Chapter 20

SUCCESSION AND STABILITY

Chapter Concepts

- Community changes during succession include increases in species diversity and changes in species composition
- Ecosystem changes during succession include increases in biomass, primary production, respiration, and nutrient retention
- Mechanisms that drive ecological succession include facilitation, tolerance, and inhibition
- Community stability may be due to lack of disturbance or community resistance

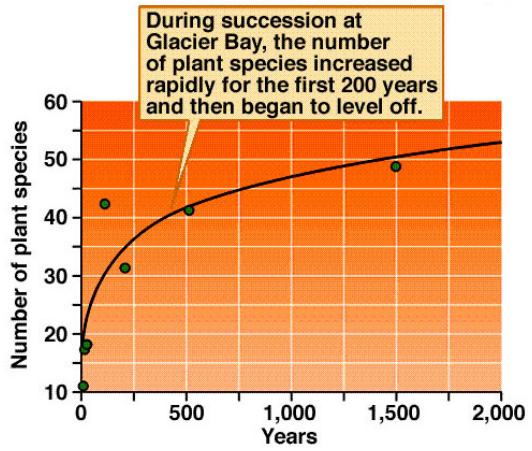
Definitions

- Succession – Gradual change in plant and animal communities in an area following disturbance
  - ✓ Primary – Succession on newly exposed geological substrates
  - ✓ Secondary – Succession following disturbance that does not destroy soil
- Climax Community – Late successional community - remains stable until disrupted by disturbance

Primary Succession – Glacier Bay, Alaska

- *Reiners et al.* (1971) studied changes in plant diversity during succession
  - ✓ Total number of plant species (species richness) increased with plot age
  - ✓ Species richness increased rapidly in early years of succession and more slowly during later stages
    - Not all groups increased in density throughout succession (different composition)

Richness and Succession



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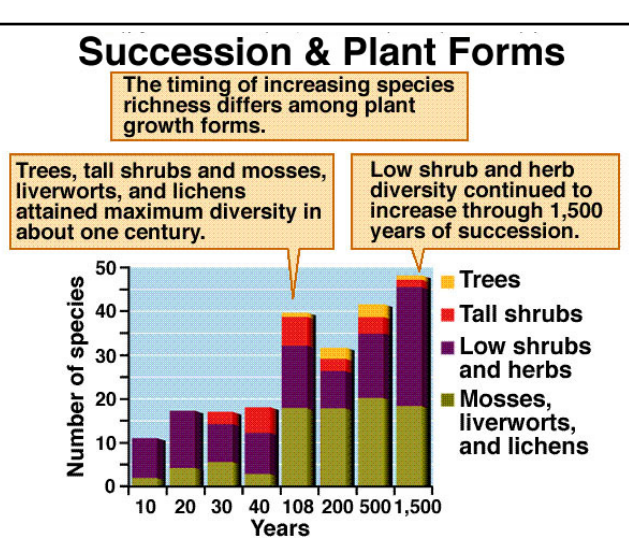
Succession & Plant Forms



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Secondary Succession in Temperate Forests

- *Oosting* (1942) found number of woody plant species increased during secondary succession at Piedmont Plateau
- *Johnston and Odum* found increase in bird diversity across successional sequence closely paralleled increase in woody plant diversity observed by Oosting

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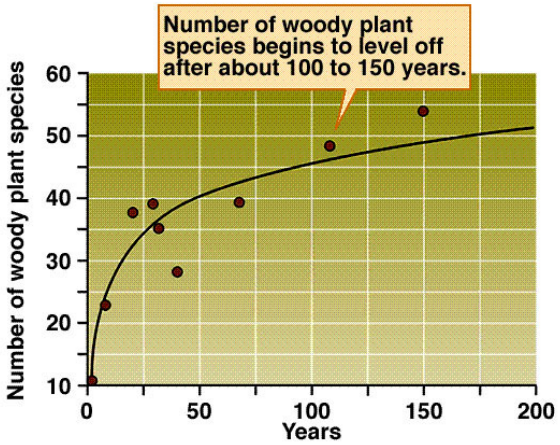
Species Richness Change



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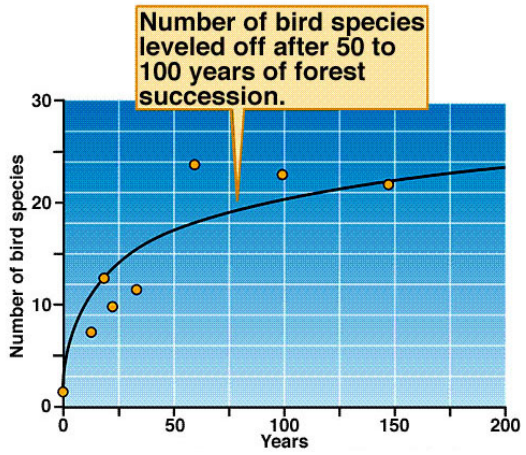
Succession & Species Number



