Belowground Ecology in a Restoration Context

- Objectives:
  – How can the foundations of and theory in soil science ↔ restoration ecology ↔ ecological restoration?
    - Topographic heterogeneity
    - Overview of soil physical, chemical and biological properties

Belowground Ecology in a Restoration Context

- Heterogeneity of ecological systems
  - Physical, chemical & biological elements of ecological systems are inherently heterogeneous across both space & time
  - Abiotic and biotic components both create heterogeneity, & respond strongly to heterogeneity
  - Habitat heterogeneity influences ecosystem structure and function
    - Increases niche space → increases biodiversity, impacts ecosystem processes (e.g., nutrient cycling)
  - "*Understanding how habitat heterogeneity regulates the structure and function of biotic communities is one of the most important challenges in modern ecology.*"

Belowground Ecology in a Restoration Context

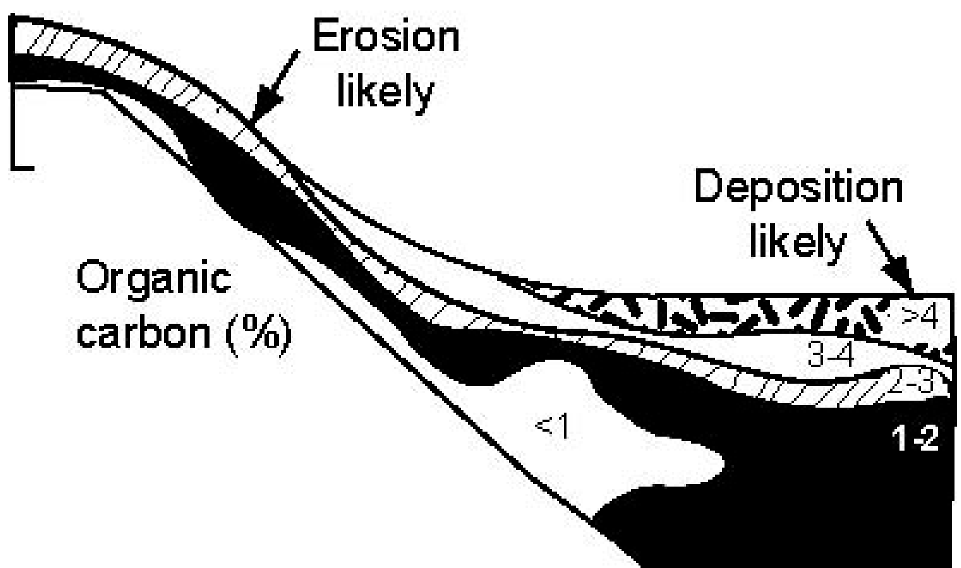
- Topographic heterogeneity
  - Topography is one abiotic factor responsible for heterogeneity in ecological systems
    - There are many other examples of heterogeneity in ecological systems, and topographic heterogeneity is just a good example
    - Controlled by both abiotic and biotic variables
      - And, in turn, influences both abiotic and biotic variables
    - Important implications for restoration
      - Human tendency is to homogenize the environment
      - As a result, restoration will often include the need to increase heterogeneity
    - "*…topographic heterogeneity should be a central component of restoration planning*."

Belowground Ecology in a Restoration Context

- Topographic heterogeneity
  - A pattern in elevation over a specific area
    - Need to consider landscapes as 3-dimensional
      - Vertical (elevation) and horizontal (frequency & distribution)
      - Leads to variability in distribution of elements, process rates, etc.
    - Result of:
      - Large temporal & spatial scales (macrotopography)
        - » Geologic activity (i.e., plate tectonics)
      - Smaller temporal & spatial scales (microtopography):
        - » Abiotic factors (H_2O movement, wind, waves, etc.)
        - » Biotic activity (burrowing by animals, tip mounds, etc.)

