Ecosystem Succession:
Who/What is Where and When

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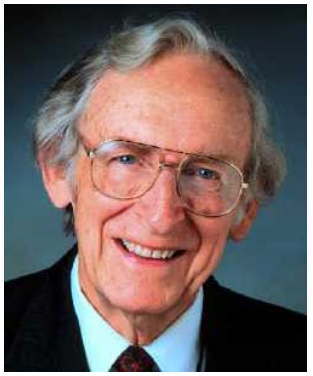
ESPM 111 Ecosystem Ecology

Succession

- From the Latin, *succedere*, to follow after
- Orderly process of community development that is directional and predictable
- Results from the modification of physical environment by the community
  - Succession is community-controlled even though the physical environment determines the pattern, rate of change and limits
- Culminates in a stabilized ecosystem in which biomass and symbiotic function between organisms are maintained per unity of available energy flow
  - *Eugene P Odum, 1969, Science*

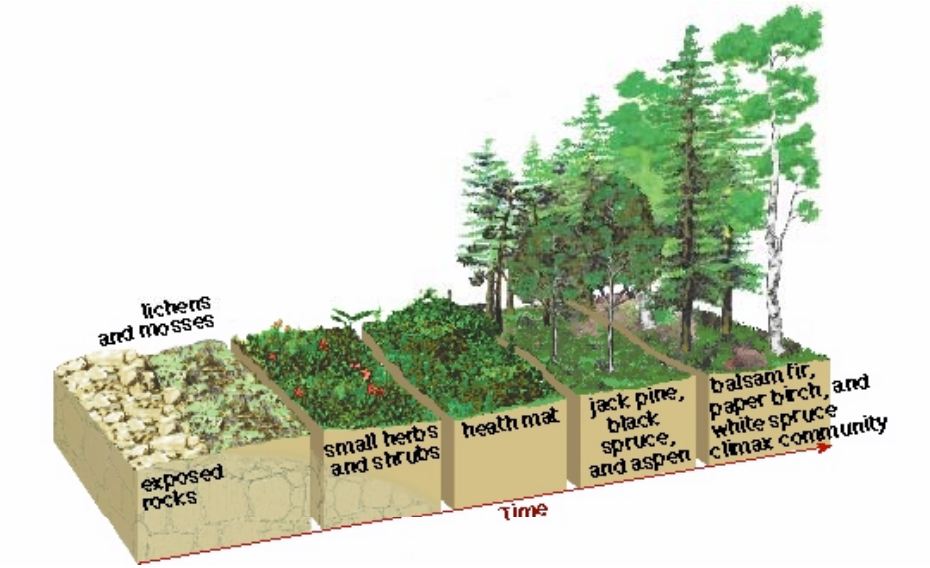


Succession

- Primary Succession
  - After severe disturbance that remove or bury products of the ecosystem
- Secondary Succession
  - After disturbance on a vegetated site. Most above ground live biomass may be disturbed but soil organic matter and plant propagules remain
- Gap Phase Succession
  - Mortality and Tree fall for gap in canopy for new vegetation to invade and establish itself

Dynamic Sequence of Vegetation

- Initial Conditions
  - Equilibrium
- Disturbance
- Colonization/Recruitment
- Recovery
- Competition
- Succession
  - Primary
  - Secondary
  - Gap Succession
- Climax
  - New Equilibrium



Disturbance

- *Relatively Discrete event, in time and space, that alters the structure of populations, communities and ecosystems and causes changes in resource availability and the physical environment.*

Chapin et al.

Examples of Natural and Human-Induced Disturbance

- Natural
  - Mortality
    - Age, Density, Self-Thinning
  - TreeFall
  - WildFire
  - Volcano
  - Flooding
  - Hurricane/Tornadoes
  - Insects/Disease
  - WindThrow
  - Tsunami
  - Landslides
  - Glaciers
  - Sea-level Rise or Retreat
- Human-Induced
  - Logging
  - Plowing
  - Mining
  - Dam Removal
  - Fire/Flooding
  - Nuclear blast/Warfare (agent Orange)

Mt St Helens

Logging

Redwood treefall

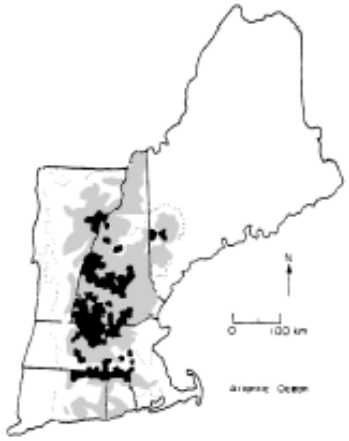
Disturbance and Succession-Type

- Primary
  - Volcano
  - Landslide
  - Flooding
  - Dune Formation
  - Lake Drainage
  - Tsunami
- Secondary
  - Fire
  - Hurricane
  - Logging

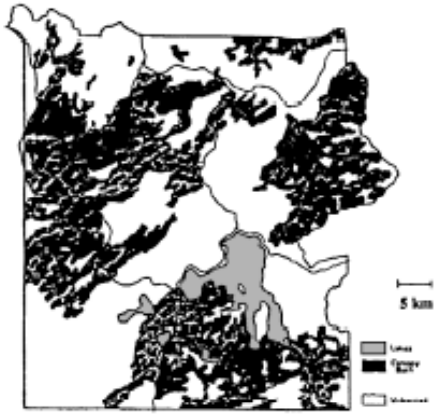
Attributes of Disturbance

- Type
- Severity, Intensity, Extent
- Frequency, Timing

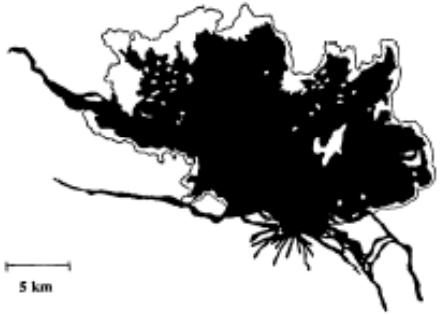
Classic Disturbance Cases in US



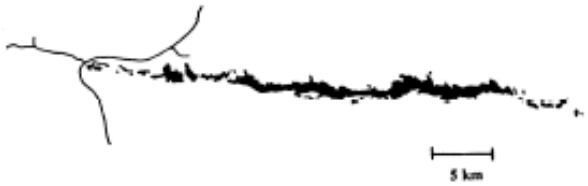
Hurricane (1938 New England)



Fire (Yellowstone National Park)



Volcano (Mount St Helens)



Tornado (Tionesta Scenic Area)

Flood (Mississippi River)

Turner, 1989, Ann Rev Ecology

Intensity and Extent

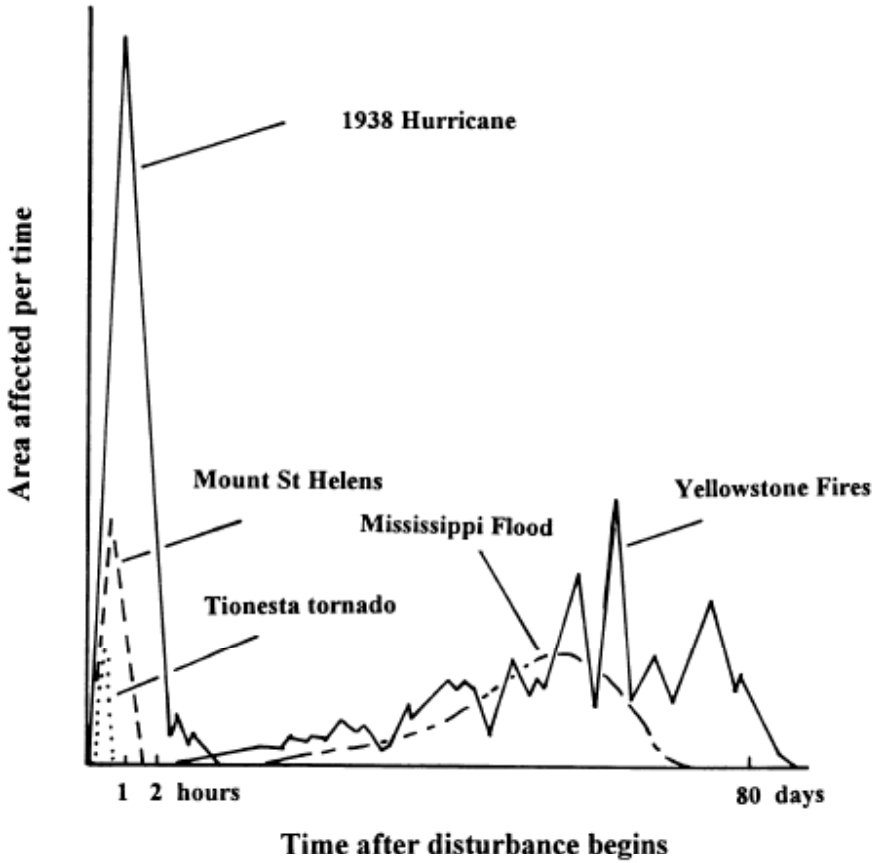
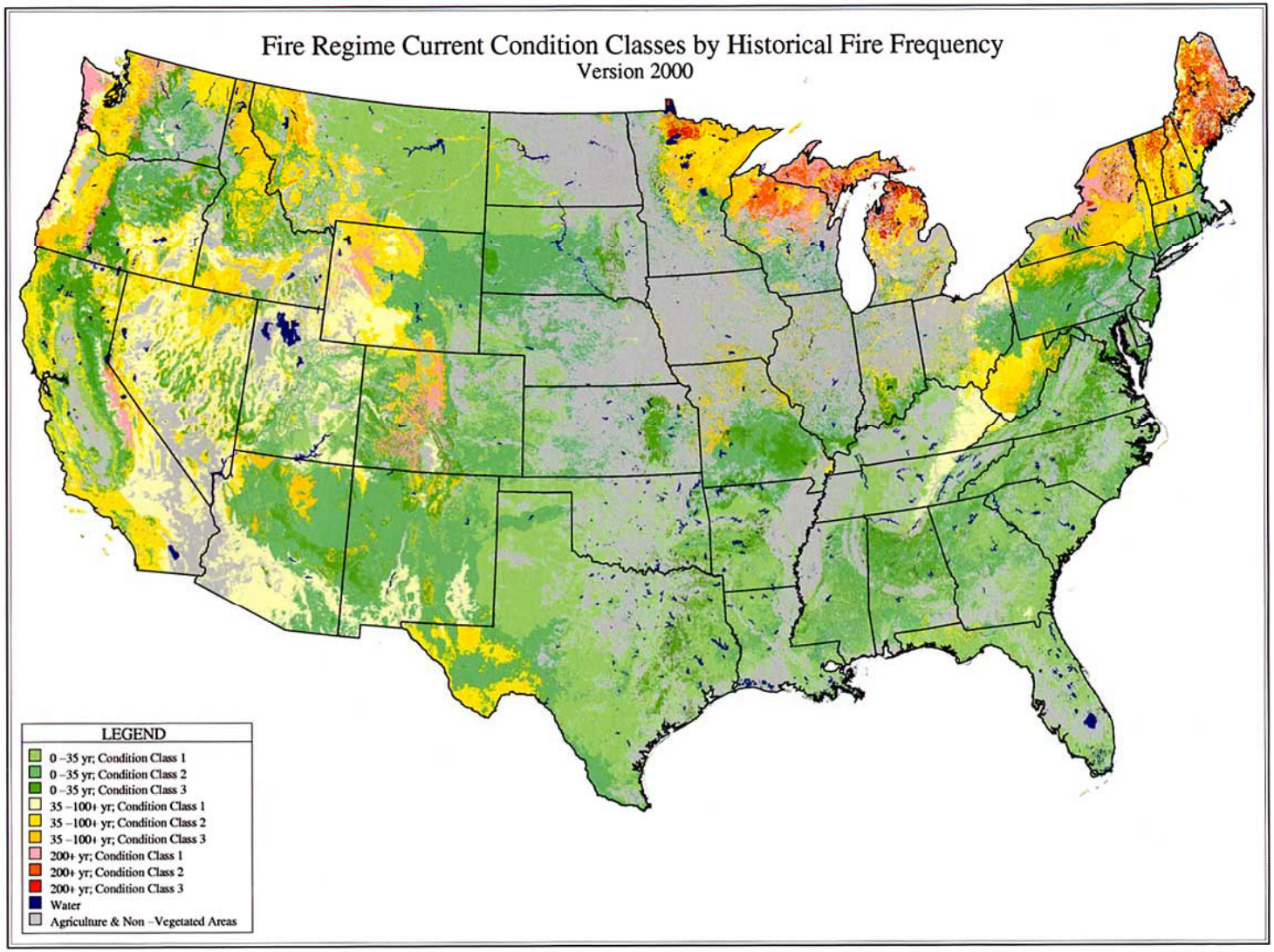


