

Theory and Practice to Manage Ecosystem Dynamics: Resilience and Adaptive Management

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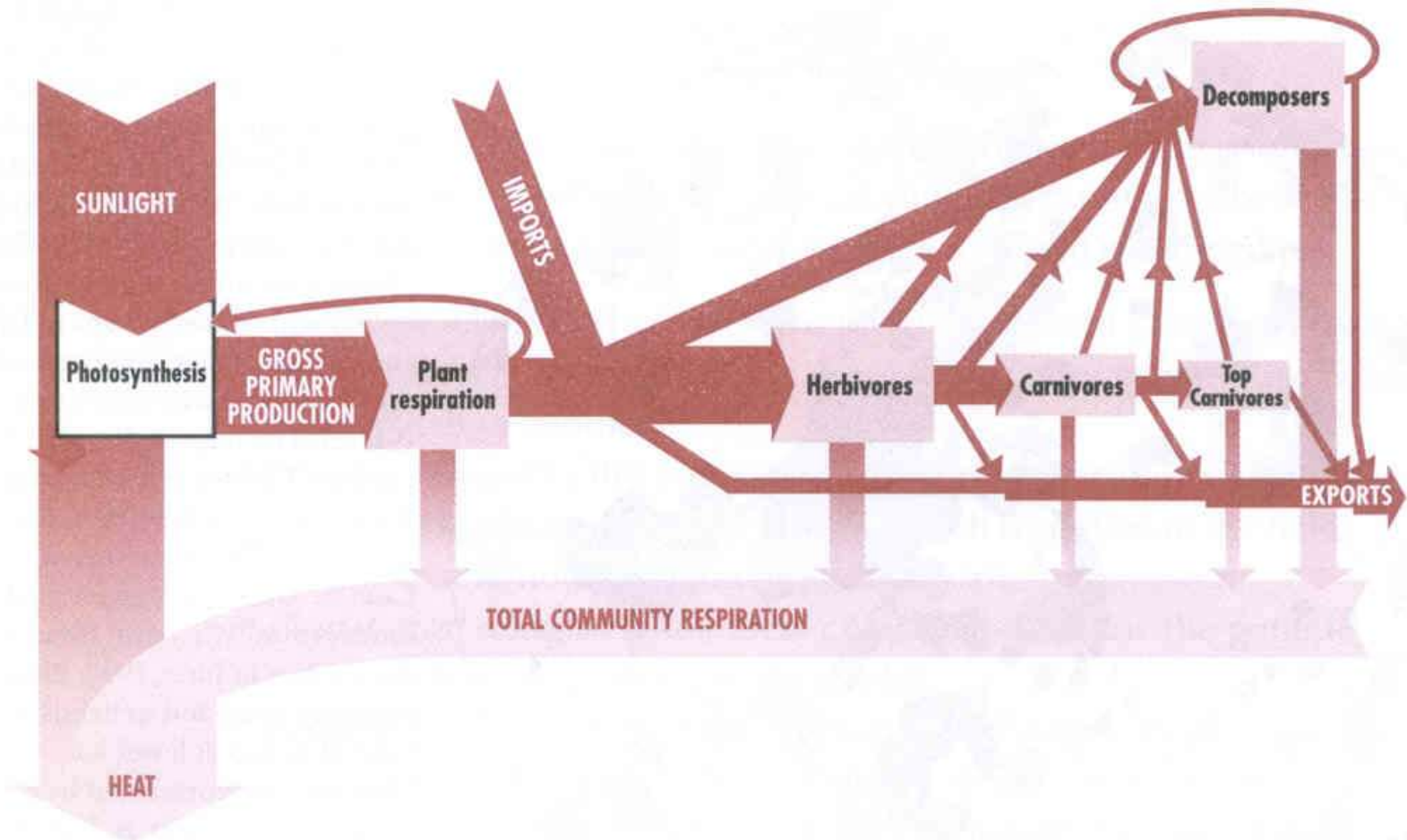
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Outline

- **Classic Ecology**
 - Production throughput and Nutrient Cycling
- **Resilience Theory**
 - Ecosystem dynamics: sources of surprise
 - Factors Influencing Resilience
 - Control of disturbance, Regulation of Renewal
- **Adaptive Management**
 - Co-evolution of learning, policy and practice
- **Summary**

