The relationship between forest biodiversity, ecosystem resilience, and carbon storage

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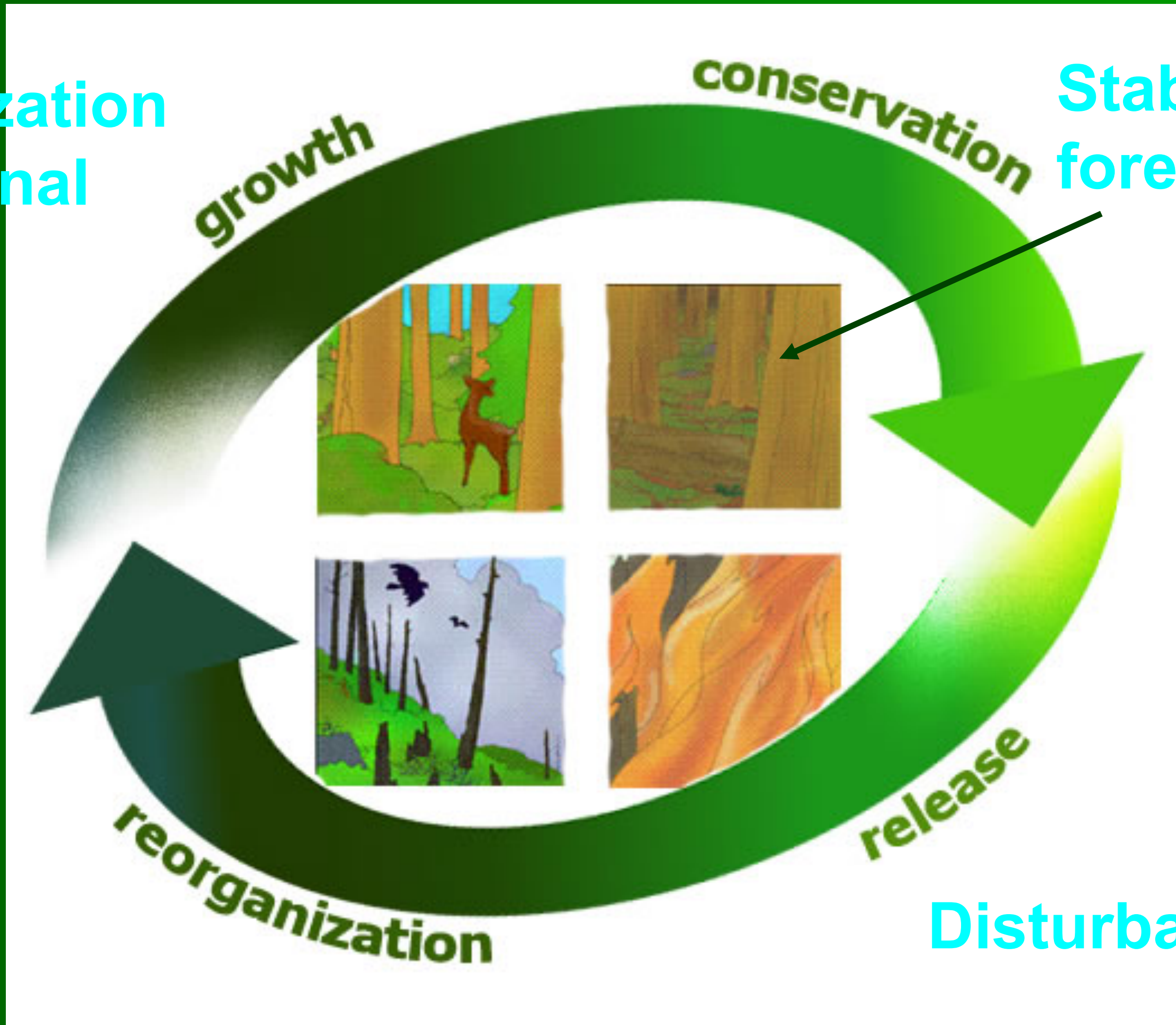
Resilience is the capacity of an ecosystem to recover after disturbance