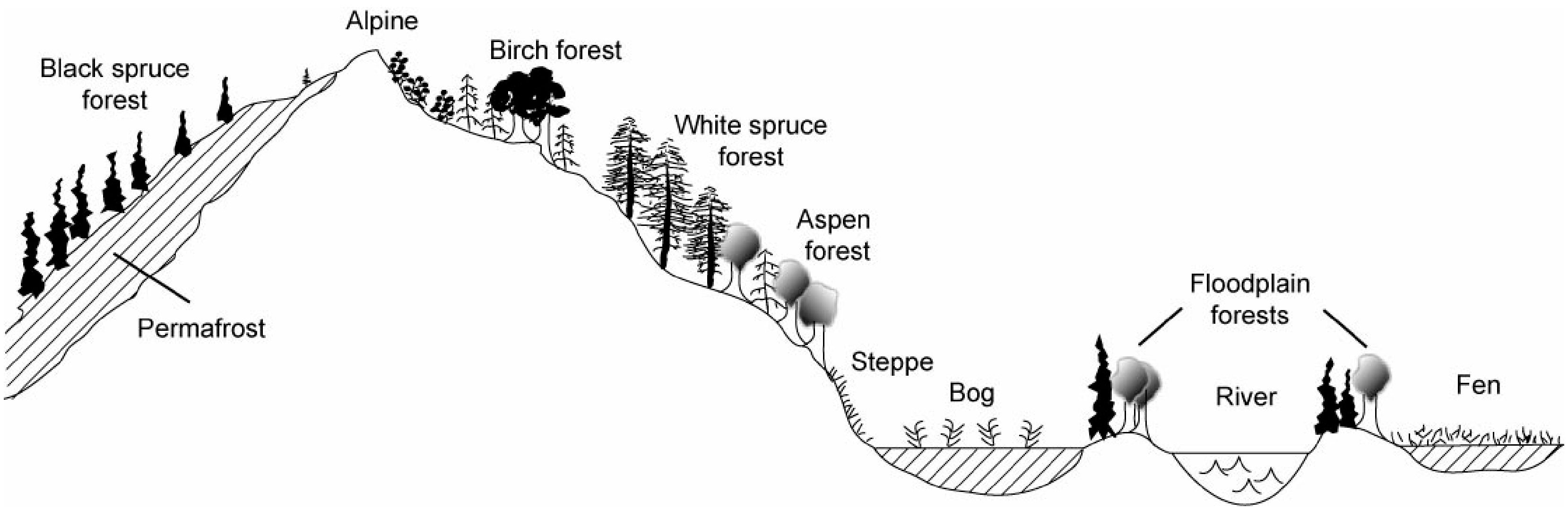
Belowground Ecology in a Restoration Context

- Topographic heterogeneity
  - Example of how topography influences soil organic carbon content
    - Lower where erosional processes dominate (e.g., hillsides)
    - Higher where depositional processes dominate (e.g., valley bottoms)
    - Takes a long time for these patterns to emerge naturally



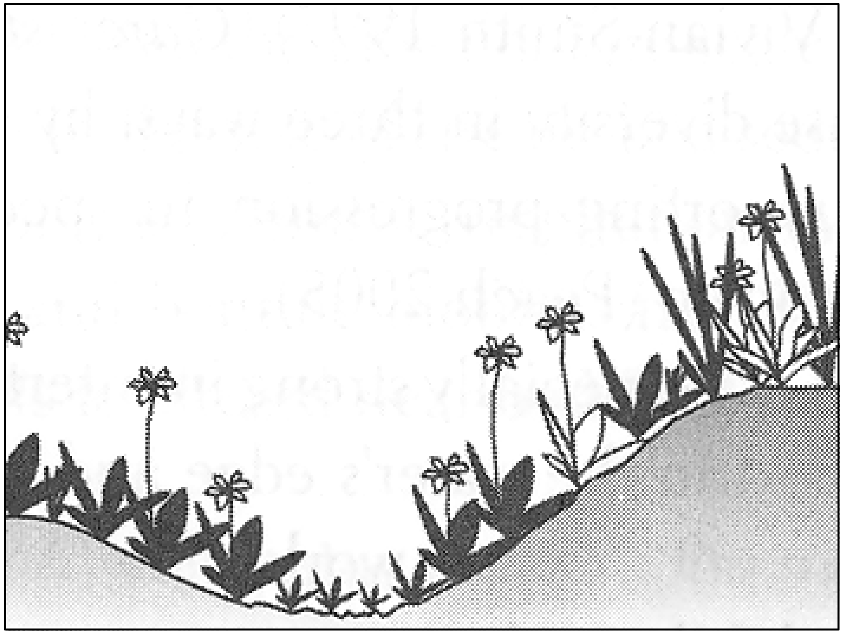
Belowground Ecology in a Restoration Context