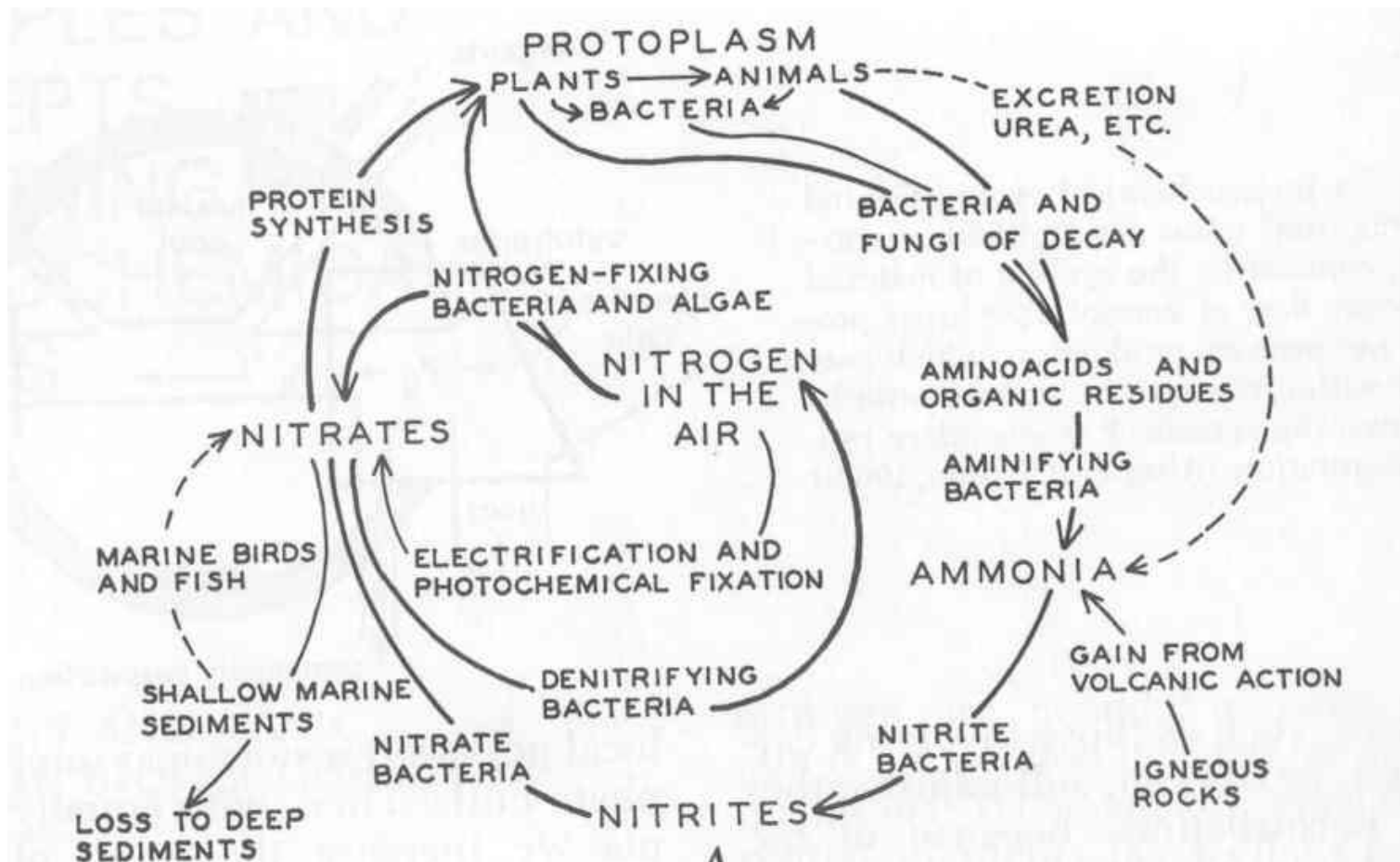
Production

Energy flow and concentration to higher quality



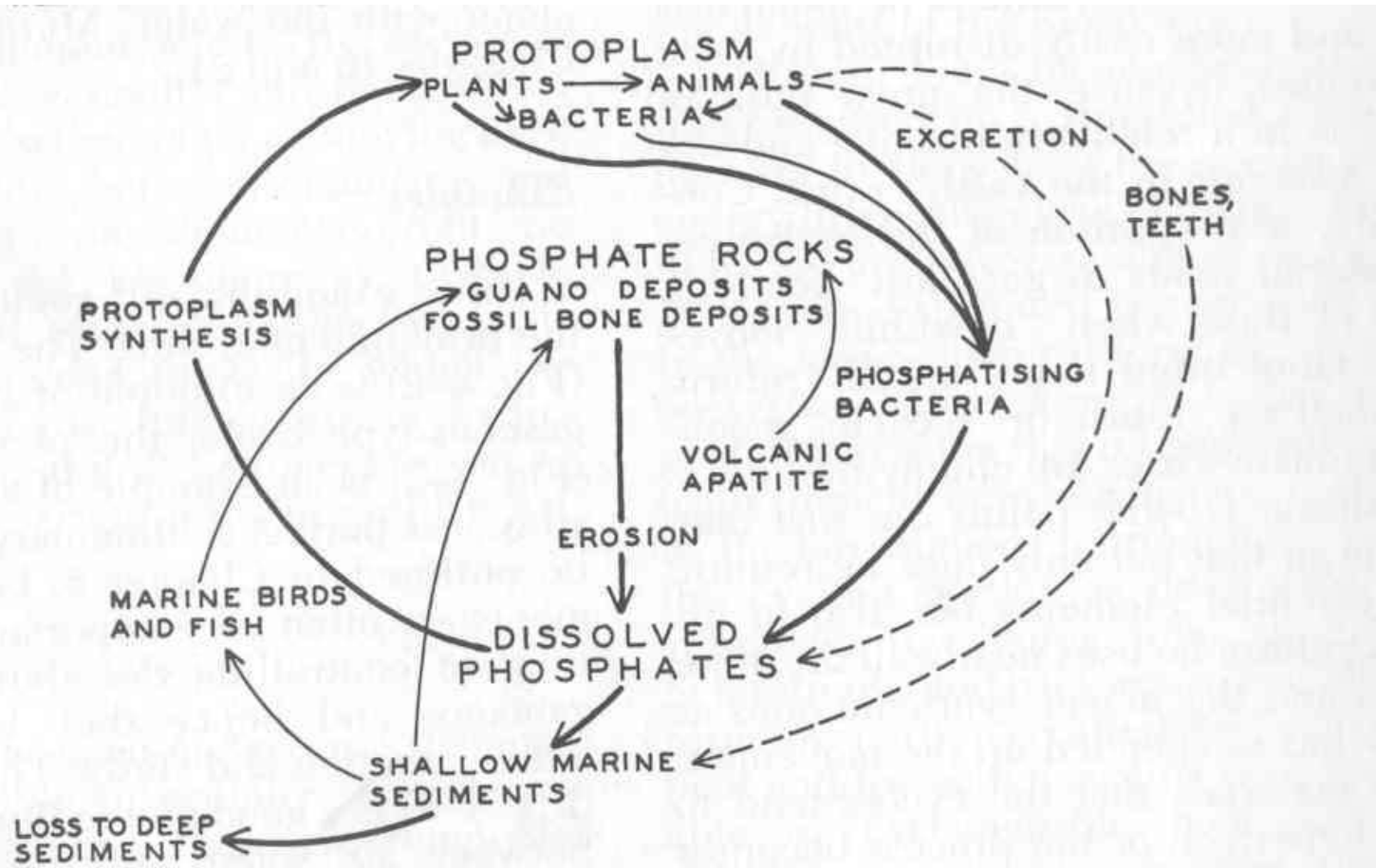
Nitrogen Cycle

Web of feedbacks links gaseous and organic phases



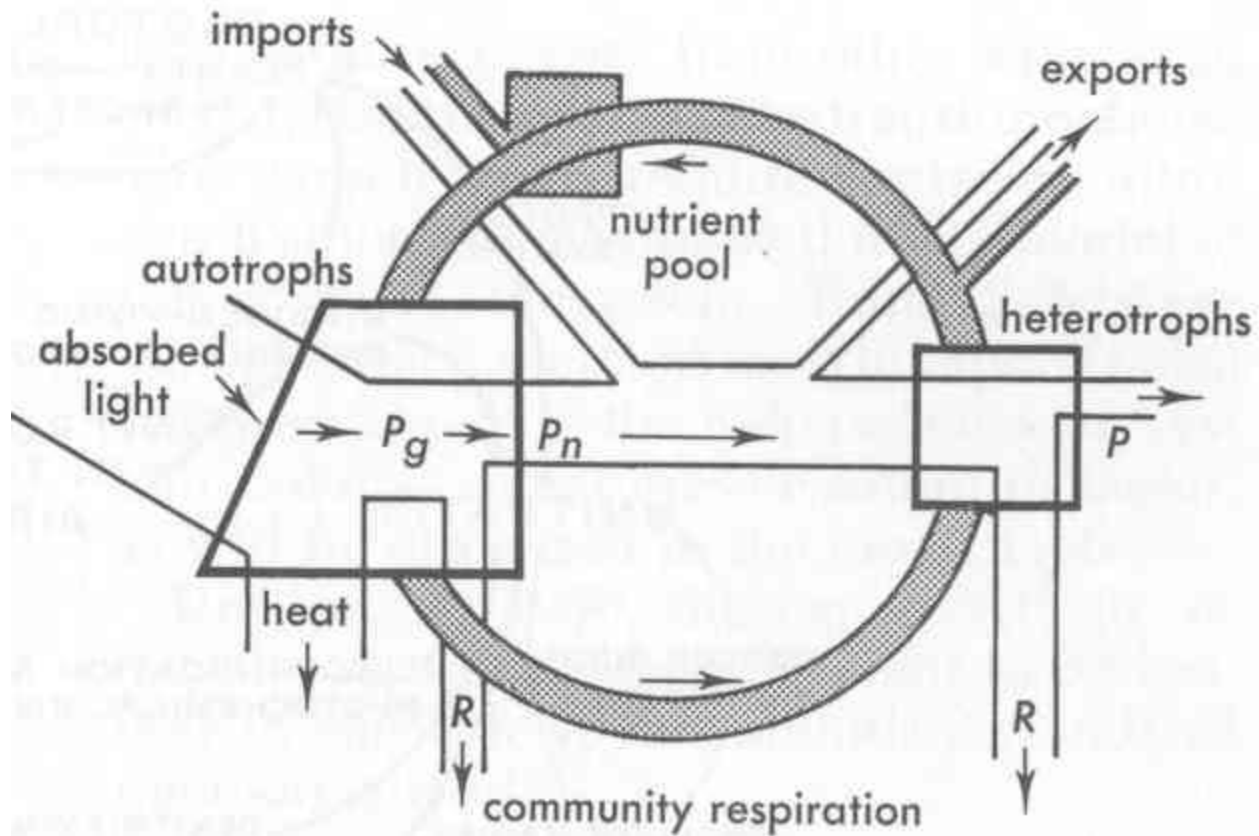
Phosphorus Cycle

Fossil storages erode and return to the sea

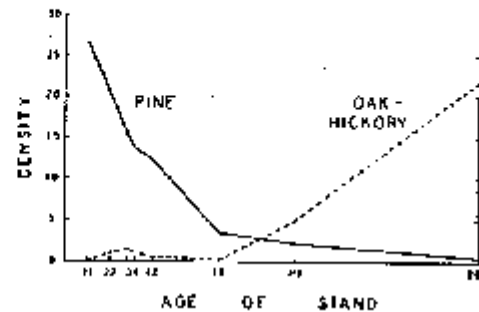
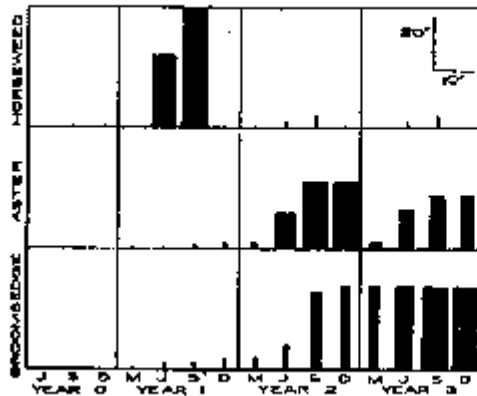
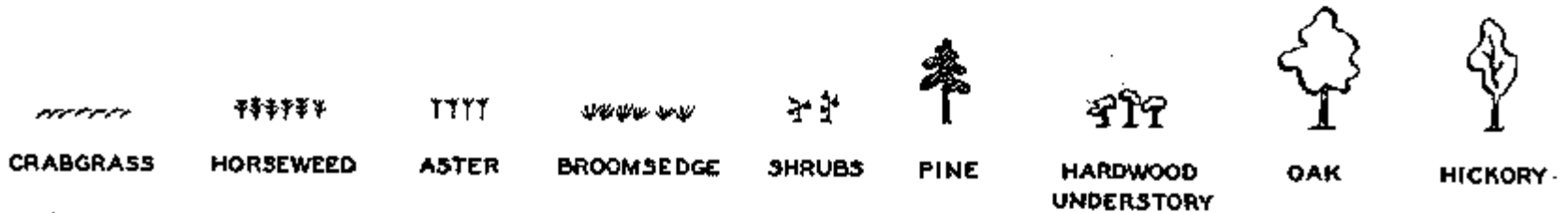
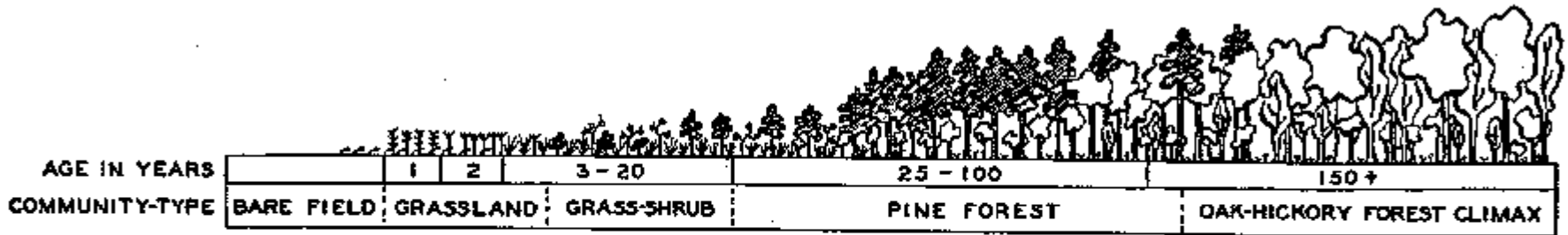