Figure 2. Comparison of the extent and duration of large infrequent disturbance by fire, flood, hurricane, tornado, and volcano.

Foster et al 1998 Ecosystems



http://www.fs.fed.us/rm/pubs/rmrs_gtr87/rmrs_gtr87_pg38.jpg

Primary Succession

- The process of biological colonization and change in systems that have:
  - no live plant material and no propagules
  - where the products of ecosystem processes are either removed or buried so that there is little or no organic matter or organisms
    - The Land is a Clean-Slate, there is no Soil.

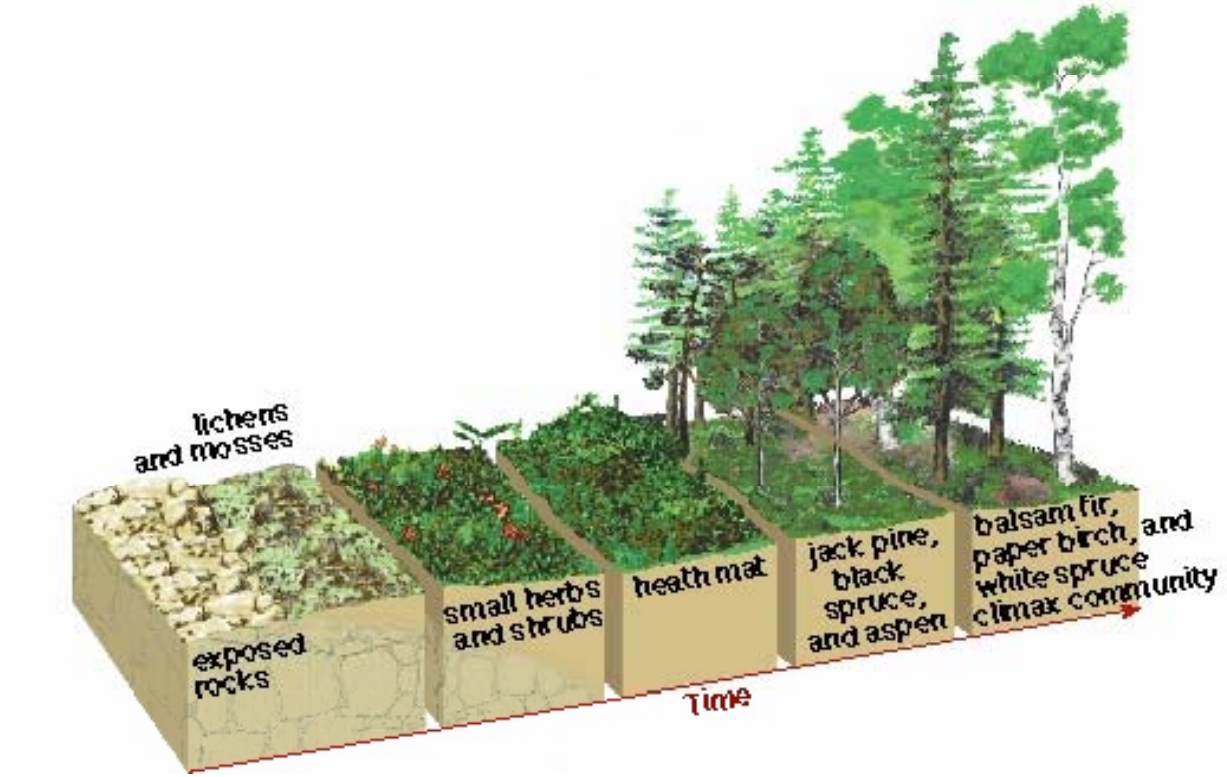
Mt St. Helens

Photo: ddb, 2002

Christmas 2004 Indian Ocean Tsunami

Photo: ddb, July, 2006, Chennai, India

Northern Example of Primary Succession

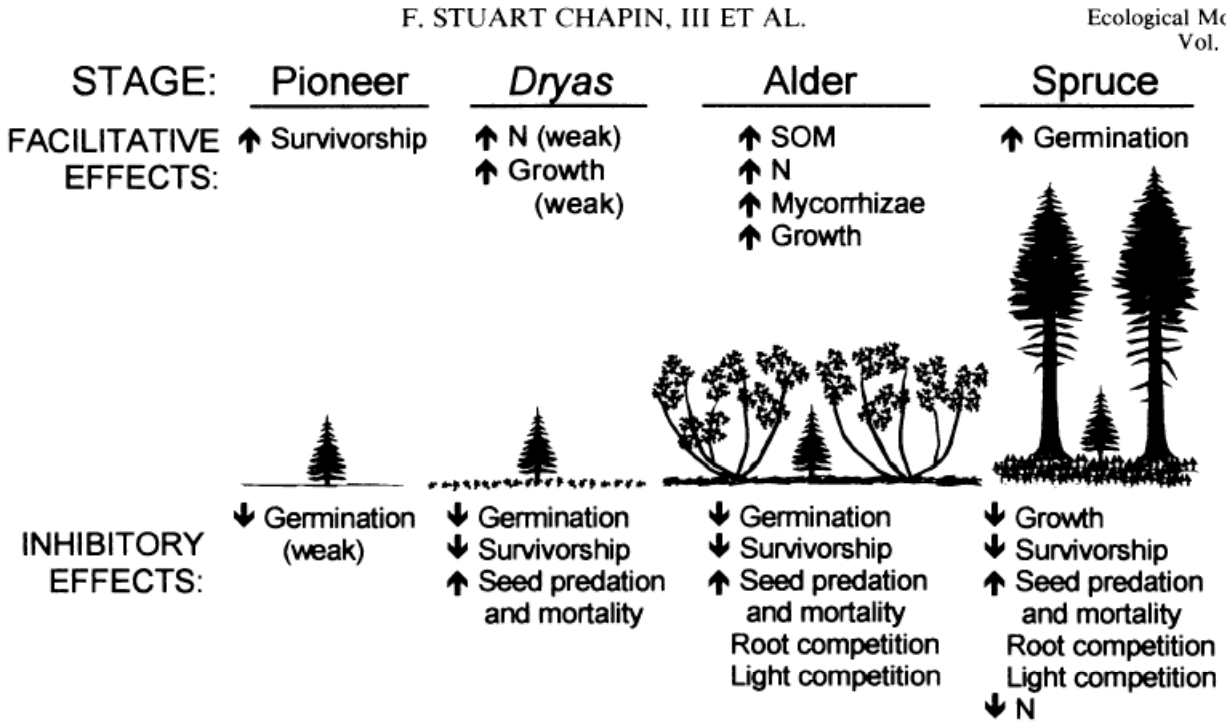


http://www.life.uiuc.edu/bio100

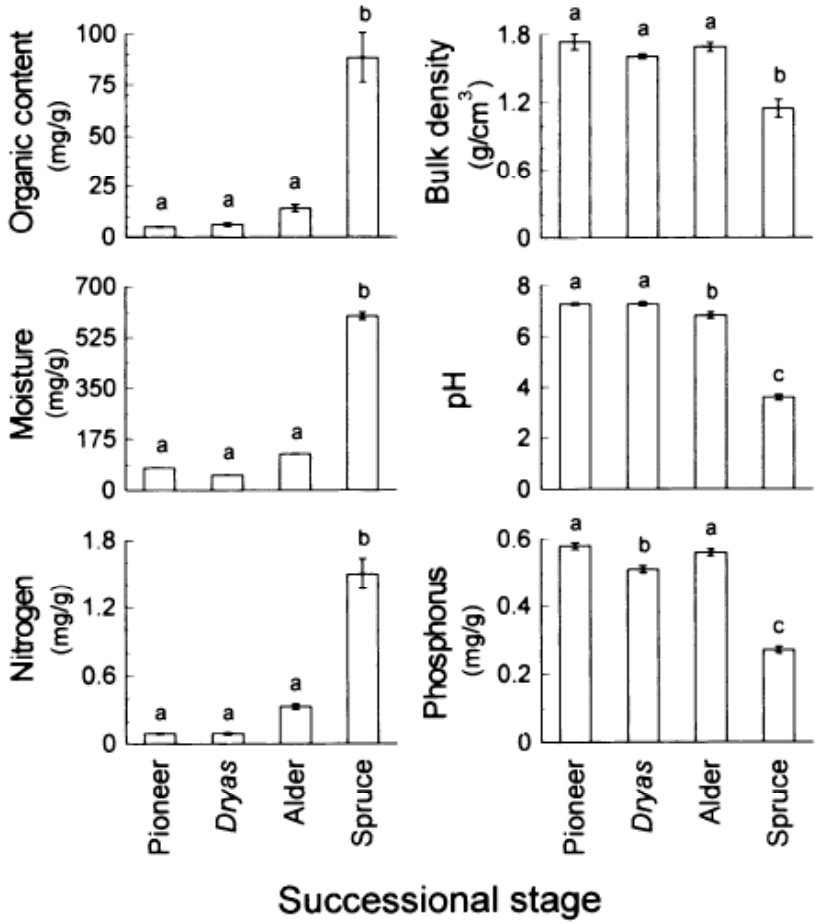
Features of Primary Succession

- Dispersal – getting to the site
  - Small seeds arrive first, wind blown
- Colonization and Recruitment
  - N Fixers dominate and facilitate the environment
  - Recruitment Success, f(soil moisture, temperature, competition (light/soil moisture), herbivory/predation)
- Establishment, Facilitation and Inhibition
  - making due with the resources you can find or make

