardson 2000



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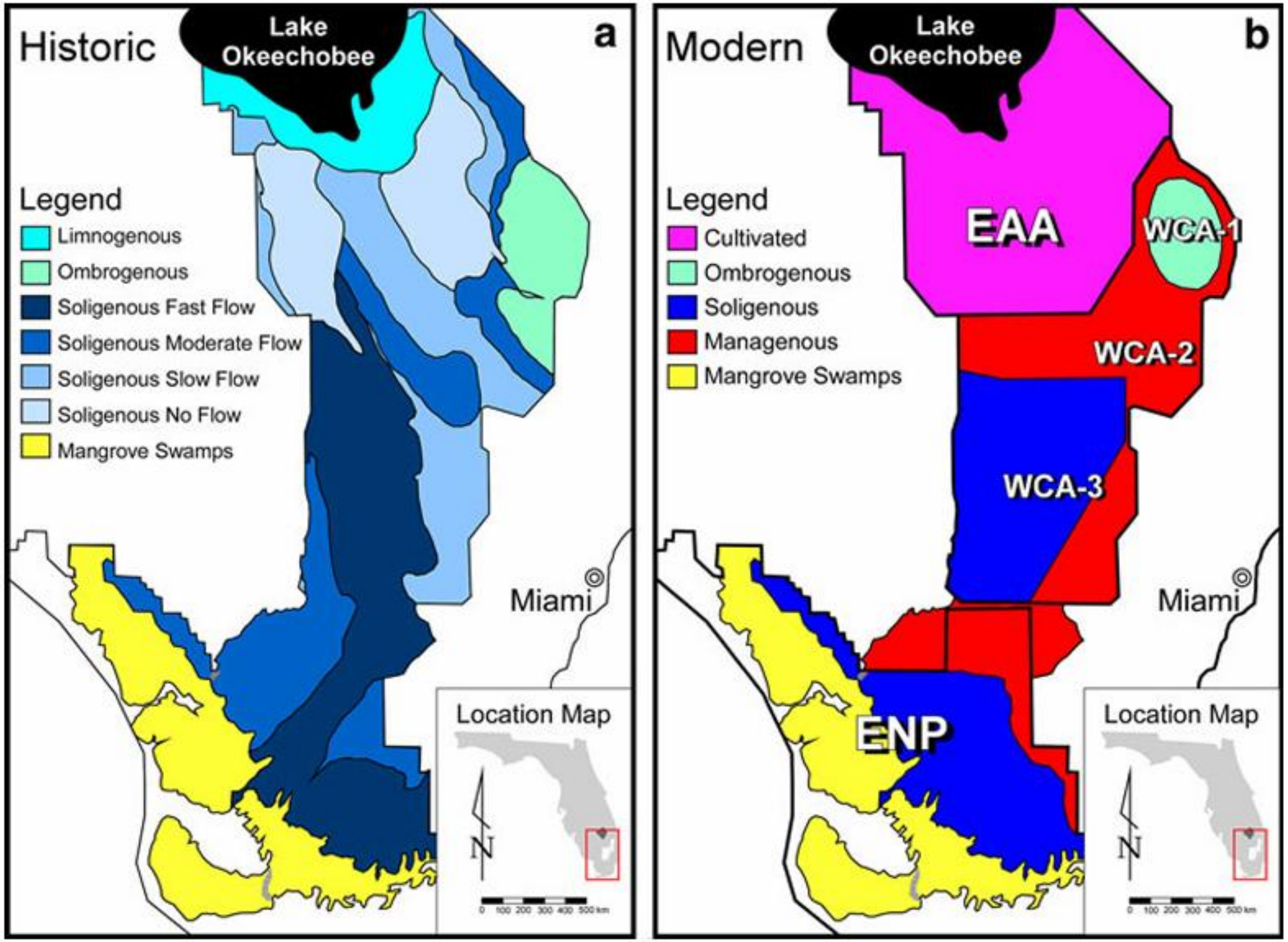
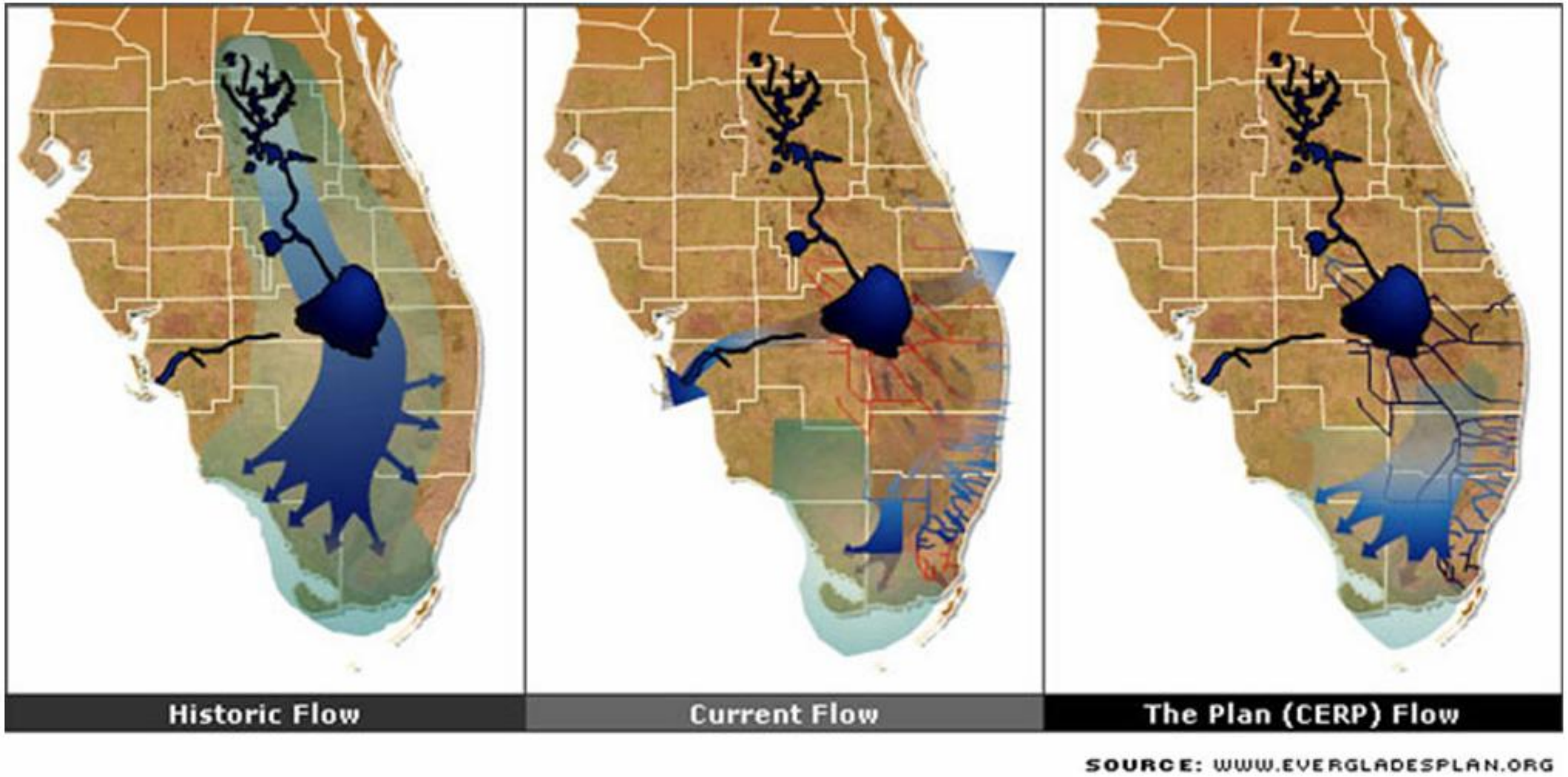


