# A review of the relationship between biodiversity and forest ecosystem resilience

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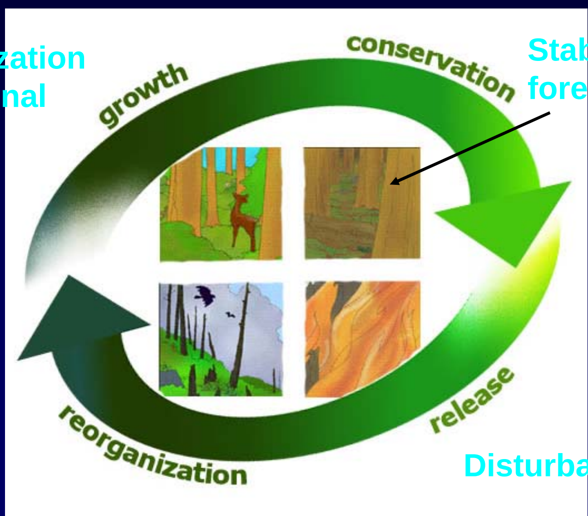
## Resilience is the capacity of an ecosystem to recover after disturbance

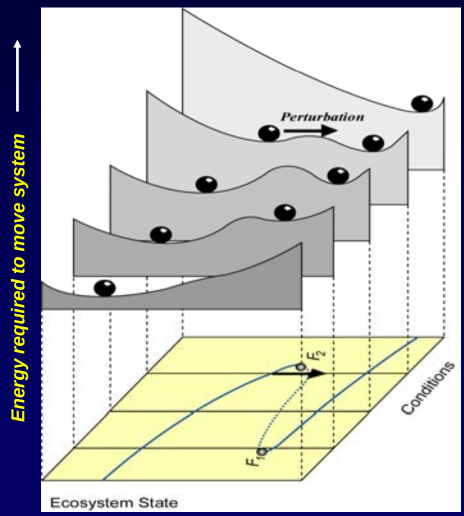
Reorganization of functional species

Stable mature forest state




Disturbance

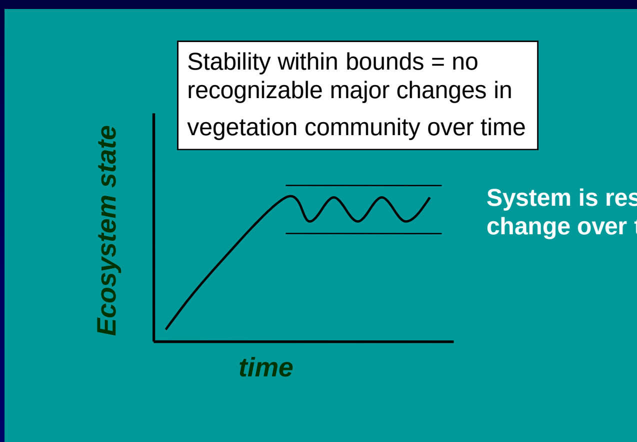
## Disturbances may move the forest to a new state or age class




Change of ecosystem state requires an energy input

Ecosystems can have multiple stable states

## Stability of a forest state is a concept related to resilience




**System is resistant to change over time**

## Boreal forests are not especially resistant to fire, but they are resilient

This boreal conifer forest will self-replace within 50-80 years, hence it is highly resilient

## Tropical wet forests are resilient, stable gap-dynamics forests

Tropical forests undergo gap dynamics in space and time, but the characteristic species remain the same and so these forests exhibit long-term resilience and resistance to natural change

## Resilience is an emergent ecosystem property

- resilience of a forest is a function of biodiversity at many scales: genes, species, and regional diversity among ecosystems
- most primary forest ecosystems are resistant and resilient to natural disturbances
- biodiversity underpins ecosystem resilience and the ecological goods and services from the forest
- loss of biodiversity may alter the forest resilience and will result in reduced goods and services
- loss of resilience means increased uncertainty about future forest condition
- more biodiversity = > resilience….is a hypothesis

## Mechanisms for the linkage between biodiversity and ecosystem stability and resilience

- biodiversity provides functional connectivity in the system: e.g., pollinators adapted to plants
- diseases and disturbances do not affect all species equally, so, more diversity = less losses
- redundancy among species: a previously less important species may fill a vacated role
- genetic capacity within species enables adaptation to environmental changes
- genes enable a species to adapt to site differences across a distribution

## Thresholds exist where the resilience capacity is overcome and the system moves to a new state that may not be a forest

- e.g., if a forest becomes dry, it loses species, is subject to increased frequency of fire, and moves to a savannah or grassland state
- this new state is stable and will require considerable change to move to another state
- the forest biodiversity has been lost and so have most of the goods and services from the ecosystem

Tropical dry forest

→

Drier climate

→

savannah

## Degraded forest systems may be highly stable or unstable

- in many systems, loss of functional species*, or invasion by superior competitors, can result in new stable and resilient states
- new functional species now ‘control’ the system by occupying most niches or out-competing endemic species
- most often, degraded forests are unstable because they lack diversity and key functional species
- degraded forests always provide fewer ecosystem services

**Functional species are key ‘drivers’ of the system. They are not necessarily the most abundant species.*

## Two examples of invasive species forming highly resilient but highly degraded ecosystems

**Removing invasive acacia forest in California**

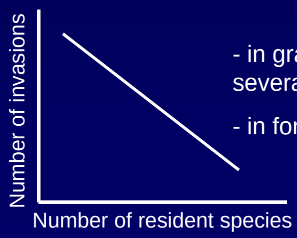
**Invasive black wattle (*Acacia mearnsii*) in South Africa - a very stable and resilient system**

## Functional redundancy - insurance hypothesis

- from: Walker (1995); Yachi and Loreau (1999); others
- hypothesis: multiple species perform the same function in many ecosystems
- loss of one species results in the role filled by another with no change in goods and services
- that is….biodiversity makes the system resilient to some level of species loss
- evidence clear that diversity supports stability in ecosystems - exact mechanism is unclear (populations, food webs, etc.)

