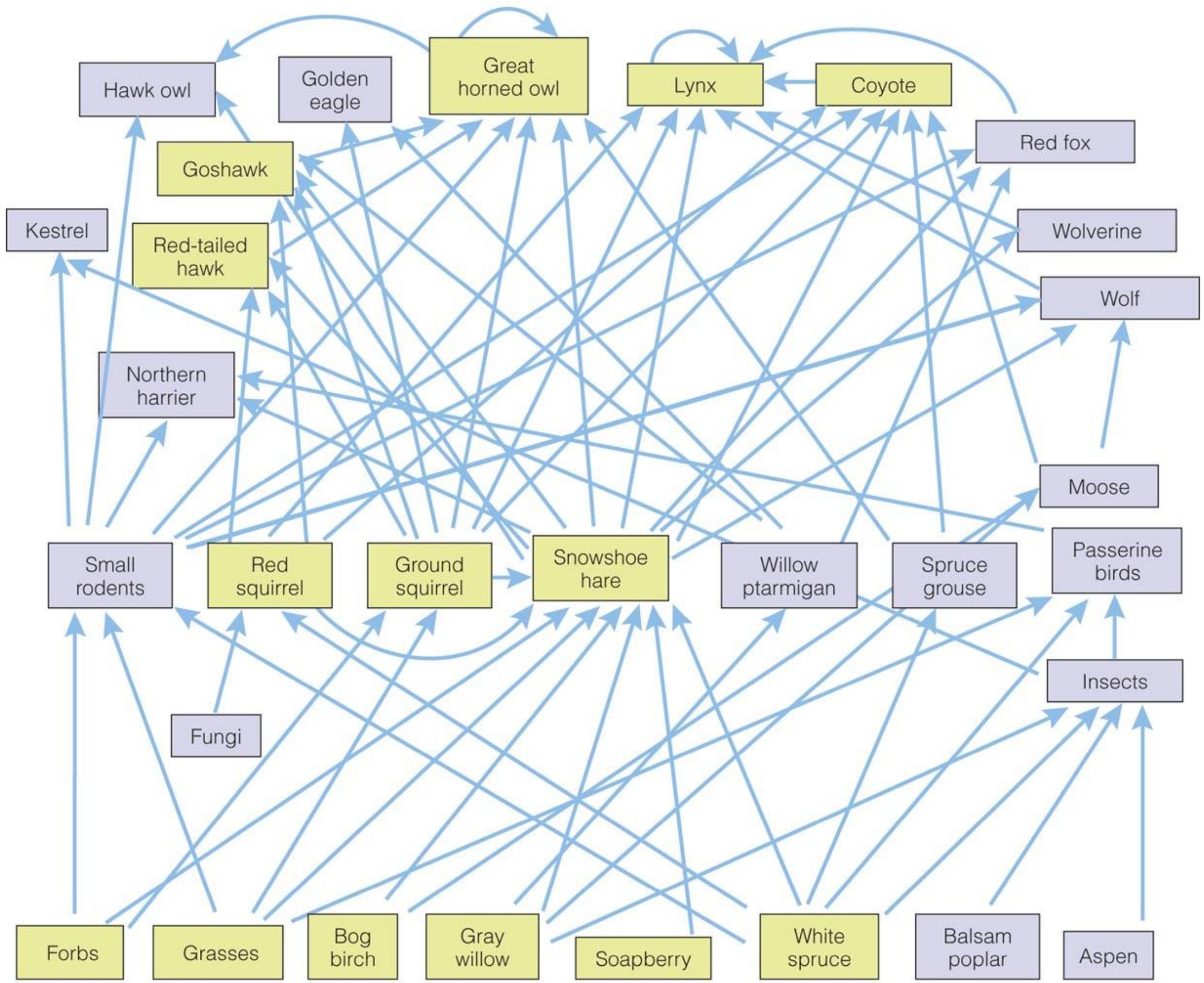
BIOL 410 Population and Community Ecology

Community stability and dynamics

Species interactions, community dynamics and **stability**



Stability and the diversity of ecosystems

- Are diverse ecosystems more productive?

- Are diverse ecosystem less likely to be invaded by non-native species?

- Are diverse ecosystems more resistant to environmental change?

- Are diverse ecosystems more resilient to environmental change?

Ecosystem function

- Ecosystem functioning can encompass a variety of phenomena
  - Ecosystem properties
    - Size of compartments
      - Pools of materials such as carbon and organic matter
      - Rates of processes: fluxes of materials and energy among compartments
  - Ecosystem goods
    - Ecosystem properties that have direct market values
      - Food, construction materials, tourism, recreation
  - Ecosystem services
    - Properties of ecosystems that directly or indirectly benefit human endeavours
      - Maintaining hydrological cycles, regulating climate, cleansing air and water, pollination, soil genesis, storage of nutrients

- Ecosystem functions of interest, and appropriate metrics, need to be defined prior to evaluating how species diversity, community structure, functional diversity, etc. affect them

Ecosystem functioning and functional traits

- Traits that characterize the ecological function of a species are termed functional traits

  - Species that share similar suits of traits are often categorized together into functional groups (similar to guild)

  - E.g Brussard et al (1997) identified four main functions of soil biota
    - Decomposition of organic matter
    - Nutrient cycling
    - Bioturbation
    - Suppression of soil borne diseases and pests

  - Not all soil species perform each of these functions
  - Therefore, categorized them into functional groups
    - Microsymbionts
    - Decomposers
    - Elemental transformers
    - Soil ecosystem engineers
    - Soil-borne pests and pathogens
    - microregulators

Functional traits, functional types, and functional diversity

- Functional traits
  - Traits that influence ecosystem properties or species responses to environmental conditions

  - Species often grouped together according to functional traits to understand general mechanism or to make studies of complex systems more tractable

- Functional group
  - Set of species that have similar effects on a specific ecosystem process or similar response to environmental conditions
  - Similar to guild concept (animal community ecology), and niche concept
  - Defining functional types can be difficult

Problems defining functional types

1. Organism effects on ecosystem properties generally fall along a continuous gradient, not into discreet groups

2. Traits that determine how species respond to environmental change will often differ from those that determine how the species affects ecosystem properties.

3. Functional types identified for a specific ecosystem property are not necessarily relevant to other properties

Functional groups

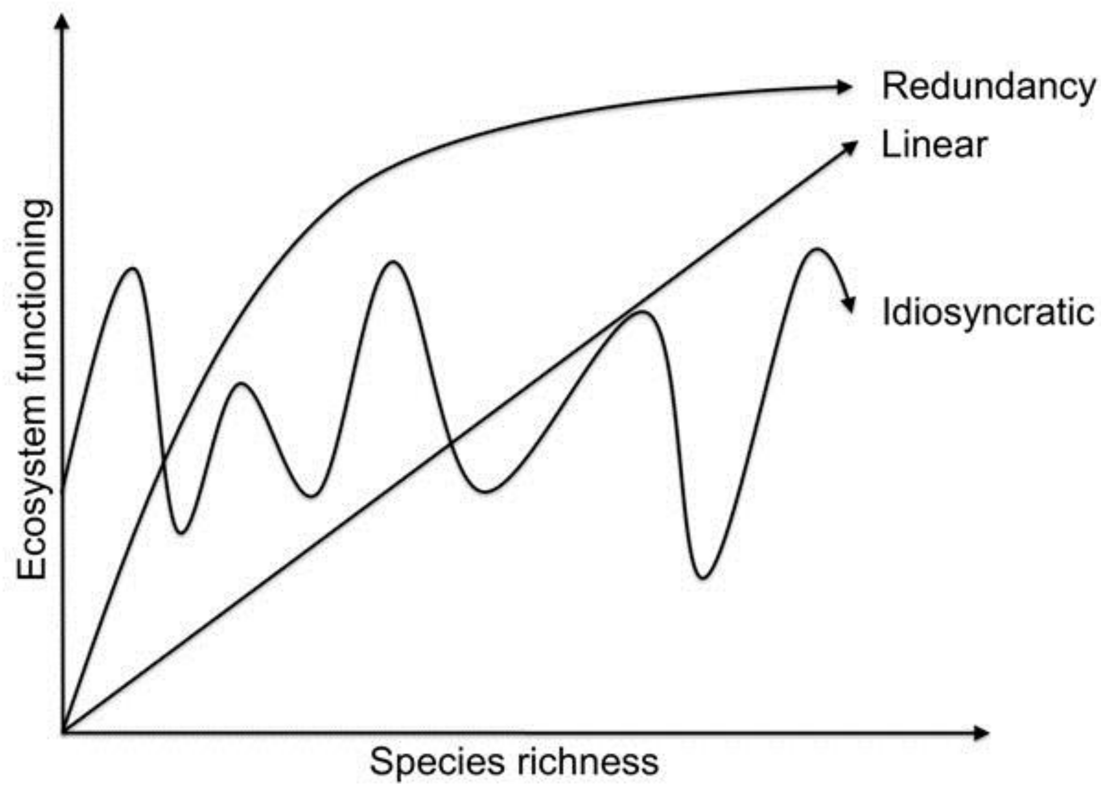
- Examples of functional groupings
  - Feeding level
  - Exploitation of common resources (guilds)
  - Photosynthetic pathway
  - Shade tolerance
  - Life history

- Groups of functionally equivalent species
- With “functionally equivalent” being **operationally** defined by the ecosystem property being measured

- Multitrophic systems
  - E.g. containing autotrophs, herbivores and/or predators
  - Functional groups may be operationally defined as trophic groups

How does species diversity and functional group diversity impact ecosystem functioning?