- Topographic heterogeneity
  - Macrotopography (hills and mountains)
    - Geology; climate; coarse-scale erosion & deposition
    - Typically outside of the scale of restoration efforts



Belowground Ecology in a Restoration Context

- Topographic heterogeneity
  - Microtopography (spatial scales of <1m)
    - Variability in chemical & biological processes over small scales
      - Which, in turn, leads to variability in organisms where those found at each location are the superior competitors in that given abiotic environment
    - Highly relevant to restoration



Belowground Ecology in a Restoration Context

- Topographic heterogeneity
  - Habitat diversity ↑ species diversity
    - Variety of distinct ecological niches operating at various spatial scales
  - Topographic heterogeneity impacts:

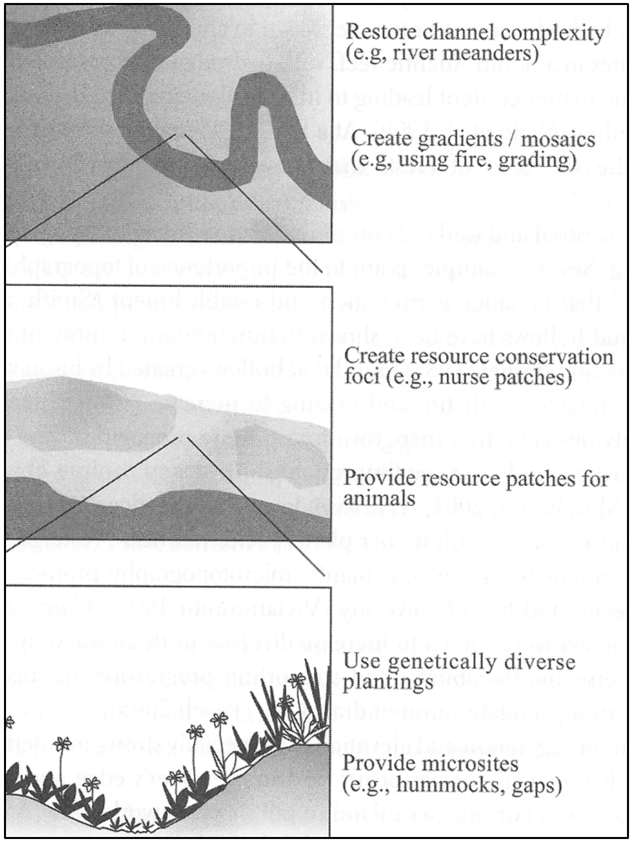
    1) Abiotic patterns & ecosystem processes