Fig. 10 **a** A comparison of hydrologic peatland classifications in the historic Everglades (1000 YBP) with **b** the present day (modern) Everglades water flow classes. Shown are the general categories of ombrotrophy and hydrologic flow, systems that control types of peatland formation

Source: http://doi.org/10.1007/s11273-009-9156-4

Fig. 11 Historic, current, and planned water flow conditions under CERP in the Everglades Watershed (Source: http://www.evergladesplan.org)



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Richardson (2010)

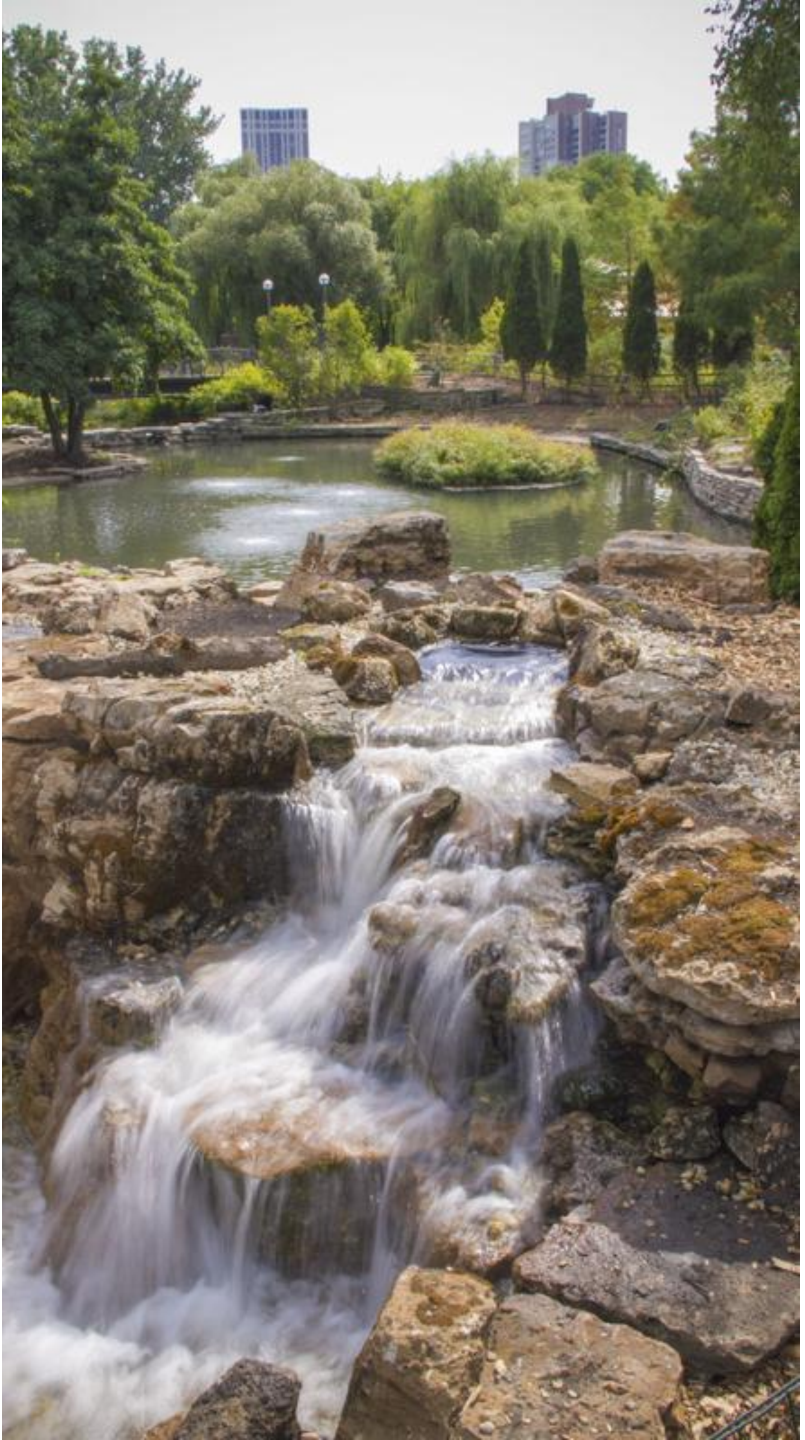
- Synthesized **long-term ecological data** on hydrology, nutrient cycling, vegetation succession, and disturbance regimes.
- He analyzed **historical changes** in the Everglades, focusing on how human interventions (canals, dikes, agriculture) disrupted natural processes.
- Documented **case studies of invasive species spread** (like *Melaleuca*) and shifts in vegetation composition (sawgrass to cattail).
- Framed the Everglades as a **model system** for understanding wetland resilience, thresholds, and successional dynamics under disturbance.

Link: http://doi.org/10.1007/s11273-009-9156-4
OR
https://www.researchgate.net/profile/Curtis-Richardson/publication/226981928_The_Everglades_North_America%27s_subtropical_wetland/links/553132270cf20ea0a071a39a/The-Everglades-North-Americas-subtropical-wetland.pdf

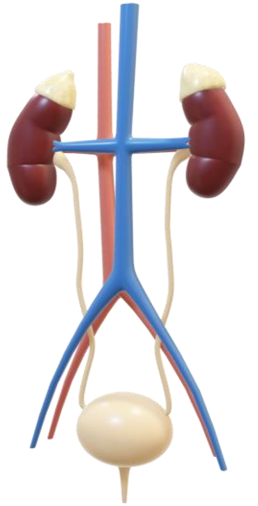

Wetland Functions and Ecosystem Services

Hydrological Regulation – Landscape Buffer

- Wetlands act as capacitors, intercepting surface runoff and storing excess water after intense rainfalls.
- **Flood Attenuation:** They reduce peak downstream flows and stabilise water movement.
- **Groundwater Recharge:** The slow infiltration through wetland soils feeds underground aquifers.