Potential positive relationships between species diversity and ecosystem functioning

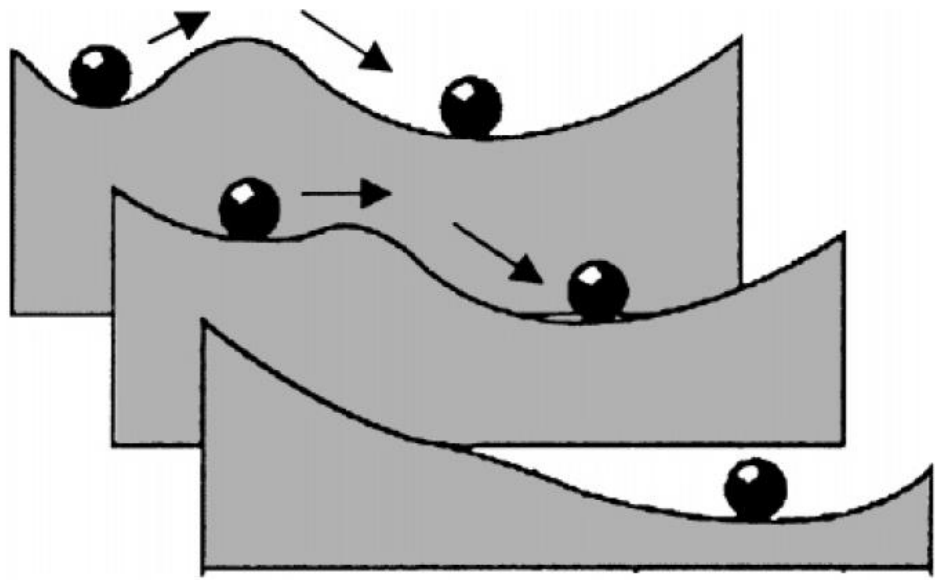


- Redundancy
  - New species only have a positive effect if function is not already found in community
- Linear
  - Addition of any new species increases functioning
- Idiosyncratic
  - Species differ in their ability to increase functioning

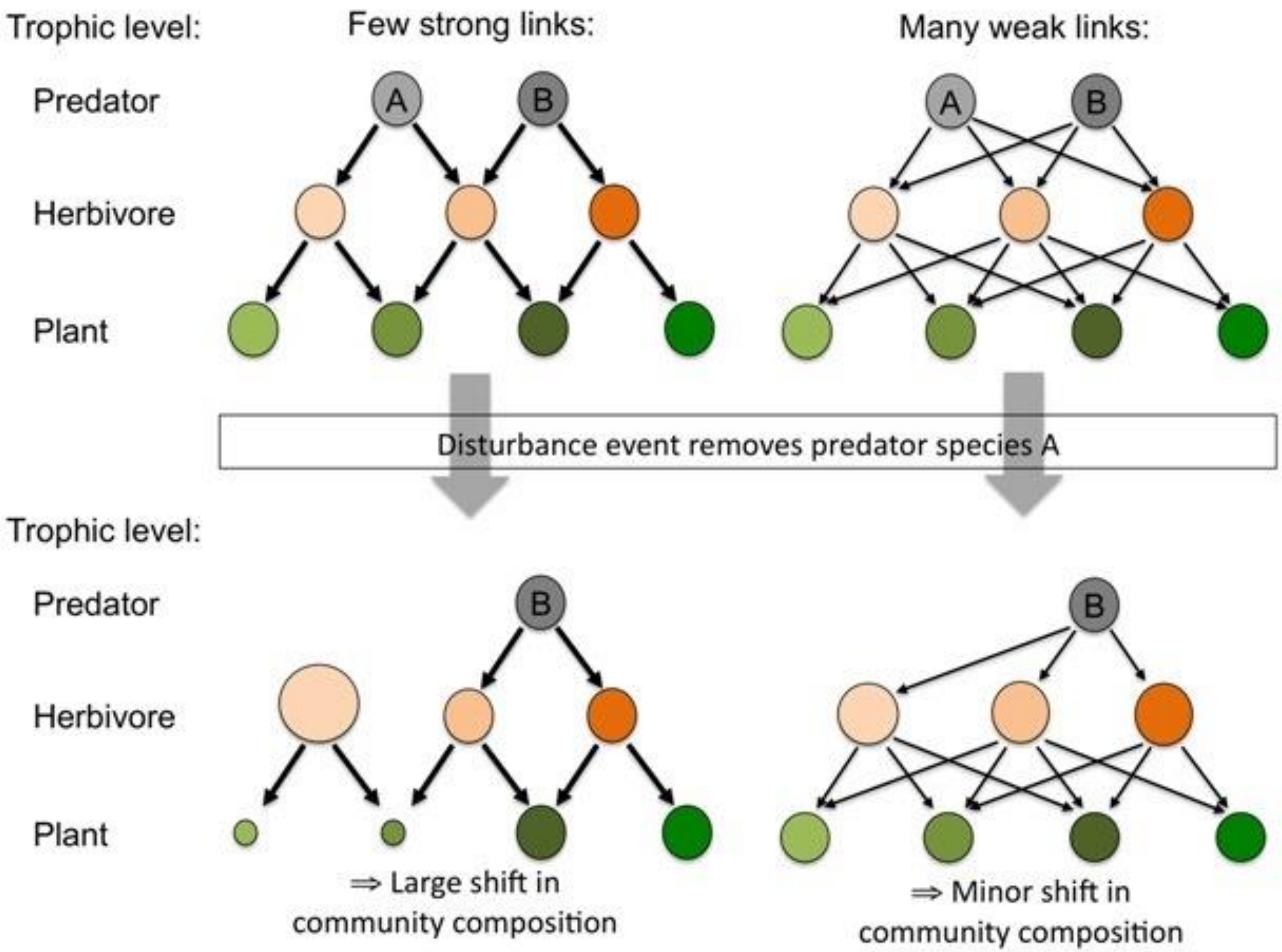
Increased functioning ~ increased stability

Ecosystem stability

- Heuristic of ecosystem stability
  - Stable ecological states (stability domain)
    - Alternate stable states may exist
      - Grass-dominated to woody-dominated semi-arid rangelands
  - Resistance
  - Resilience
    - Engineering resilience (slope surrounding stability domain)
    - Ecological resilience (width of stability domain)



Interaction number, strength and community stability



Ecosystem reliability

- Does biodiversity represent a form of biological insurance against the loss of selected species?

- Ecosystem resistance and resilience can be hard to measure
- “Ecosystem reliability”
  - Will a system provide a consistent level of performance over a given time unit?

Ecosystem reliability

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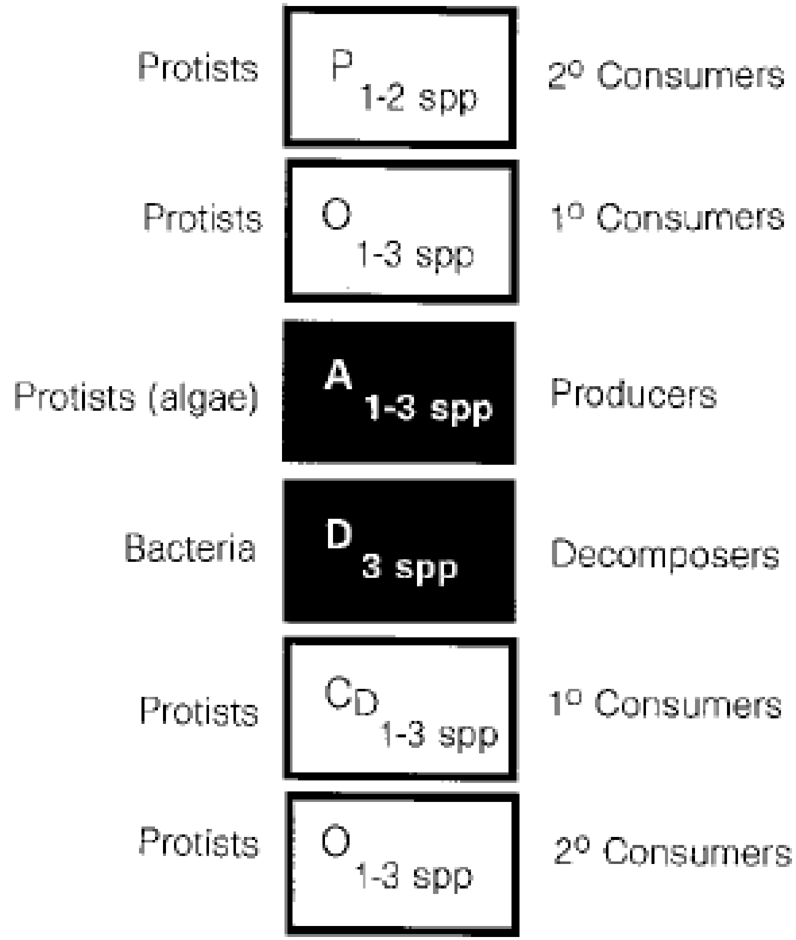
Biodiversity enhances ecosystem reliability