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Succession in Rocky Intertidal Communities

- Easy manipulation
- The first species – green alga (*Ulva*) and the barnacle
- The next – perennial red algae
- Finally - perennial red algae (*Gigartina canaliculata*) dominated
- 1.5 years as compared to 1500 yrs in Glacier Bay and 150 yrs in Piedmont Plateau

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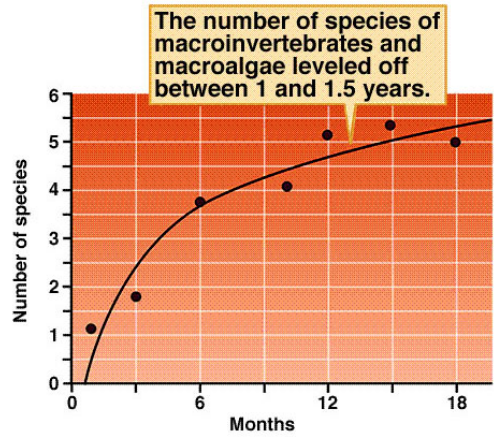
Succession in Species Number



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Succession in Stream Communities

- *Fisher et al.* (1982) studied rapid succession in Sycamore Creek, AZ
  - ✓ Evaporation nearly equals precipitation – flows generally low and intermittent
    - Subject to flash floods (disturbance)
  - ✓ Observed rapid changes in diversity and composition of algae and invertebrates
    - Invertebrates found refuge because many adults in aerial stage
      - Re-colonized after flooding

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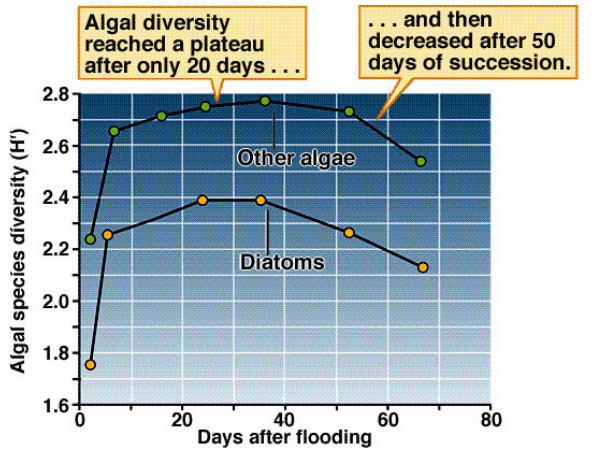
Succession & Species Diversity



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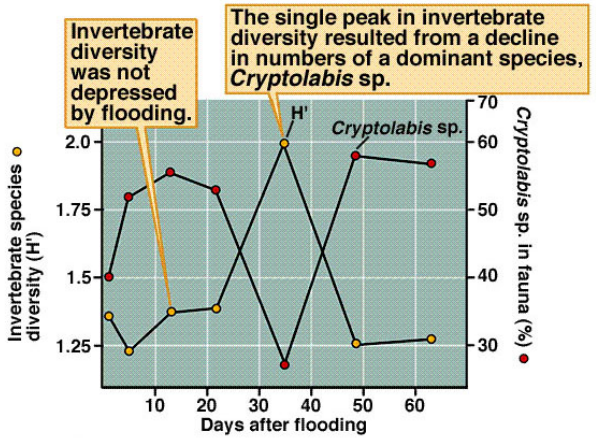
Succession & Invertebrates



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Ecosystem Changes During Succession

- Ecosystem changes during succession include increases in biomass, primary production, respiration, and nutrient retention

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Ecosystem Changes at Glacial Bay

- *Chapin* (1994), Glacier Bay
  - ✓ Total soil depth and depth of all major soil horizons show significant increase from pioneer community
  - ✓ Soil properties (influencing the kinds of organisms that can grow) also changed during succession, i.e.,
    - Organic content, moisture, and N concentrations all increased
      - Physical and biological systems inseparable

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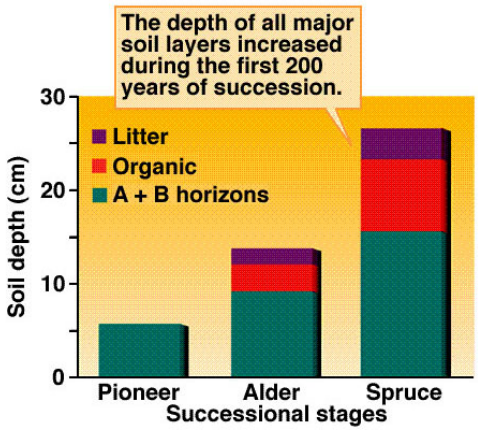
Soil Building & Succession



