Freshwater Sediments and Biodiversity

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Palma Declaration on Biodiversity Research

"Biodiversity loss is probably the greatest challenge human societies face today.

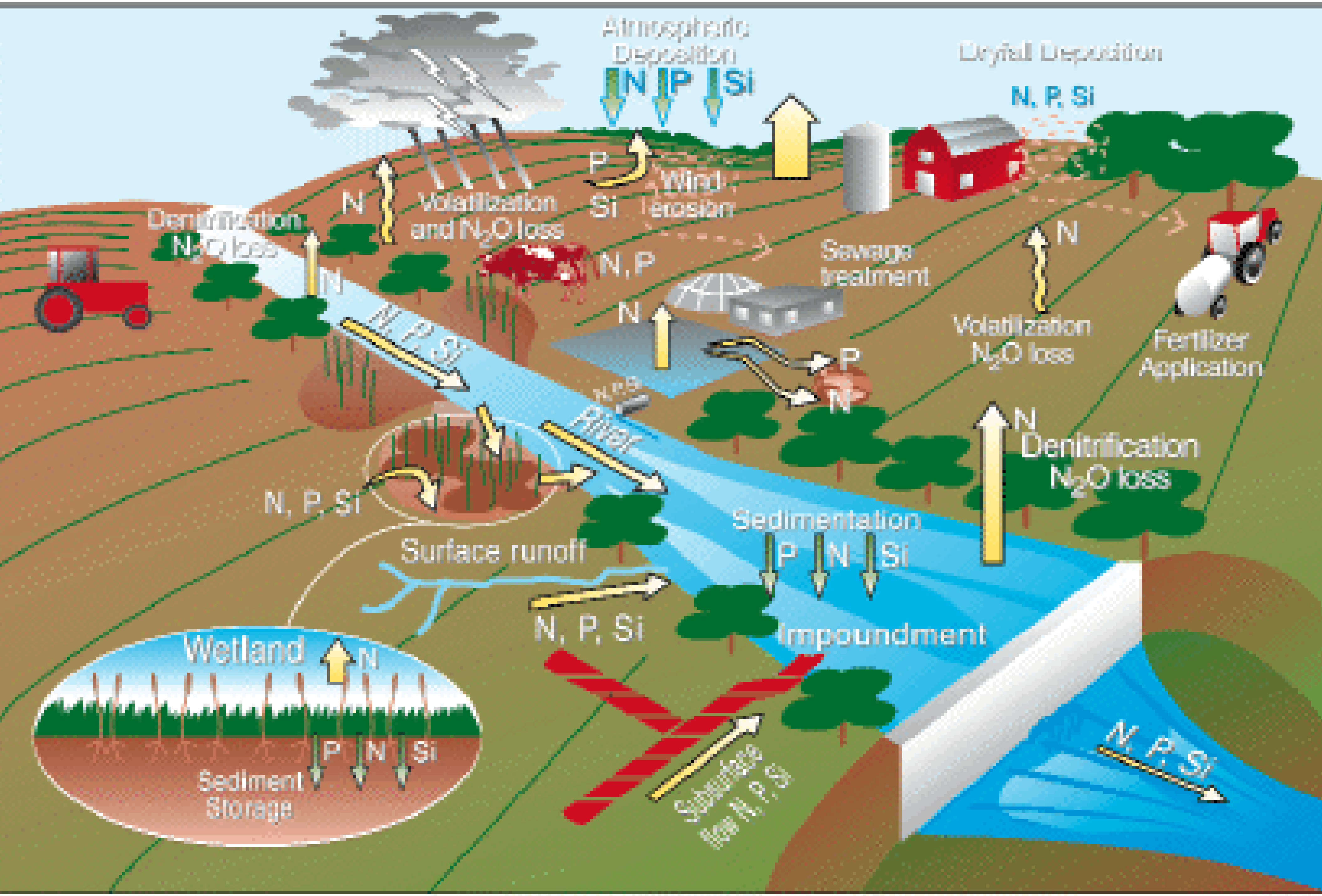
European Platform for Biodiversity Research Strategy, 2010

Outline of Main Points

Climate warming increases variability in freshwater sedimentary habitats and decreases benthic biodiversity and functional diversity of species.

The number, intensity and duration of floods and droughts can *decrease benthic biodiversity* and *decrease freshwater ecosystem services* such as decomposition rates and carbon storage as well as water quality.

Comparisons across regions will be needed to compare rates of change in nutrient cycling, primary productivity, and invasive species that affect sustainable ecosystem services.


Atmospheric Deposition
N P Si
Dryfall Deposition
N, P, Si
P
Si
Wind erosion
N
Volatilization and N_2O loss
Denitrification N_2O loss
N
N, P
Sewage treatment
N
Volatilization N_2O loss
Fertilizer Application
N, P, Si
River
P
N
N
Denitrification N_2O loss
N, P, Si
Sedimentation
P N Si
Surface runoff
N, P, Si
Impoundment
Wetland
N
P N Si
Sediment Storage
Subsurface flow N, P, Si
N, P, Si

What are the effects of flooding?

How can river bank development change the river's biodviersity?

What are some values of ecosystem processes that sustain food webs, migratory water fowl, other wildlife, and fisheries production?

Sustainable Management of the Sava River
and
Importance of Native Benthic Species in Ecosystem Services

1. How does the natural flow regime influence the fluvial geomoprhology and biodiversity of large rivers?

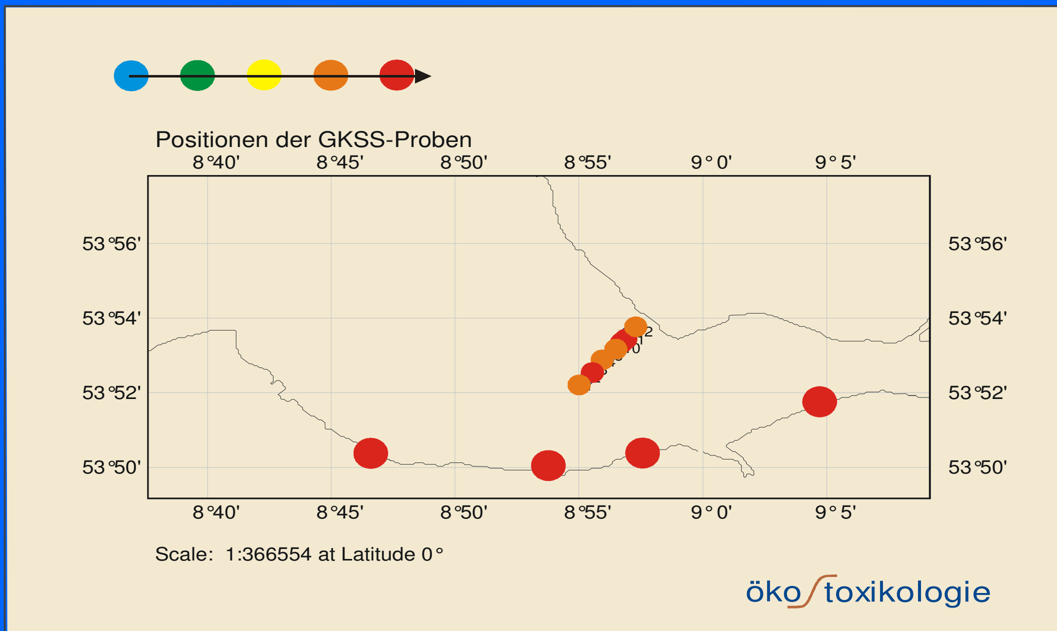
2. What is the importance of the relative abundances of native and non-native species in processing organic matter?

3. How many native species are needed to provide natural ecosystem services such as "self-purification" of river water that is suitable for supplies of municipal drinking water, industrial cooling, and recreational fishing and boating?

4. Does the introduction of non-native species increase the likelihood that additional non-native species will be invade rivers in the near future?

5. Can shipping and industrial development be managed to reduce the invasions of non-native species?

Other results?



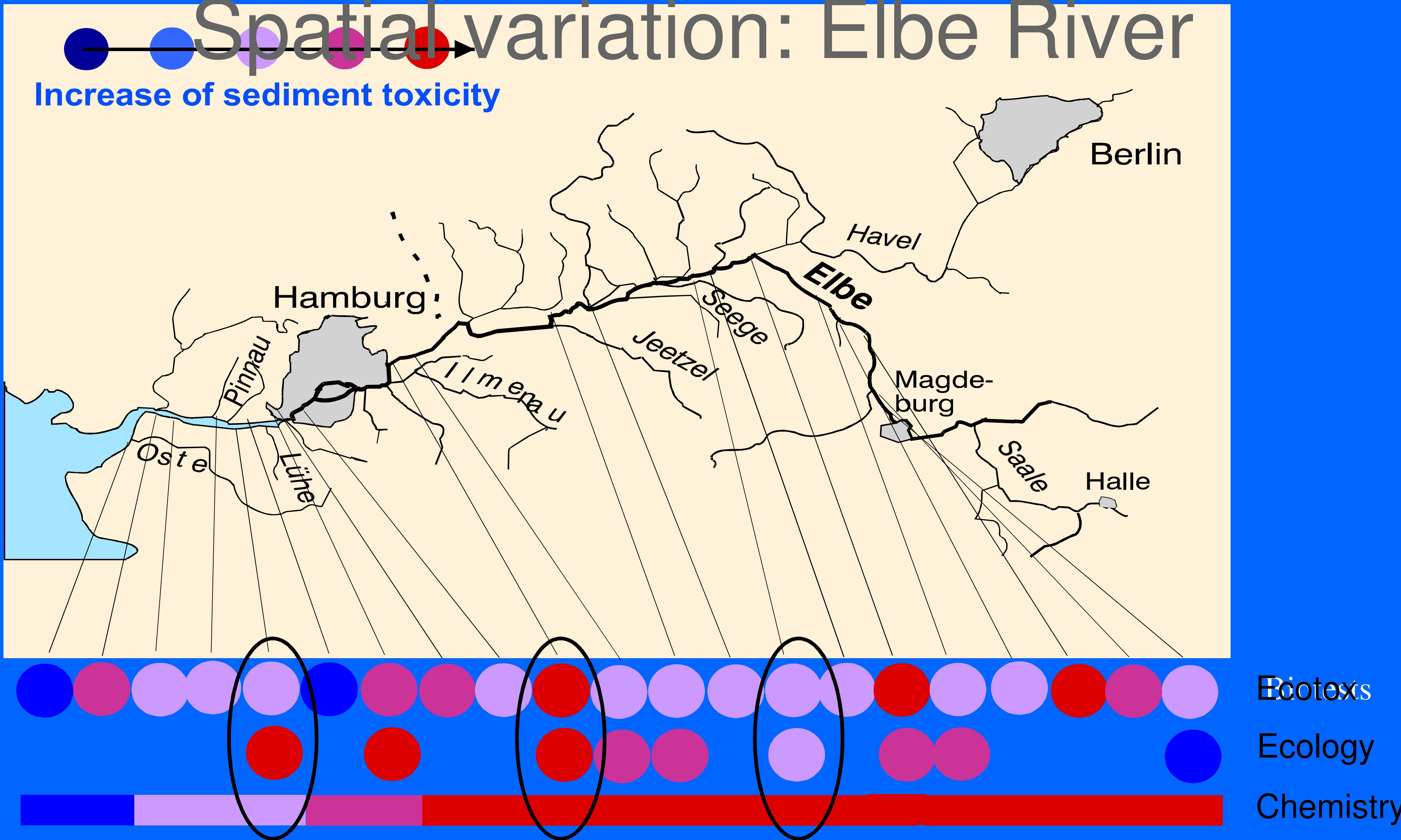
Increased toxicity with algae (elutriate), bacteria and nematodes (sediment)