Bio-geochemical Cycles

Linking Production and Energy Transfer



Succession of Forest in temperate Southeast USA



Malfunctioning Human Ecology

- Destruction of natural systems through development, mining, agriculture, toxics generation
- The economic system and national accounts (GDP) do not take into account the destruction of natural systems nor the depletion of resources
- Humans are appropriating vast portions of biomass and water and are moving enormous quantities of materials
 - Humans are coopting 40% of terrestrial and 30% of aquatic Net Primary Production (NPP) (Vitousek et al 1986))
 - Humans are coopting 26% of all evapotranspiration and 54% of available water runoff, a net of about 30% of all the solar powered hydrologic cycle (Postel 1997)
 - Humans are moving more material than all natural forces combined (Schmidt-Bleek 1997)

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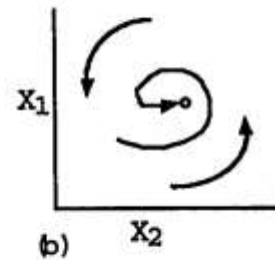
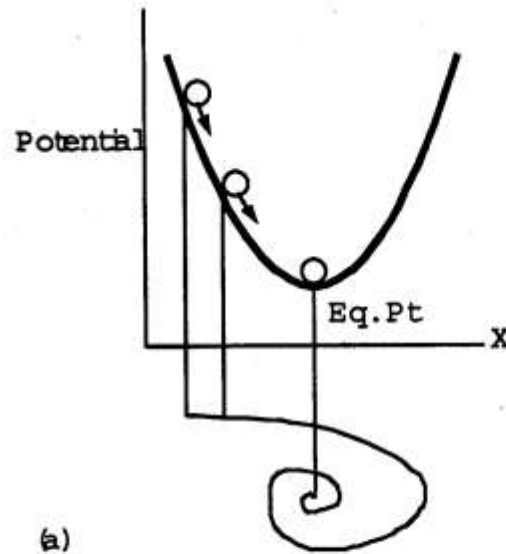
Resilience Theory

- Invert the normal pessimism
 - *“If the world really is collapsing, why do so many ecosystems persist?”*
- Develop common tools to study the decline, collapse or persistence of ecological, economic and social systems.
- You are resilient if your identity persists:
 - In the face of shock or disturbance the same set of organizing processes remain to control the behavior and appearance of a resilient system.

The Dynamics of Change: Paradoxical Twins

- Unpredictable Change - Surprises
 - Smooth, continuous change suddenly interrupted by reversal or collapse.
- Predictable Change - Return Times
 - Fires, Floods, Pest Outbreaks
- How do we reconcile these contradictions?

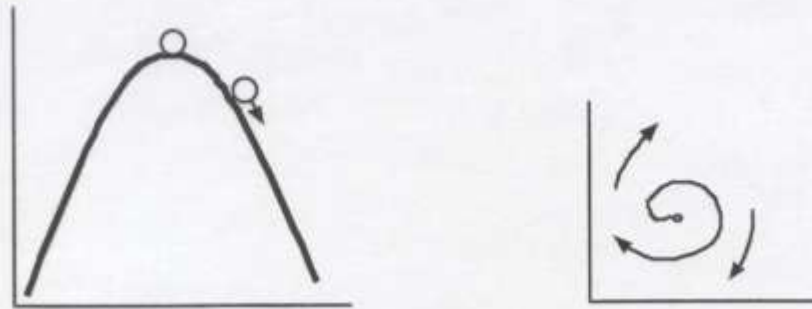
Landscape and State Space Views of Industrial Optimism



x_1	x_2
Wolf	Sheep
Algae	Reed

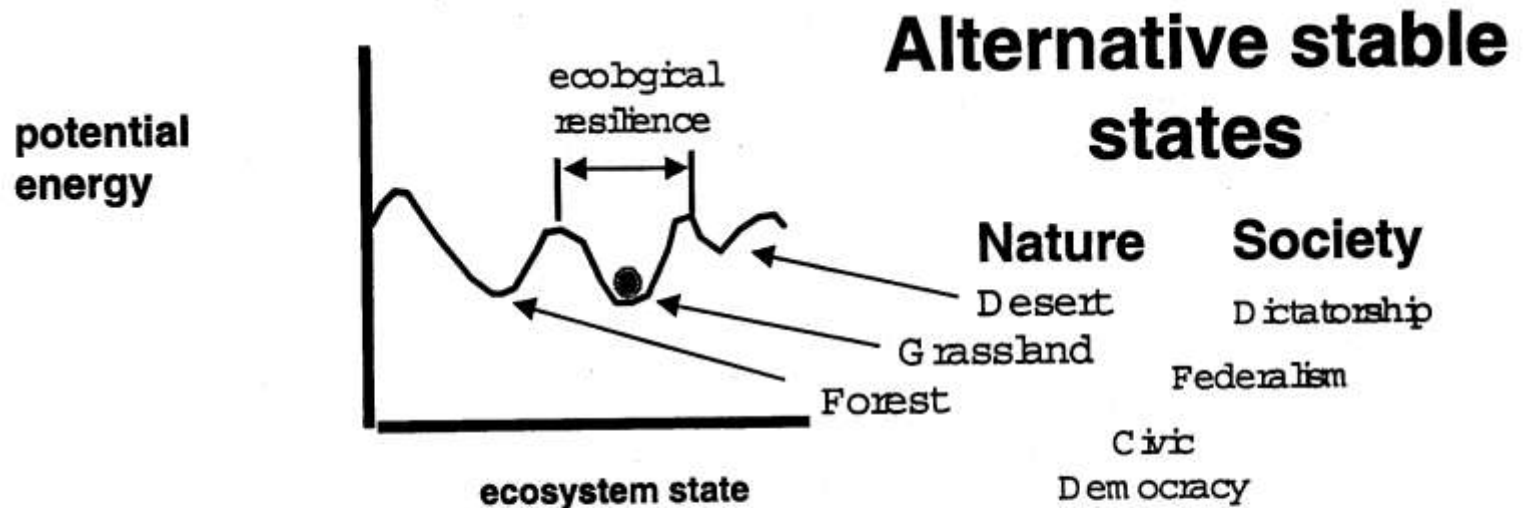
Two views of a stable equilibrium

Stability Landscape View of Ecological Pessimism



**Unstable Equilibrium (Cassandra):
The world is ephemeral and may collapse
at any minute for any small reason.**

Stability Landscape View of Multiple Stable States



An ecosystem may have several different organizations that are stable.