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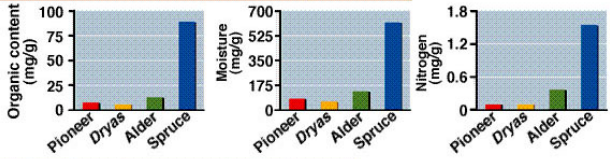
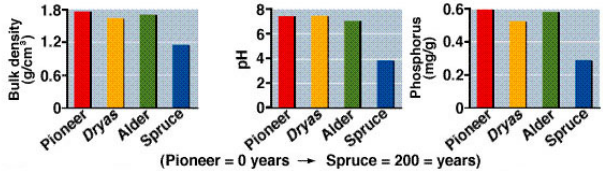
Soil Properties & Succession

During succession, nitrogen, moisture, and organic matter content increased , . . .



. . . while phosphorus content, pH, and bulk density decreased.



(Pioneer = 0 years → Spruce = 200 = years)

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Four million years of changes

- Studies at Glacial Bay
- Chronosequence – the sequence of ages represented by the study sites

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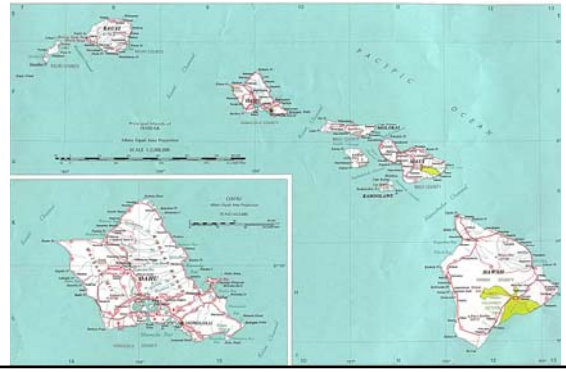
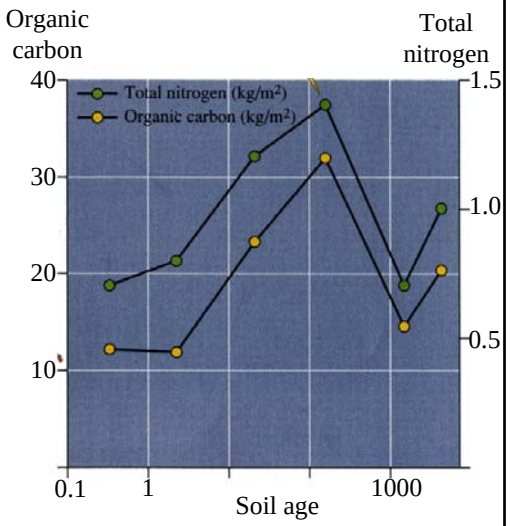
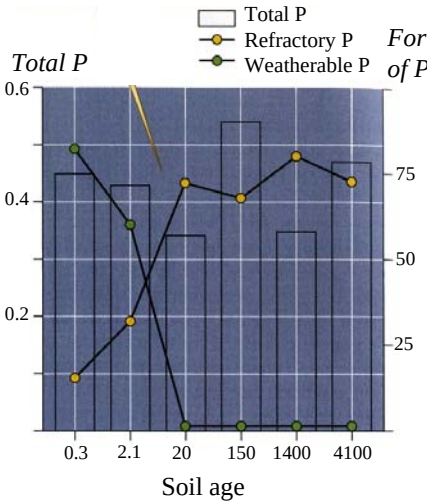
- Hedin et al. (2003) – Hawaii islands, chronoseqence of forest ecosystem
  - ✓ Different islands have different historic development (300 to 4,100,000 yrs) in their rocks due to volcanic lava flows



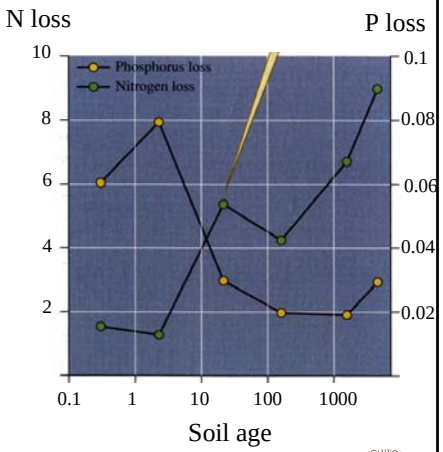
- Organic matter increased in soils over the first 150,000 years
- Analogous increases in soil organic matter
- Also, the changes in soil N content followed precisely