## Resilience and invasion of ecosystems

- complex issue, not all systems react in the same way
- successful invasion depends on: vacant niche, competitive superiority, lack of enemies, climate
- most experimental work has been in grasslands
- loss of species = increased invasibility, e.g., temperate forests
- uncontrolled effects make understanding difficult in natural systems
- natural tropical systems are least invaded

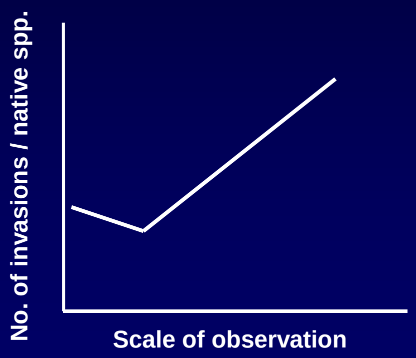



- in grasslands, from several studies

- in forests?

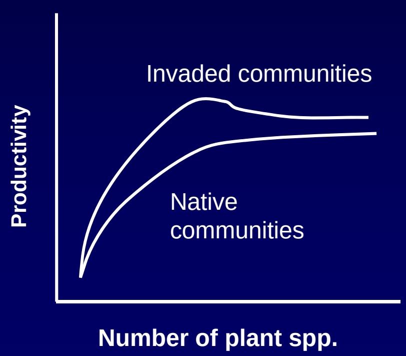
## Invasion paradoxes

- small scales = a negative relationship with diversity
- large scales = a positive relationship




From: Fridley et al. 2007, Ecology 88: 3-17.

- invasive species often have a positive effect on production (increased N into system)




From: Rout and Callaway 2009, Science 324: 734-735.

## Biodiversity and ecosystem functioning

Literature summary of studies on the effect of biodiversity loss on ecosystem function:

| | Schlapfer and Schmid 1999 | Cardinale et al. 2006 | Balvanera et al. 2006 |
|---|---|---|---|
| **+ effect** | 19/23 | 108/108 | 485/771 |
| **No effect** | 4/23 | 0/108 | 286/771 |

- various ecosystems, various measures
- shapes of curves differ among response variables (primary production, C storage, transpiration, etc.)
- depended on number of species removed
- effects are strongest at the community level

## Biodiversity and productivity in forests

Literature summary of studies on the effect of increasing species richness on production in forests:

| | **Boreal** | | **Temperate** | | **Tropical** | | **Trop. Plantation** | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| | Expt. | Obs. | Expt. | Obs | Expt. | Obs | Expt. | Obs | |
| **+ effect** | 1 | 1 | 2 | 2 | 8 | 1 | | 14 | **30** |
| **No effect** | | | 1 | 2 | 1 | 1 | | | **5** |

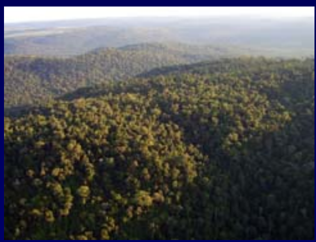
- if higher biodiversity ~ increased productivity (or functioning)
- and if higher biodiversity ~ increased resilience
- then a hypothesis is that:
  - increased productivity (function) should ~ increased resilience

## Biodiversity, resilience, and climate change

• so, diversity matters in whether or not an ecosystem can maintain its resilience under climate change

• forest systems may adapt based on dispersal capacity of species and genetic diversity within species

• dispersal may be affected by landscape structure – connected is better



This

Not this

## Biodiversity and carbon storage in forests

• current estimates are that forest loss results in 12-15% of human caused increase in atmospheric $CO_2$

• biodiversity-related processes play a key role in carbon storage through functional diversity

• primary forests store more carbon than managed forests

• evidence suggests that maintaining resilience through SFM and recovering resilience in degraded forests can help offset C losses

**primary**

**vs.**

**degraded**

## Ecological principles for managing forests to improve stability and resilience

- diverse systems can be more productive, stable, and produce more goods and services than simple ecosystems (e.g., monotypic plantations)
- re-forest by using native species and by using natural forests as models
- maintain landscape connectivity
- manage to maintain genetic diversity (e.g., reduce selective harvest of 'best' trees, and re-plant several seed stocks)
- protect species at the edges of their ranges
- plan to reduce invasive species

## Conclusions

- biodiversity at many scales most confers resilience within a forest ecosystem
- mechanisms include: redundancy, resistance to disease, increased productivity, genetic capacity to adapt to change
- loss of biodiversity can result in an ecosystem state that is difficult to change and provides an uncertain future
- degraded forests may be stable, although most often they are not, but they always provide less goods and services
- alter a system sufficiently and resilience will be overcome
- important to manage for resilience under climate change