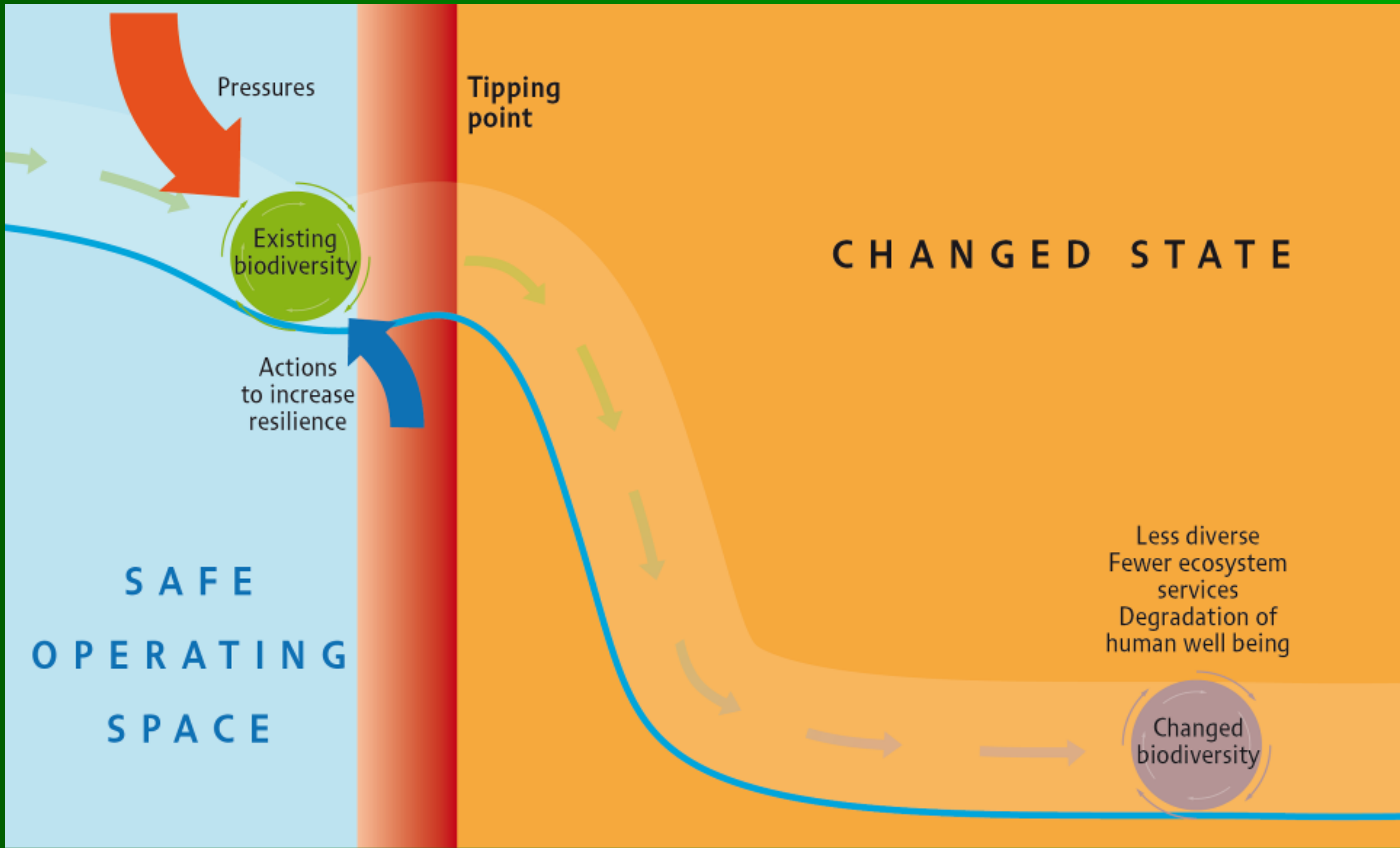
Reorganization of functional species

Stable mature forest state

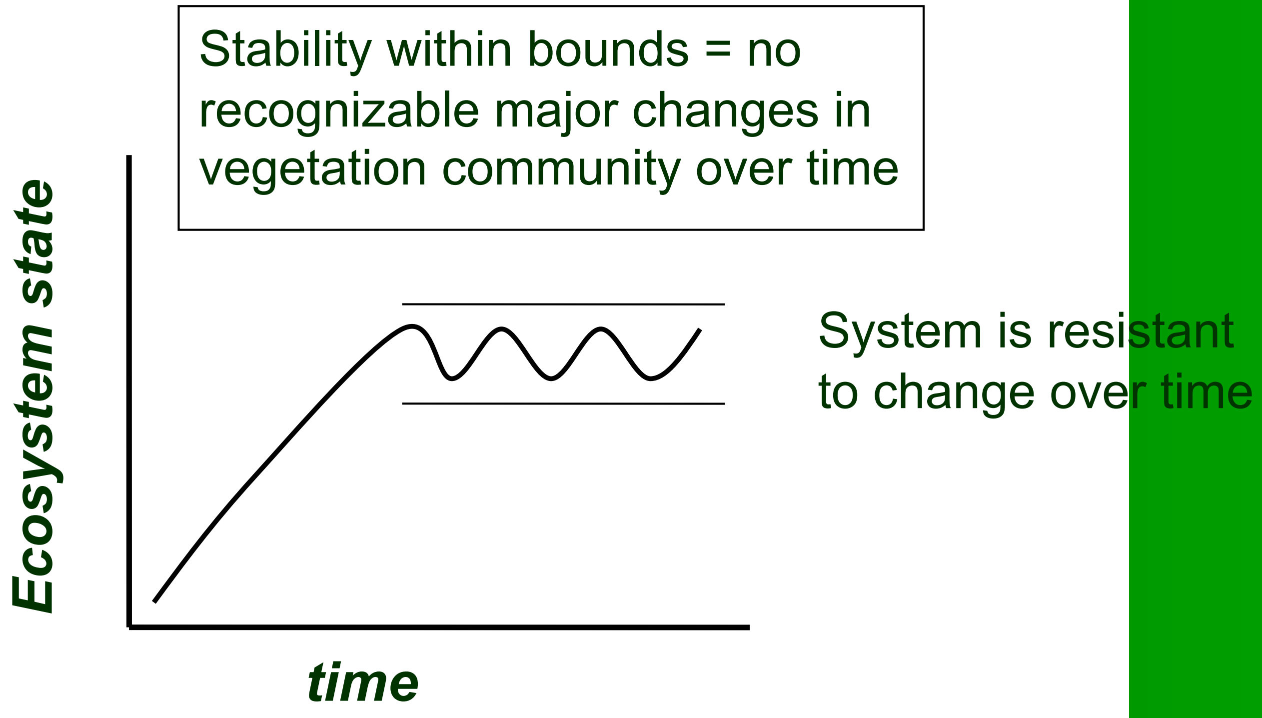


Disturbance

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



Stability of a forest state is a concept related to resilience



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

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

Tropical wet forests are resilient and 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 change

Resilience is an emergent ecosystem property

- Resilience of a forest is a function of biodiversity at all scales: genes, species, landscapes, and regional diversity among ecosystems
- Most primary forest ecosystems are resilient to natural disturbances; many are also resistant
- Loss of biodiversity may alter the forest resilience and will result in reduced goods and services (e.g., carbon storage
- Loss of resilience means uncertainty about future forest condition

Tipping points exist where the resilience capacity is overcome and the system moves to a new state

• 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 biodiversity has been lost and so have most of the goods and services from the ecosystem, including carbon storage

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 functionality
- 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

Mechanisms for the linkage between biodiversity and ecosystem stability and resilience

- biodiversity results in strong functional connectivity in the system: e.g., pollinators adapted to plants and vice versa
- diseases and disturbances do not affect all species equally, more diversity = less losses
- redundancy among species - lose one driver, another previously less important species fills the vacated role
- genetic capacity within species enables adaptation to environmental changes
- general tendency for greater productivity in diverse forest = more goods and services (e.g., carbon storage)

Functional species in forest ecosystems

- primary production: dominant tree species
- pollination: many insects, some birds, some bats
- pest reduction: many birds, many bats
- decomposition: insects, fungi, micro-organisms