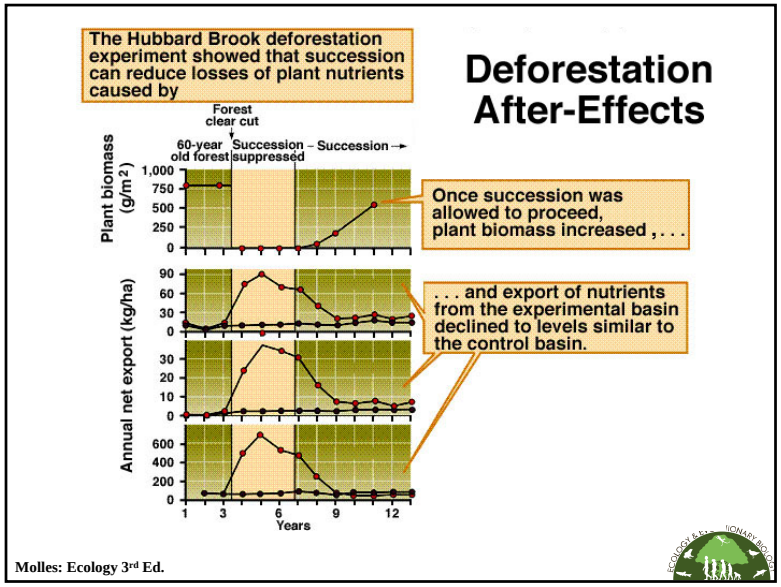
- Change pattern in P content in soils was different
- No obvious pattern was found
- But, the form of P changed substantially
- Become a limiting factor on primary production when the content is low in older soils

- There are changes in *rates* of nutrient loss across the chronosequence
- Higher rate of N loss
- Decreased rates of P loss
- Most of the losses are due to leaching to groundwater



Recovery of nutrient retention after disturbance

- *Bormann and Likens* (1981) in the Hubbard Brook Experimental Forest
- Cut forest and suppress vegetation growth by herbicides
- High nutrient losses during the suppressed period
- When the herbicide applications were stopped, succession proceeded and nutrient losses decreased dramatically



Model of Ecosystem Recovery

- Bormann and Likens proposed the biomass accumulation model
- Four phases
  - ✓ Reorganization (10-20 yrs)
    - Forest loses biomass and nutrients
  - ✓ Aggradation (100+ yrs)
    - Ecosystem reaches peak biomass
  - ✓ Transition
    - Biomass declines from peak
  - ✓ Steady-State
    - Biomass fluctuates around mean

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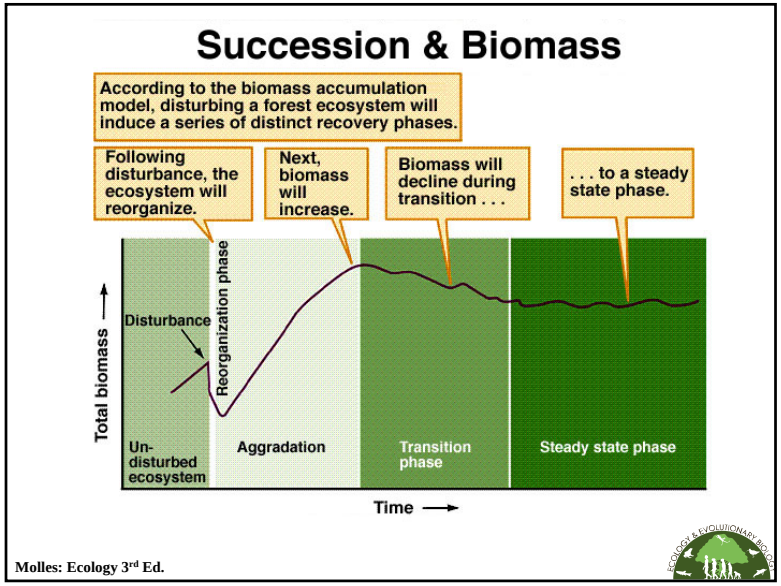

Succession and stream ecosystem properties

- Sycamore Creek, Arizona
- Succession happened within in 63 days after flooding
- Show similar pattern as proposed by the biomass accumulation model

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Succession and stream ecosystem properties

- Algal biomass increased rapidly for the first 13 days and then decreased more slowly afterwards
- Ecosystem metabolic parameters (e.g., photosynthetic rate) show leveling off
- The level of retention increased rapidly during succession, then leveling off to eventually 0 (balance state, input = output)

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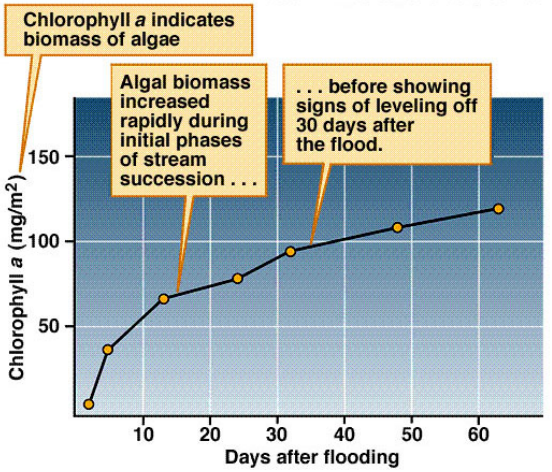
Biomass & Stream Succession