Succession after Glacial Retreat



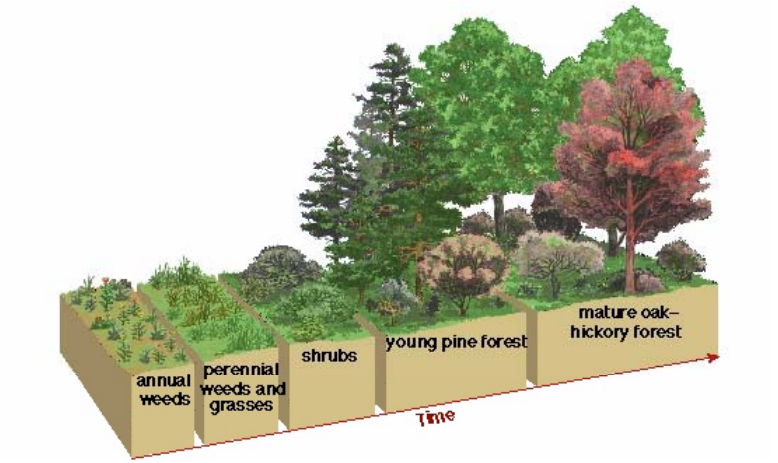
Changes in Soil Properties during 1º Succession



Chapin et al., 1994, Ecol Monograph

Secondary Succession

- Follows disturbance of an existing community that removes or damages the vegetation, but does not remove, destroy, or cover the soil.
- Starts **WITH SOIL**.
- **PIONEER PLANTS** of secondary succession start from roots or seeds remaining in the soil or from seeds carried in by wind or animals from surrounding communities.
- Faster than primary succession

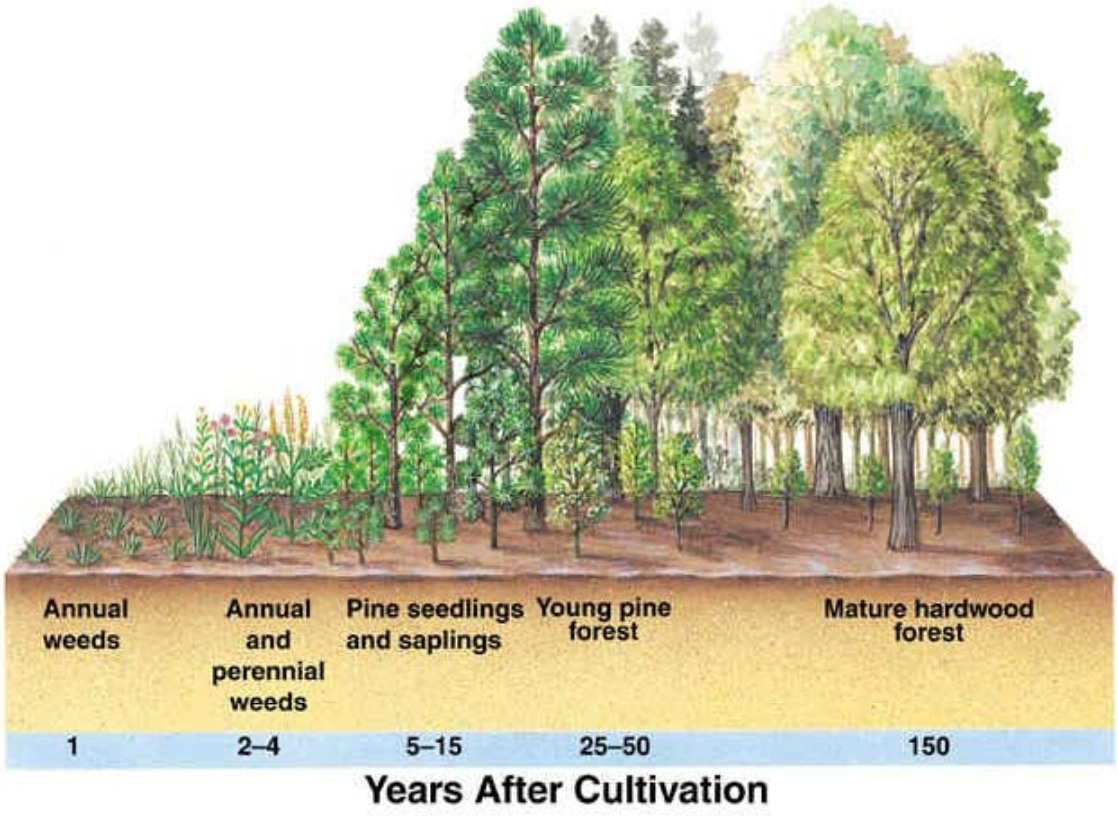


Start of Secondary Succession

Snags, after Yellowstone Forest Fire

Example of Secondary Succession

Raven/Berg, Environment, 3/e
Figure 5.17

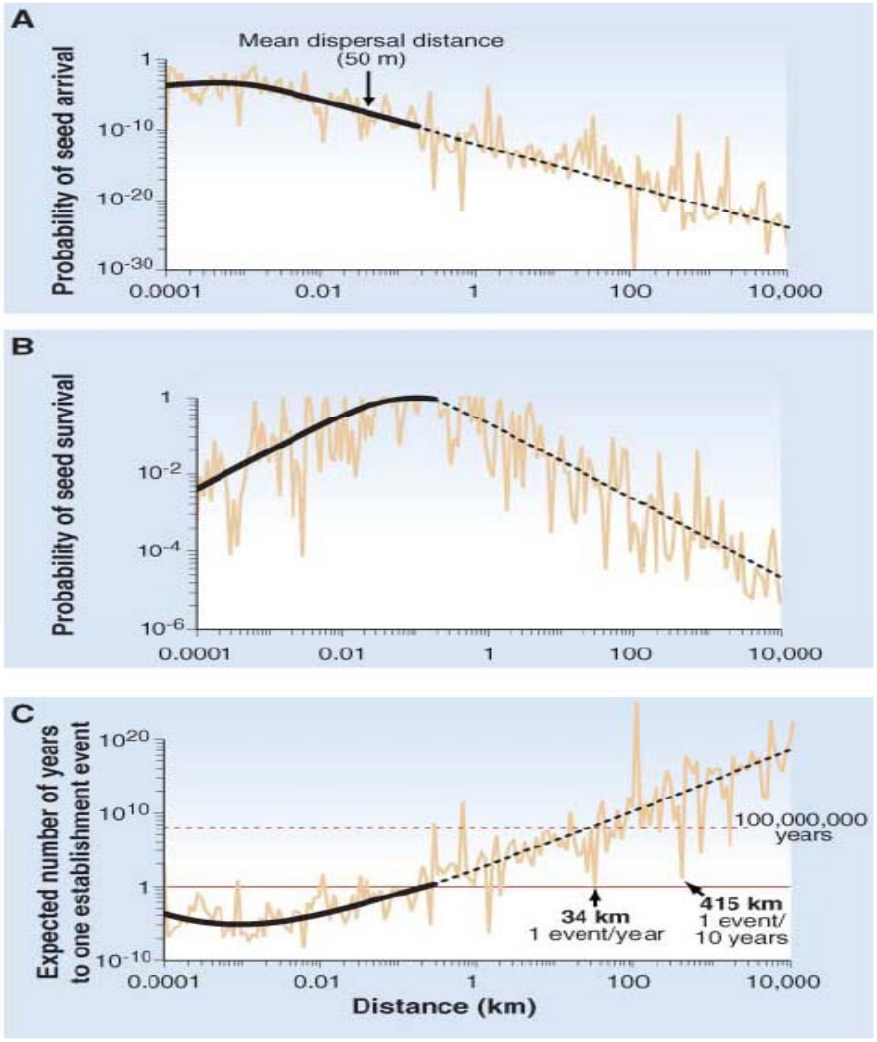


Harcourt, Inc.

Features of 2nd Succession

- Colonization
  - Sprouting from root and stems
  - Germination from soil seed bank
  - Advanced regeneration by long-lived, shade tolerant seedlings
  - Dispersal and In-fill from adjacent gaps
    - Wind blown seeds, Birds, Animals
- Facilitation
  - Hydraulic Lift
  - Shade and protection of seedlings from desiccation
- Competition
- Herbivory and Pathogens