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**

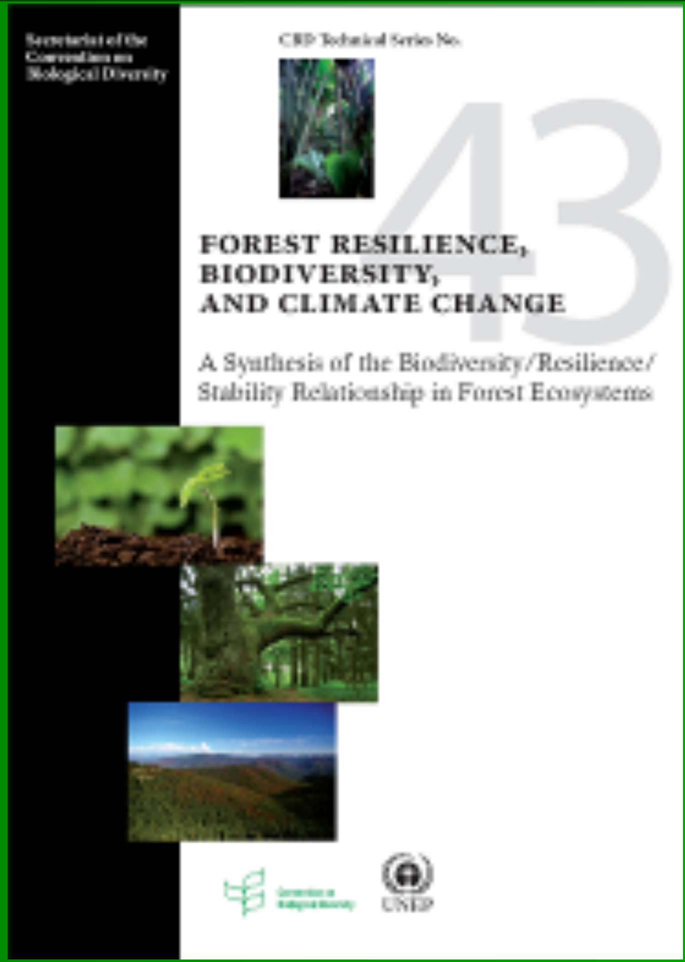
- if higher biodiversity ~ increased productivity (or functioning)
- and if higher biodiversity ~ increased resilience
- then a hypothesis is that:
  - increased productivity (function) should ~ increased resilience

Links between biodiversity and forest carbon Links between biodiversity and forest carbon

- Synthesis of 400+ peer-reviewed articles: Forest resilience and stability depend on biodiversity, at multiple scales (Thompson et al., 2009, see also Diaz et al., 2009)

- Implications e.g. for REDD permanence: biodiversity essential for stability/carbon permanence

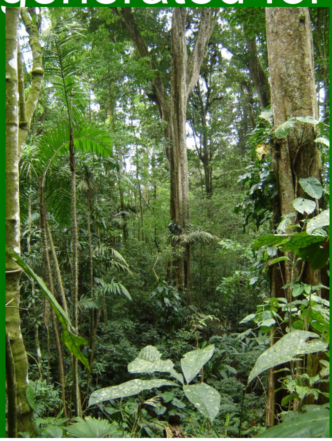
- Biodiversity is enabling condition for SFM and REDD-plus



Biodiversity, resilience, and carbon storage in forests

- current estimates are that forest loss results in 12-15% of human caused increase in atmospheric CO_2
- evidence suggests that maintaining resilience through SFM and recovering resilience in degraded forests can help offset C losses
- Generally, strong correlation between forest carbon stock and biodiversity (e.g. Strassburg et al., 2010) - both are highest in primary forests
- Carbon in plantations is on average 28% lower than in primary or other naturally regenerated forests (Liao et al., 2010)

primary



vs.

degraded

Ecological principles for restoring degraded forests to improve stability and resilience

• biologically diverse systems tend to be more productive, stable, and store more carbon than do 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 plant several seed stocks

• protect primary forests and species at the edges of their ranges

• plan to reduce invasive species

Conclusions

- biodiversity confers resilience within a forest ecosystem at many scales and provides most ecosystem services and thus the long-term stability of the forest carbon stock
- 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 condition
- degraded forests may be stable, although more often they are not, but they will provide <u>reduced</u> carbon storage
- important to manage for resilience under climate change