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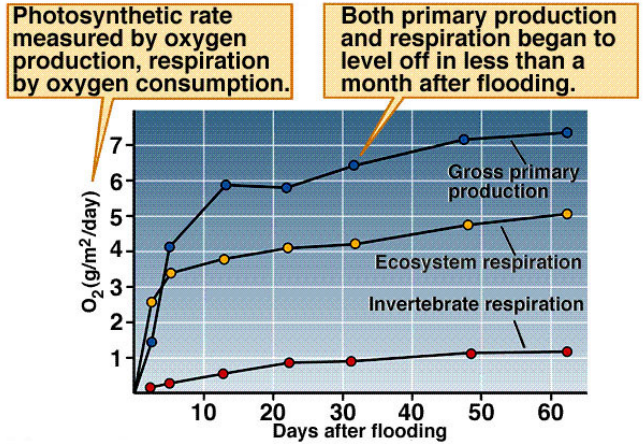
Succession Processes



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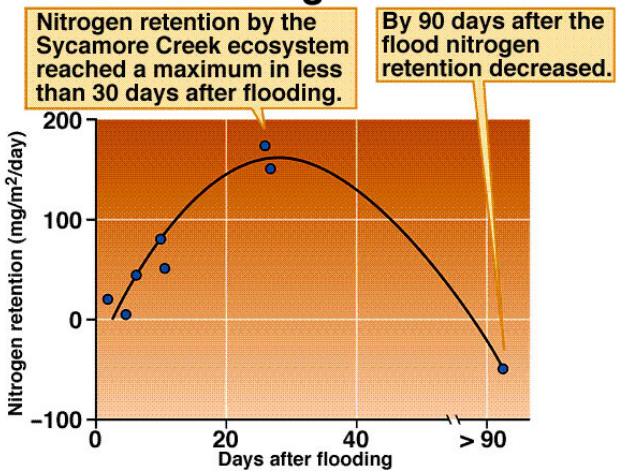
Stream Nitrogen Retention



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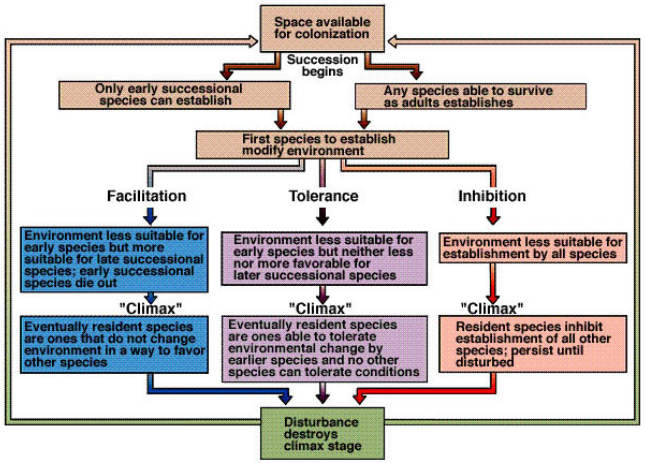
Mechanisms of Succession

- *Clements* (1916)*:*
  - ✓ Facilitation
- *Connell and Slayter* (1977)*:*
  - ✓ Facilitation
  - ✓ Tolerance
  - ✓ Inhibition
- Most of the current evidences support the facilitation model, the inhibition model, or some combination

Successional Mechanisms



Facilitation

- Proposes many species may attempt to colonize newly available space
  - ✓ Only certain species will establish
    - Colonizers – “Pioneer Species” – modify environment so it becomes less suitable for themselves and more suitable for species of later successional stages

Tolerance

- Initial Stages of colonization not limited to Pioneer Species
  - ✓ Early successional species do not facilitate later successional species

Inhibition

- Early occupants of an area modify env. in a way that makes it less suitable for both early and late successional species
  - ✓ Early arrivals inhibit colonization by later arrivals
  - ✓ Assures late successional species dominate an area because they live a long time and resist damage by physical and biological factors

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Successional Mechanisms in Rocky Intertidal Zone

- *Sousa* investigated mechanism behind succession of algae and barnacles in intertidal boulder fields.
  - ✓ If inhibition model is in effect, early successional species should be more vulnerable to mortality
    - Results showed early successional species had lowest survivorship and were more vulnerable to herbivores