(*Heise et al. 2003*)

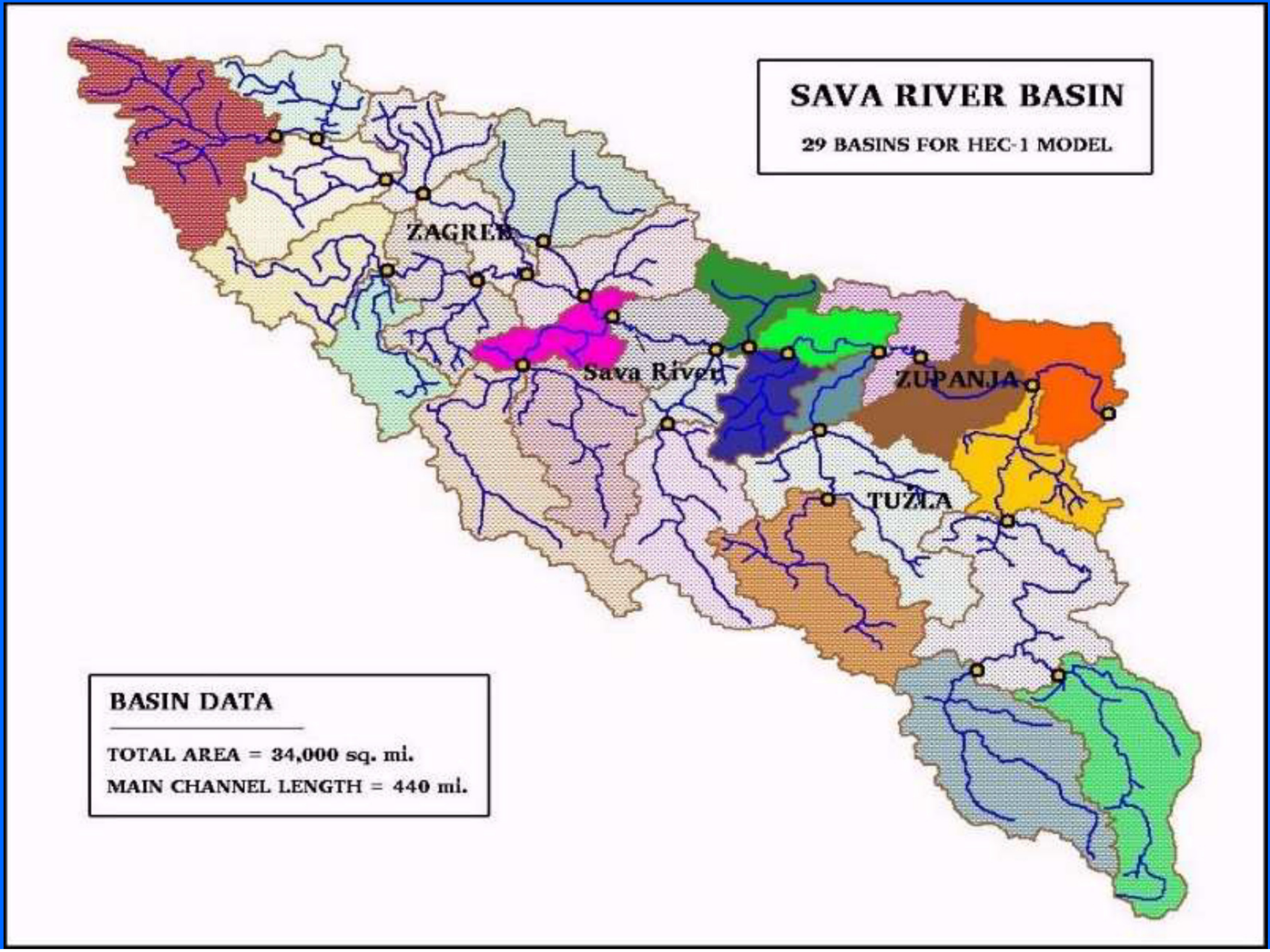
Ötken et al. 2005: No effects of estuarine sediments after the flood on *Chironomus riparius* (insecta) and *Potamopyrgus antipoda*rum (gastropoda)

Einsporn et al. (2005): toxic effects in flatfish and mussels after the flood. Flatfish were most affected in the Elbe estuary and near Helgoland. High levels of organic contaminants in fish liver and mussels.

Spatial variation: Elbe River

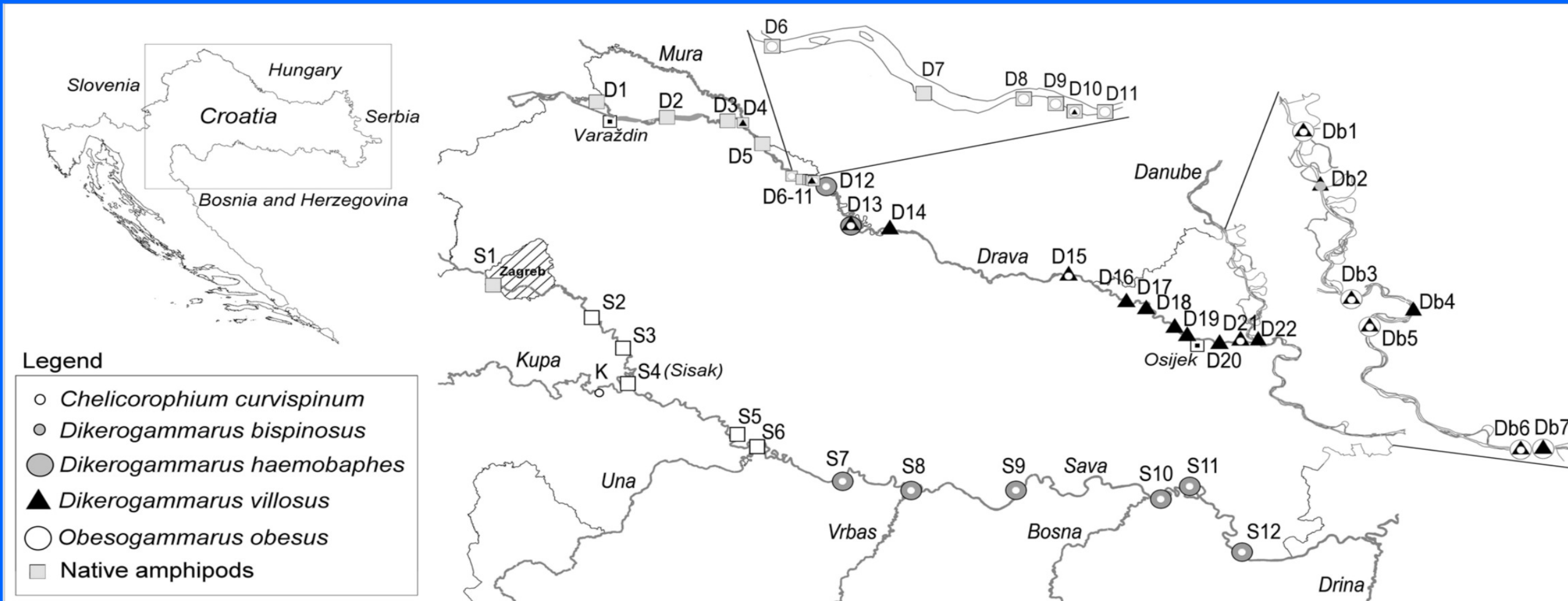


Considering Upstream – Downstream Connections




Lonjsko Polje
Nature Park

Invasive Non-Native Amphipod Species Along the Sava River



Zganec, K., S. Gottstein and S. Hudina 2009. Ponto-Gaspian amphipods in Croatian large Rivers. Aquatic Invasions 4: 327-335.

Diversity and Dispersal of Native and Non-Native Species

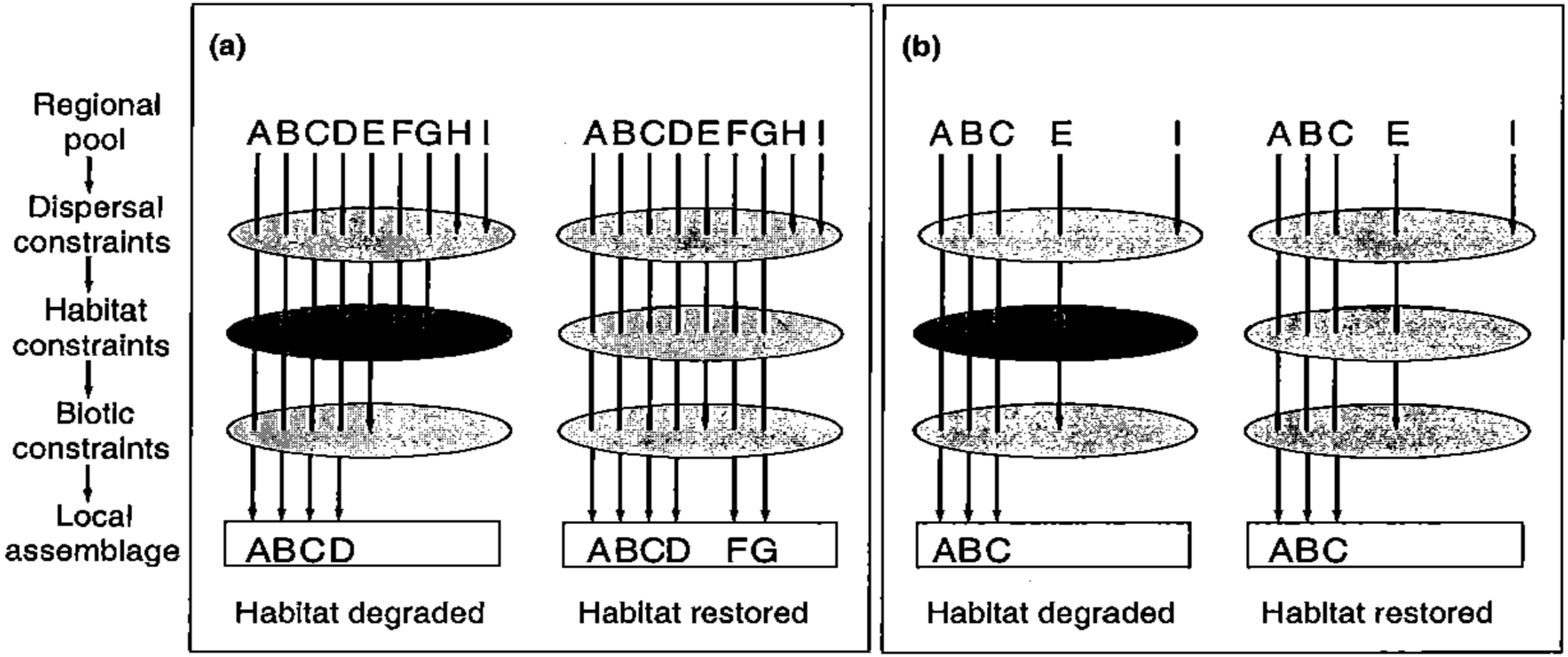


Fig. 2 Hypothetical outcomes of habitat restoration on a local species assemblage with (a) intact and (b) depleted regional species pools. Restoring habitat when the regional species pool is intact allows species F and G to pass through the environment-constraint filter and thus contribute to the local assemblage. However, when the species pool is depleted, comprising only resistant species, restoring habitat does not result in species additions at the local scale (adapted from Rahel 2002).