    2) Distribution of organisms

    3) Genetic, reproductive, & developmental attributes

    4) Animal habitat use, behavior, & trophic interactions

    5) Soil physical, chemical & biological properties

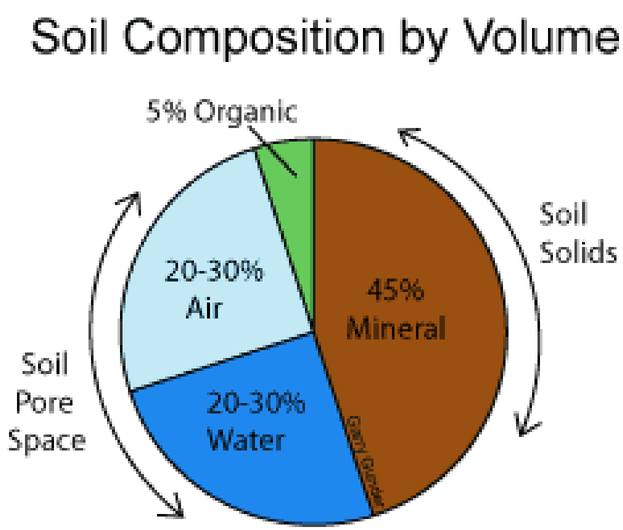


Belowground Ecology in a Restoration Context

- Soils: *The Final Frontier*
  - Long underappreciated in ecology
    - Hard to study what you cannot see
  - Crucial for understanding & managing all terrestrial ecosystems
  - Plants need 5 things for growth and survival, & **soils provide 3 of those**
    - **Physical medium for support**
    - **Water**
    - **Nutrients**
    - Radiant Energy
    - CO_2
  - Also primary habitat for many organisms

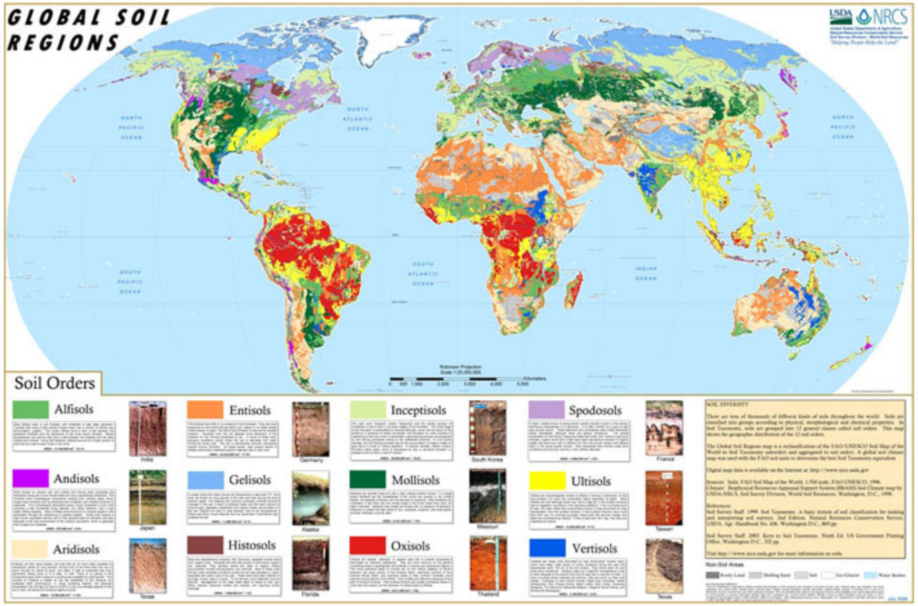
Belowground Ecology in a Restoration Context

- Soils: *The Final Frontier*
  - *Soil*: porous medium consisting of minerals, organic matter, and pore space (water and/or gases)
  - Within a given climatic regime, soils are <u>the major control</u> over ecosystem distribution, structure & function
  - Soil formation is ultimately a function of interactions between soil development, erosion, and deposition



Belowground Ecology in a Restoration Context

- Soils: *The Final Frontier*
  - On the coarsest scale, soil is divided into 12 orders
    - 10 soil orders found in Hawaii
    - ≥190 soil series in Hawaii
  - 5 state factors that control soil (& ecosystem) development
    - Topography, parent material, climate, time, potential biota