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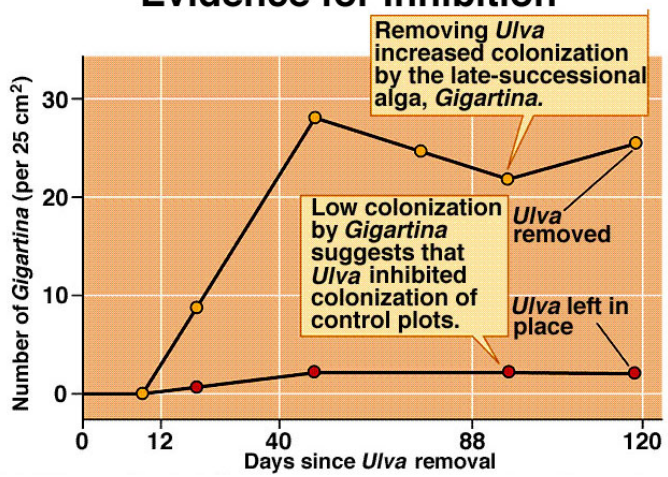
Evidence for Inhibition



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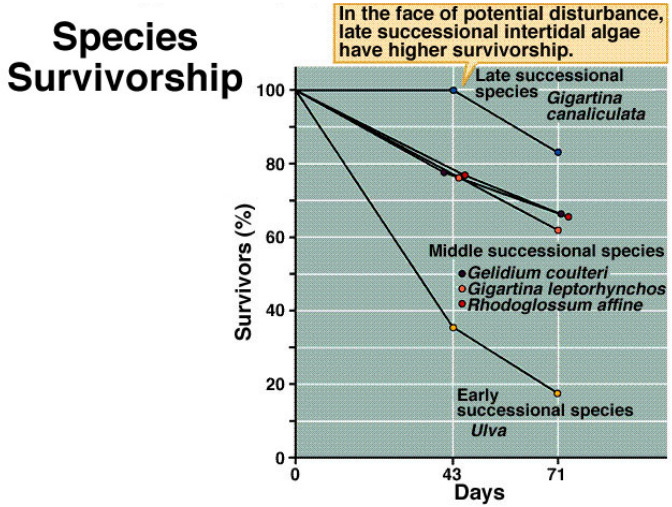
Species Survivorship



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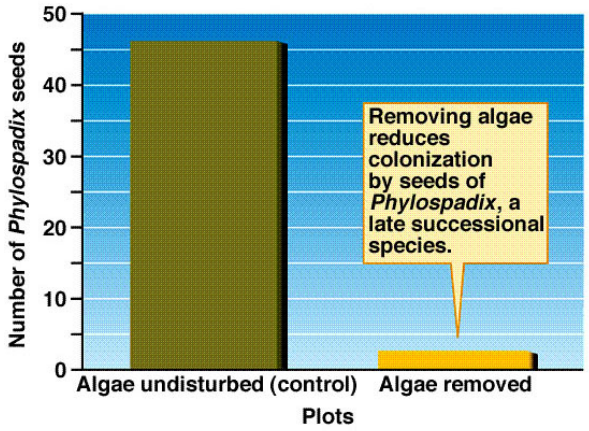
Colonization Facilitation



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Successional Mechanisms in Forests

- Hundreds of years
- Old field succession
- Primary succession on a volcanic substrate
- Primary succession following deglaciation

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Mechanisms in Old Field Succession

- Keever (1950), Piedmont Plateau
- What was the causes of early species replacements?
- Results support the inhibition model and the facilitation model

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Mechanisms in Primary Succession on a Volcanic Substrate

- 1980 - Mt St. Helens, Washington erupted
  - ✓ Disturbance set stage for succession
    - Avalanche debris, hot volcanic ash and pumice killed all plant life
- *Morris and Wood* studied influences of facilitation, tolerance, and inhibition on early succession on pumice plains
  - ✓ Found complex blend of influences

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Mount St. Helens

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Three pioneering species

- Pearly everlasting (*Anaphlis margaritacea*)
- Fireweed (*Epilobium angustifolium*)
- Perennial Lupine (*Lupinus lepidus*) – a N-fixer

- The first two species disperse by wind and rapidly colonize
- The third species does not disperse easily

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Pearly everlasting (*Anaphlis margaritacea*)

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Fireweed (*Epilobium angustifolium*)

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Perennial Lupine (*Lupinus lepidus*)

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Experiment results

- Consistent with the inhibition and facilitation models
- Seedling survival during the first growing season was highest on the barren control plot (inhibition)
- But, during the second growing season, the pattern reserved, the survival seedlings was lowest (facilitation)

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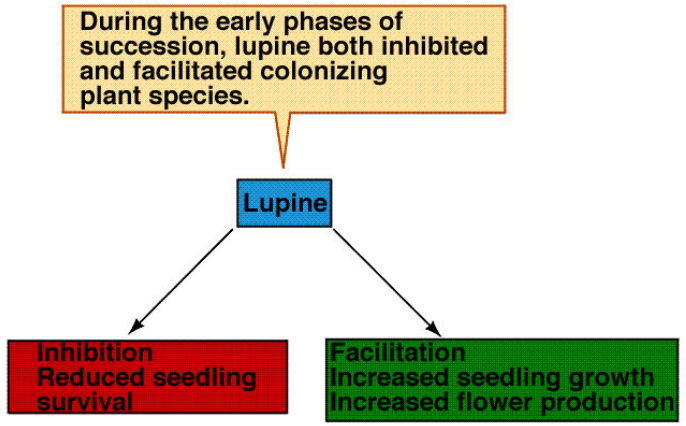
Lupine & Colonization