Definitions

Alien = exotic = nonindigenous = nonnative

Invasive = spreads and causes (net) harm

Invasive alien = focus of concern

www.invasivespecies.gov

Alternative Paths to Restoration

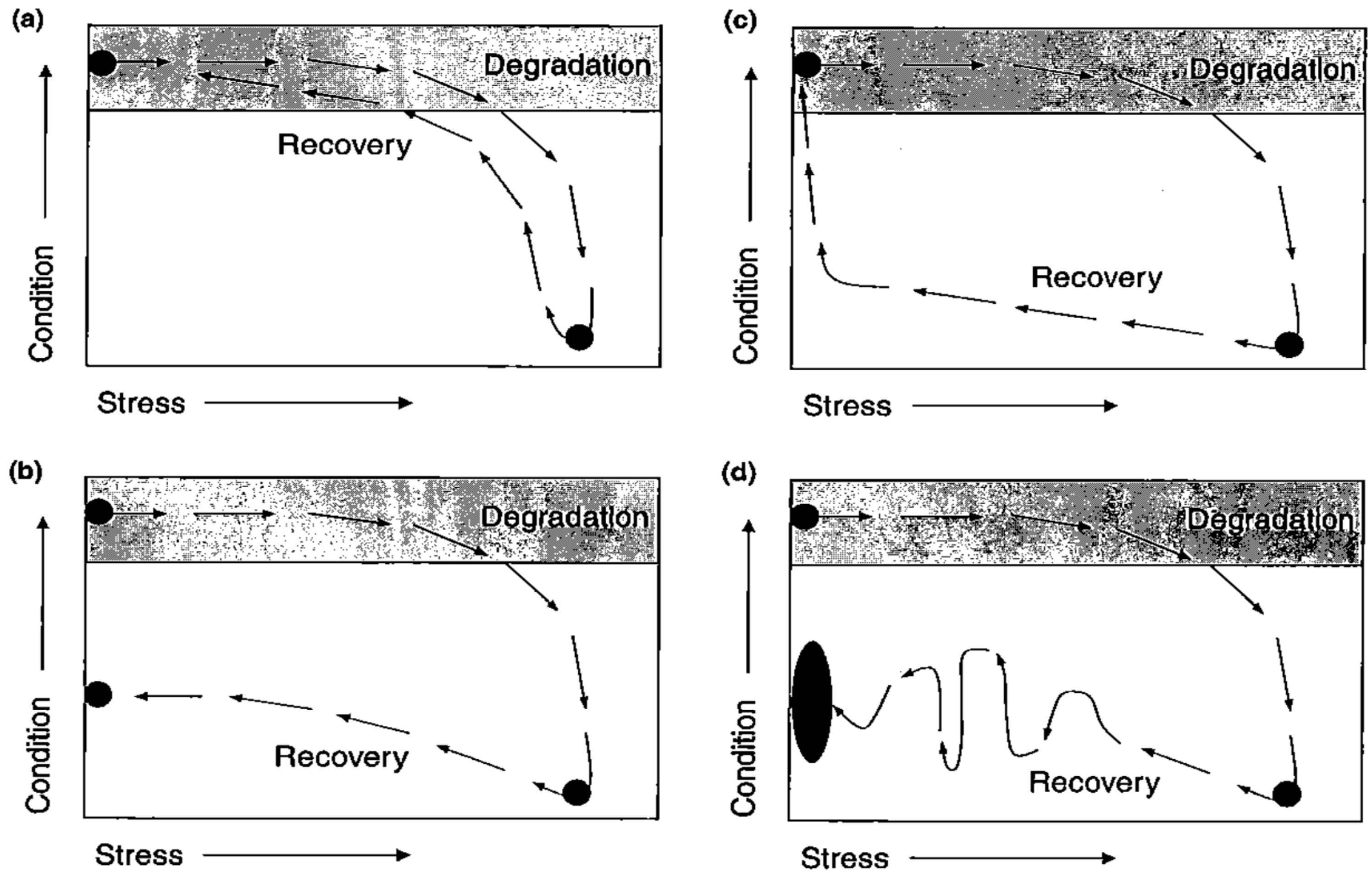
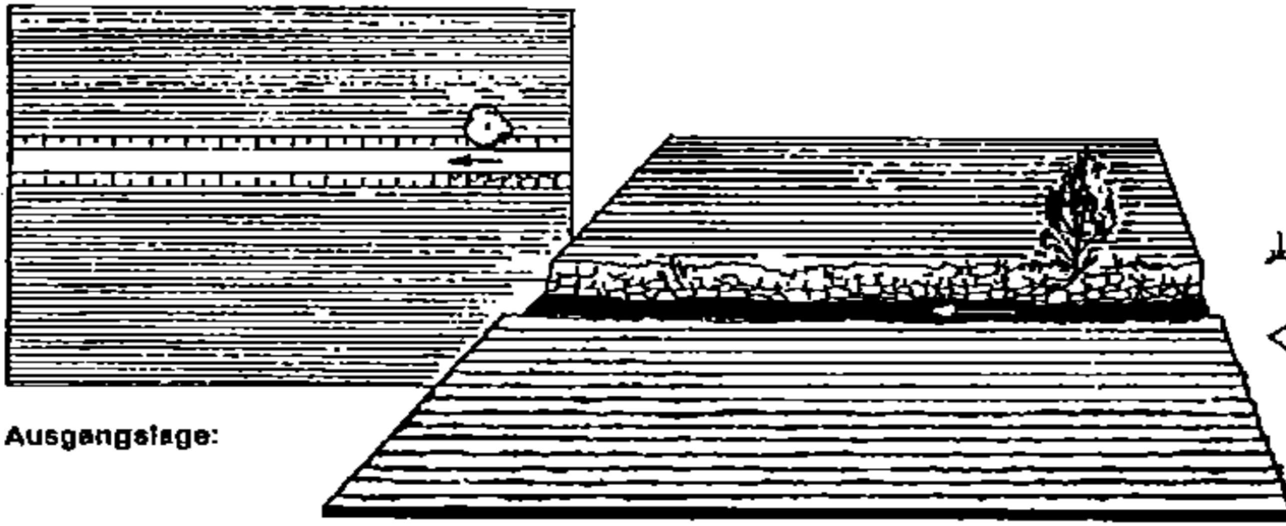
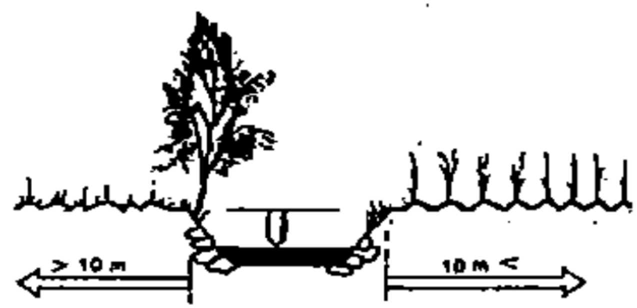


Fig. 3 Four potential degradation-recovery pathways (adapted from Sarr, 2002): (a) the 'rubber band' model in which recovery follows closely the pathway of degradation, (b) the 'hysteresis' model in which recovery follows a lengthy, non-linear pathway as stress is removed, (c) the 'Humpty–Dumpty' model in which recovery could follow various trajectories but the endpoint is distinct from the predegraded condition and (d) the 'shifting target model', an extension of the 'Humpty–Dumpty' model in which the recovery pathway itself is unpredictable and the endpoint becomes a shifting target bounded by distinct limits (hatched area). Condition on the *y*-axis corresponds to any indicators adopted as targets within the restoration project.

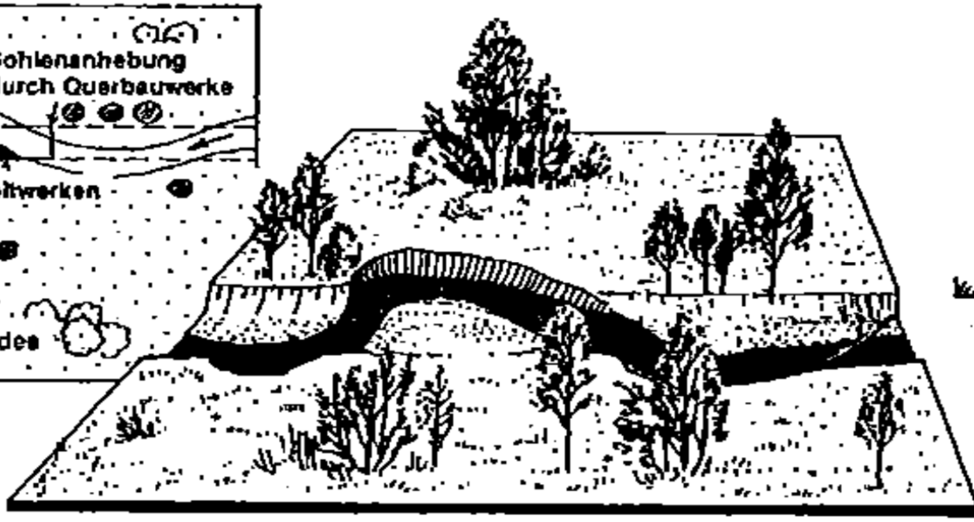
Ausgangslage:

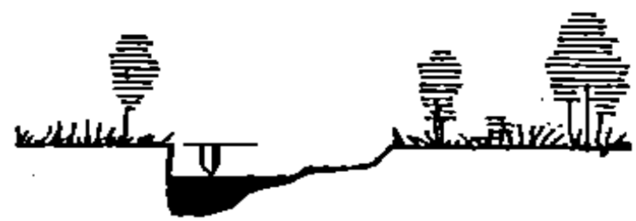




Uferstreifen bereitstellen (Grunderwerb)
Ufersicherung (Steinwurf) entfernen
Nutzungsumstellung