Belowground Ecology in a Restoration Context

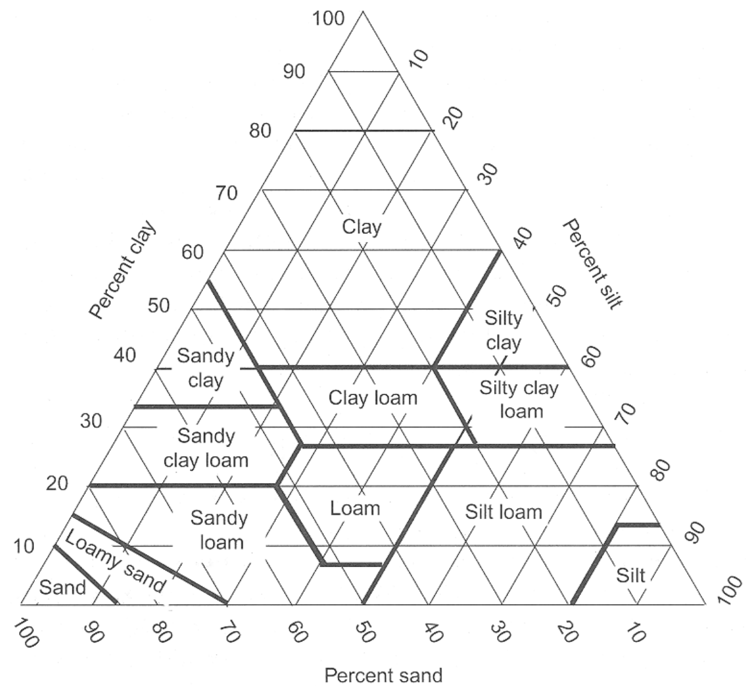
- Soils are characterized by physical, chemical & biological properties
  - All are influenced by topography (and, therefore, topographic heterogeneity), along with the other 4 state factors
  - Alone, and in combination, soil properties largely control *the availability and cycling of H_2O and nutrients*
  - Restoration often involves manipulation of soil properties to restore belowground structure, function, biota and/or *resource availability*

Belowground Ecology in a Restoration Context

- Soil physical properties
  - Influence the availability and cycling of H_2O & nutrients (i.e., belowground resource availability)
    - Texture
    - Structure
    - Bulk density
    - Water-holding capacity; soil water potential

Belowground Ecology in a Restoration Context

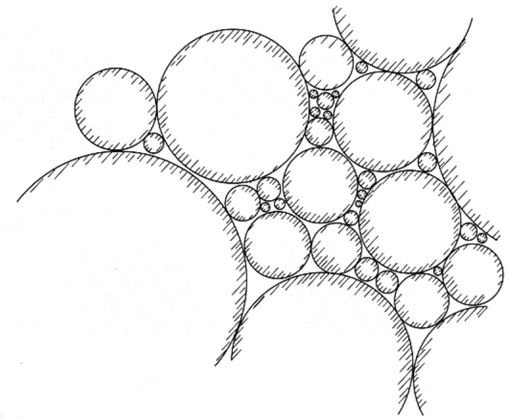
- Soil physical properties
  - Texture
    - % sand, silt, and clay
      - Size classification
    - How does texture influence resource availability?
      1. Surface area : Volume
         » Small particles → High SA:V → High WHC
      2. Clay (2° mineral) is an important source of rock-derived minerals & nutrients
      3. Strongly influences cation exchange capacity (C.E.C.)



Clay: <0.002mm
Silt : 0.002 – 0.02mm
Sand: 0.02 – 2.0mm

Belowground Ecology in a Restoration Context

- Soil physical properties
  - Soil structure
    - "Arrangement" of soil particles
    - "Glued" by OM, roots, & microbes into soil aggregates
  - Cracks and channels
    - Physical weathering & bio. activity
    - Preferential movement of H_2O, etc.
  - How does soil structure influence resource availability?
    1. H_2O infiltration rates
    2. Aerobic vs. anaerobic microsites → nutrient cycling
    3. "Protects" SOM from decomposition