Shahid Naeem & Shibin Li

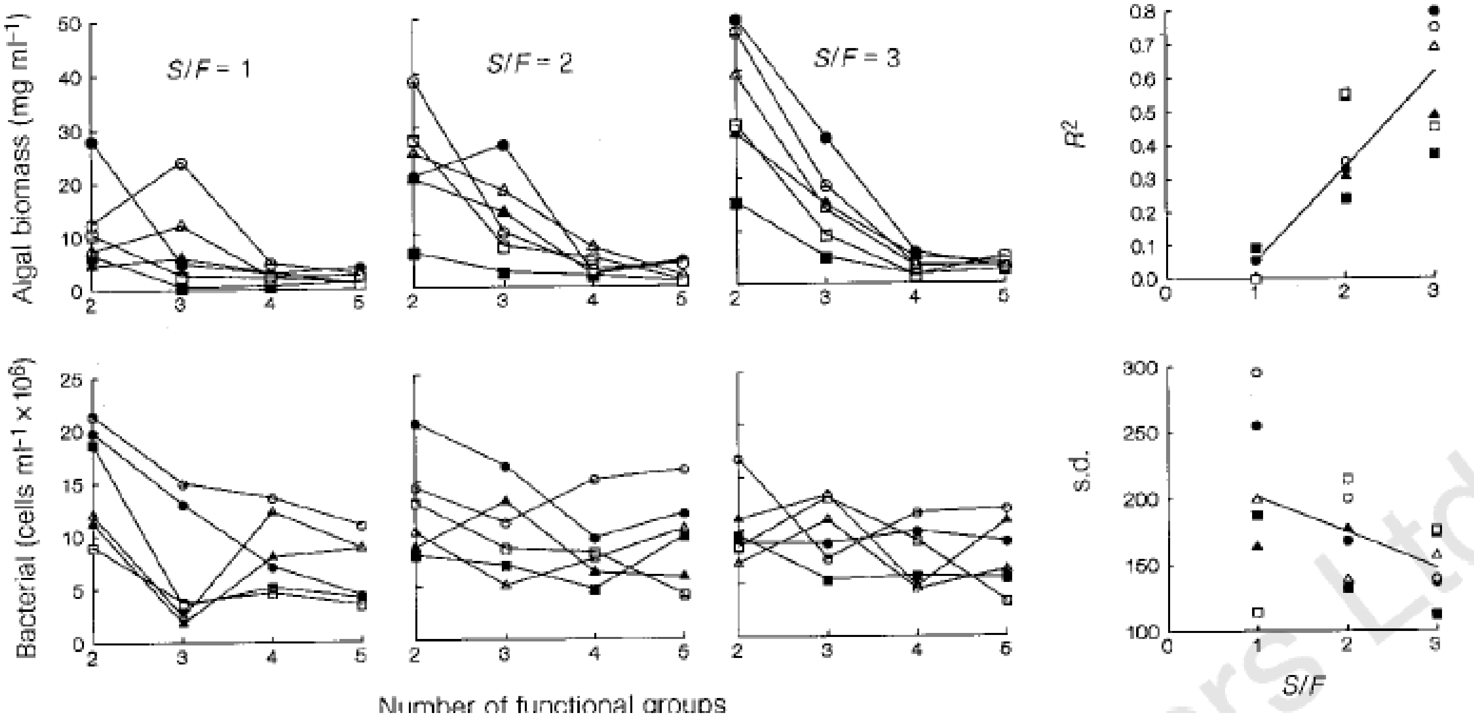
- Empirical evidence that biological diversity increases ecosystem reliability is rare
- Experiment where number of species per functional group is varied
  - Microcosm experiment using protists and bacteria
- Ask question: are communities with more species per functional group more "reliable"
  - Consistent in biomass and density
  - Ecosystem property



Ecosystem reliability

Biodiversity enhances ecosystem reliability

Shahid Naeem & Shibin Li



Autotroph biomass becomes increasingly predictable as S/F increases

Variation in bacteria density declines with increasing S/F

- Support for the biological insurance hypothesis for biodiversity
- Ecological basis for biological insurance is compensatory growth

Diversity and invasion resistance

Species Diversity and Invasion Resistance in a Marine Ecosystem

John J. Stachowicz,[1*] Robert B. Whitlatch,[1] Richard W. Osman[2]

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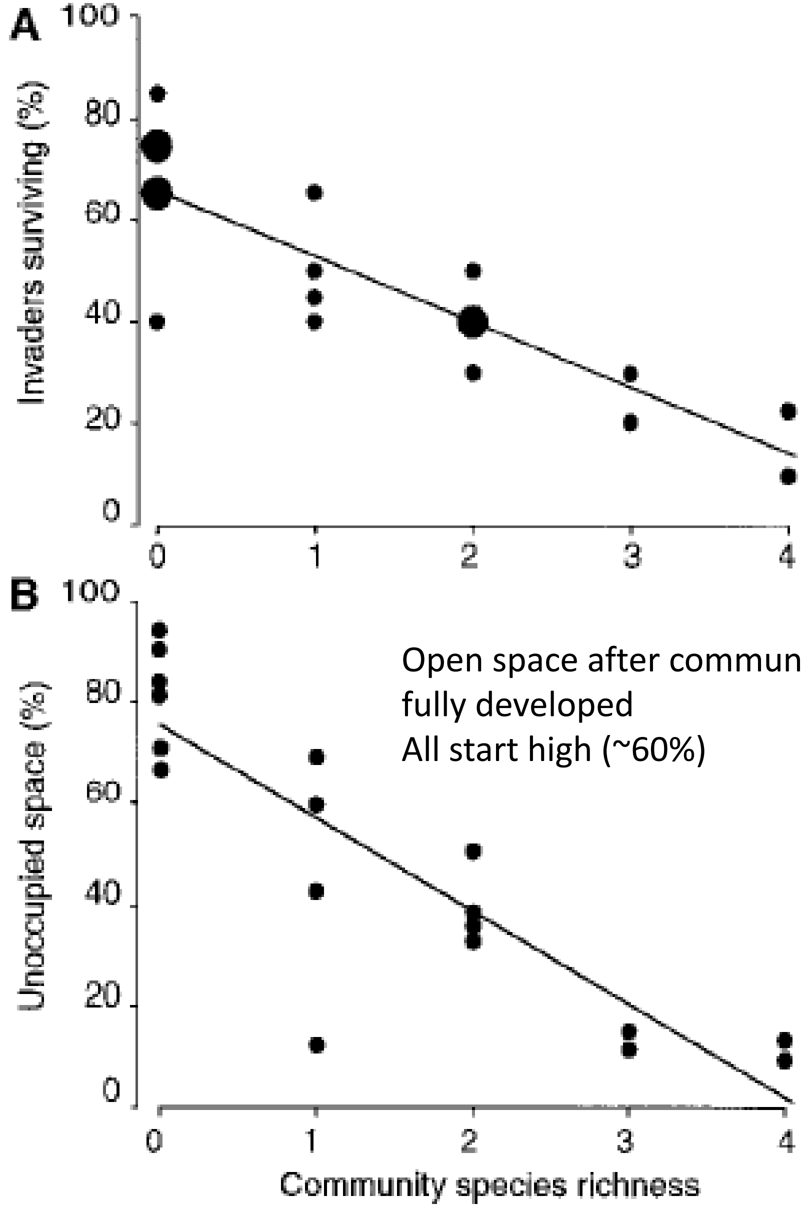


Open space after community fully developed
All start high (~60%)