Examples of Multiple Stable States

➤ **Coral Reefs**

- coral vs. algae

➤ **Arid Landscapes**

- shrubland vs. grassland

➤ **Shallow Lakes**

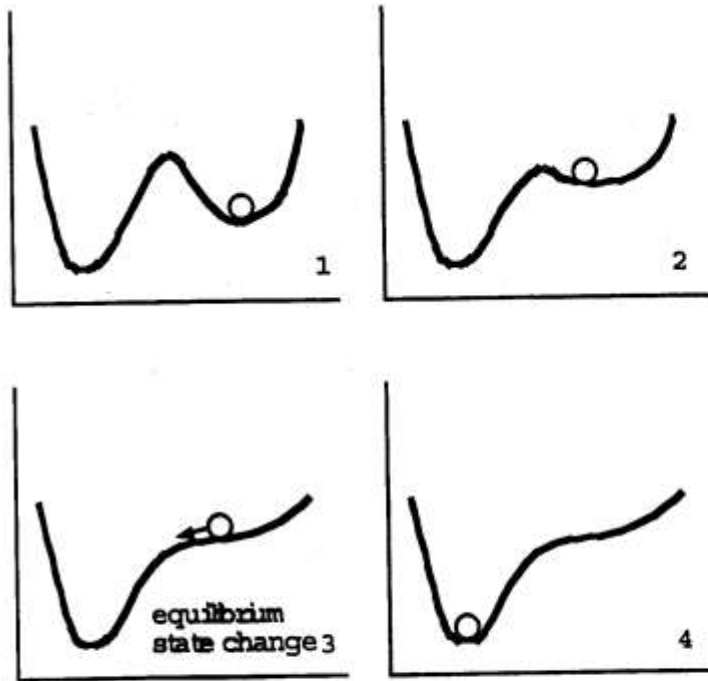
- eutrophic vs. clear

➤ **North Florida Forest**

- longleaf pine savanna & fire vs.
hardwood forest without fire

Stability Landscape View of Evolution

Shift from one domain to the next
as the rules change



Landscape and state space
views of evolving nature.

The system modifies its own possible states, as it changes. In this example as time progresses, a progressively smaller perturbation is needed to change the equilibrium state of the system from one domain to the other, until the system spontaneously changes state. (a) landscape representation. (b) equivalent state space representation

Ecosystem Resilience

Dynamic Exchanges between Stability and Disturbance

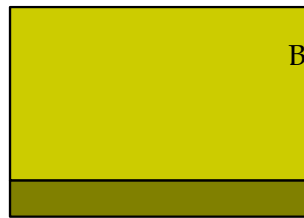
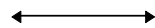
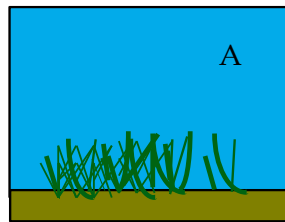
- **Stability** is recognized for its contributions to productivity and bio-geochemical cycles.
- Like 'invigorating' gymnastics, **disturbances** contribute to diversity, structure and resilience.
- The engine of evolution and resilience.
 - Not disturbance alone
 - Nor stability alone
 - But the cycling between them

Collapse of Resilience

⌘ Surprise from Cross-scale Interactions

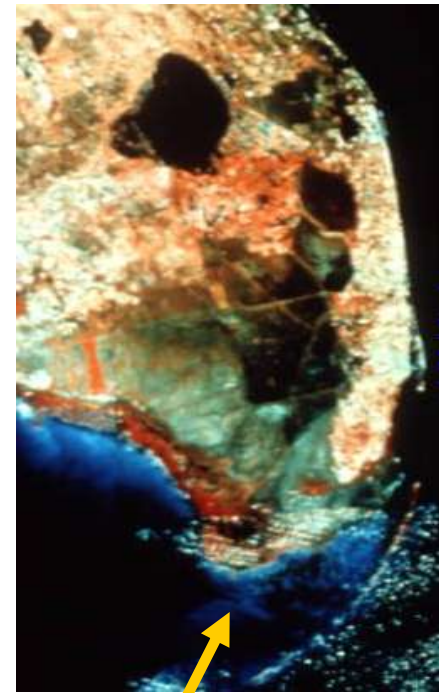
- Occasionally Natural systems develop to a stage of “over-maturity” where elements are over-connected.
- They become accidents waiting to happen.
- Then collective activities of small scale processes can “cascade upward” and cause the system to flip to another system type.