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Mechanism of primary succession

- Glacial Bay
- Field observations, field experiments, and greenhouse experiments
- *Chapin* (1994) found no single factor or mechanism determines the pattern of primary succession – complex influences

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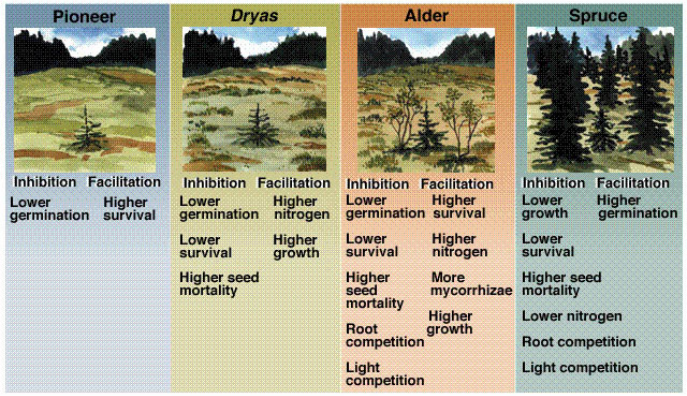
Spruce & Succession



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Community and Ecosystem Stability

- Community stability may be due to lack of disturbance or community resistance
- Stability – Absence of change
- Resistance – Ability to maintain structure and function in face of potential disturbance
- Resilience – Ability to recover from disturbance

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- Succession restores a community disrupted by disturbance
- Succession is the basis of resilience
- Take long time to study

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Park Grass Experiment

- Hertfordshire, England
  - ✓ Studied effects of fertilizer treatments
    - Continued for almost 150 years
- *Silverton* (1987) investigated ecosystem stability
  - ✓ Used community composition variability as measure of stability
  - ✓ Represented composition as proportion of community consisting of each plant form

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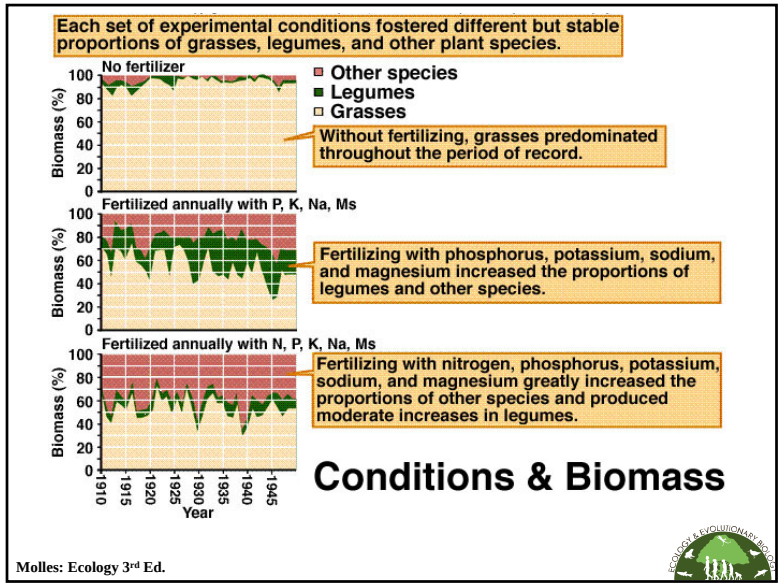

- The proportions of grasses, legumes, and other species remained fairly constant
- Mainly affected by precipitation
- However, population of individual species changed substantially

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Community and Ecosystem Stability

- *Dodd et al. (1995)* showed although community stability is present, populations of individual species can change substantially
  - ✓ Stability depends on spatial resolution an area is investigated at
  - ✓ Landscape, form, and species levels