Community structure and dynamics

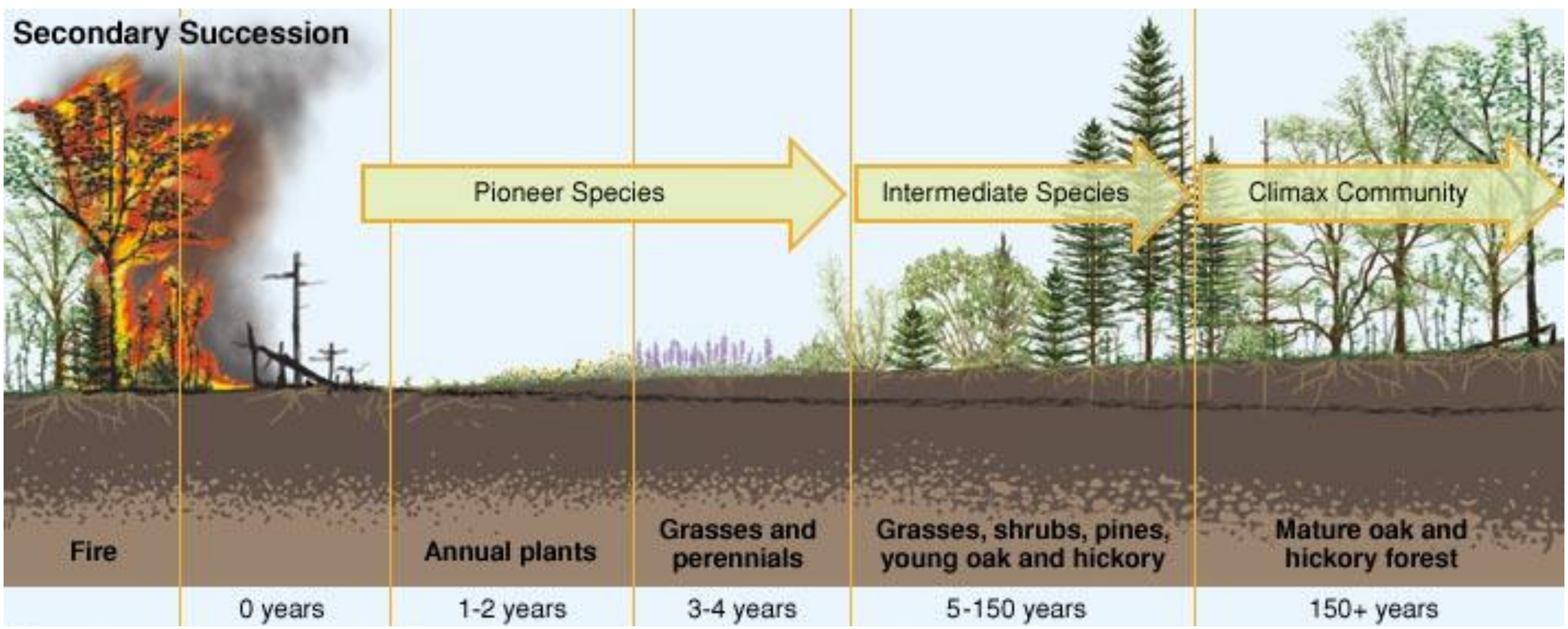
Communities are not static

Communities change through time

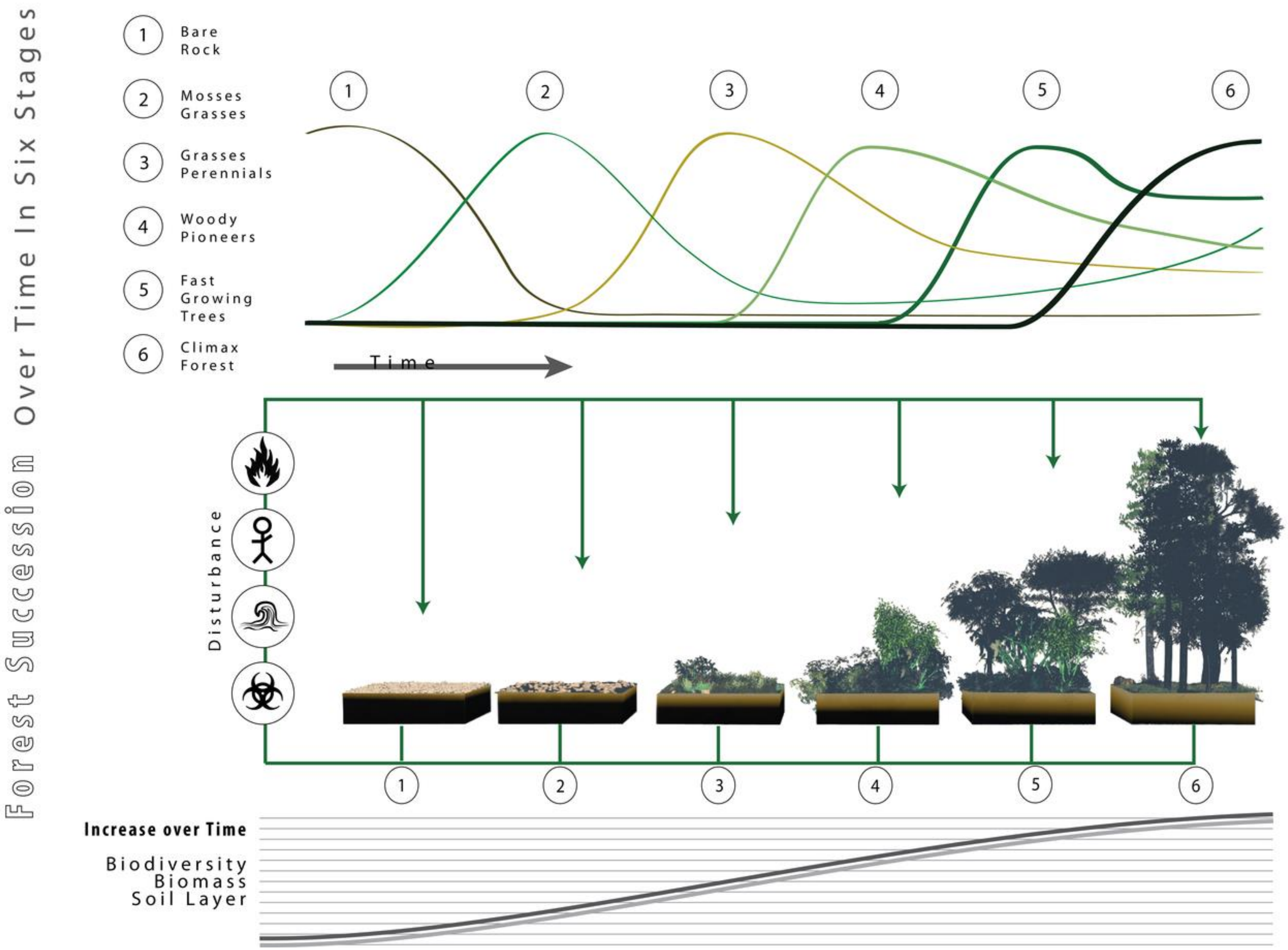
How does ecosystem function and stability change through time?

Succession & Communities

- Communities can often be defined into collections of patches in discreet stages, and transitions between these stages are predictable



Succession



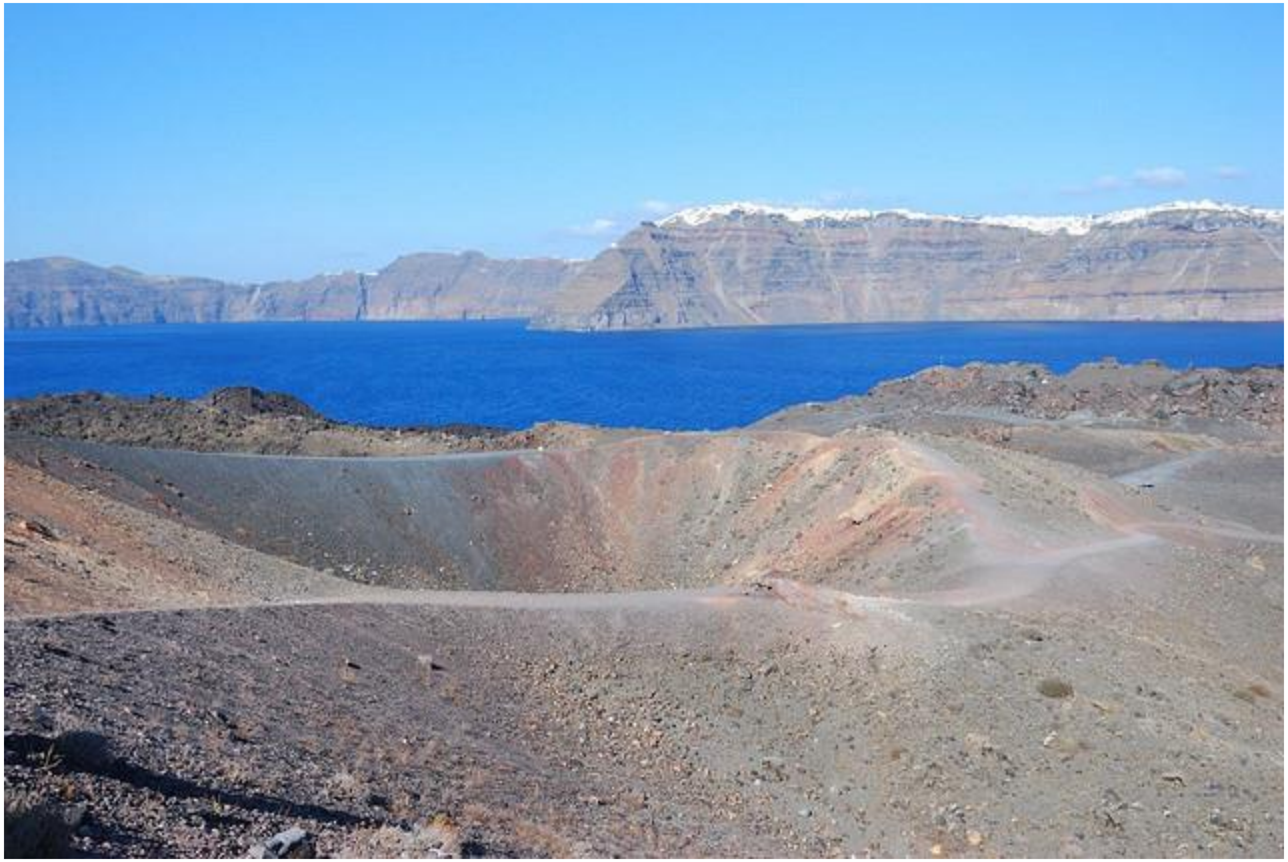
Forest Succession Over Time In Six Stages
1 Bare Rock
2 Mosses Grasses
3 Grasses Perennials
4 Woody Pioneers
5 Fast Growing Trees
6 Climax Forest
1
2
3
4
5
6
Time
Disturbance
1
2
3
4
5
6
Increase over Time
Biodiversity
Biomass
Soil Layer

Succession

- Succession
  - the change in community structure (species/area) with time
  - Starting point – “empty” or “open” state containing no species. e.g. disturbances that ‘reset the clock’
- Primary vs. secondary

Primary Succession

***Primary succession* – colonization of newly created substrate (e.g. volcanic island)**



Secondary Succession

Secondary succession **– re-colonization of previously established community**

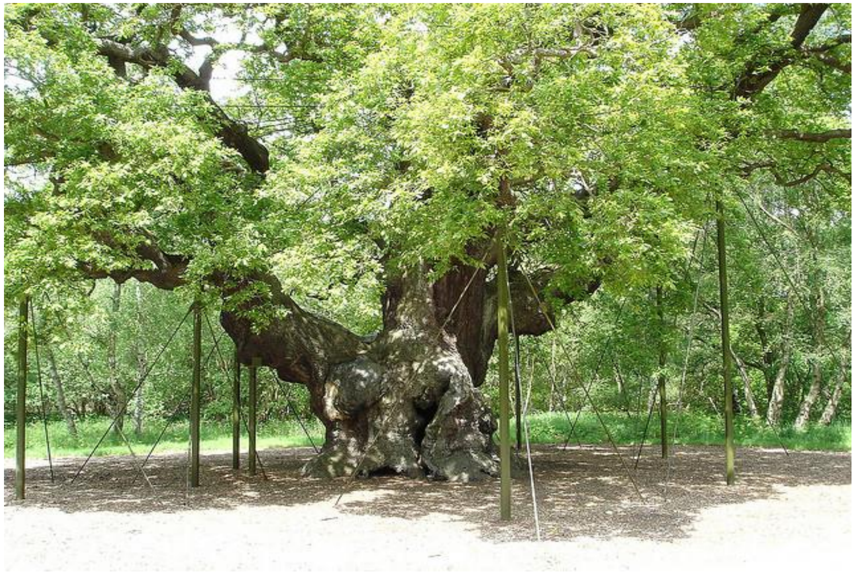
Who colonizes following disturbance?