Long Distance Dispersal of Plants



Nathan 2006, Science

Conceptual Paradigm: NEP is a function of age

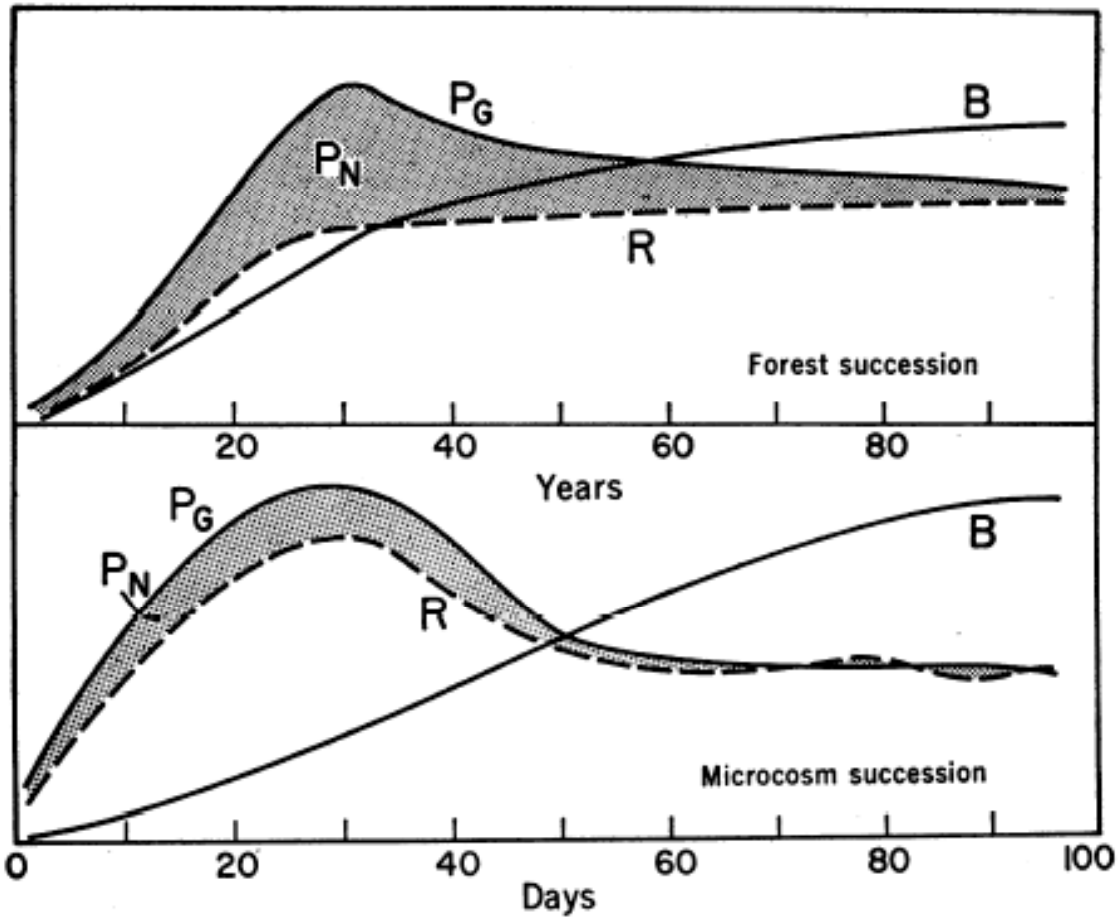
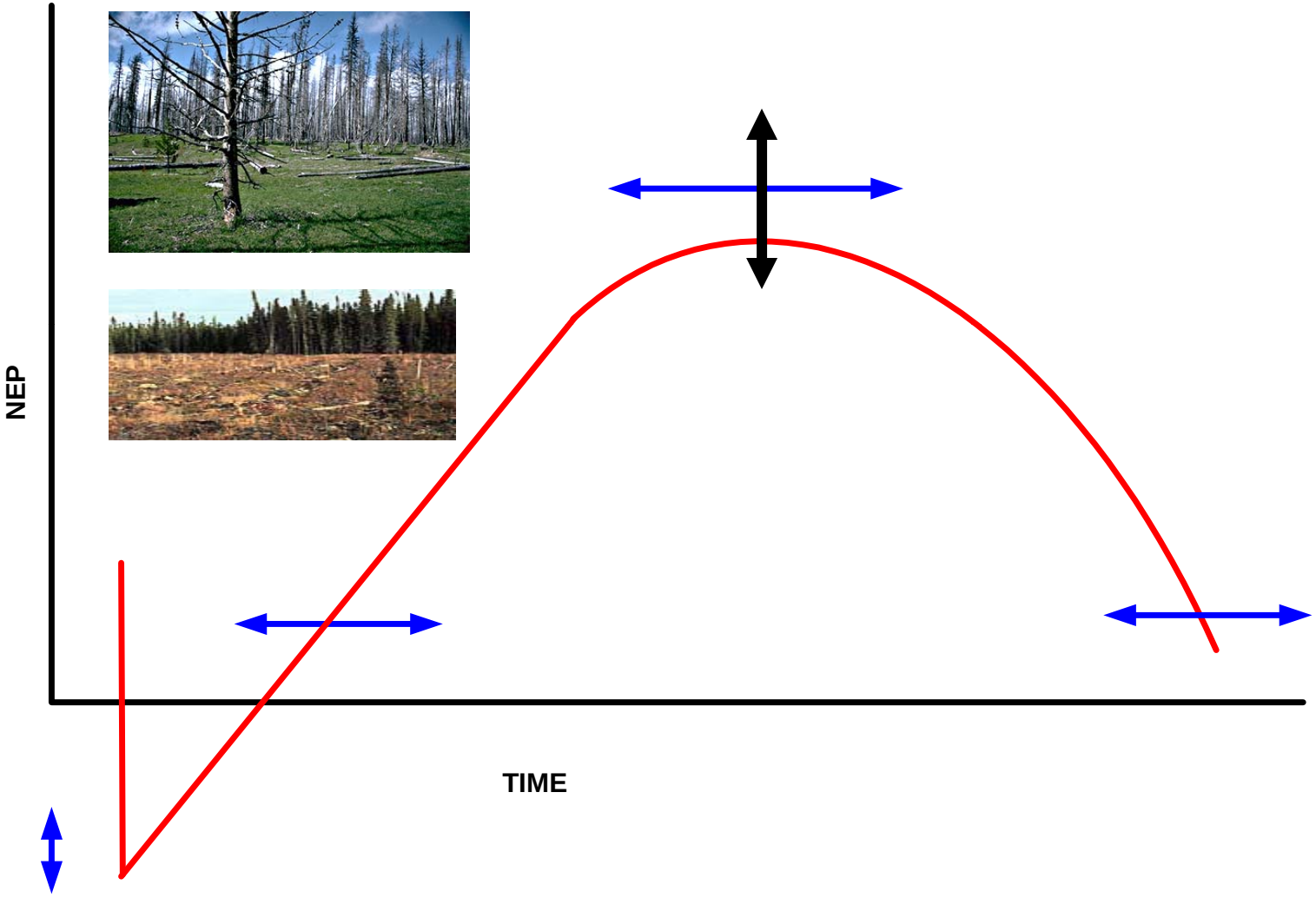


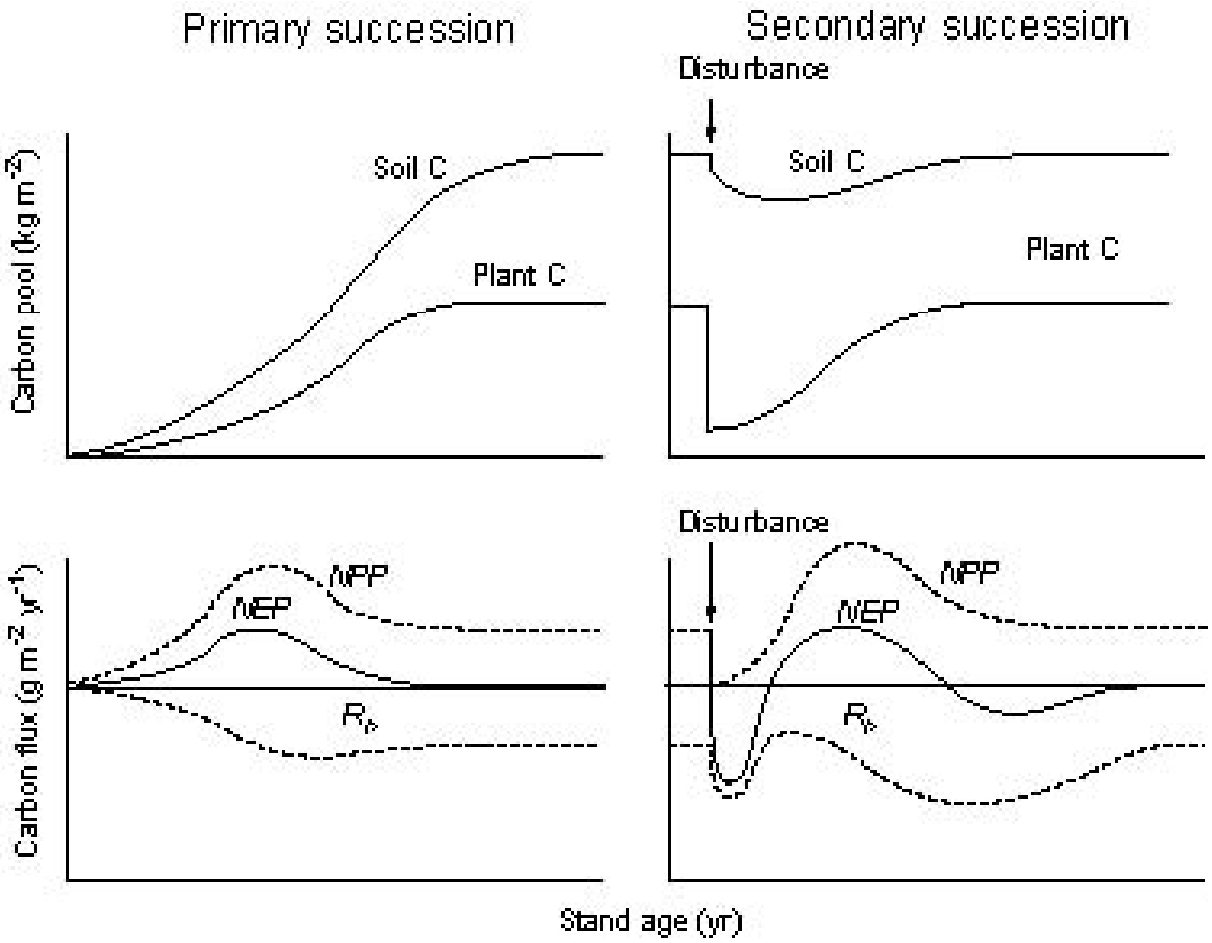
Fig. 1. Comparison of the energetics of succession in a forest and a laboratory microcosm. P_G, gross production; P_N, net production; R, total community respiration; B, total biomass.

Odum, 1969, Science

Roles of Climate, Forest Type and Succession Type on Disturbance on NEP



Stand Carbon Dynamics and Disturbance

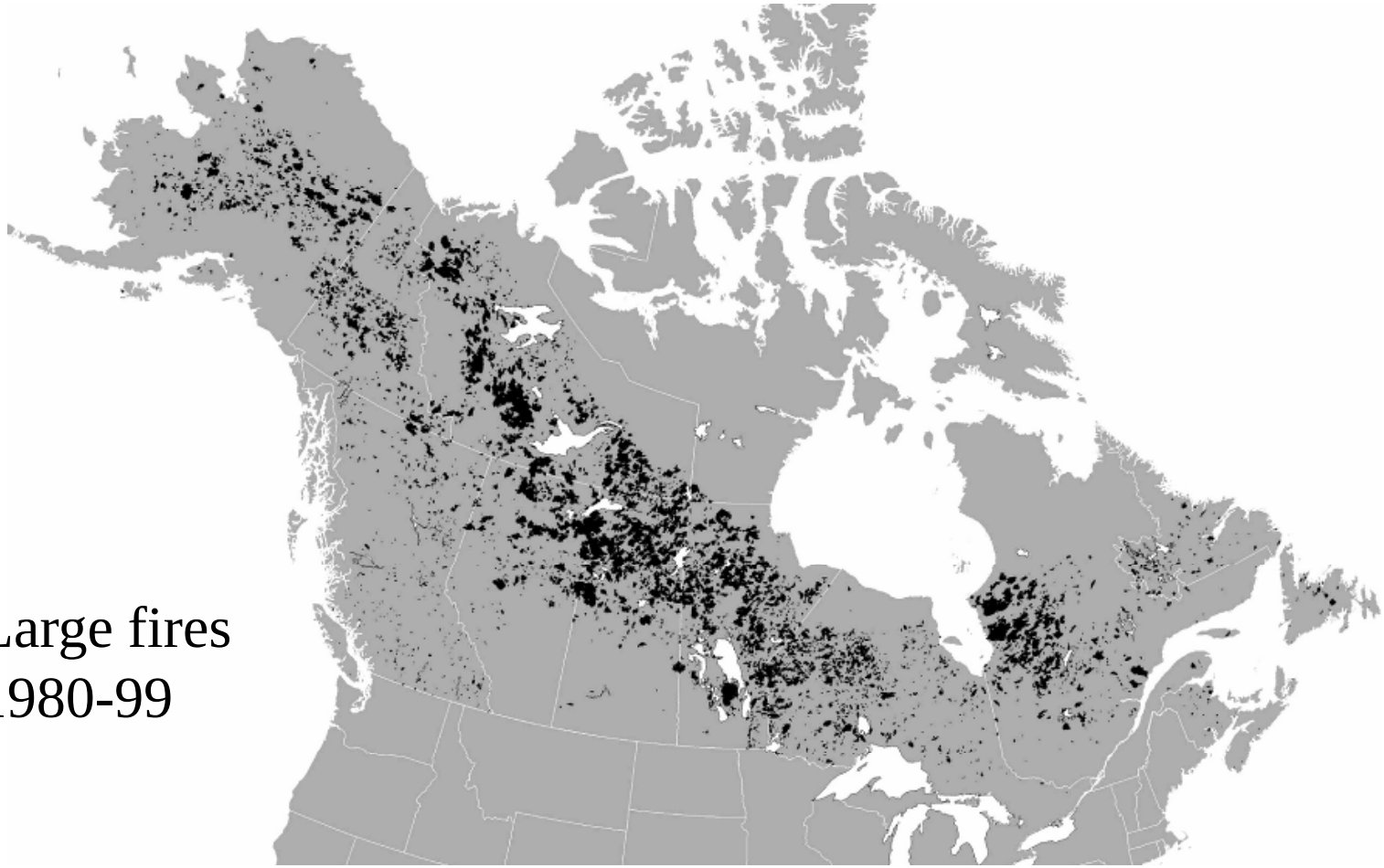


Chapin et al.