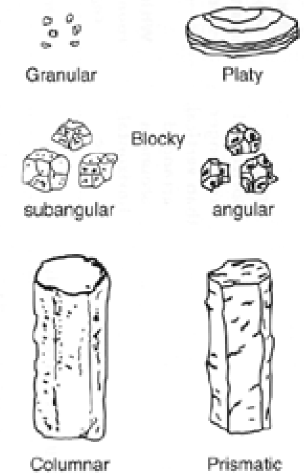
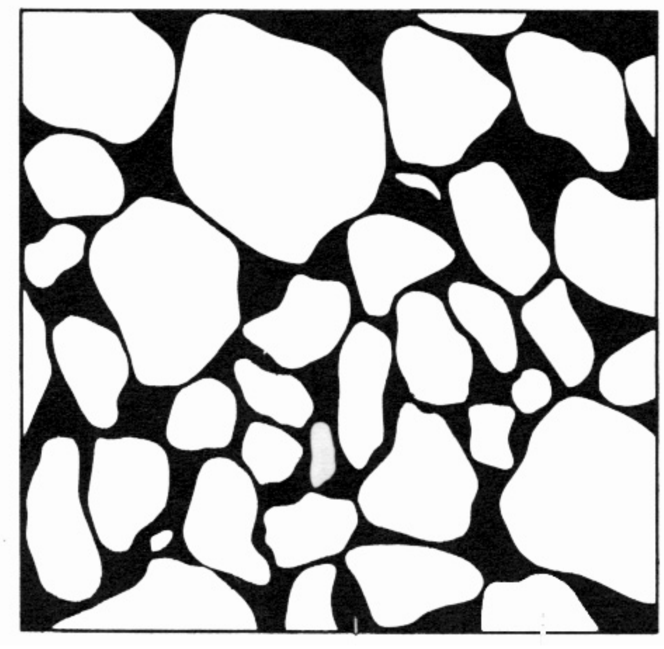


Fig. 5.5. Observable forms of soil aggregation.

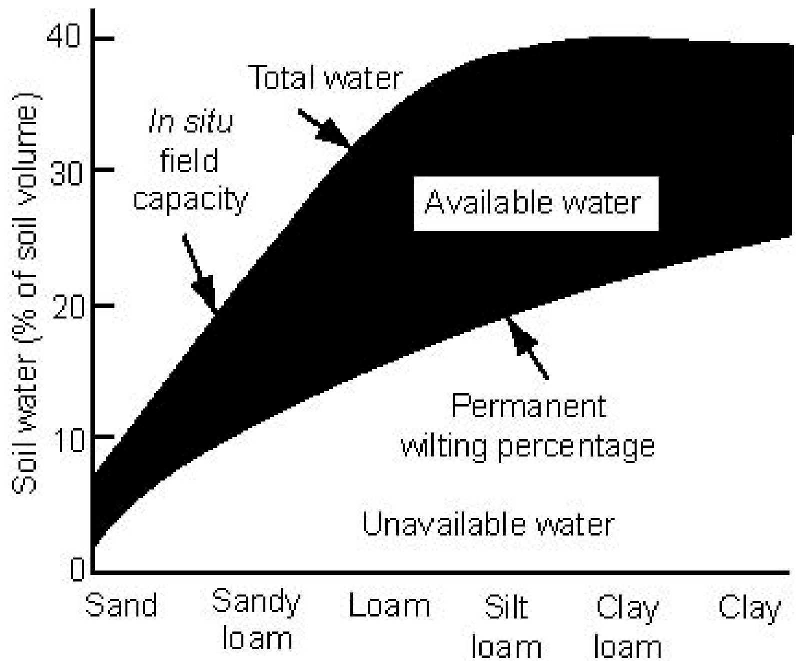
Belowground Ecology in a Restoration Context

- Soil physical properties
  - Bulk density
    - Soil mass : Soil volume
      - Typical soil is ~25% H_2O & 25% Air
    - Influenced by: mineralogy & chemical composition, soil fauna, and humans
      - *Compacted soils are common problem in restoration*
    - How does bulk density influence resource availability?
      1. H_2O infiltration rates
      2. Nutrient content (% conc. X bulk density)
      3. Root development