Biogeochemical Functions – "Nature's Kidneys"



- Wetlands remove, transform, and store materials as water moves through them.
- **Water Purification:** Sediment Settling and physical filtration by plant debris remove pollutants.
- **Nitrogen Removal:** Coupled nitrification-denitrification converts bioavailable nitrogen into harmless N_2 gas.

The Global Carbon Sink

- Wetlands cover only 6% of Earth's surface but store a disproportionate share of global soil carbon.
- **Peatlands:** Store twice as much carbon as all the world's forests combined.
- **Blue Carbon:** Coastal wetlands (mangroves/salt marshes) bury carbon in anoxic sediments at much higher rates per hectare than terrestrial habitats.

Biological and Socio-economic Values

- **Nurseries of Life:** Support complex food webs and provide breeding grounds for 75% of commercial fisheries in some regions.
- **Livelihoods:** Millions depend on wetlands for food (fish, rice), raw materials (timber, mats), and tourism.
- **Biodiversity Refuge:** Critical habitat for migratory birds and many threatened/endangered species.

Case Study (Functions) – East Kolkata Wetlands (EKW), India

- **Overview:** A 12,500ha Ramsar site comprising fish farms, agriculture, and settlements.
- **Natural Wastewater Treatment:** Naturally treats 900 MLD of city sewage, saving Kolkata Rs. 4,680 million annually in treatment costs.
- **Nutrient Reuse:** Sewage-fed ponds produce 20,000 MT of fish and 50,000 MT of vegetables annually.
- **Climate Role:** Locks in over 60% of carbon from wastewater, significantly reducing regional greenhouse gas emissions.

Wetland Management and Conservation

Principles of "Wise Use"

- Defined by the Ramsar Convention as the "maintenance of ecological character, achieved through ecosystem approaches, within the context of sustainable development".
- Recognises that wetlands should continue to support human uses but only within limits that preserve their ecological function.

Ramsar

CONVENTION ON WETLANDS

CONVENTION SUR LES ZONES HUMIDES

CONVENCIÓN SOBRE LOS HUMEDALES

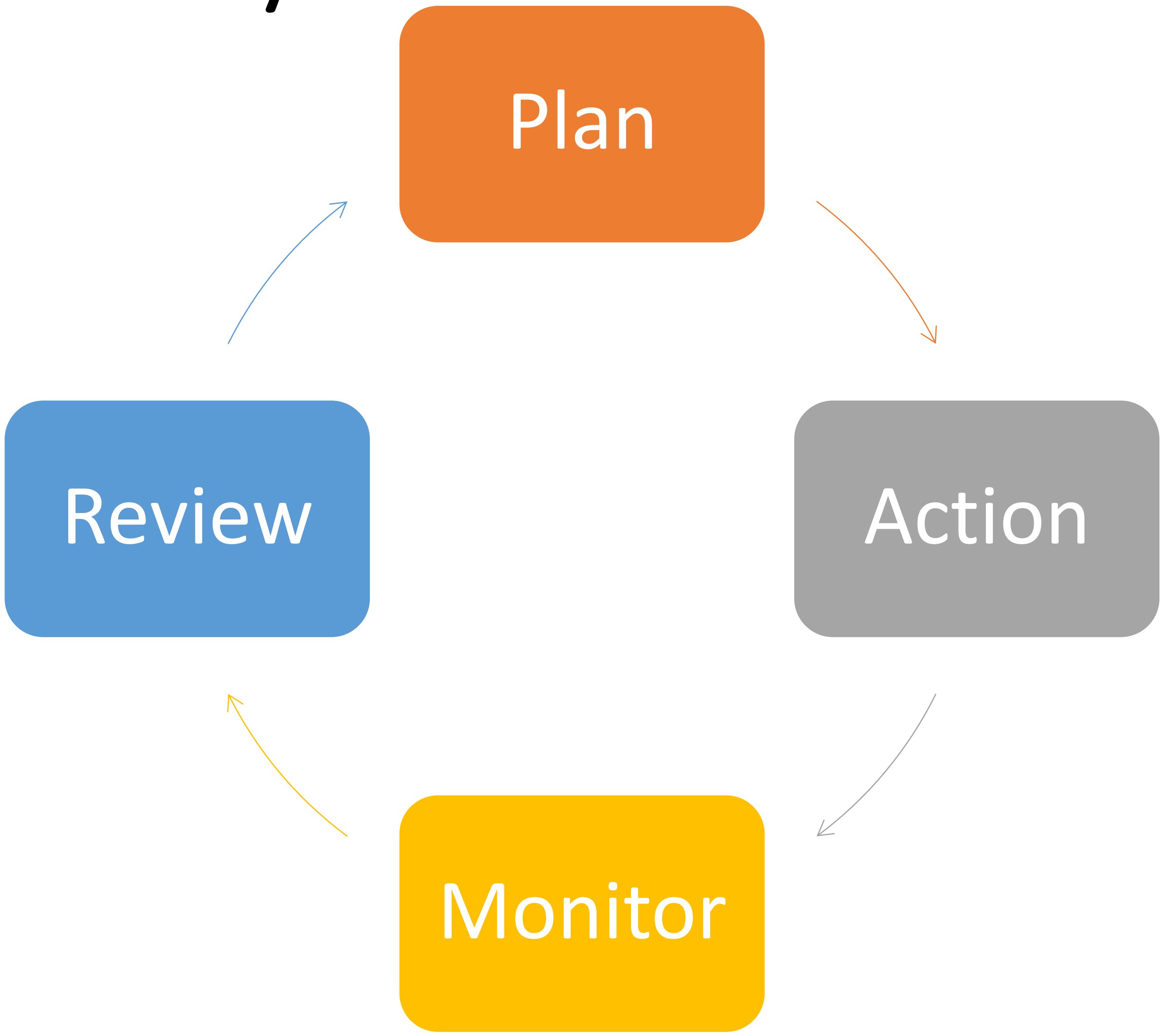
(Ramsar, Iran, 1971)