Entwicklungsphase I





Förderung der Eigenentwicklung durch Maßnahmen der Gewässerpflege

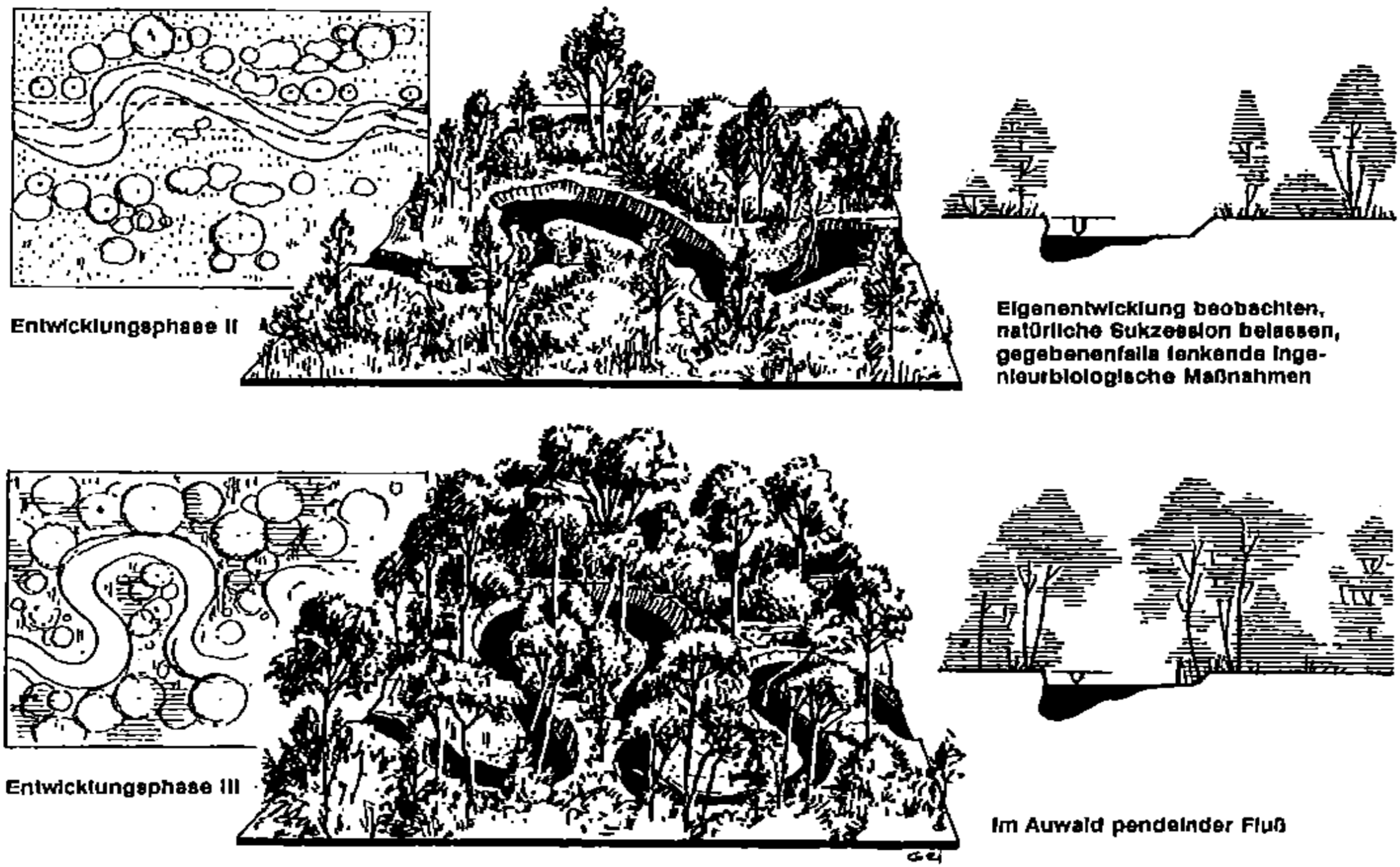
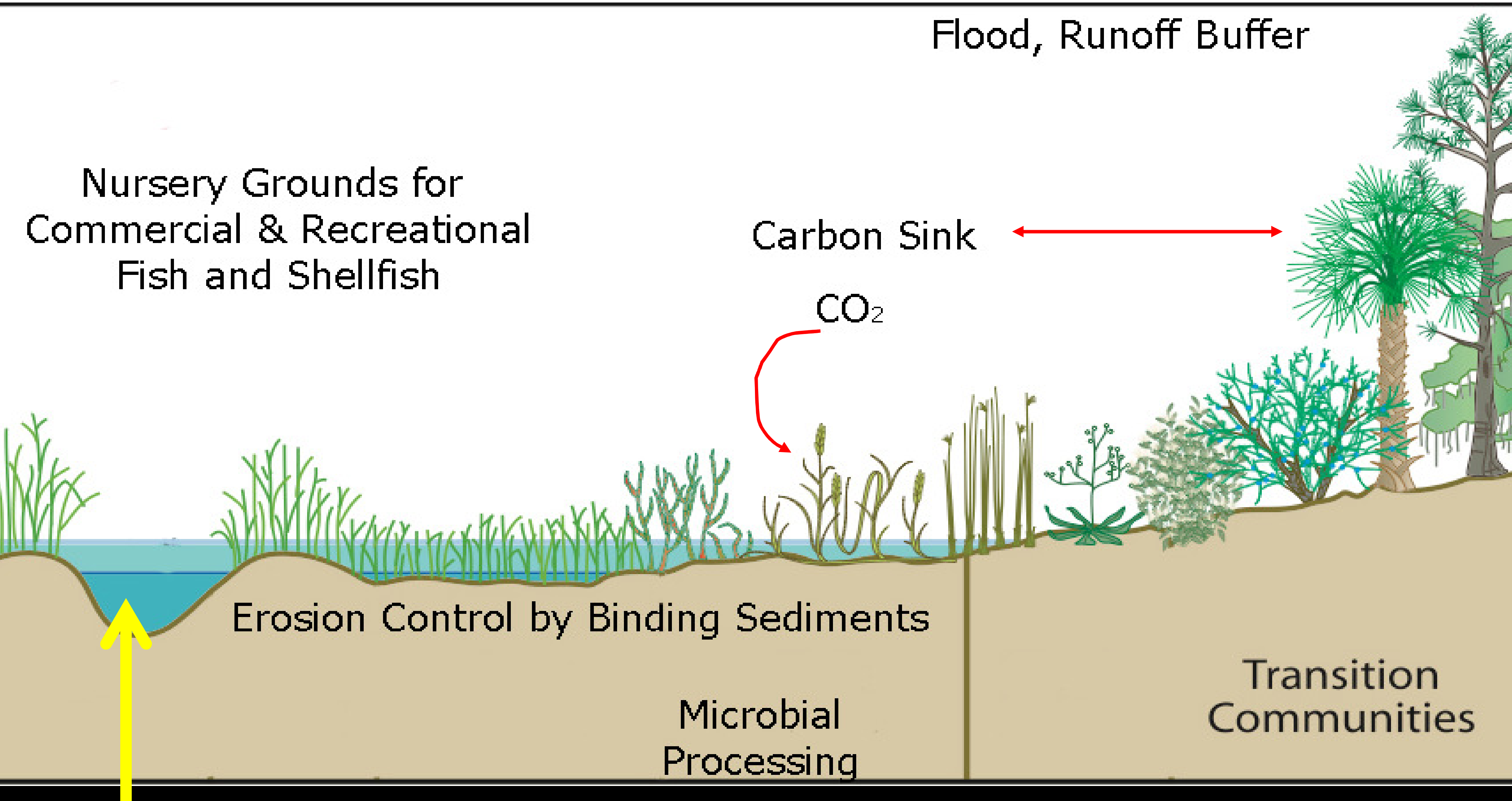


Figure 2. From static to dynamic. Steps of river restoration from a channelised, back to a natural river.



What is the legacy of sediment contaminants?
How does sedimentary phosphorus recycle?

J. R. Sedell & J. L. Froggatt, Importance of streamside forests

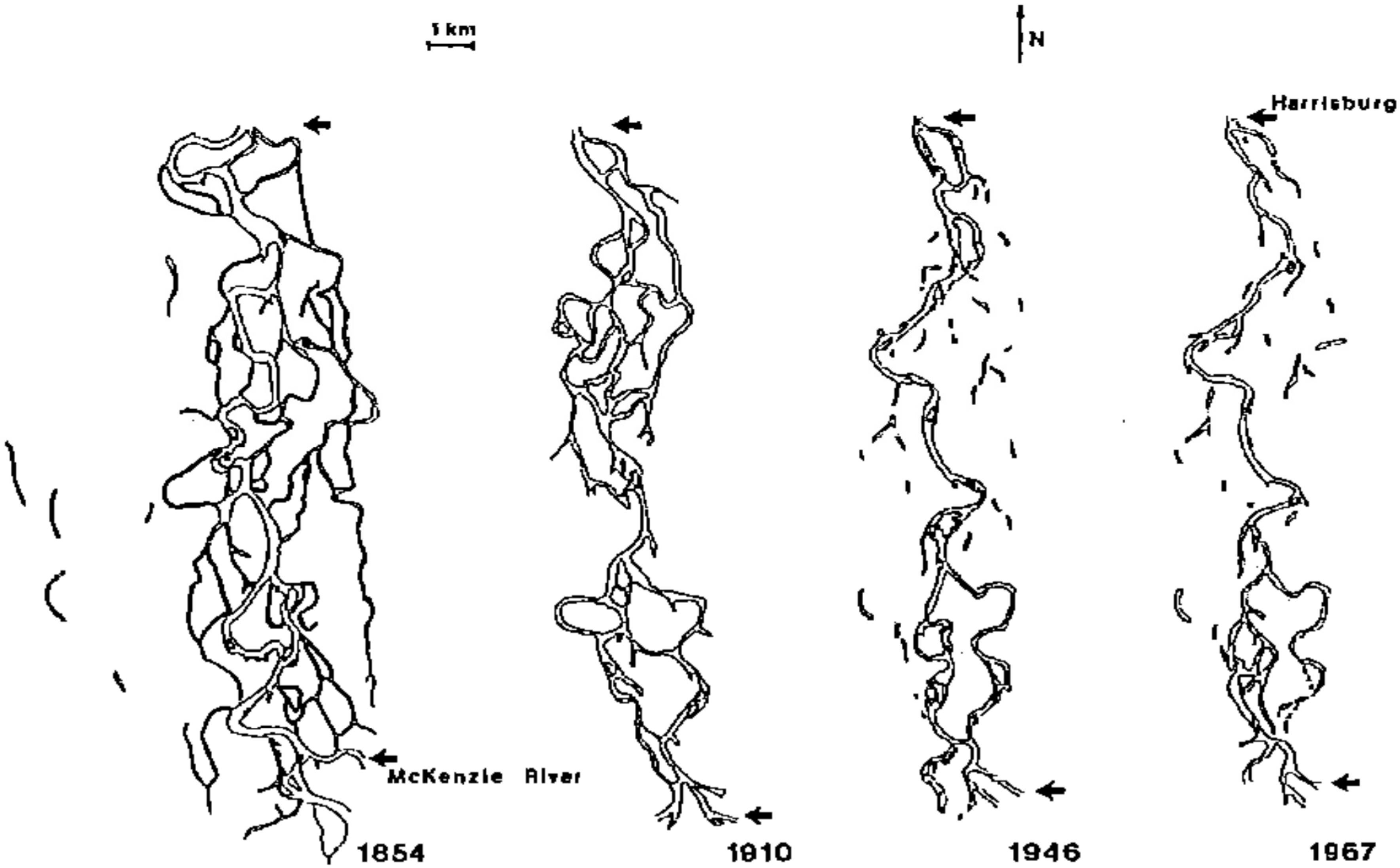
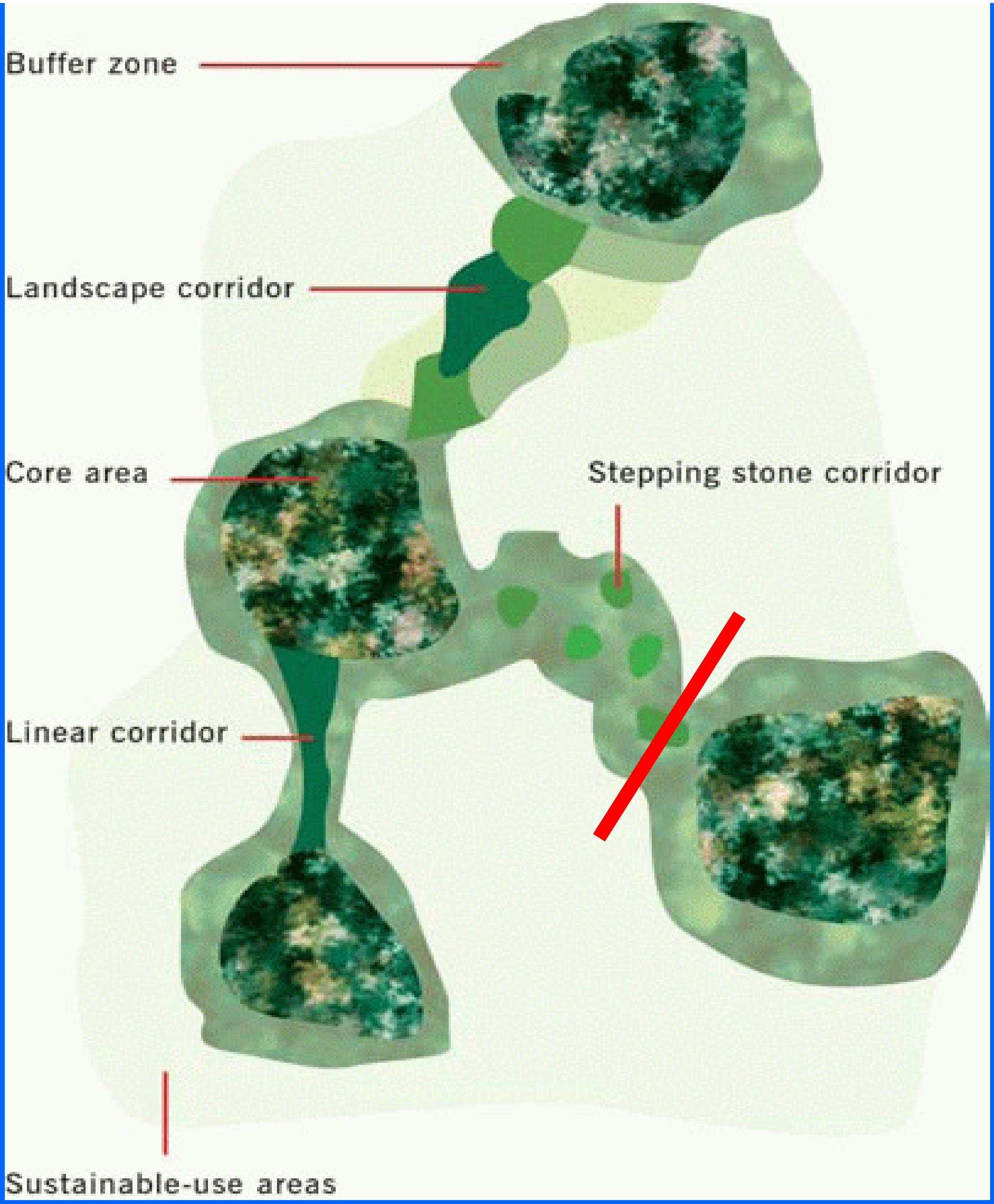