Belowground Ecology in a Restoration Context

- Soil physical properties
  - Water holding capacity (WHC)
    - WHC = Field Capacity (FC) - Permanent Wilting Point (PWP)
      - Enhanced by clay and OM (high surf. area : vol. ratios)

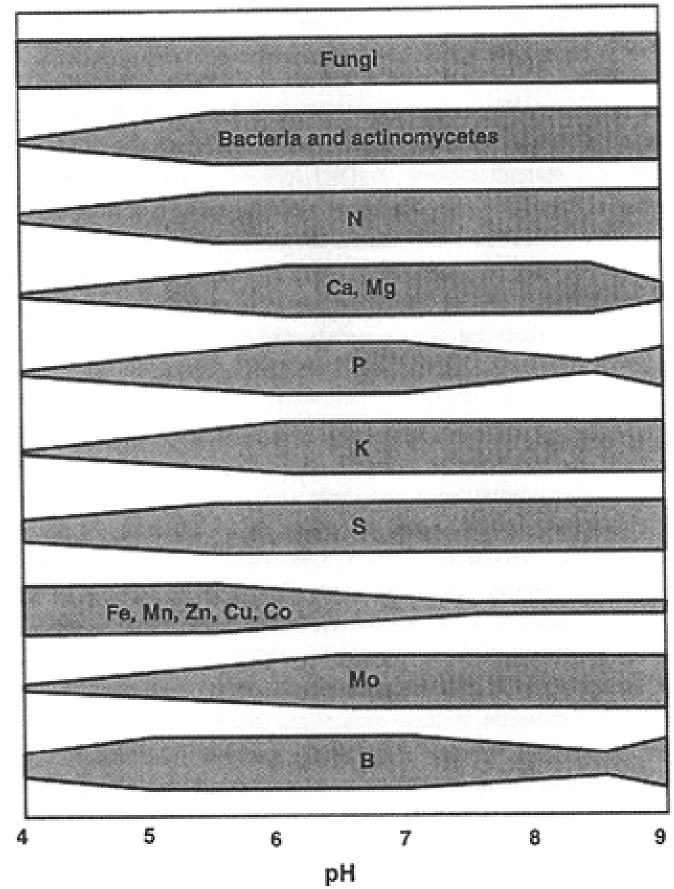


Belowground Ecology in a Restoration Context

- Soil chemical properties
  - Influence the availability and cycling of H_2O & nutrients (i.e., belowground resource availability)
    - pH
    - Organic matter content
    - Ion exchange capacity

Belowground Ecology in a Restoration Context

- Soil chemical properties
  - pH: Negative log of H^+ ion activity in solution (0-14; 7 is neutral, below 7 is acidic)
    - Strongly impacts nutrient solubility in soil solution (i.e., nutrient availability)



Belowground Ecology in a Restoration Context

- Soil chemical properties
  - Soil organic matter (SOM) content strongly influences:
    - WHC
    - Soil Structure
    - Bulk Density
    - Pools, availability & retention of micro- and macro-nutrients
    - C.E.C.
    - Soil formation and development
    - Etc.
  - SOM content is a critical component of soil health/fertility/sustainability/etc.
    - Typically concentrated in surface soils, which are the first to erode when degraded

Belowground Ecology in a Restoration Context

- Soil chemical properties
  - Cation exchange capacity (C.E.C)
    - Capacity of a soil to hold exchangeable cations (+ ions)
    - Driven by negatively charged sites on minerals and OM
    - Provides a steady reservoir of soil nutrients for plants and microbes
    - Most soils characterized by C.E.C.
  - Anion exchange capacity (A.E.C)
    - Capacity of a soil to hold exchangeable anions (- ions)
    - Driven by positively charged sites on minerals
    - More commonly seen in highly weathered tropical soils (e.g., Oxisols and Ultisols)