- Pioneer species – species with life-history traits that can survive and colonize ‘harsh’ landscapes
  - High fecundity
  - High dispersal
  - Rapid population growth
  - Low competitive ability

  - Trade-offs

Colonization following Disturbance

- Climax Communities – species that are invasive resistant and self-replacing
  - Low fecundity
  - Invest in growth and competitive ability
  - Weak dispersers



Models of succession

- Facilitation model
  - Initial colonization by pioneer species
    - Good dispersers that can survive in poor conditions, but not good competitors
  - Each stage modifies physical environment to facilitate change to next stage

- Inhibition model
  - Initial colonists gain a foothold, and suppress settlement of other species
  - Only if disturbance takes the patch back to open can another species invade

- Tolerance model
  - Initial colonists neither inhibit or facilitate the colonization of later species
  - Life history characteristics (rather than experienced environmental conditions) guide transitions

Succession models: Defining the stages

- Stages represent discreet and *mutually-exclusive* communities of organisms.
  - Can represent sets of species (“algal mat”)
  - Alternately can represent stands of single species (“red oak”)
  - Stage can set spatial scale, as each patch in the landscape has to be defined as holding one discreet stage
  - In addition to species/species groups, models will include an “Open Space” stage representing a state immediately after a disturbance has removed the local community.

Stage examples

- Konza Prairie Nature area – Flinthills, Kansas

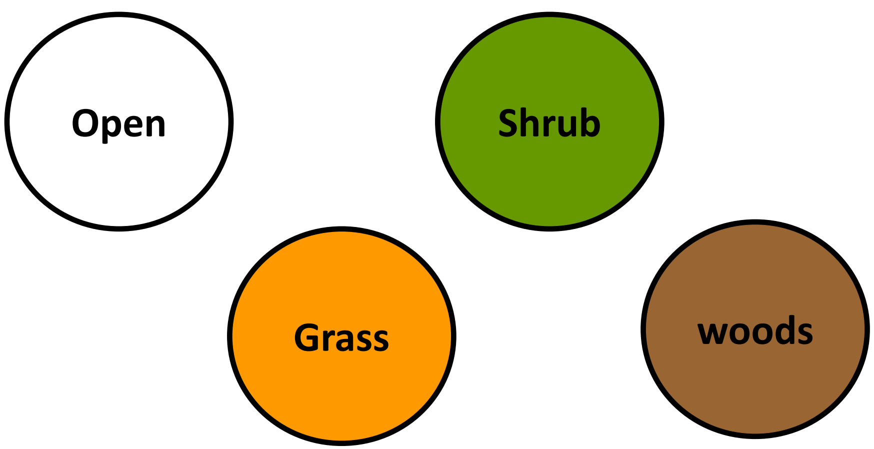
native tall-grass prairie
university research plots

Stage examples

- Konza Prairie Nature area – Kansas

- Tall grass prairie
  - maintained by recurrent grass fires (lightening strikes)
  - Maintained by grazing (bison)

- Reduced frequency of fires or grazing results in"
  - replacement of grasses by encroaching shrubs
  - then eventually woods (normally restricted to riparian areas)



Models – Specifying Time Step

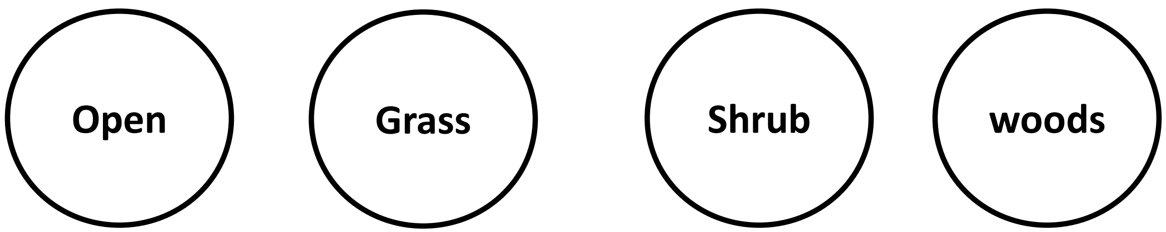
- Like age-structured populations, the time units in succession studies are discreet units (years, decades etc).

t?

Time of persistence of different stages

Models – stage vector

- Once a small number of manageable stages are defined, a stage vector (*s*) is used to define the number of patches in the community in each stage
- Stages can't overlap



- **Assume 500 surveyed patches of 0.5ha each after large fire**
- **250 open, 100 grass, 80 shrub and 70 woods**

$$\boldsymbol{s(t) = [250, 100, 80, 70]}$$

Models – transition matrix

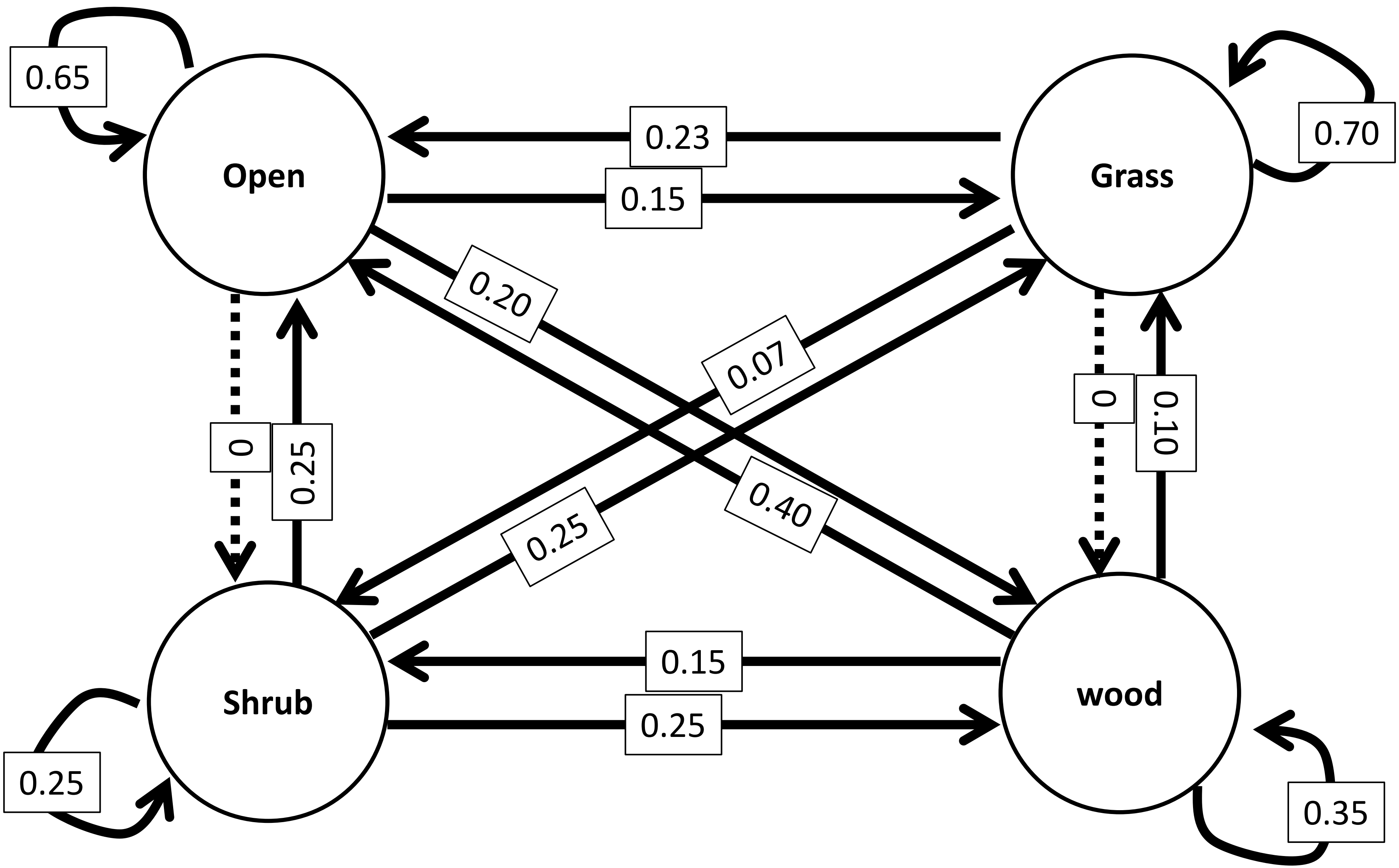
- Like a Leslie Matrix, the transition matrix (A) shows the transitions between a specific current stage (column) and a possible future stage (rows)

Stage at time t (present)

Stage at time t +1 (future)

	Open	Grassland	Shrub	Woods
Open	**0.65**	**0.23**	**0.25**	**0.40**
Grassland	**0.15**	**0.70**	**0.25**	**0.10**
Shrub	**0.00**	**0.07**	**0.25**	**0.15**
Woods	**0.20**	**0.00**	**0.25**	**0.35**

Models – Loop Diagrams



Model – Projecting Community Change

- Determining the number of patches that will be within a specified stage in the next time step

$$\boldsymbol{s}(\boldsymbol{t}+\mathbf{1}) = \boldsymbol{A}\,\boldsymbol{s}(\boldsymbol{t})$$

Model – projecting community change

- How many of 500 patches will be **woodland** in next time step (t+1)?

$$s(t+1) = A\, s(t)$$

$\boldsymbol{s(t) = [250, 100, 80, 70]}$

	Open	Grassland	Shrub	Woods
Open	**0.65**	**0.23**	**0.25**	**0.40**
Grassland	**0.15**	**0.70**	**0.25**	**0.10**
Shrub	**0.00**	**0.07**	**0.25**	**0.15**
Woods	**0.20**	**0.00**	**0.25**	**0.35**

Model – projecting community change

- How many of 500 patches will be woodland in next time step (t+1)?