Fig. 2. The Willamette River from the McKenzie River confluence to Harrisburg, showing reduction of multiple channels and loss of shoreline 1854—1967.



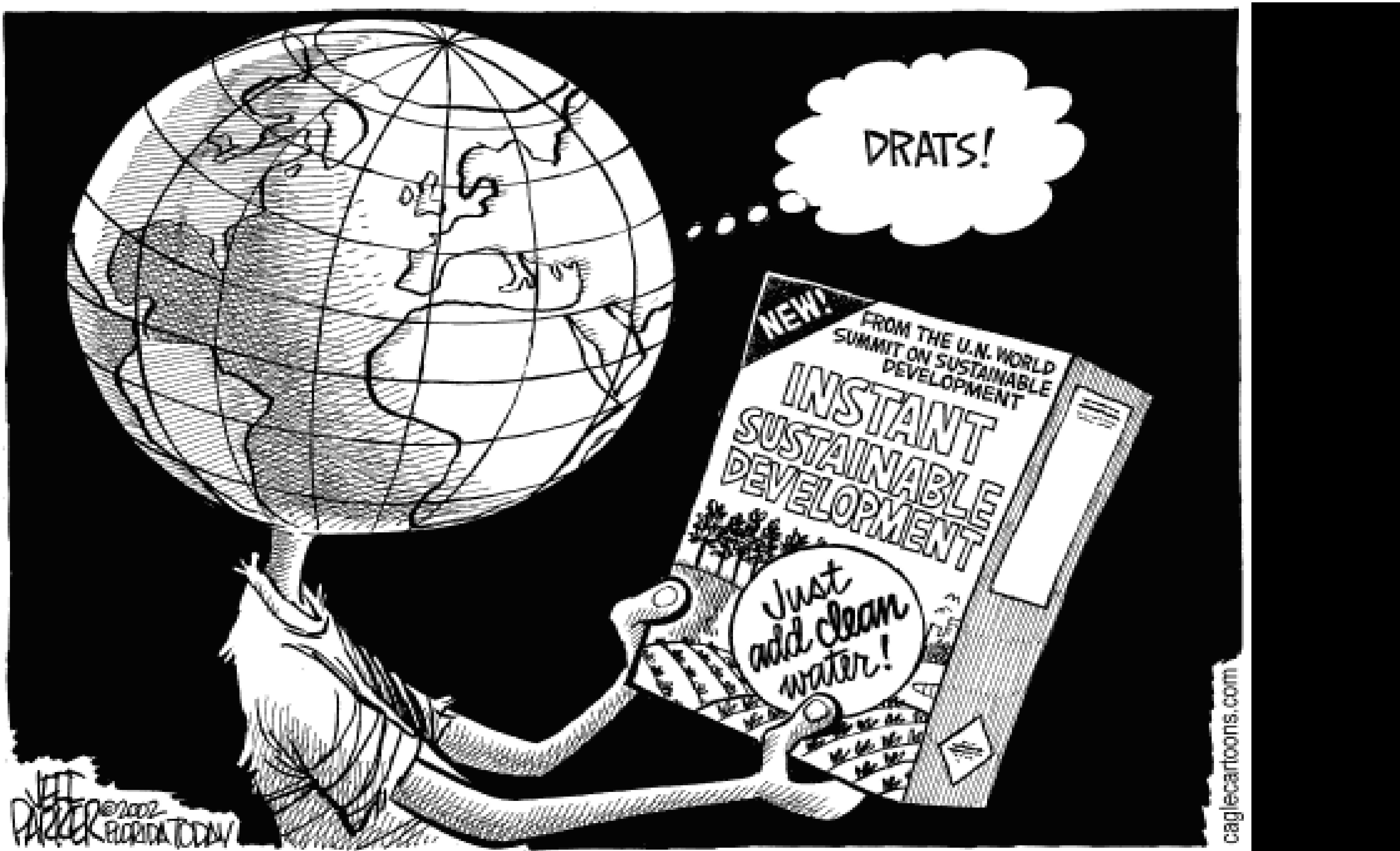
Buffer zone
Landscape corridor
Core area
Stepping stone corridor
Linear corridor
Sustainable-use areas

What is the problem?

Provisioning of ecological services by natural processes depends on a better understanding of how biodiversity losses can change ecosystem processes and services.

Global Changes

A warming world alters evaporation and precipitation, and raises sea levels. These changes affect benthic biodiversity, the basis for essential ecosystem services of freshwater ecosystems.



To sustain ecosystems, just add water!

Sustaining Ecosystem Services Requires Anticipating How Global Change Will Affect Biodiversity

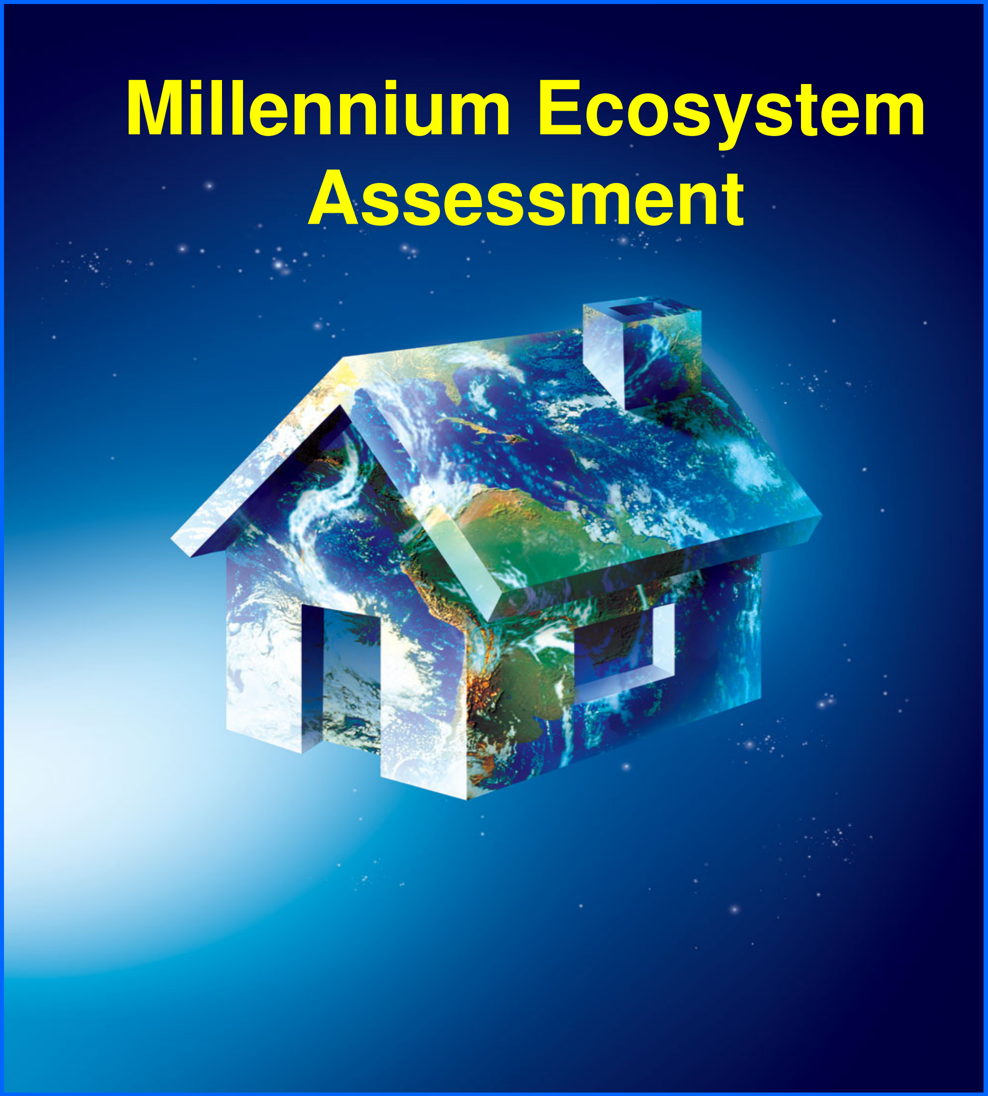
Freshwater Ecosystem Services are Declining