Surprise in Florida Bay



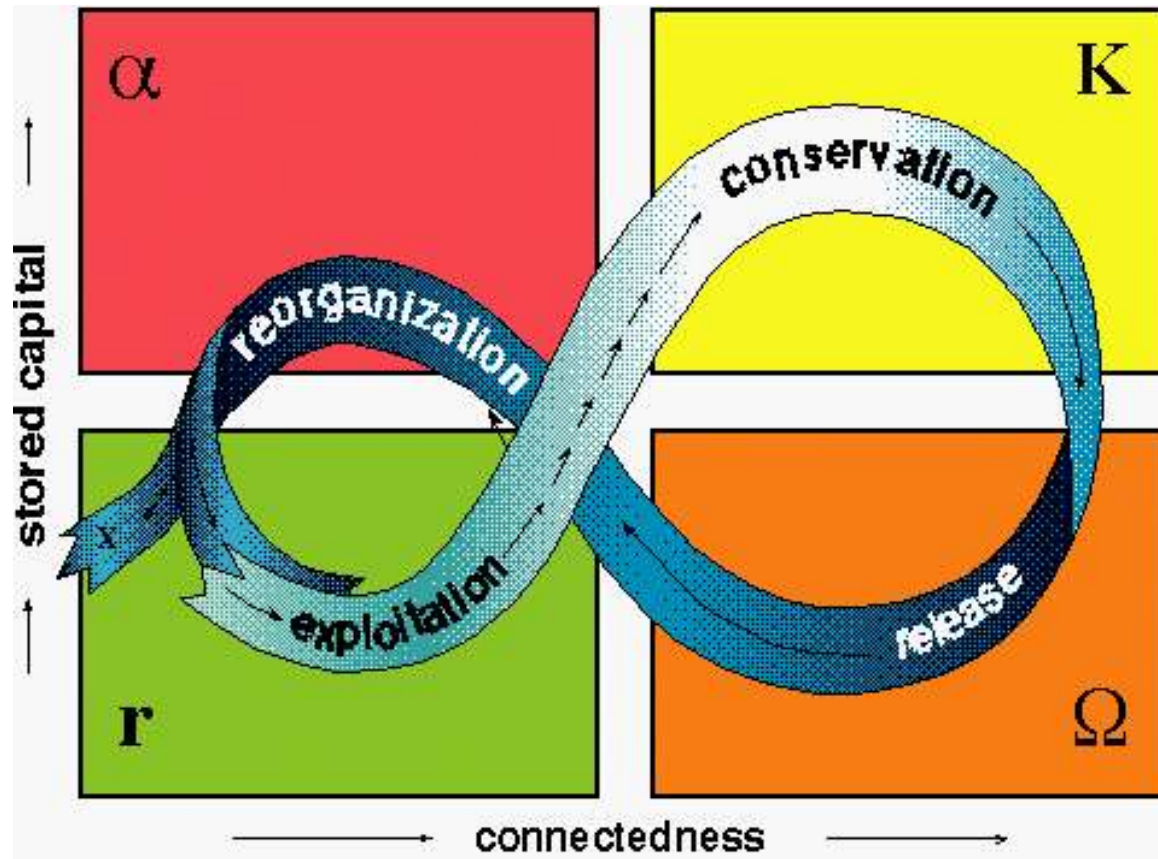
Sea grass
Clear Water

Muddy Water
Algae Blooms



Florida Bay

System Dynamics



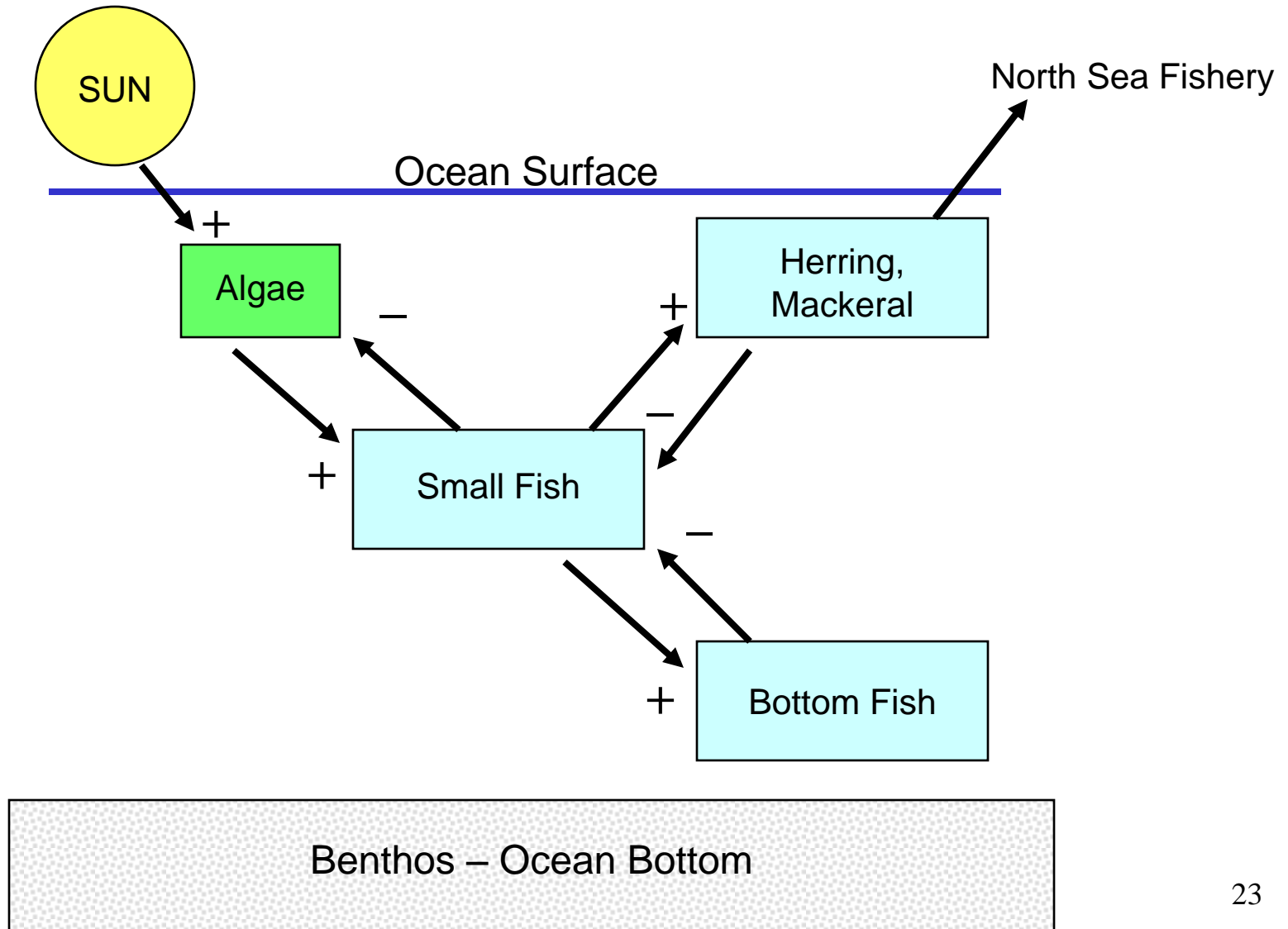
Temporal Surprise

Variables dislocated in time and space

- **Pelagic Fishery in North Sea**
 - Surface fish (herring and mackerel) eliminated by fishing pressure → Surprise: Bottom fish explode!
 - Loss of surface predators relaxed pressures on **smaller fish** (sand eels, Norway pout, young stages of bottom dwellers).
 - Smaller fish migrate to bottom carrying energy and nutrients.
 - Bottom fish populations increase suddenly.

Net Positive Feedback

Lose 1 Negative Feedback → Balance Shifts to Positive



Temporal Surprise

Variables dislocated in time and space

- **Pelagic Fishery in Lake Victoria, Kenya**
 - Surface fish (herbivores) eliminated by new predator → Surprise: Bottom fish die off!
 - New sport fish (Nile Perch) eliminates surface herbivores → algae sinks to bottom rather than recycled in epilimnion.
 - Algae accumulates on bottom → driving huge bacteria explosion → consume all oxygen.
 - Bottom fish populations die from anoxia and migrate to shallow areas near shore.

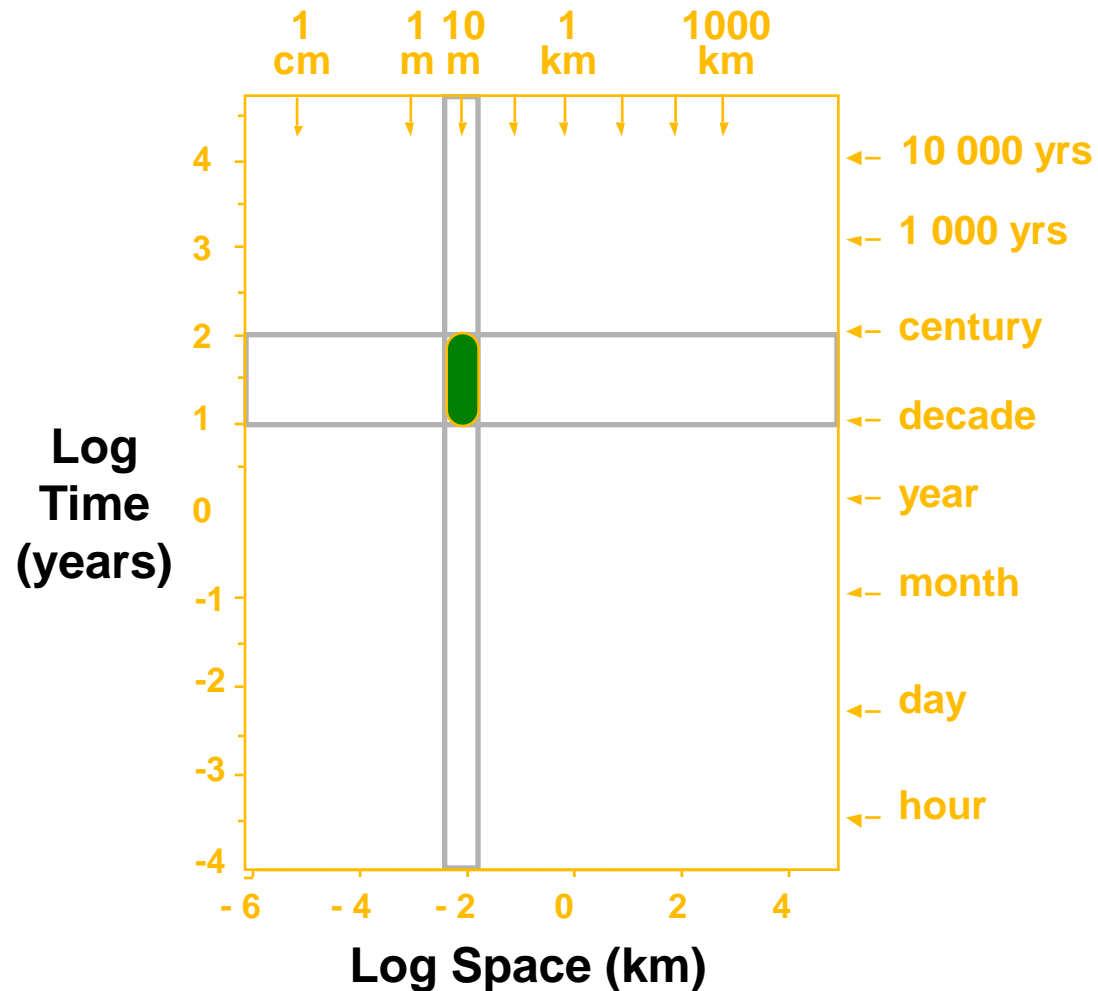
Sources of Uncertainty

- Spatial complexity hampers prediction
 - Natural systems are patchy and heterogeneous in the distribution of objects and in the scales at which processes operate.
- Summary
 - Different sets of processes dominate at different scales to generate different structures characteristic of those scale ranges.

Ecological Scaling

Scale is the spatial and temporal frequency of a process or structure.