Integrated Watershed Management (IWM)

- Traditional water management focuses on single engineering solutions; IWM treats the river basin as the natural spatial unit.
- Recognises that upstream activities (e.g., deforestation) directly impact downstream wetland health and hydrological connectivity.
- Coordinates land use, water resources, and biodiversity conservation across administrative boundaries.

The Adaptive Management Cycle

- Effective management follows the "Plan - Action - Monitor - Review" cycle.
- **Steps:**
  - (1) Description of ecological character
  - (2) Evaluation of priority features
  - (3) Setting clear objectives
  - (4) Specific management actions
  - (5) Monitoring for effectiveness.

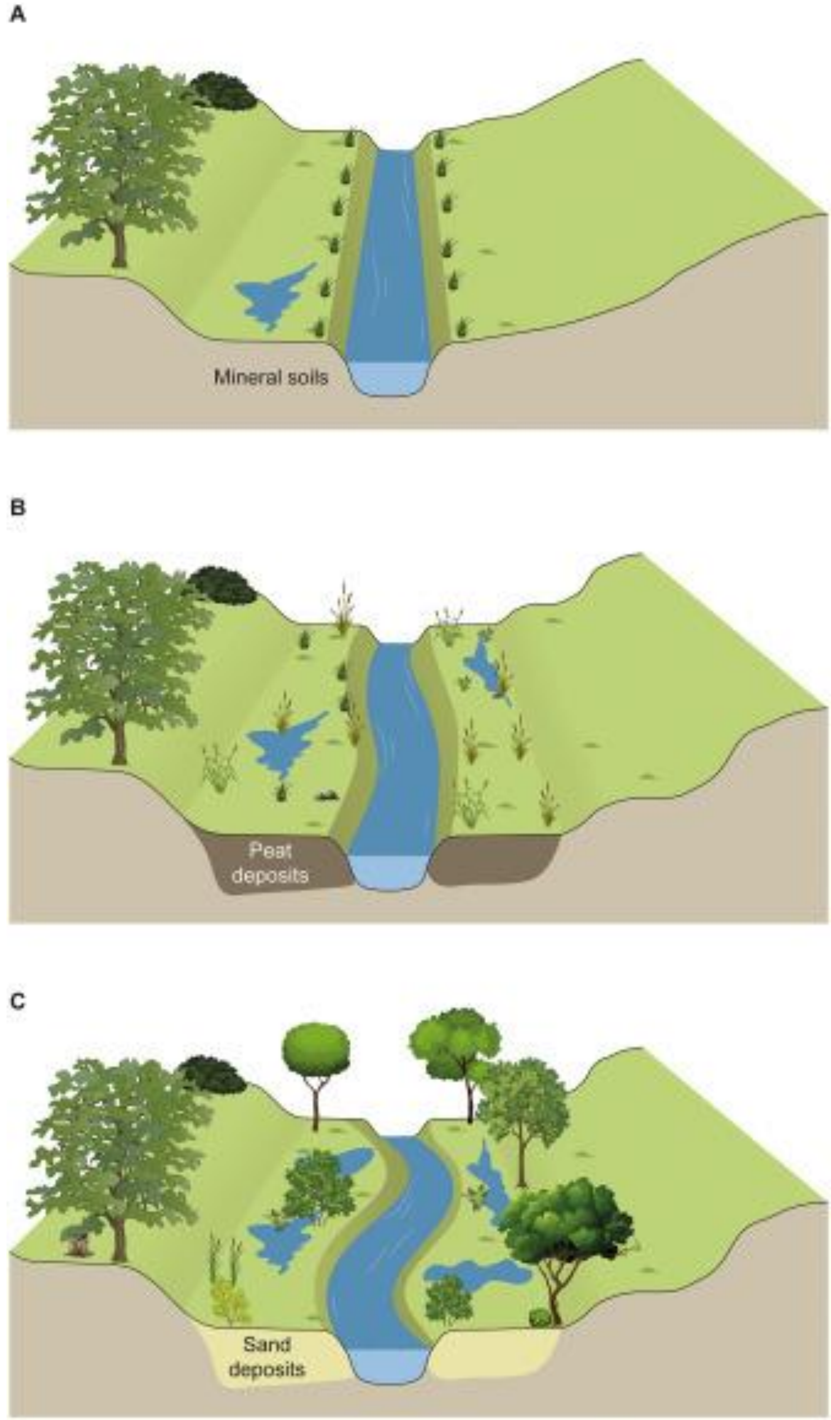


Nature-Based Solutions (NbS)

- Management increasingly uses wetlands as NbS for climate change mitigation and disaster risk reduction.
- Example: Restoring tidal hydrology in mangroves rather than relying solely on engineered sea walls.
- Coastal wetlands provide protection from storm waves and reduce erosion during hurricanes.

Management Techniques and Buffer Zones

- **Buffer Zones:** Critical zones (15m to 300m+) required to protect wetlands from nutrient runoff, pesticide drift, and physical encroachment.
- **Hydrological Restoration:** Re-establishing river-to-basin connectivity to reactivate microbial nutrient removal pathways.
- **Invasive Control:** Active management required to prevent systems from shifting to degraded alternative stable states.



Governance – Global Laws and Conflicts

- **Ramsar Convention (1971):** The primary international treaty for wetland conservation.