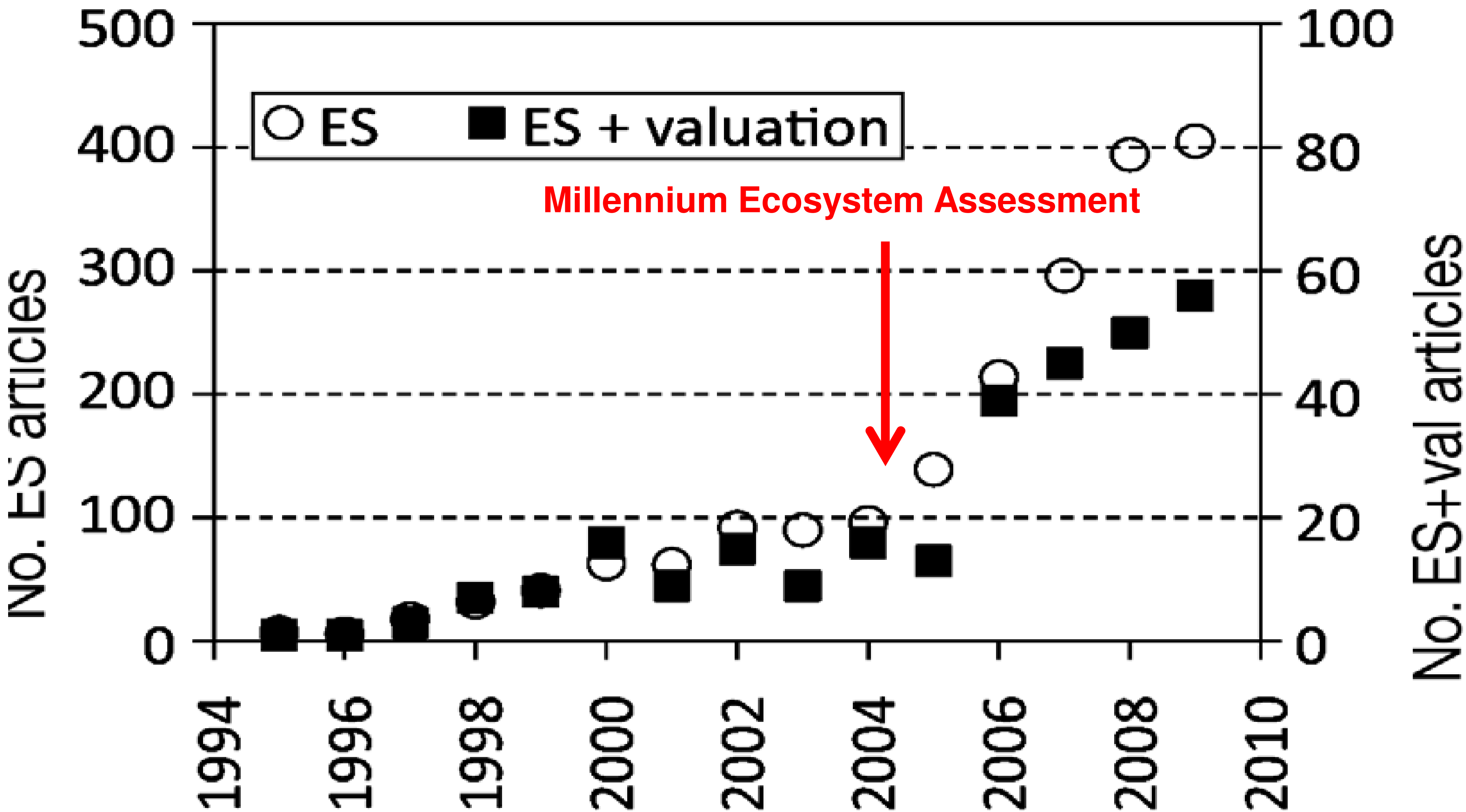
Global assessment of 24 ecosystem services

Status, trends, and futures to year 2050

1360 authors from 95 countries

www.MAweb.org





Eight times more studies on ecosystem services than studies *with valuation* of ecosystem services.

Cornell. 2010. Valuing ecosystem benefits in a dynamic world. Climate Research 45: 261-272

Defining Ecosystem Goods and Services

Ecosystem processes generate goods and services with specific dimensions and attributes of quality and quantity under specific climatic conditions. Values can shift in response to environmental and economic conditions.

Ecosystem goods are defined as tangible materials *generated* by ecosystem processes and functions (e.g., fish, shellfish, and clean water) which are useful and valuable to people.

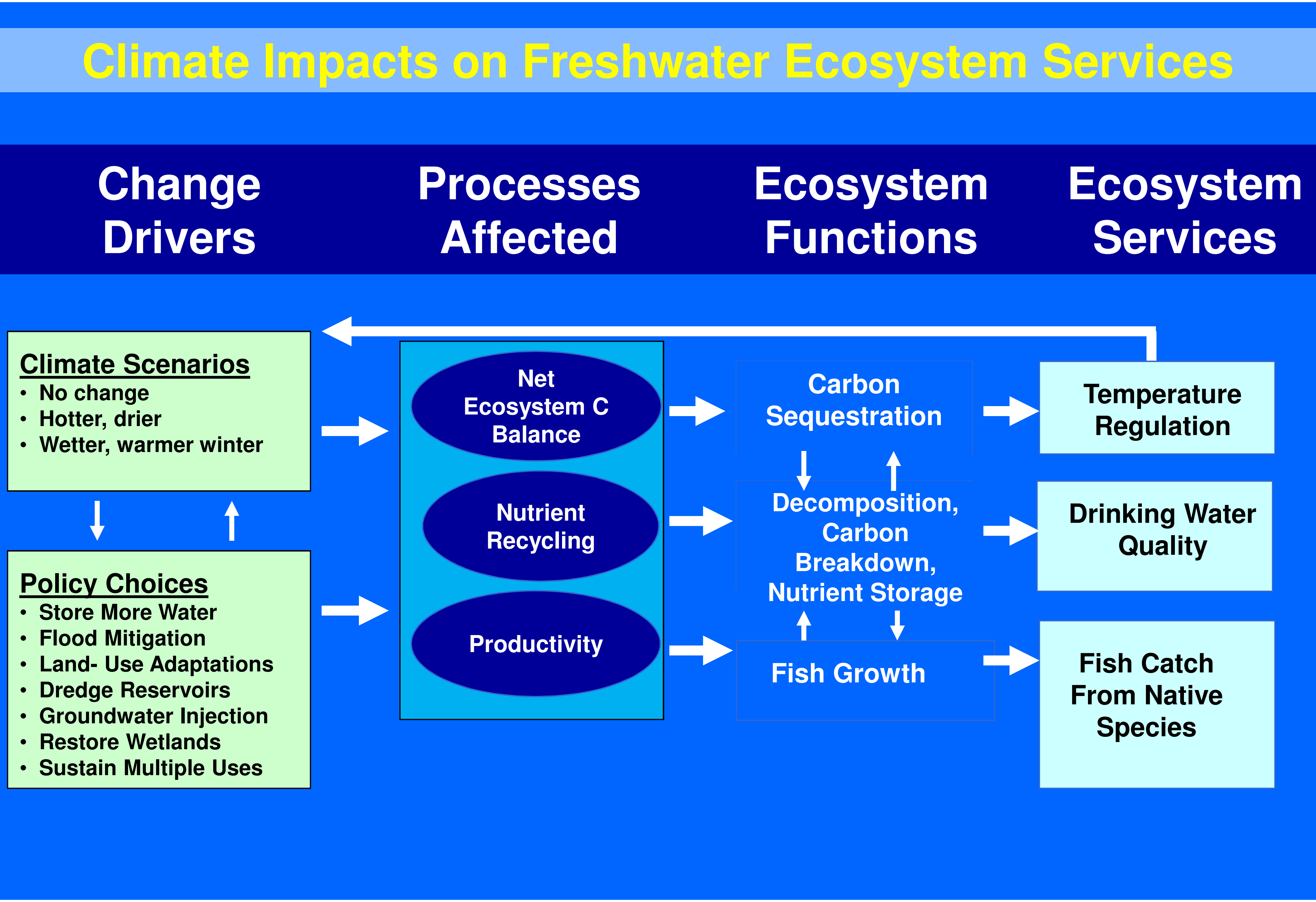
Ecosystem services are defined as changes in the condition or location of processes which are useful and valuable to people (e.g., carbon storage, flood mitigation).

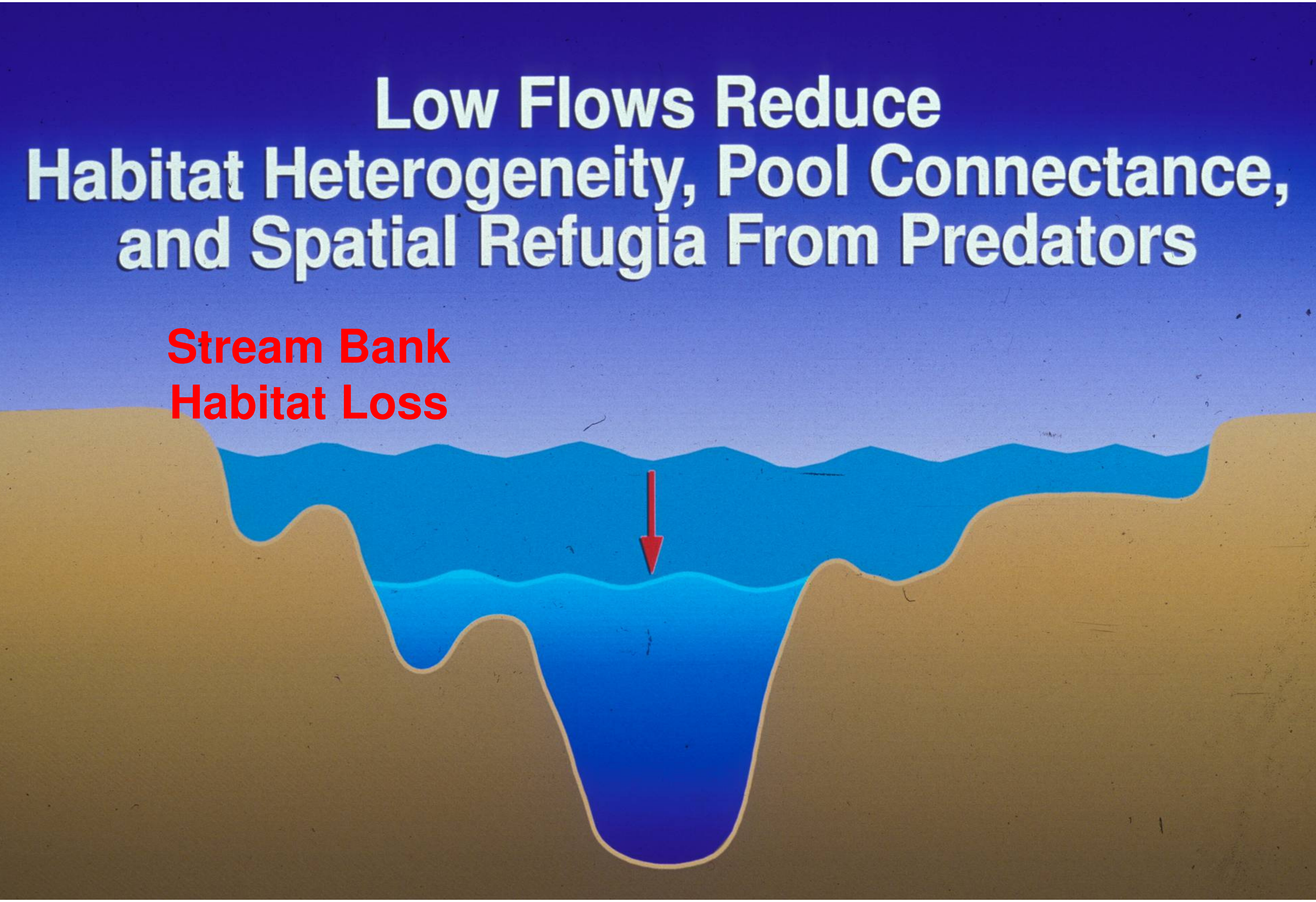
How Could the Sava River Commission Use Valuation of Ecosystem Services?