Ecosystem Dynamics, Cases

Fire
Logging
Treefall
Old Field Succession

The boreal forest is dominated by fire



Large fires
1980-99

Courtesy of Brian Amiro, Univ Manitoba

Combustion losses
CO_2, CO, CH_4

Decomposition

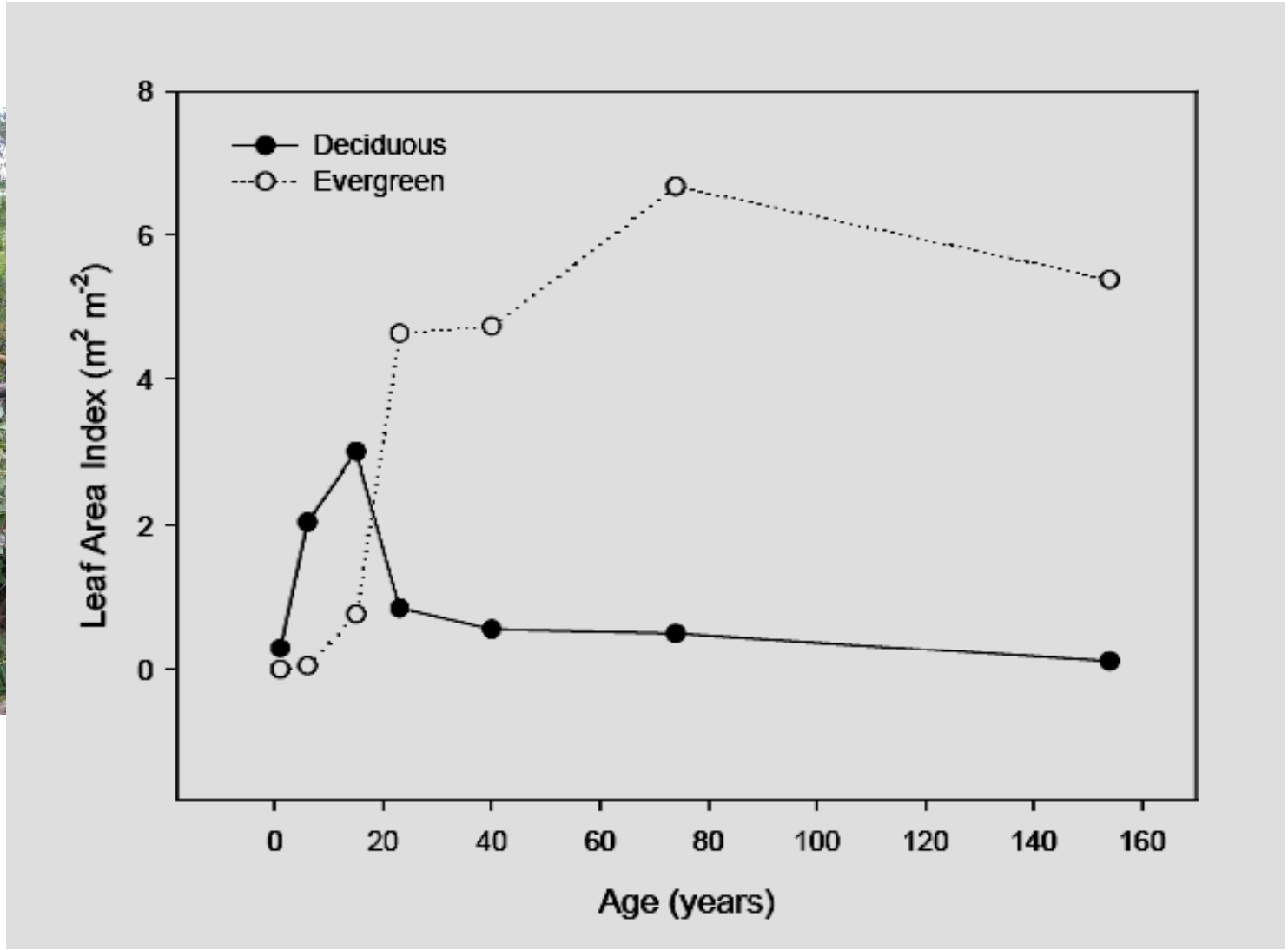
Decomposition
CWD,
regeneration

Successional
vegetation to crown
closure

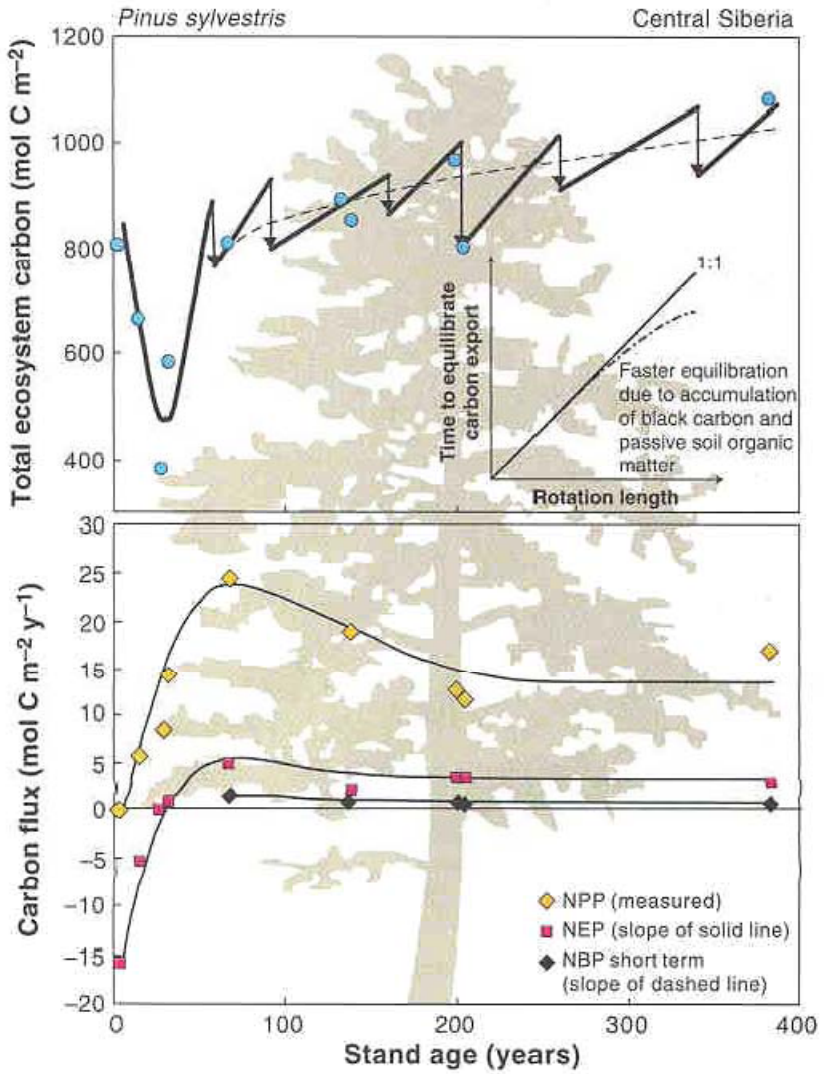
Renewed
mature
forest stand

Successional trajectory (Goulden et al. Northern Manitoba Black Spruce chronosequence)