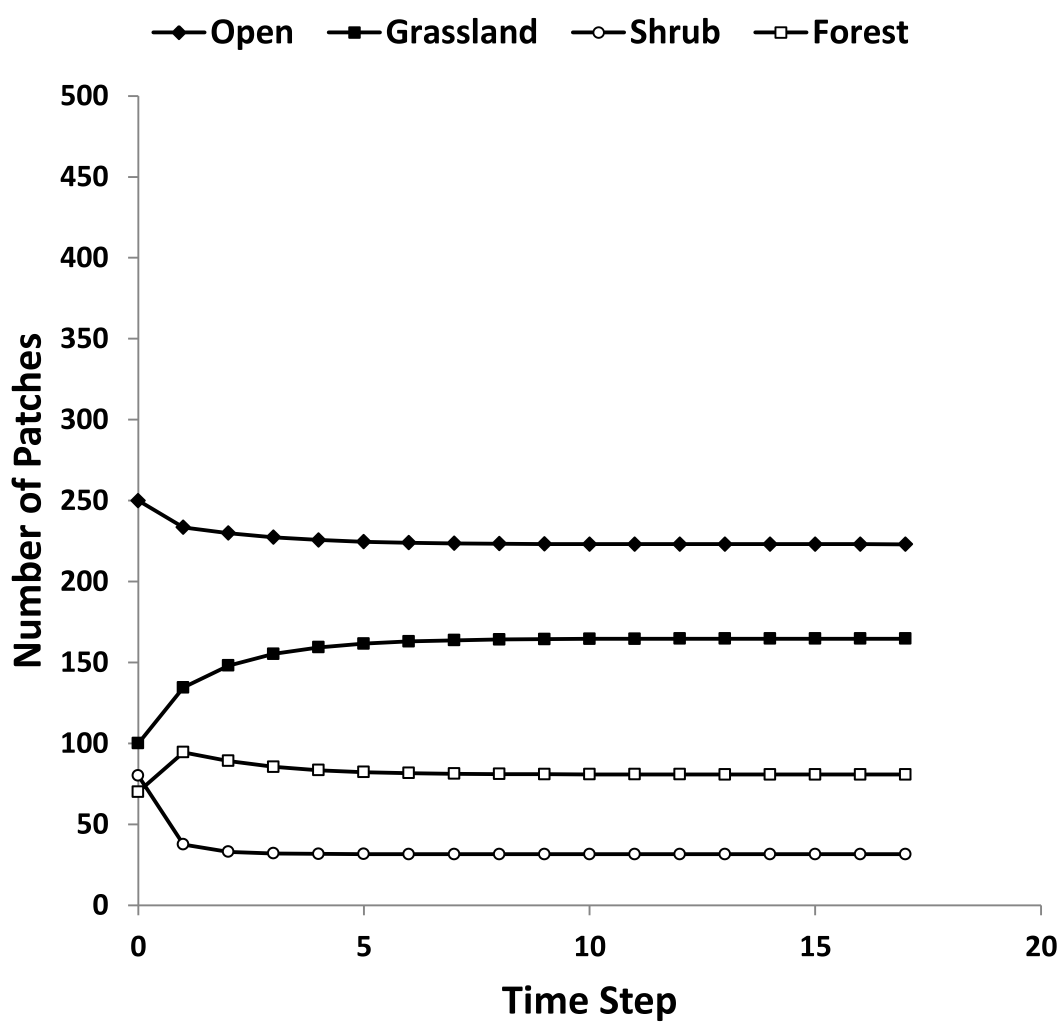
$$\boldsymbol{s(t+1) = A\, s(t)}$$

- $\boldsymbol{Woods(t+1) = (0.20)(250) + (0.00)(100) + (0.25)(80) + (0.20)(70)}$
- $\boldsymbol{s(t+1) = 94.5\, Woods}$
- Repeat with:
- Open = 233.5
- Grasslands = 134.5
- Shrub = 37.5
- $\boldsymbol{s(t+1) = [233.5 \quad 134.5 \quad 37.5 \quad 94.5]}$

Equilibria and community succession

- After several time steps of a stage model, the community enters an equilibrium – the stage vector doesn't change with each additional time step

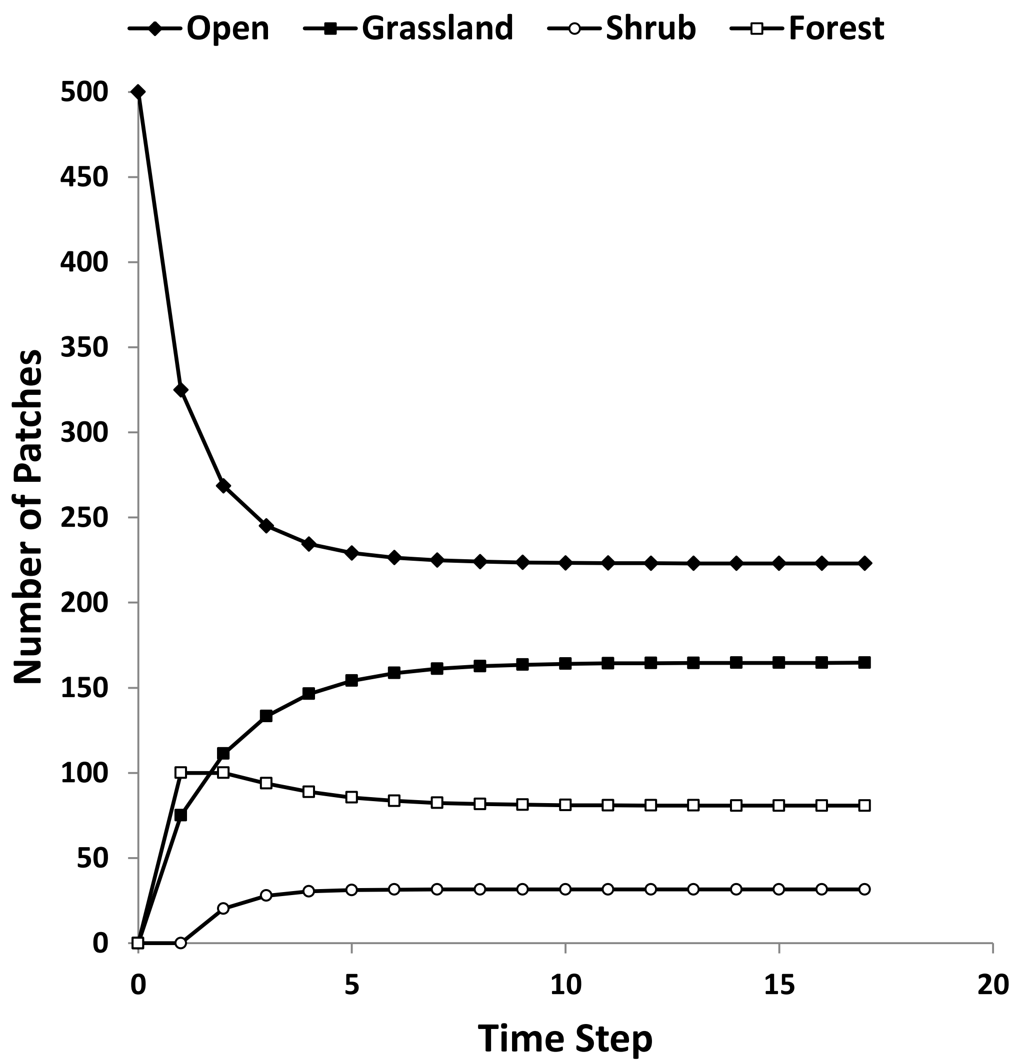
$$\boldsymbol{s(t) = [250, 100, 80, 70]}$$