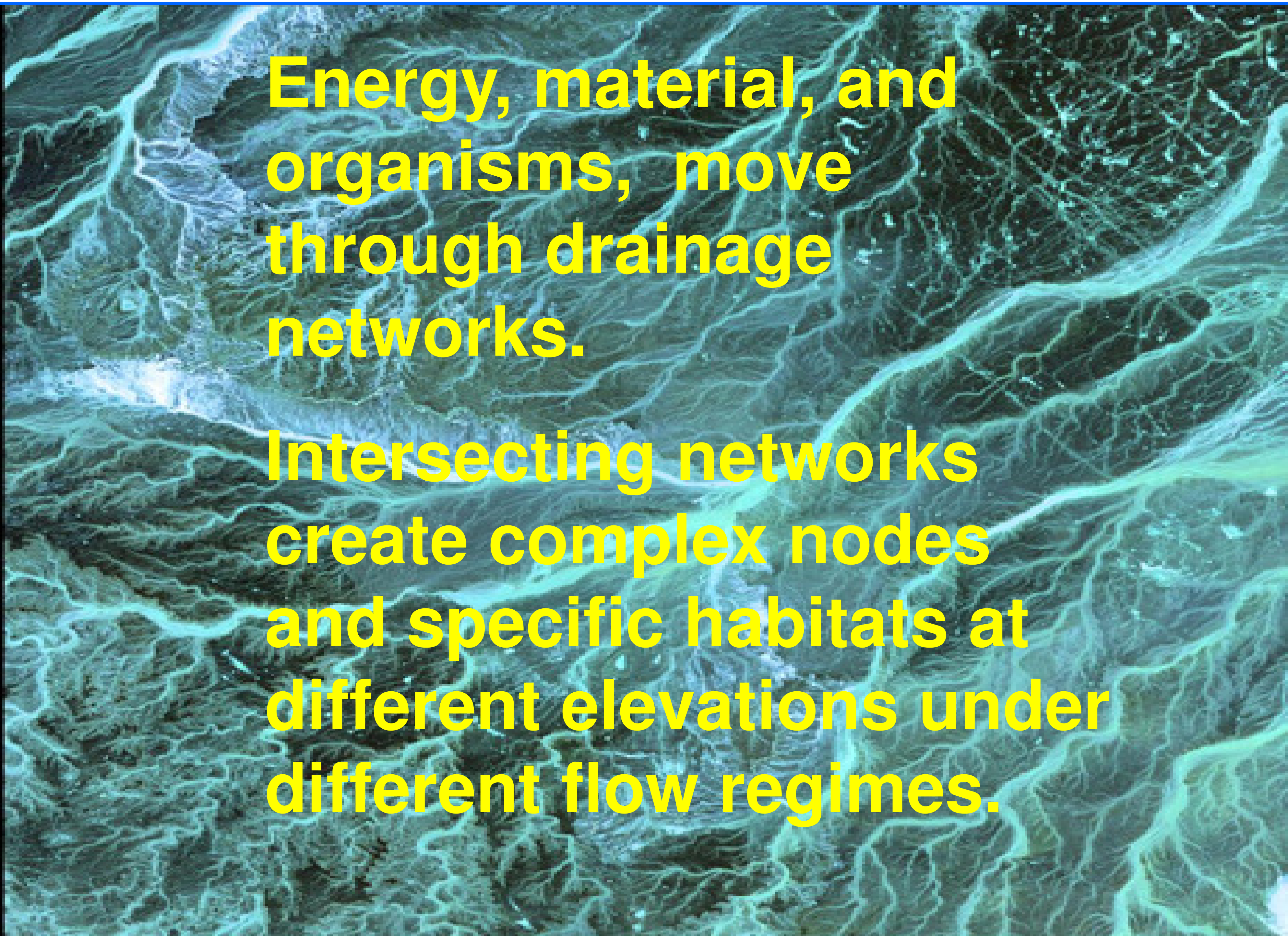
- Having information on values of natural processes in rivers and associated wetlands can help explain how these areas provide benefits to local communities by sustaining production of specific goods and services that are useful to many people.

- These values can be used to compare different locations and under different climatic or economic conditions. These benefits complement those already known from economic analyses of the values for river transportation, cooling waters, etc..

- These values consider multiple natural processes in the context of the size and locations of rivers (from very small to large) relative to concentrations of human populations.


Climate Impacts on Freshwater Ecosystem Services
Change Drivers
Processes Affected
Ecosystem Functions
Ecosystem Services
Climate Scenarios
• No change
• Hotter, drier
• Wetter, warmer winter
Policy Choices
• Store More Water
• Flood Mitigation
• Land- Use Adaptations
• Dredge Reservoirs
• Groundwater Injection
• Restore Wetlands
• Sustain Multiple Uses
Net Ecosystem C Balance
Nutrient Recycling
Productivity
Carbon Sequestration
Decomposition, Carbon Breakdown, Nutrient Storage
Fish Growth
Temperature Regulation
Drinking Water Quality
Fish Catch From Native Species

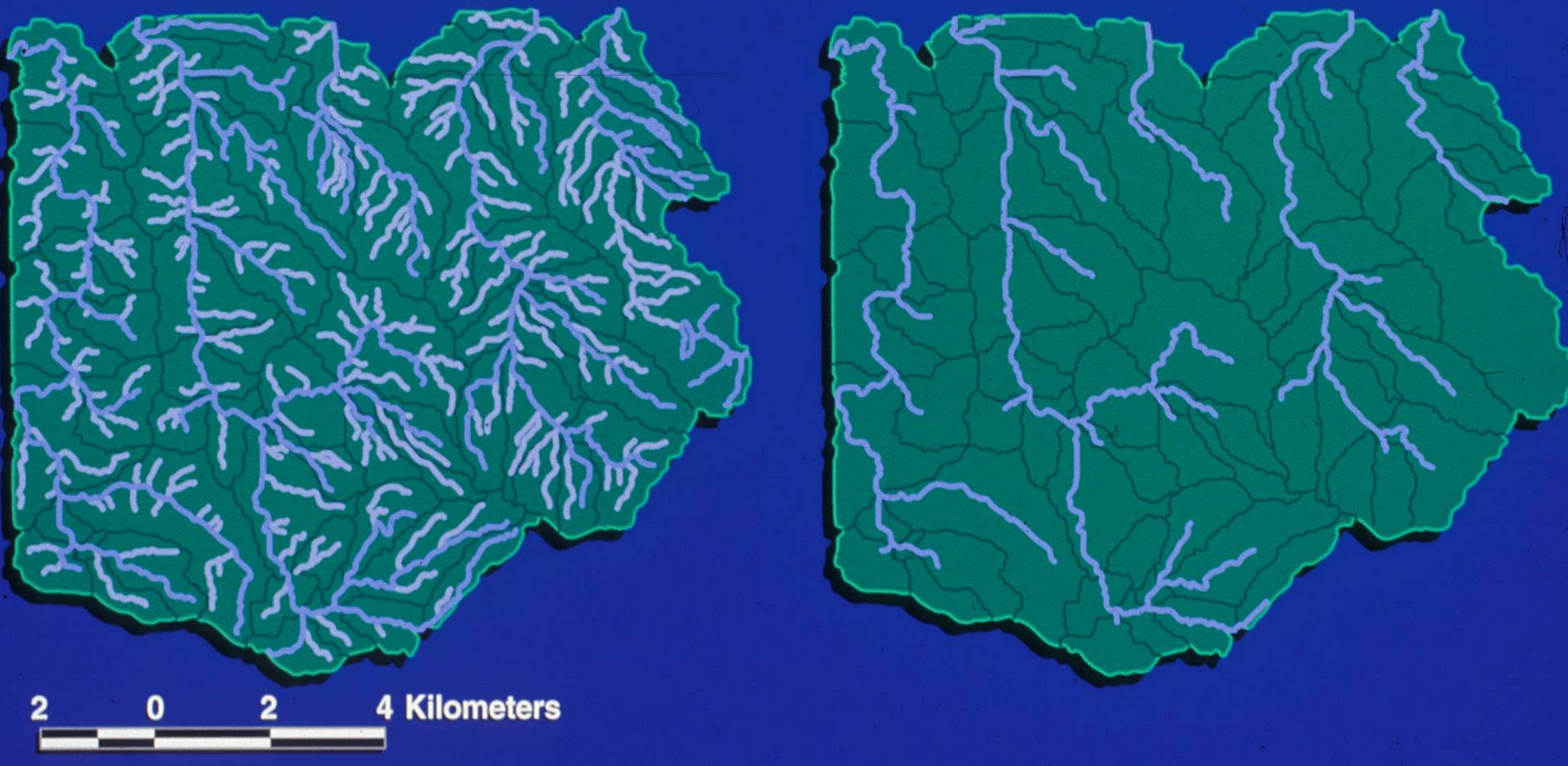

Low Flows Reduce
Habitat Heterogeneity, Pool Connectance,
and Spatial Refugia From Predators
Stream Bank
Habitat Loss


Energy, material, and organisms, move through drainage networks.
Intersecting networks create complex nodes and specific habitats at different elevations under different flow regimes.

Model Stream Flow: Luquillo Experimental Forest

High Rainfall Network
(100 cell threshold)

Low Rainfall Network
(1000 cell threshold)



River Network Connectivity

Hierarchical network structure varies greatly.

Increased complexity of nodal locations in braided streams and anabranches reduces velocities of flows.

Bi-Directional River Networks

Fish and many other species migrate *upstream* during some phases of their life histories. Larvae and/or adults migrate *downstream* to complete their life cycles.

Network Structural Characteristics

Simple	Complex
Few Nodes, Links	Many Nodes, Links
Low Connectivity	High Connectivity
Weak Hierarchy	Strong Centrality
Linear Dynamics	Non-Linear Lags
Short Path Lengths	Long Path Lengths
No or Few Refugia	More Locations for Refugia
Low Biodiversity	**High Biodiversity**

Expectations

More frequent droughts will <u>decrease</u>:

- Biodiversity
- Rates of litter decomposition
- Water quality
- Recreational fishing and swimming

Ecosystem Services

Ecological processes such decomposition produce goods and services beneficial to society.