1989 burn

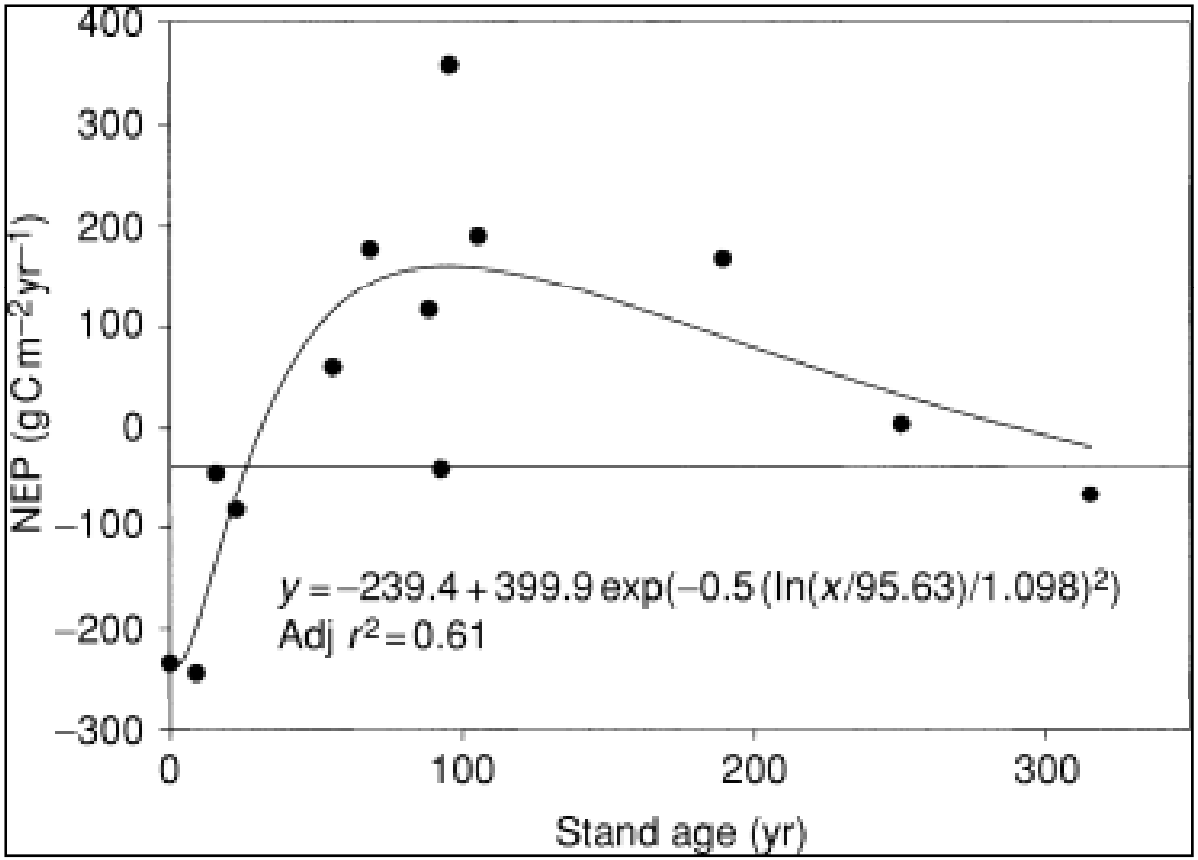


Role of Repeated Surface Fires



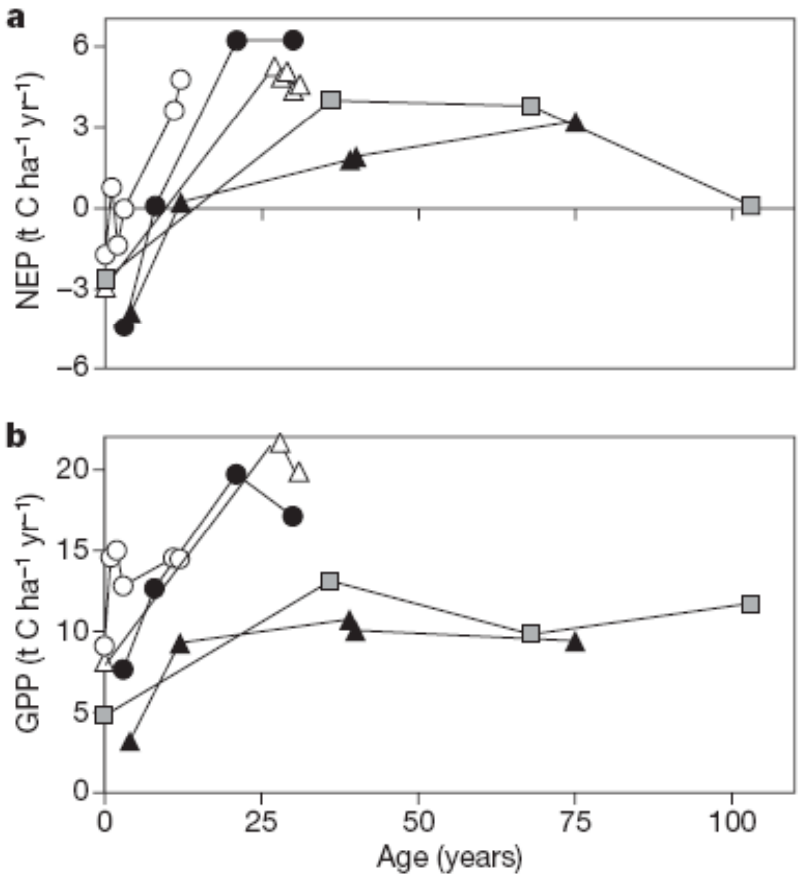
Schulze et al 2000, Science

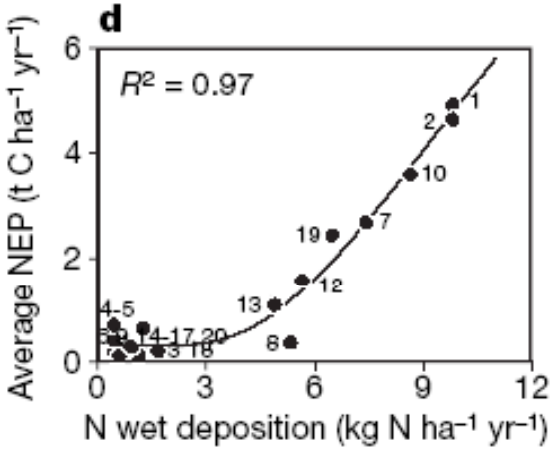
Effects of Stand Age: After Logging



Law et al. 2003 Global Change Biology

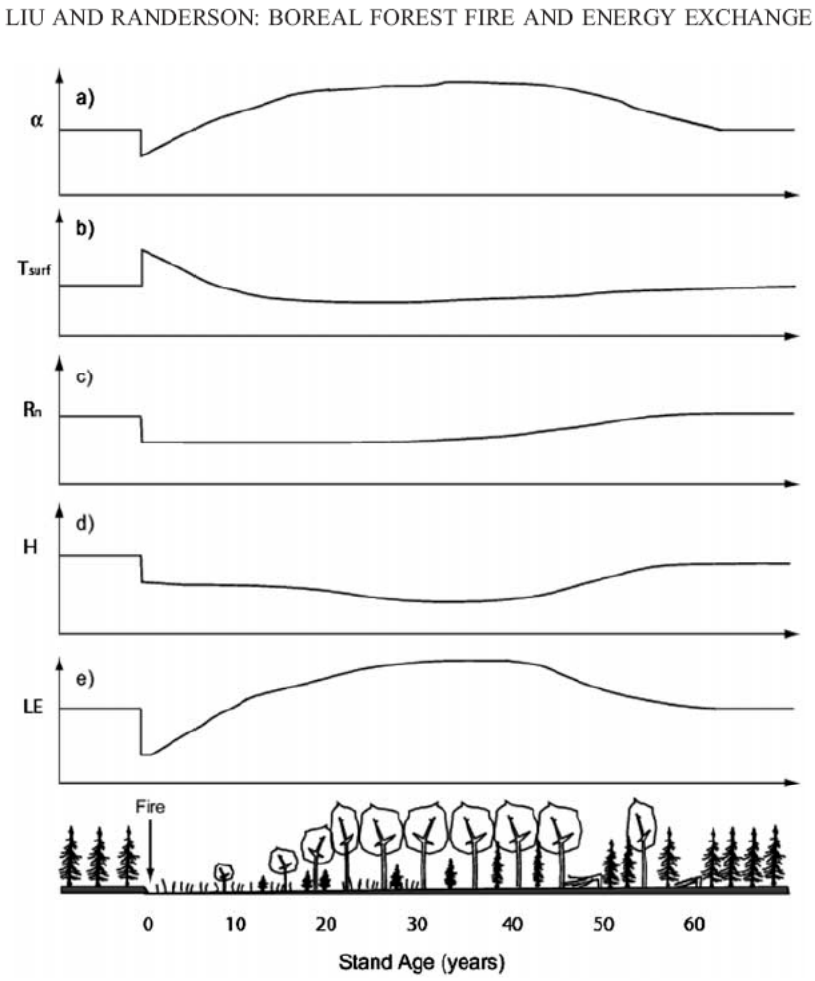
Role of N deposition on NEP and GPP Dynamics across Europe



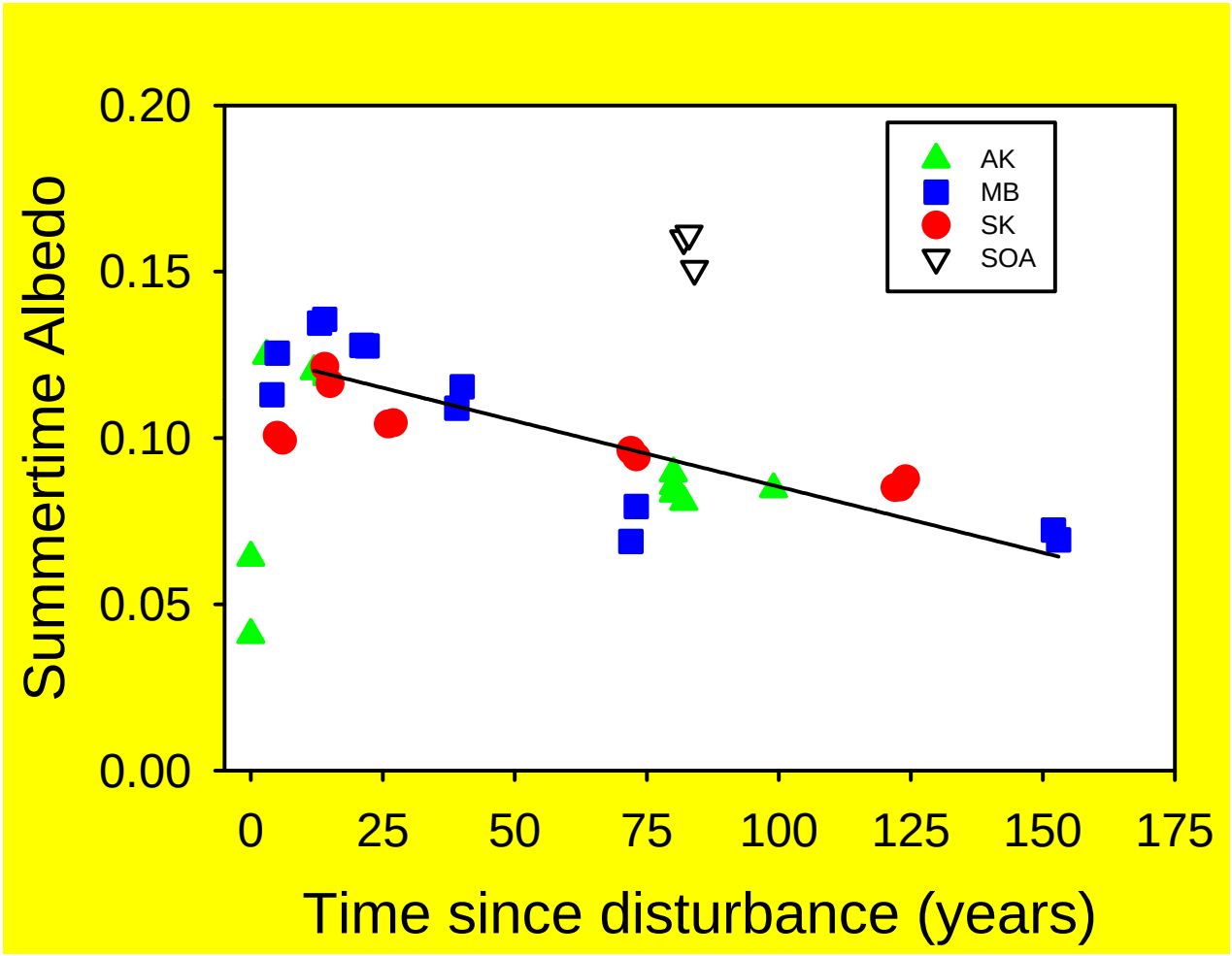


Magnani et al 2007 Nature

Energy Exchange and Stand Age



Boreal Forest



Amiro et al., 2006 AgForMet

Ave ET along a chronosequence, 2001-2005

- Abandoned old agricultural Field. 562 mm
- Successional *Pinus taeda*, 658 mm
- Old hardwood forest, 617 mm