Equilibria and Community Succession

- Equilibrium state arises regardless of starting stage vector

$$\boldsymbol{s(t)} = [\mathbf{500, 0, 0, 0}]$$

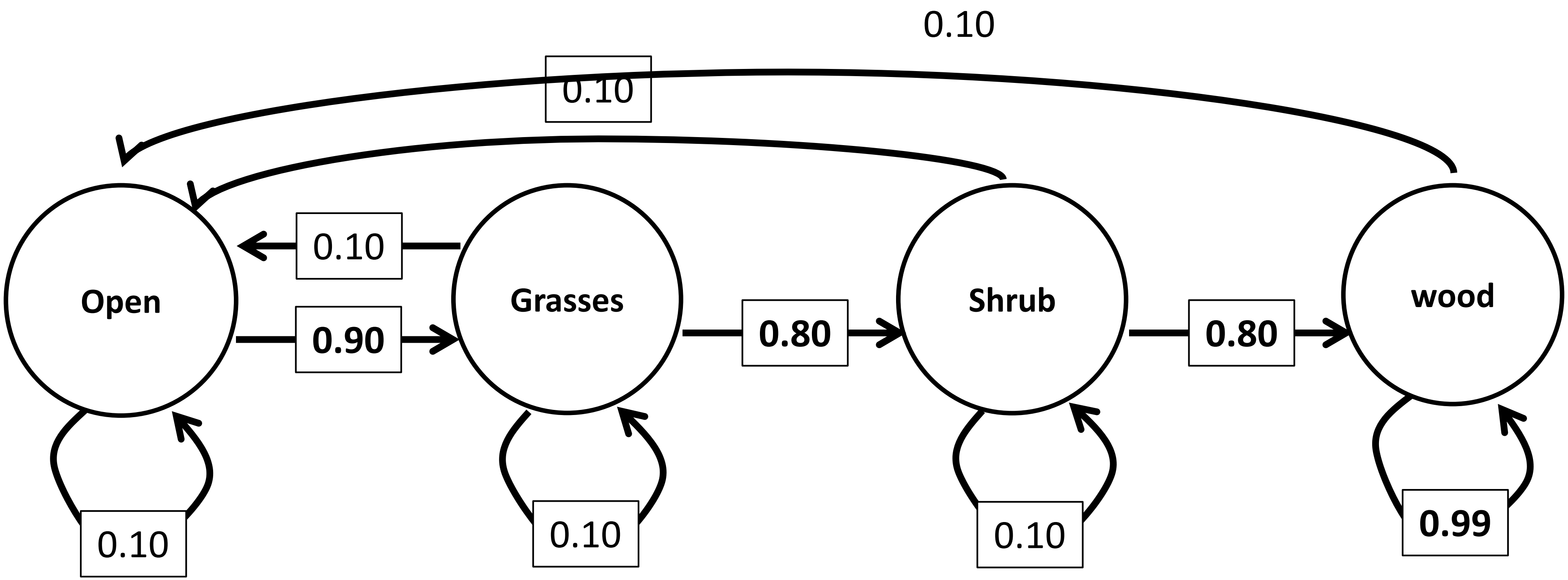


Model Assumptions

1. Communities can be represented as discrete states
2. Time is measured in discrete, evenly spaced units
3. Transition matrix is homogenous
   - *constant and doesn't change from one time step to the next*
4. No spatial structure
   - *transition probabilities do not depend on patch's position relative to other patches*
   - *Markov model*
5. No Density Dependence
   - transition probabilities do not change as a function of relative frequency of a patch
6. Large Number of Patches
7. No Time Lags

Facilitation Model

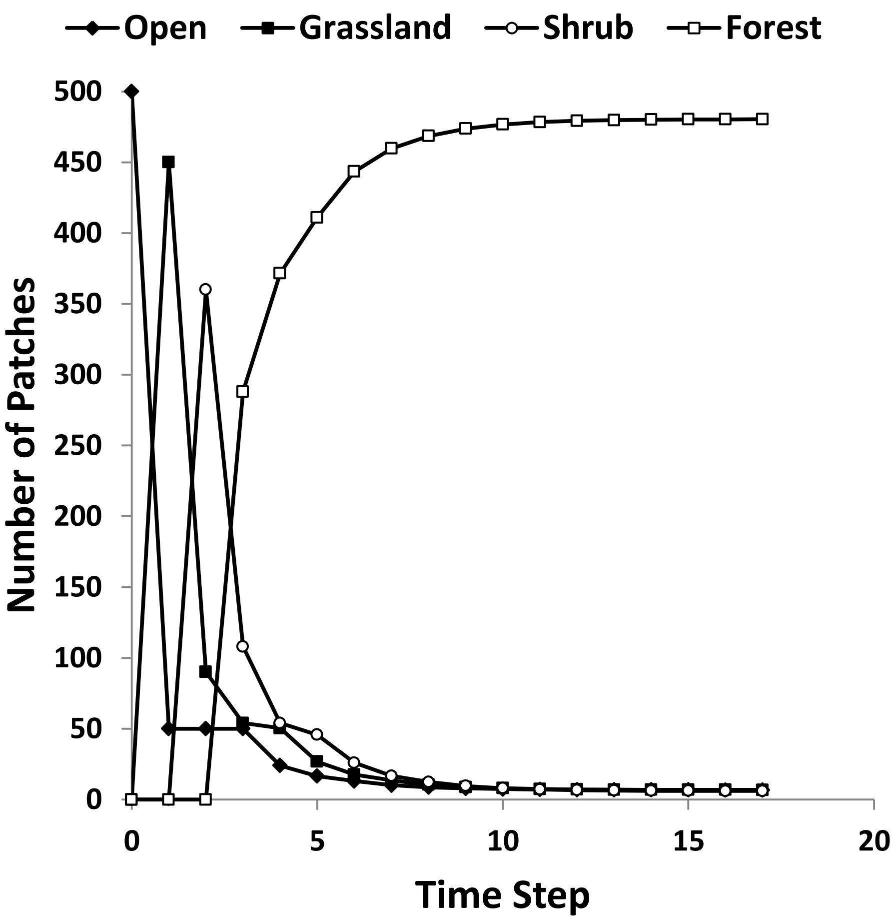
- Directional pattern to succession



Facilitation Model

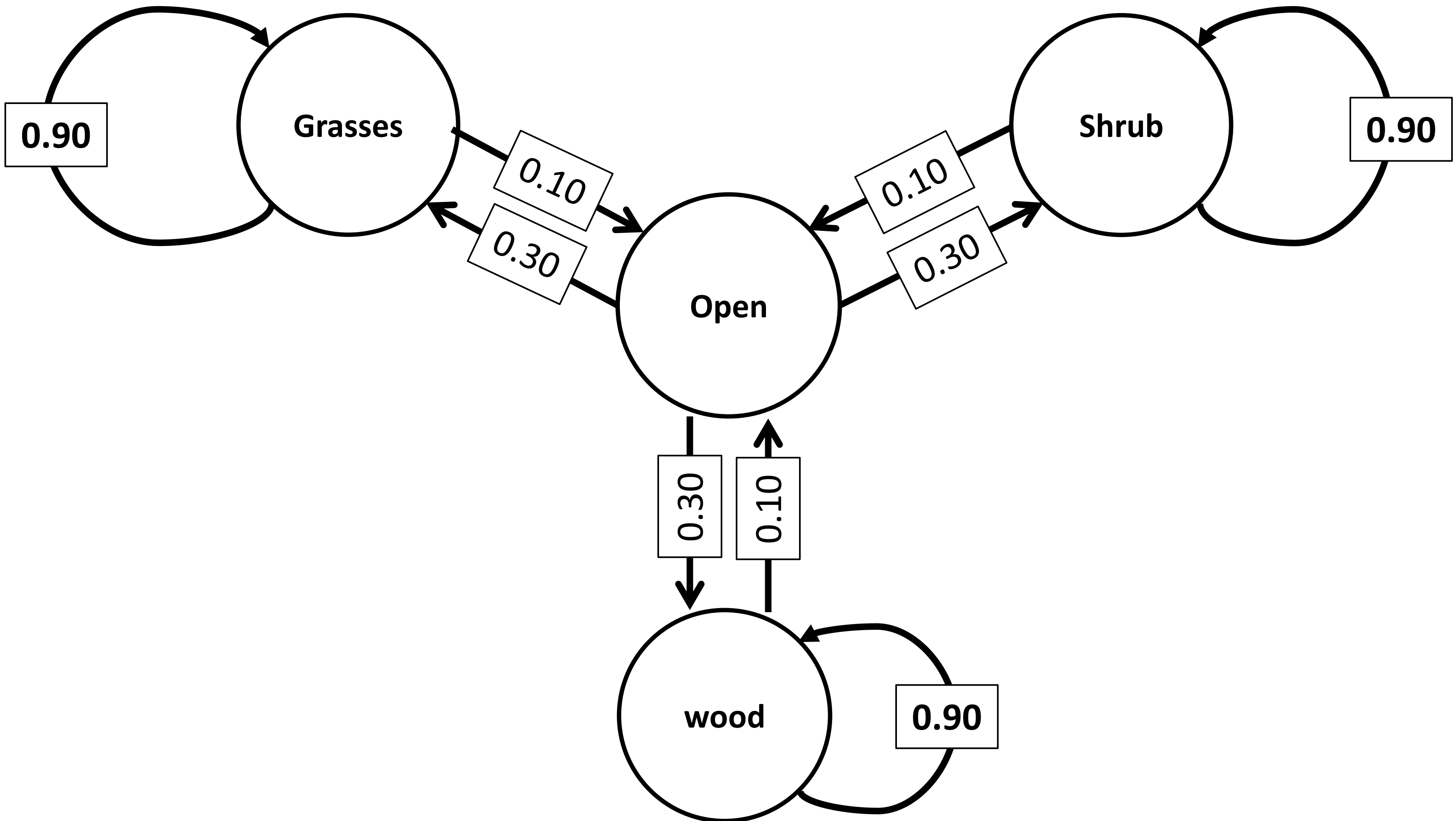
	Open	Grassland	Shrub	Woods
Open	0.10	0.10	0.10	0.01
Grassland	*0.90*	0.10	0.00	0.00
Shrub	0.00	*0.80*	0.10	0.00
Woods	0.00	0.00	*0.80*	*0.99*