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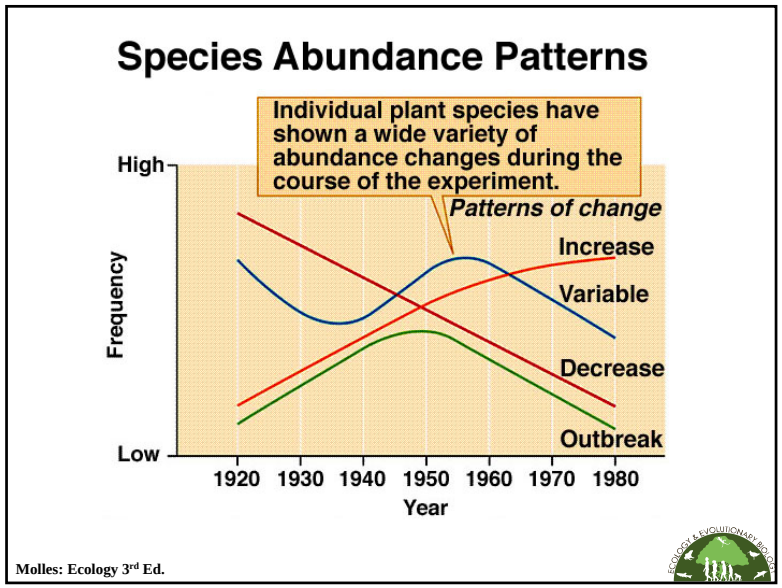


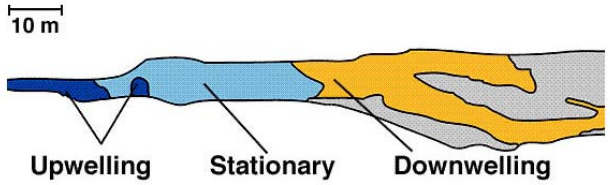
Replicate Disturbances and Desert Stream Stability

- Sycamore Creek, Arizona
- *Valett et al*. (1994) tested the hypothesis that ecosystem resilience is higher where hydrologic linkages between the surface and subsurface water increase the supply of N – a nutrient limiting the primary production

- *Valett* studied interaction between surface and subsurface waters
  - ✓ Flash floods devastated biotic community
    - Spatial relationships of zones stable
      - Geomorphology of landscape

- Measured vertical hydraulic gradient – hydrologic maps
  - ✓ Positive vertical – flow from streambed to the surface – upwelling zone
  - ✓ Negative vertical – flow from the surface to the streambed – downwelling zone
  - ✓ Zero vertical – stationary zone

Upwelling and Downwelling



Zones of vertical water exchange

- The concentration of nitrate in surface water varies directly with vertical hydraulic gradient
- Upwelling zones – have the highest nitrate concentration due to upwelling from the sediments
- Nitrate concentrations gradually decline

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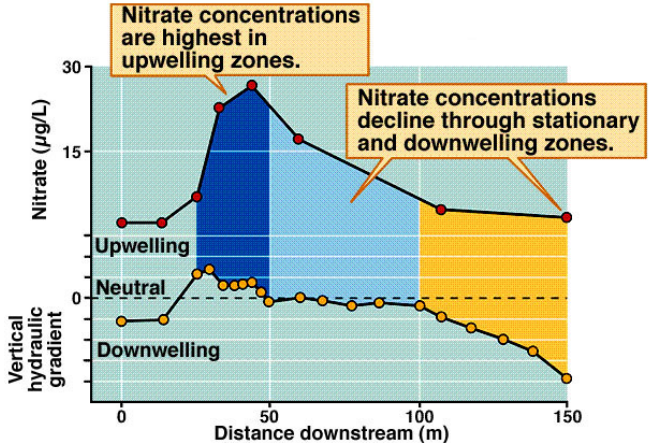
Nitrate & Hydraulic Gradient



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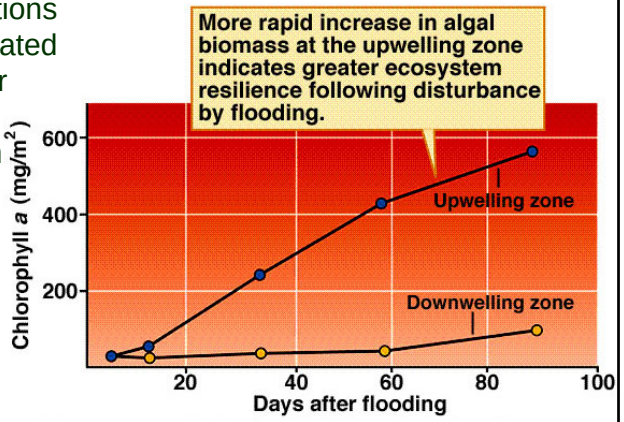
The higher nitrate concentrations are associated with higher algae production

Chlorophyll & Flooding



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- The rate of algal biomass accumulation can be used as a measure of rate of recovery from disturbance
- Therefore, the rate of ecosystem recovery is higher in upwelling zones since the rate of algal biomass accumulation is higher in this region
- i.e., algal communities in upwelling zones are more resilient

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Summary

- Community changes during succession include increases in species diversity and changes in species composition
- Ecosystem changes during succession include increases in biomass, primary production, respiration, and nutrient retention
- Mechanisms that drive ecological succession include facilitation, tolerance, and inhibition
- Community stability may be due to lack of disturbance or community resistance

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