Belowground Ecology in a Restoration Context

- Soil biological properties
  - Influence the availability and cycling of H_2O & nutrients (i.e., belowground resource availability)
    - Presence/activity of soil organisms
      - Roots
      - Microbes
        - » Bacteria, archaea, fungi, actinomycetes
      - Mesofauna
        - » Nematodes, protozoa
      - Macrofauna
        - » Earthworms, rodents
      - Soil organisms can be beneficial or detrimental, depending on context

Belowground Ecology in a Restoration Context

- Soil biological properties
  - Soil organisms are fundamentally important to soil structure and function
    - Mix soil horizons
      - Transport materials thru the soil profile
    - Soil Biogeochemistry
      - Microbes mediate transformations of all important nutrients (C, N, S, P, etc.), and as such are critical for all biogeochemical processes
    - Rhizosphere processes
      - Region of soil that is directly influenced by root secretions and associated soil microorganisms (as opposed to bulk soil)
    - Mycorrhizal symbioses
      - Most plants rely on mycorrhizae for establishment and survival
    - Soil-borne pathogens and diseases
      - Weaken and/or kill plants

Belowground Ecology in a Restoration Context

- Restoration
  - Manipulation/modification of soil physical, chemical & biological properties often necessary in restoration
    - Baseline information needed (target reference conditions)
      - Spatial and temporal variability that is inherent in all soils should be considered
        - » Soils, and soil properties, are very heterogeneous across short spatial and temporal scales
    - Restoration of topographic heterogeneity
      - More relevant for highly degraded and/or highly homogenized landscapes
        - » Sooner the better
        - » Active vs. passive manipulation

Belowground Ecology in a Restoration Context

- *A Striking Profile: Soil Ecological Knowledge in Restoration Management and Science* (Dec. 2008 Special Issue in *Restoration Ecology*)
  - "*…an absence of in-depth discussion of how soils, and in particular the ecology of soils, can be integrated into the developing theory of restoration science.*"
  - "*…soil is a complex, heterogeneous, and vital entity and adoption of this point of view can positively affect restoration efforts worldwide.*"

(Callaham *et al*. 2008)

Belowground Ecology in a Restoration Context

- 2015 is the International Year of Soils!
  - Declared by the 68th UN General Assembly
  - Objectives:
    - *Raise … awareness … about the profound importance of soil for human life*
    - *Educate the public about the crucial role soil plays…*
    - *Support effective policies & actions for the sustainable management & protection of soil resources*
    - *Promote investment in sustainable soil management activities…*
    - *Advocate for rapid capacity enhancement for soil information collection & monitoring at all levels (global, regional & national)*

http://www.fao.org/soils-2015/en/

Week 8 Readings/Lecture Slide Highlights

1. In terms of both biotic and abiotic components, ecological systems are inherently heterogeneous across space and time. This habitat heterogeneity (e.g., topographic heterogeneity) influences ecosystem structure and function primarily by increasing niche space which, in turn, promotes increased biodiversity and impacts ecosystem processes.

Week 8 Readings/Lecture Slide Highlights

2. Plants need five resources for survival and growth – physical medium for support, water, nutrients, radiant energy, and CO_2 – and soils provide three of these resources. In as much, most terrestrial ecological restoration projects will require implicit consideration of soil ecology at all stages of the restoration process.

Week 8 Readings/Lecture Slide Highlights

3. Soil is a porous medium consisting of minerals, organic matter (SOM), and pore space that is filled with either water and/or gases (i.e., air). Soils are characterized by physical, chemical and biological properties that alone and in combination influence the availability and cycling of belowground resources (i.e., water and nutrients).

Week 8 Readings/Lecture Slide Highlights

4. Soil organic matter (SOM) content is a critically important property of soils that influences physical, chemical, and biological properties. As a result, consideration of SOM content should be a central component of any restoration project that considers belowground dynamics, from establishing restoration objectives to monitoring restoration success.

Week 8 Readings/Lecture Slide Highlights

5. Soil organisms are fundamentally important to soil physical, chemical, and biological properties. Soil microbes, in particular, mediate the transformation of all important nutrients and are critical for all biogeochemical processes/cycles (e.g., nutrient cycling and availability).