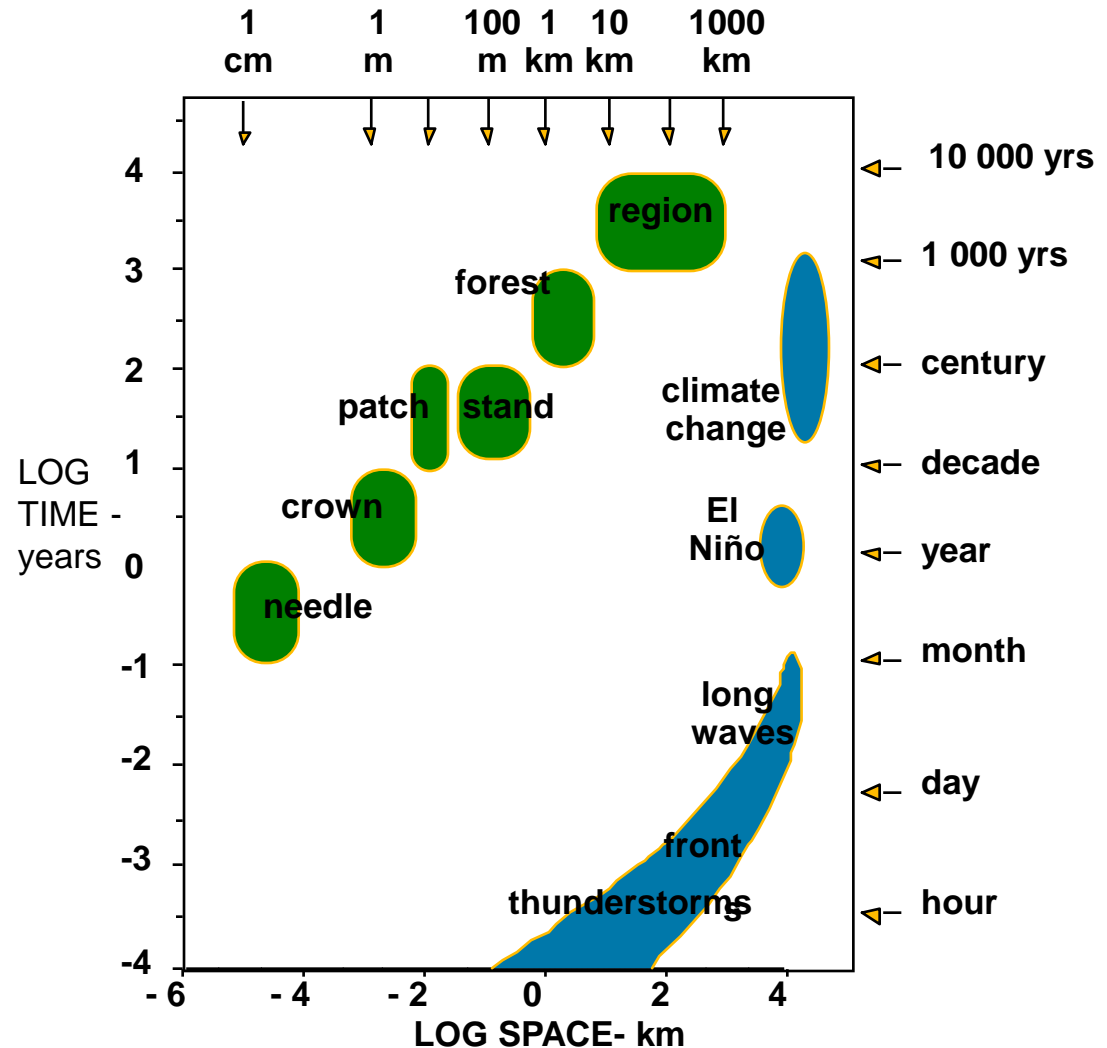
A scale domain is bounded by the grain size of processes detected and the extent or span of processes attended.



Vegetative & Atmospheric Scales

Atmospheric processes occur faster than vegetative processes occurring at the same spatial scale.

- Vegetative Structures
- Atmospheric Processes



What Processes Produce the Forest Mosaic of Bialowieza?



Time and Space Scales of Processes Structuring the Bialowieza Forest

No.	Process	Time (Cycle Time)	Space (Window Edge)
1	Competition (Light)	Seconds	Centimeters
2	Senescence/Wind Throw	Days to Months	Cm – 5 meters
3	Browsing by Megafauna	Months to Years	Cm – 5 meters
4	Contagious Agents (Moths, Fire)	Year to 10 Years	50 m - kilometer
5	Agriculture, tree harvest	Year to 80 years	100 m - kilometers
6	Drought	10 to 100 years	100 kilometers
7	Geomorphology (Glaciers)	1000 to 10 000 yrs	1000 kilometers

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Ecological Resilience

- ❑ **Measures system integrity as the capacity to absorb disruption and remain the same kind of ecosystem.**
- ❑ **Emerges from cross-scale interactions**
- ❑ **Depends upon:**
 - **Control of Disturbance**
 - **Regulation of Renewal**



What Promotes Resilience?

□ Control of Disturbance

- Disturbance Frequency and Intensity**
 - Technical Restrictions**
 - Chesapeake Shellfish Fishery**
 - Herbivore grazing/browsing**
 - Fire or logging in forests**
 - Development in floodplain**
 - Local rain cycle in river basins**

What Promotes Resilience?

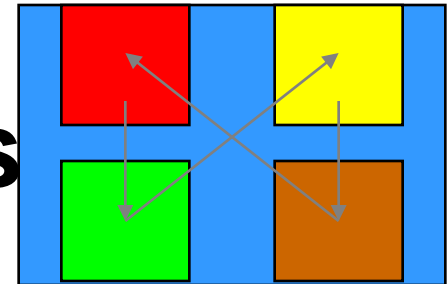
□ **Control of Disturbance**

- **Capacity to Absorb Disturbance**
 - Landscape morphometry
 - Room for the River Program - Rhine river
 - Habitat availability
 - Ability to migrate (connectivity of landscape)
 - Spatial Heterogeneity (mangroves, eel grass)
- **Processing and Cycling of Resources**
 - Cross-scale functional reinforcement
 - Within-scale functional diversity

What Promotes Resilience?

□ Regulation of Renewal (or Regenerative potential)

–Stored Resources



–Soil depth, organic content, seed bank

–Water (aquifer, lake, river)

–Nutrients in biomass

What Promotes Resilience?

□ Regulation of Renewal

– Facility of Response

– Recolonization distance

– Proximity of Youth (Kobe Earthquake)

– Biodiversity

– Cross-scale functional diversity

– Capacity to adapt, to generate novelty, to innovate

What Promotes Resilience?

□ **Regulation of Renewal** (Regenerative potential)

– **Availability of Information**

– **Viability of cultural information transfer - *Cultural Capital***

– Language (Norway surrenders to English)

– Customs (education, discourse)

– Politics and institutions

– **Human Memory & Population Age Structure**

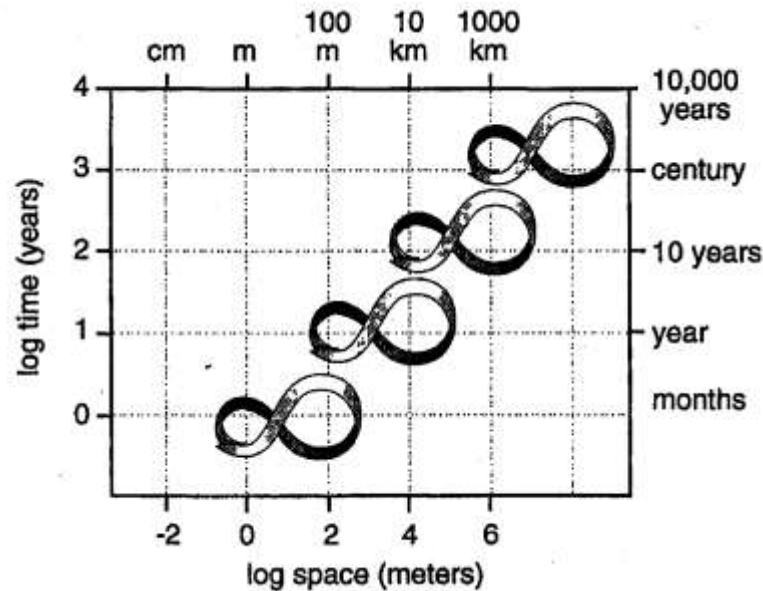
– Cree People and Caribou (Birkes)

Why Panarchy Theory?

- Rationalize the interplay between:
 - Predictable and unpredictable
 - Evolutionary change and persistence
- Explore the world where different variables are nested inside of one another and change at different scales in space and time.

Panarchy

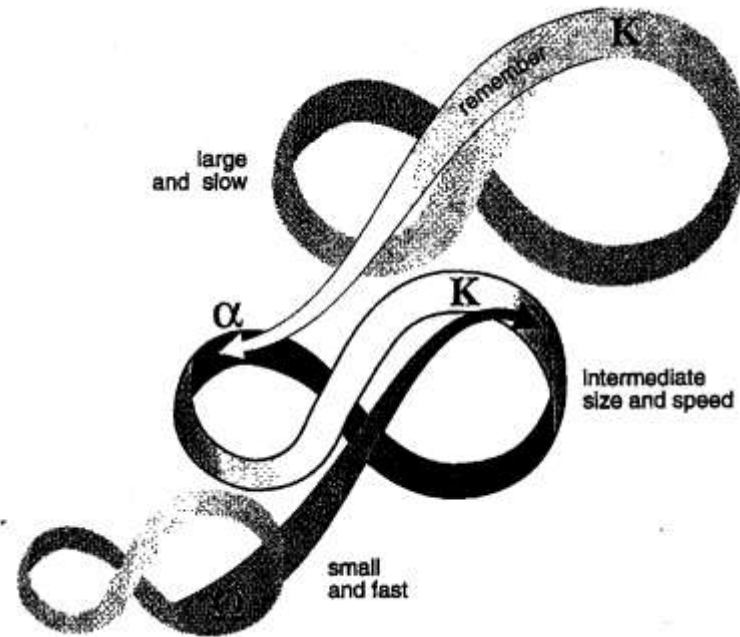
A Cross-scale Nested Set of Adaptive Cycles