- **U.S. Clean Water Act (CWA):** Recently impacted by the *Sackett v. EPA* Supreme Court decision, which narrowed the definition of protected "Waters of the United States".
- **India's Wetland Rules (2017):** Established the "zone of influence" and mandated the creation of State Wetland Authorities for decentralized governance.

The "3Rs" and Stakeholder Engagement

- Success depends on participatory processes involving local and indigenous communities.
- Governance frameworks must navigate the "3Rs": Identifying Rights, Risks, and Responsibilities of all stakeholders.
- Integration of multiple values across governmental sectors (agriculture, urban development) is vital.

Conclusion

- Wetland management is an iterative process requiring an understanding of ecological thresholds.
- Current loss rates are accelerating, making the Implementation of "wise use" more urgent than ever.
- Future restoration must be guided by indicators that evaluate interactions between organisms and their abiotic template.

Suggested readings

- Batzer, D., Pennings, S., & Faust, D. (n.d.). *Module 2: An Introduction to Wetland Functions and Values*. Society of Wetland Scientists.
- Keddy, P. A. (2010). *Wetland Ecology: Principles and Conservation* (2nd ed.). Cambridge University Press.
- Mitsch, W. J., Gosselink, J. G., Anderson, C. J., & Fennessy, M. S. (2023). *Wetlands* (6th ed.). Wiley.
- Moseley, K. (2018). *Wetland Ecology – Basic Principles*. USDA Natural Resources Conservation Service.
- Ramsar Convention Secretariat. (2018). *Global Wetland Outlook: State of the World's Wetlands and Their Services to People*.
- Reddy, K. R., & DeLaune, R. D. (2008). *Biogeochemistry of Wetlands: Science and Applications*. CRC Press.
- Simpson, M. (n.d.). *Wetland Management Guide*. Ramsar Regional Center – East Asia.


Thank
You