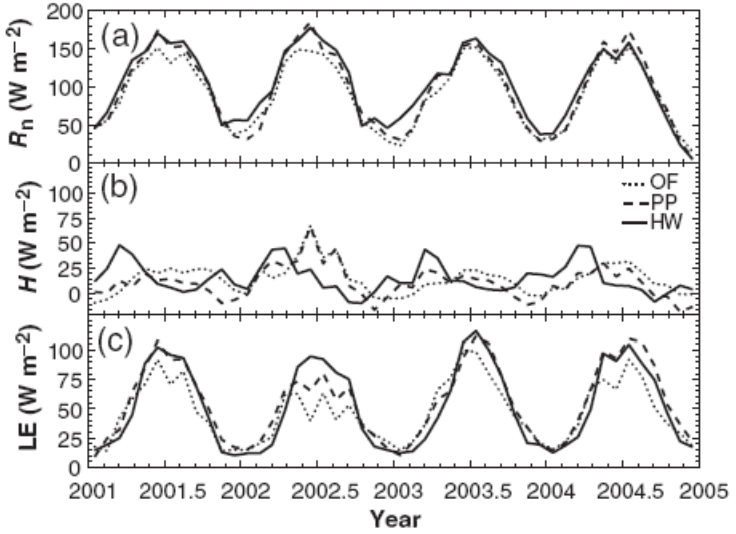
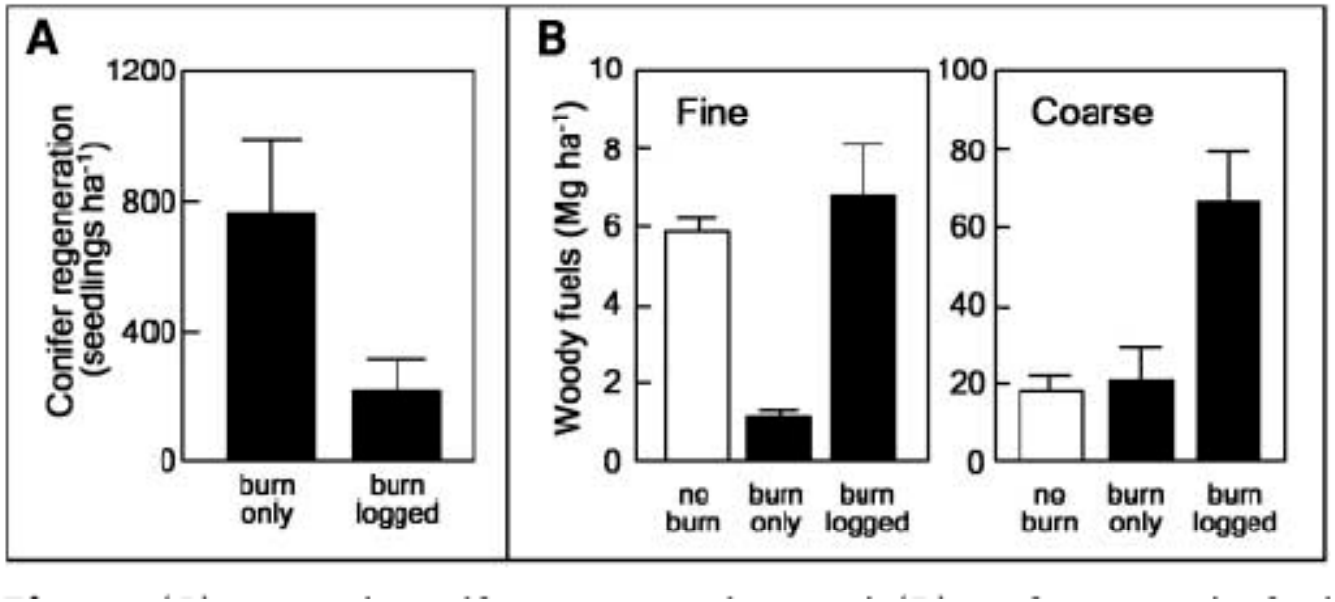


Fig. 4 Monthly average net radiation (R_n a), latent heat (LE, b), and sensible heat (H, c) fluxes for the three study ecosystems.

Stoy et al. 2006 GCB

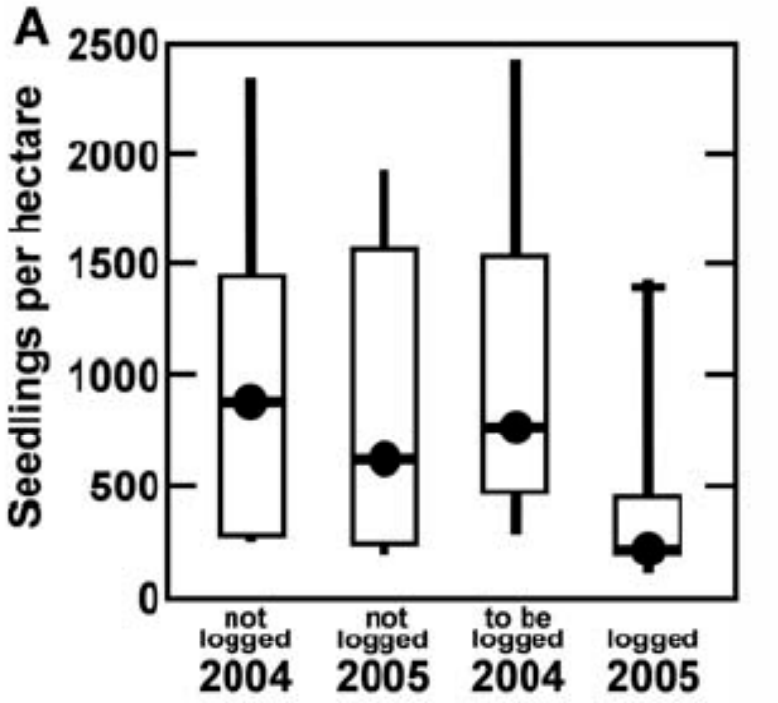
Regeneration after Fire: Salvage Log or Not???



Post-Fire Logging can be counter-productive to the goals of forest regeneration and fuel reduction by removing naturally seeded conifers and increase surface fuel load

Donato et al 2005 Science

Regeneration after Fire



Donato et al Science, 2005

Oak Recruitment/Colonization in California

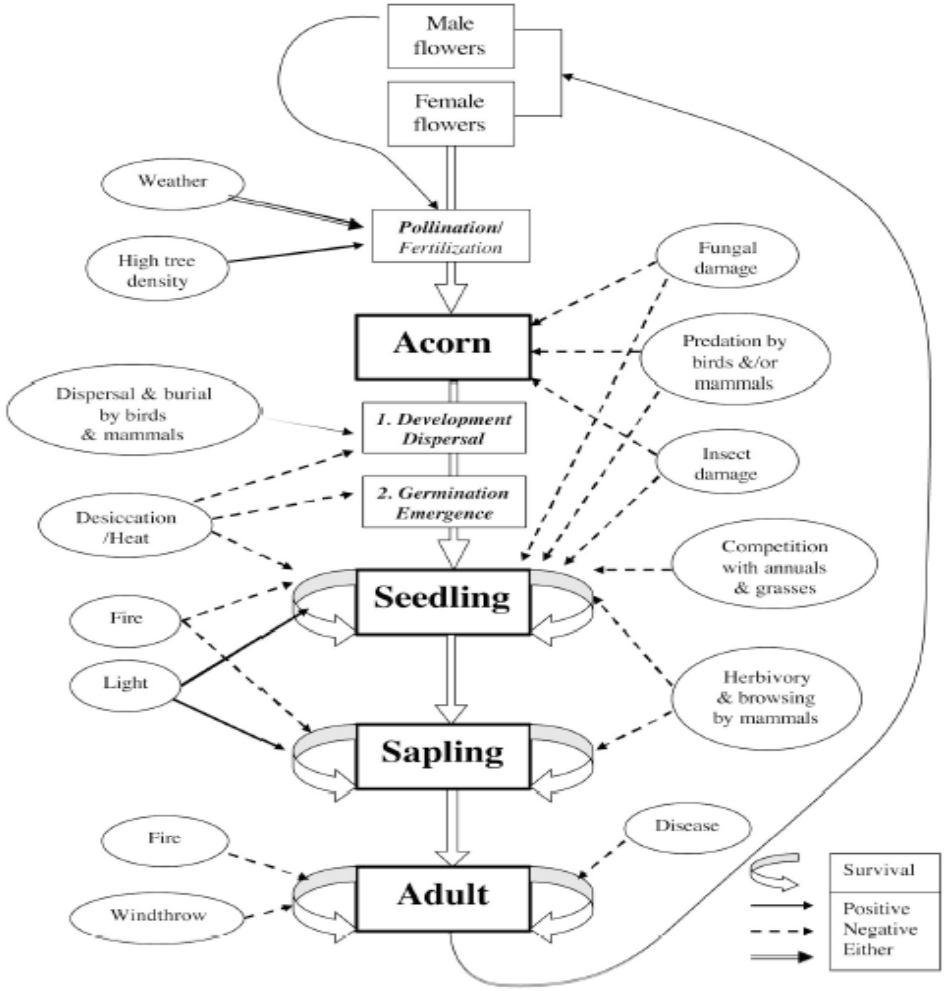
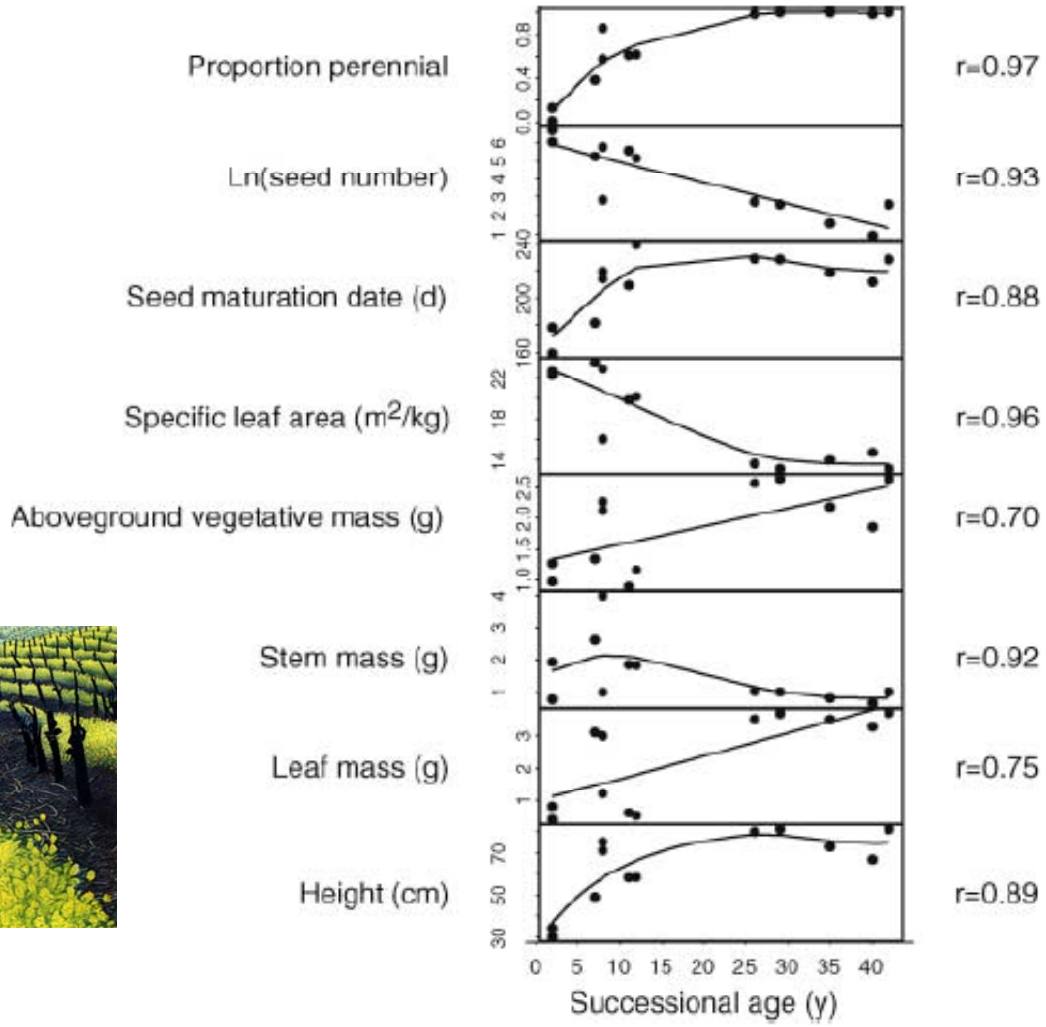