Why Panarchy Theory? To Account for Dynamics

- Within a level
 - Adaptive cycle describes the engine of novelty, Creative Destruction, and renewal or reorganization.
- Between levels
 - Revolt – the cascade upward of tiny events
 - Remember – the context of the next larger level at climax constrains the next smaller level in times of renewal

Cross-Scale Interactions: Revolt and Remember



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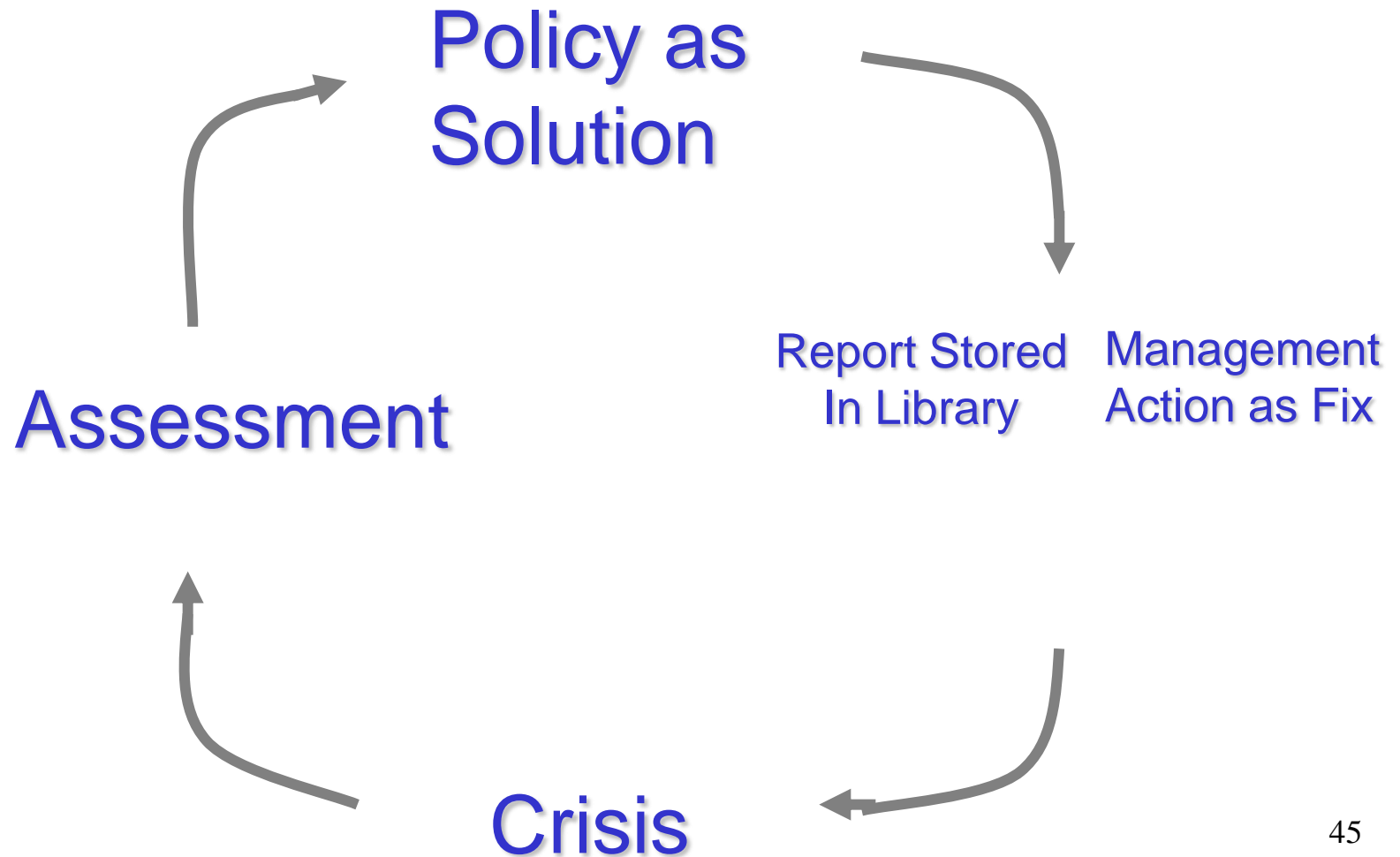
Mandate to Counter-pose Theory and Practice

- Science can't address problems alone
 - *Control, replication and isolation* of single causative variables are impossible in a multi-variate arena (interface of nature/society).
- Problem causes and solutions are dynamic
 - Uncertainty emerging from change is increased by society's attempts to learn and manage. We need adaptive ways to understand and implement new ideas that flexibly integrate theory and practice.

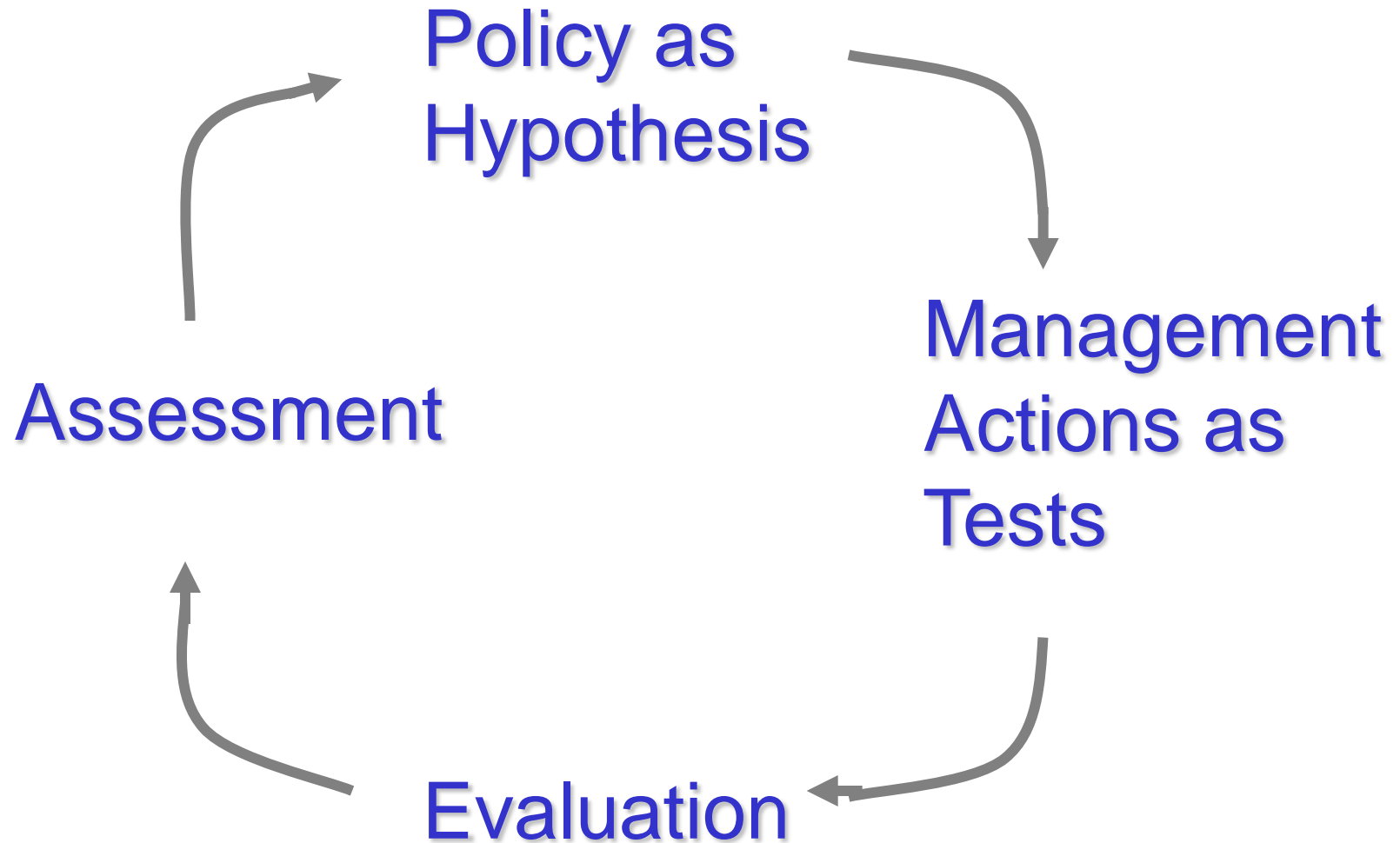
Learning That Persistently Adapts

- Truth is not constant but evolutionary
- Social and natural systems continue to change
- Initial responses to crises were not as important as the sustained capability to learn and respond accordingly.