$$s(t) = [500, 0, 0, 0]$$



Inhibition Model

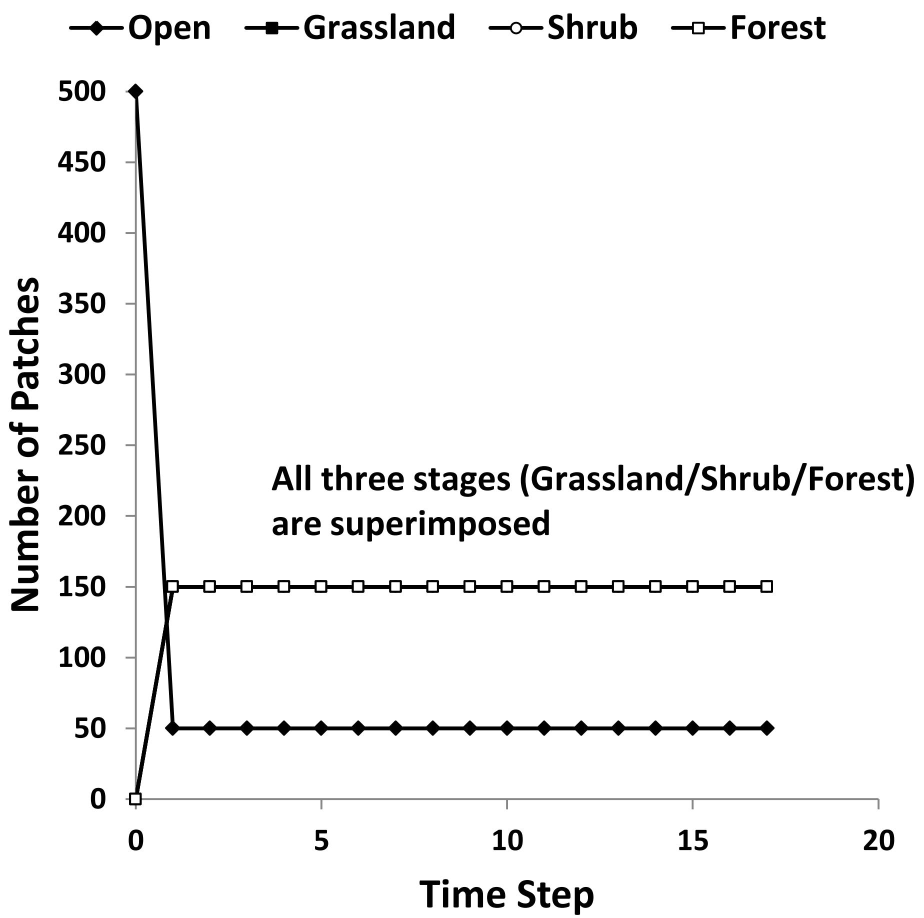
- Stage replacement occurs only following additional disturbance



Inhibition Model

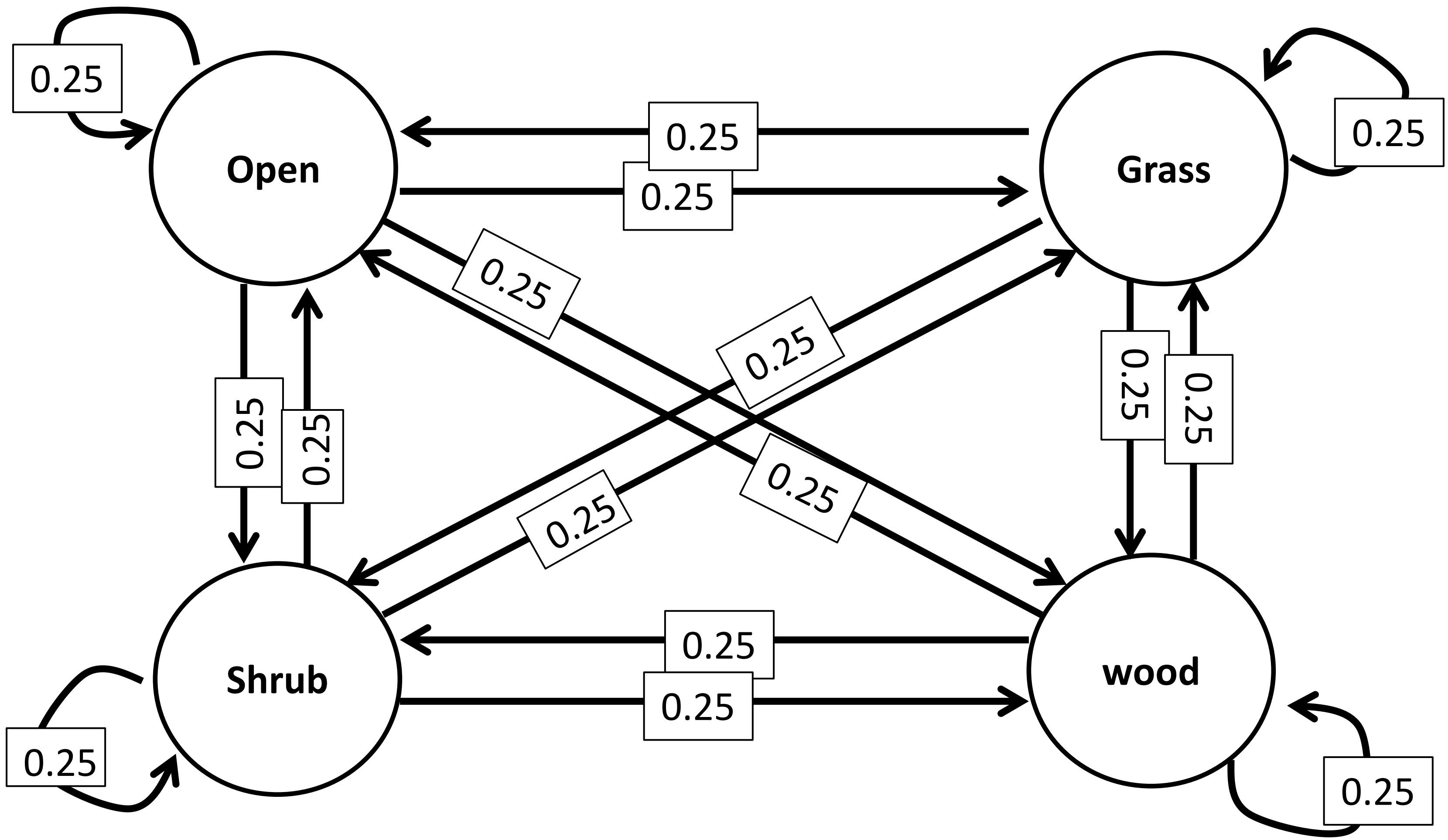
	Open	Grassland	Shrub	Woods
Open	0.10	0.10	0.10	0.01
Grassland	0.30	*0.90*	0.00	0.00
Shrub	0.30	0.00	*0.90*	0.00
Woods	0.30	0.00	0.00	*0.90*

$$s(t) = [500, 0, 0, 0]$$



Tolerance Model

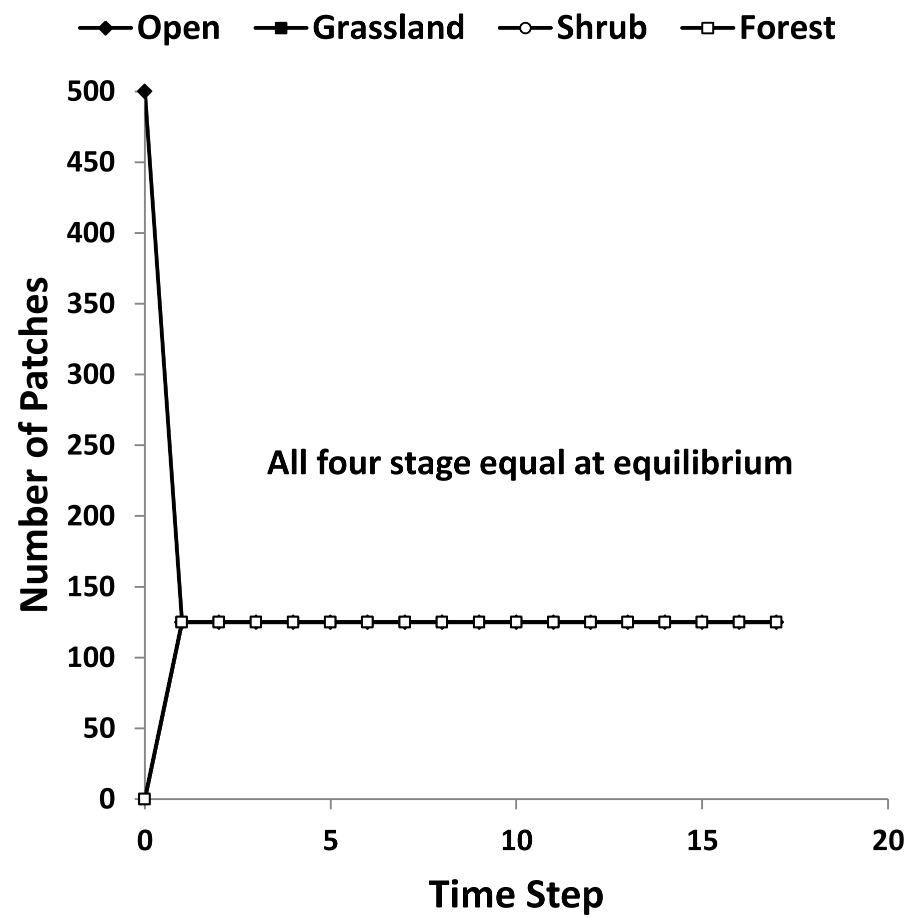
- All transition equally likely



Tolerance Model

	Open	Grassland	Shrub	Woods
Open	0.25	0.25	0.25	0.25
Grassland	0.25	0.25	0.25	0.25
Shrub	0.25	0.25	0.25	0.25
Woods	0.25	0.25	0.25	0.25

$$s(t) = [500, 0, 0, 0]$$



Forest succession