FIGURE 4. CONCEPTUAL MODEL OF THE LIFE-HISTORY STAGES OF OAKS

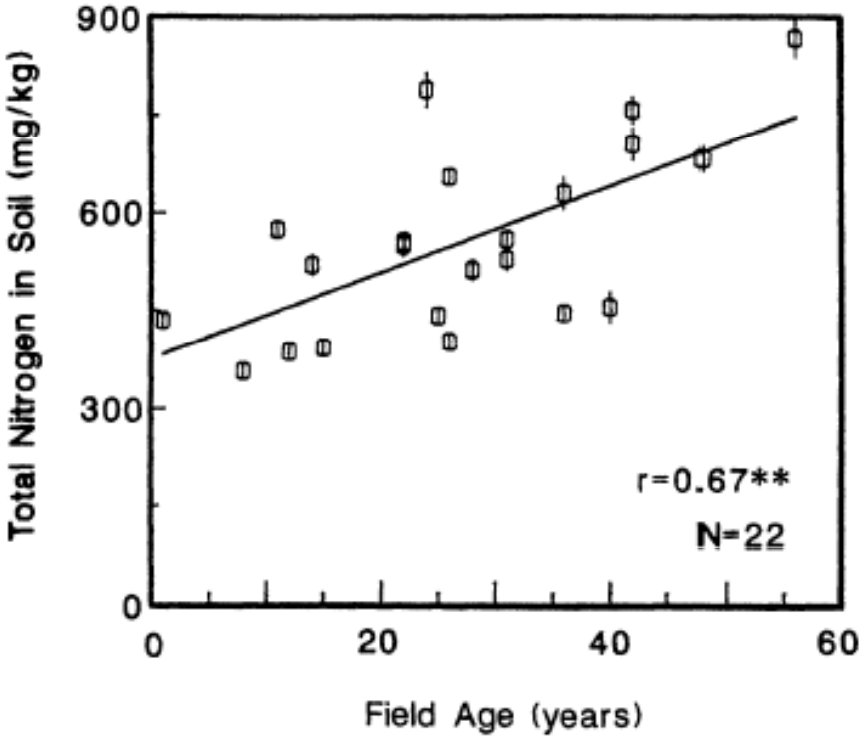
Tyler et al 2006 Quart Rev Biol

Old-Field Succession
42 year Chronosequence of abandoned vineyards in France



Shipley et al 2006 Science

Succession and Resources



Soil N plays a role in composition, species richness and successional dynamics

Tilman 1987 Ecol Monograph

Community Energetics

	Developmental Stage	Mature Stage
Gross Production/Respiration	>1	~1
Gross Production/Standing Biomass	high	low
Yield	High	Low
Food Chains	Linear, grazing	Web-like

Odum, 1969

Community Structure

	Developmental Stage	Mature Stage
Total Organic Matter	Small	Large
Inorganic Nutrients	extrabiotic	Intra biotic
Species Diversity	Low	High
Growth Form	Rapid growth, r selection	Feedback control, K selection
Niche Specialization	Broad	Narrow
Life Cycle	Short, Simple	Long, Complex

Odum, 1969

Ecological Succession - Overview

- From the Latin, *succedere*, to follow after
- "Change in the species composition of a community over time." (Lewis, *Life* glossary)
- **Primary Succession** follows the formation of new land surfaces consisting of rock, lava, volcanic ash, sand, clay, or some other exclusively **mineral substrate**.
  - This means that there is **NO SOIL** present.
  - Soil is a mixture of mineral material, decaying organic material, and living organisms.
- **Secondary Succession** follows the destruction or partial destruction of the vegetation area by some sort of disturbance, like a fire, windstorm, or flood that leaves the soil intact.
- **Pioneer species** initiate recovery following disturbance in both primary AND secondary successions
- Pioneers "pave the way" for later colonists by altering the biotic and abiotic environment:
  - soil stabilization
  - soil nutrient enrichment (organic matter and biological nitrogen fixation)
  - increased moisture holding capacity
  - light availability
  - temperature
  - exposure to wind
- Species composition tends towards a **Climax Community** through succession.
- The climax community describes an end product of succession that persists until disturbed by environmental change.
- Succession occurs at large scales involving higher plants and animals, but may involve microbial communities on a smaller scale.

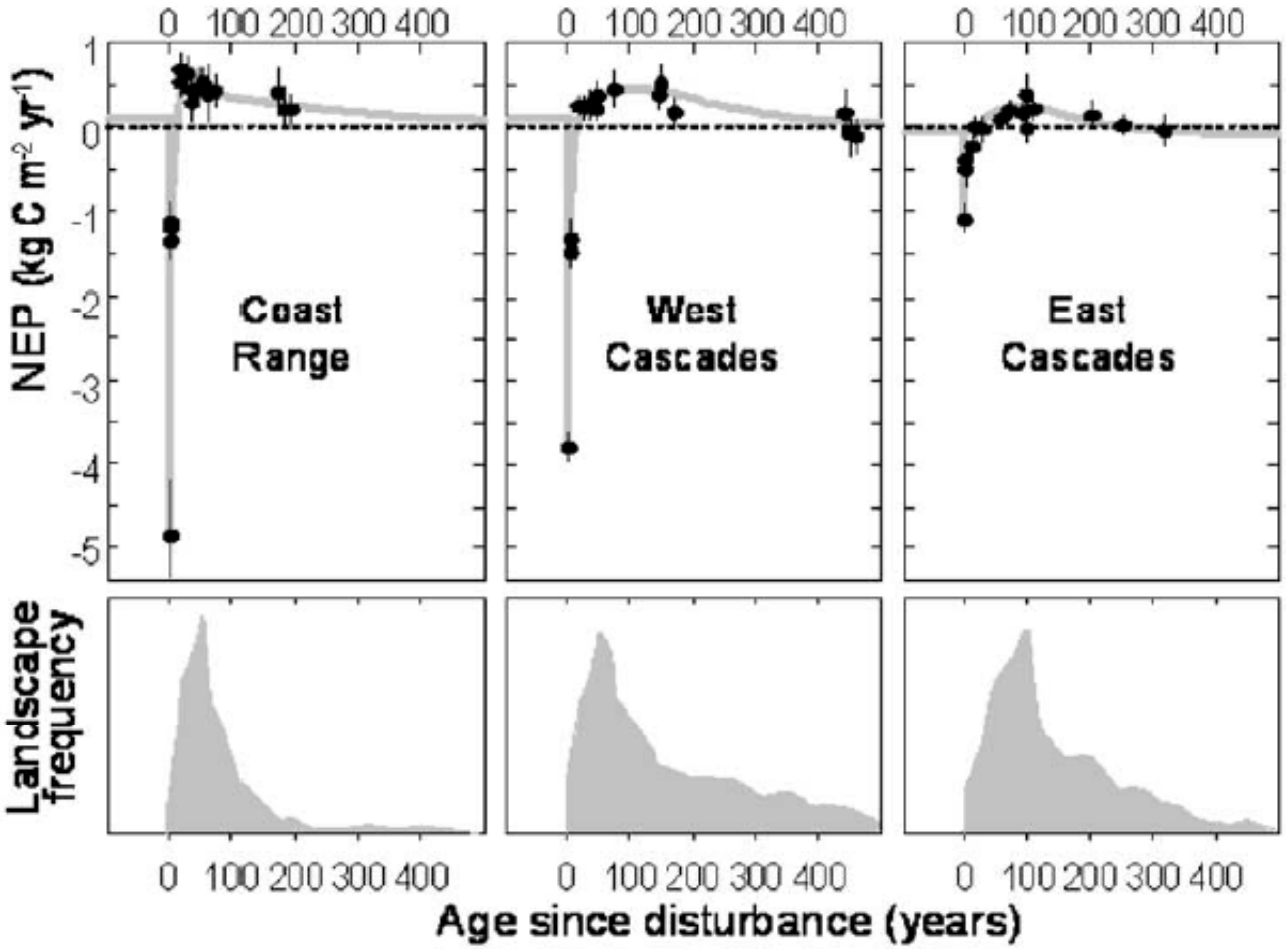
Points to Ponder

- Do Ecosystems Reach Climax states?
  - Does the frequency of Disturbance prevent climax states from Occurring?
  - When? Where??
- How does the disturbance induced time series of NEP, GPP and Reco vary with logging vs fire?
- What are the Pros and Cons of Facilitation?
  - e.g. recruitment of ponderosa pine seedlings under ceanothus or bitterbrush and effects on water, light and nutrients

Table 1. A tabular model of ecological succession: trends to be expected in the development of ecosystems.

Ecosystem attributes	Developmental stages	Mature stages
Community energetics		
1. Gross production/community respiration (P/R ratio)	Greater or less than 1	Approaches 1
2. Gross production/standing crop biomass (P/B ratio)	High	Low
3. Biomass supported/unit energy flow (B/E ratio)	Low	High
4. Net community production (yield)	High	Low
5. Food chains	Linear, predominantly grazing	Weblike, predominantly detritus
Community structure		
6. Total organic matter	Small	Large
7. Inorganic nutrients	Extrabiotic	Intrabiotic
8. Species diversity—variety component	Low	High
9. Species diversity—equitability component	Low	High
10. Biochemical diversity	Low	High
11. Stratification and spatial heterogeneity (pattern diversity)	Poorly organized	Well-organized
Life history		
12. Niche specialization	Broad	Narrow
13. Size of organism	Small	Large
14. Life cycles	Short, simple	Long, complex
Nutrient cycling		
15. Mineral cycles	Open	Closed
16. Nutrient exchange rate, between organisms and environment	Rapid	Slow
17. Role of detritus in nutrient regeneration	Unimportant	Important
Selection pressure		
18. Growth form	For rapid growth ("r-selection")	For feedback control ("K-selection")
19. Production	Quantity	Quality
Overall homeostasis		
20. Internal symbiosis	Undeveloped	Developed
21. Nutrient conservation	Poor	Good
22. Stability (resistance to external perturbations)	Poor	Good
23. Entropy	High	Low
24. Information	Low	High

Odum, 1969


0 100 200 300 400
1
0
-1
-2
-3
-4
-5
NEP (kg C m-2 yr-1)
Coast Range
West Cascades
East Cascades
Landscape frequency
Age since disturbance (years)