Conventional Response to Crisis: Reliving Mistakes



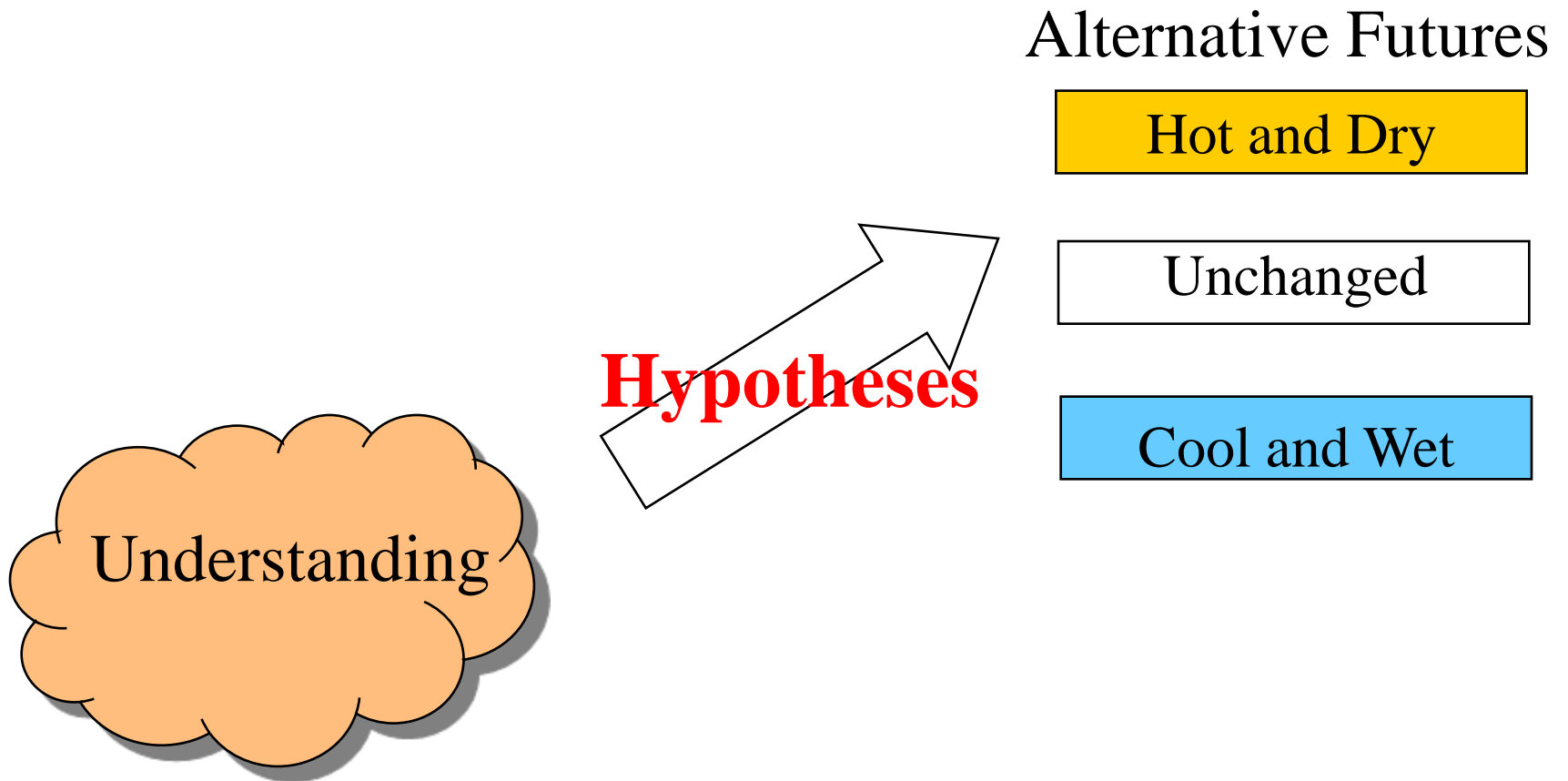
Research and Management Linked in a Cycle of Integrated Learning



Assessing Both the Known and the Uncertain

- Use disagreements to reveal gaps in understanding.
- Common gaps and links in understanding can bridge the various backgrounds .
- Computer models do not equal vehicles of truth; they integrate peoples' understanding.
- Ponder uncertainties to the point that they can be clearly stated as hypotheses.

Connecting our Understanding to the Future

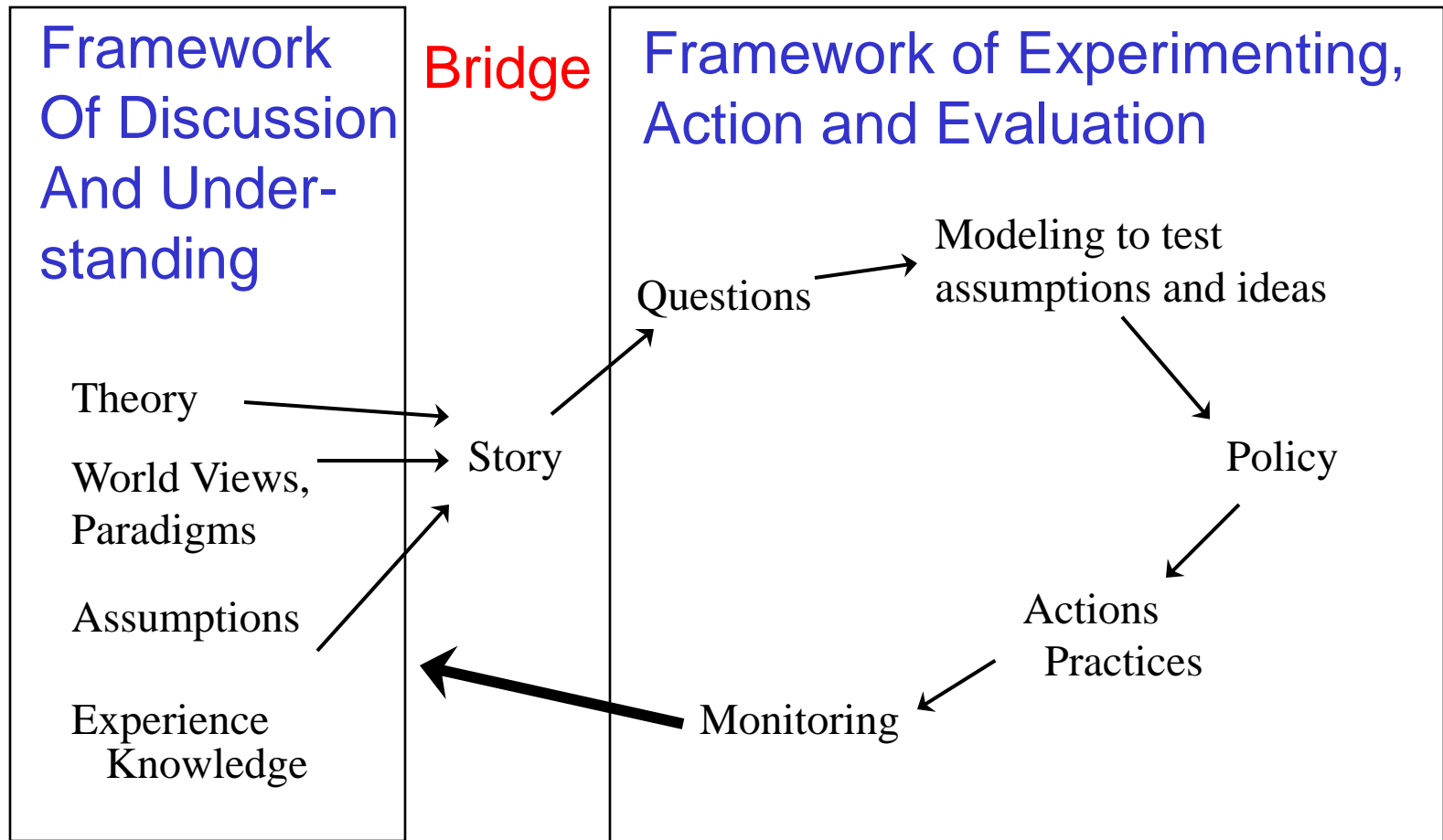


Adaptive Management (AM): Policies as Hypotheses

■ Policies

- are the question set based on experience that sets the stage of further action.
 - are not magic bullets that address the right mix of objectives to solve a problem, rather they are astute hypotheses about how the world works
 - are “Questions masquerading as answers”
-
- AM embraces uncertainty by trying to find the best questions, avoiding the trap of assuming certainty by rallying around ‘solutions.’

Little Stories with Large Impacts



Summary

- *Classic Ecology* – the basis of system productivity and stability.
- *Resilience theory* describes how different variables influence system dynamics at different scales.
- *Adaptive Management* allows us to integrate research, policy and practice to adapt our understanding and methods to a changing world.