Invertebrates and microbes work 24 hours, 7 days a week at no cost to society and provide clean drinking water by breaking down organic matter and recycling nutrients.

Why Do We Need Ecosystem Services?

Our almost total dependence on market prices to indicate value, means that we generally do not measure economic values of the goods and services that nature provides...

United Nations Environment Programme 2010.

Valuation of Ecosystem Services
One of Several Approaches

- While economic value estimates are important in making resource management responsive to other public benefits, these values are among other inputs to an integrative, collaborative decision-making process involving many disciplines.

- Economic value estimates can be integrated into a GIS mapping approach along with other factors affected by climate, adjacent land uses or demography.

Issues in Valuation

- The value of natural ecosystem processes is cultural as well as ecological and economic.

- Some ecologists reject the premise that natural ecosystem processes can be evaluated by use of economic methods.

- Others are testing different economic models to determine if "willingness to pay" or "willingness to give up" provide measures for determining trade-offs among options.

”The value of ecosystem services is conditional on a well functioning *whole* ecosystem…

A major research challenge remains in fostering an understanding of dynamic processes in environmental management.”

Cornell, S. 2010. Valuing ecosystem benefits in a dynamic world. Climate Change 45: 261-272

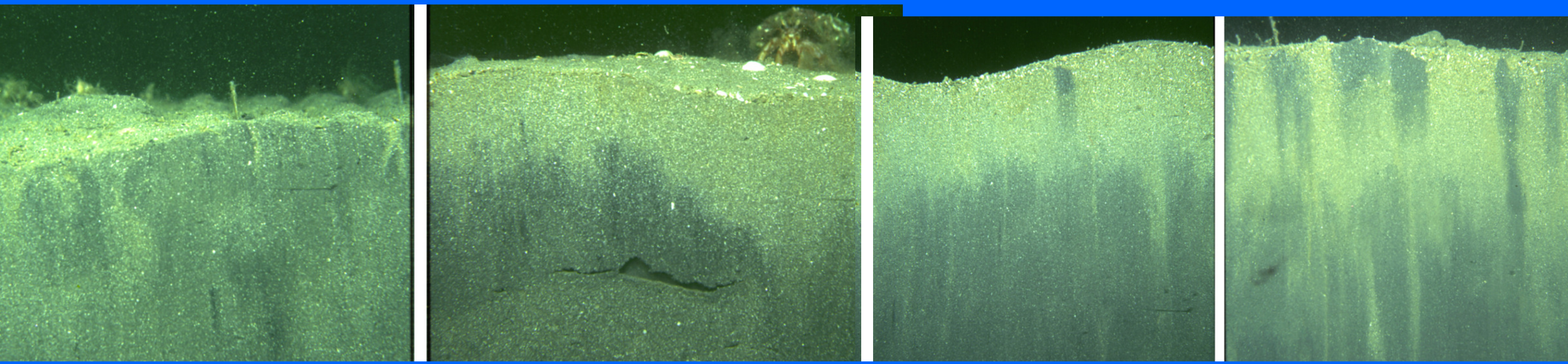
Is Species Richness Related to Rates of Ecosystem Processing?

- The number of species is important - but not as important as the unique role played by each species under different conditions.

- Some species interact to increase rates of ecosystem processes; others may do so under different environmental conditions.

- Positive relationships among species often depend on relative sizes, timing of their feeding activities, reproduction, and life spans.

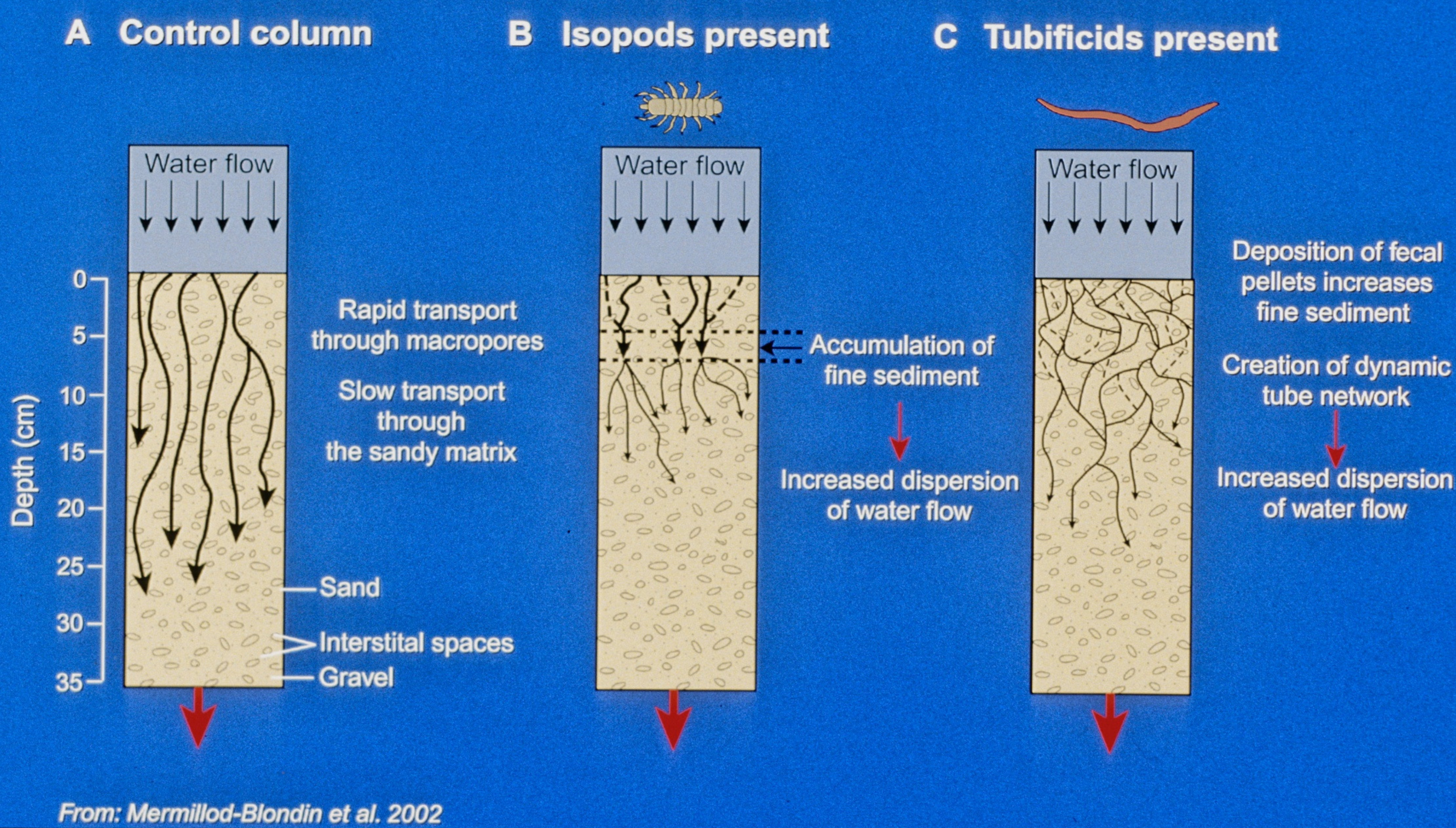
Benthic Invertebrates Mix Surface and Sub-Surface Sediments



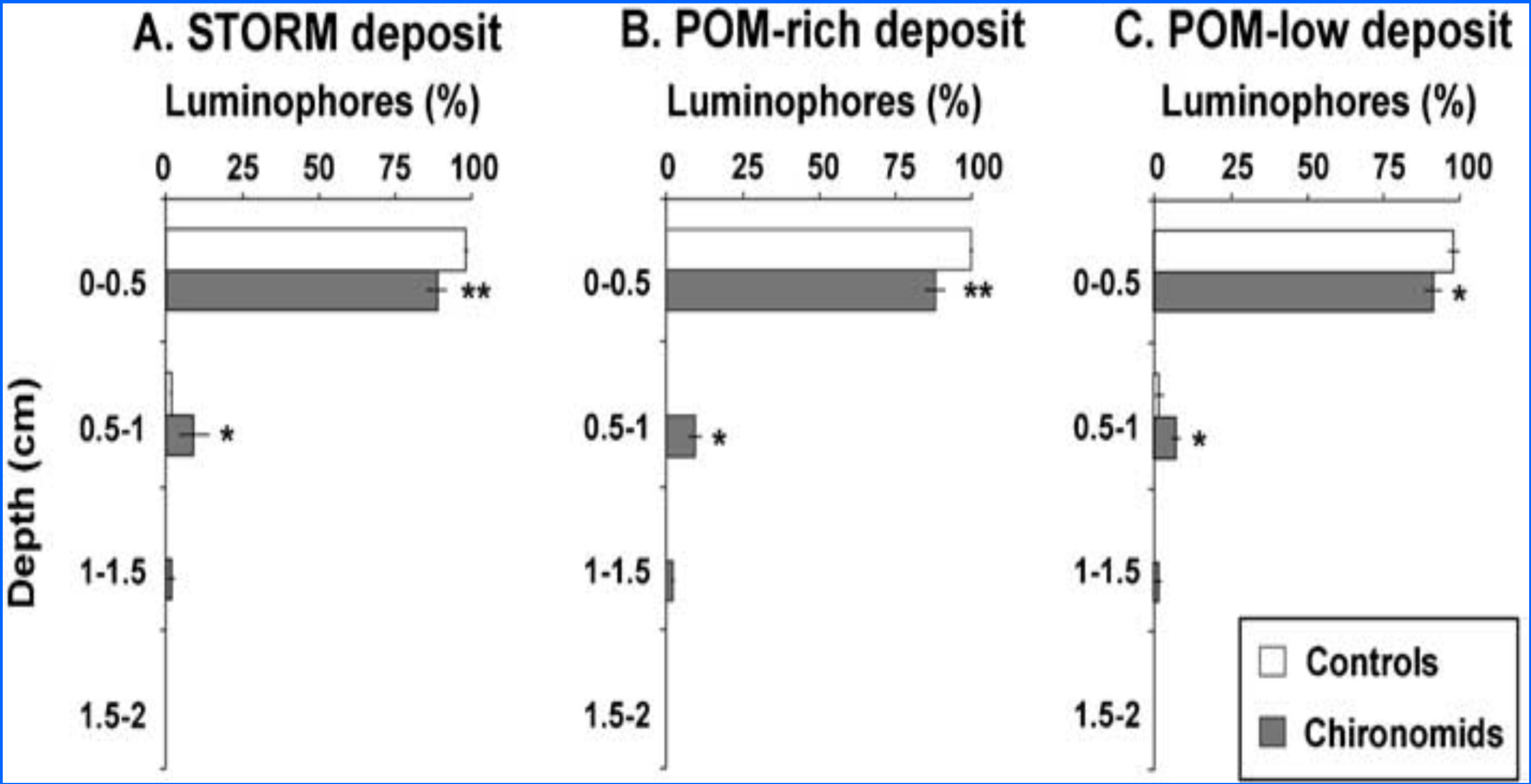
How Deeply Mixed are Sediments?

What are the Effects of Overlying Water?

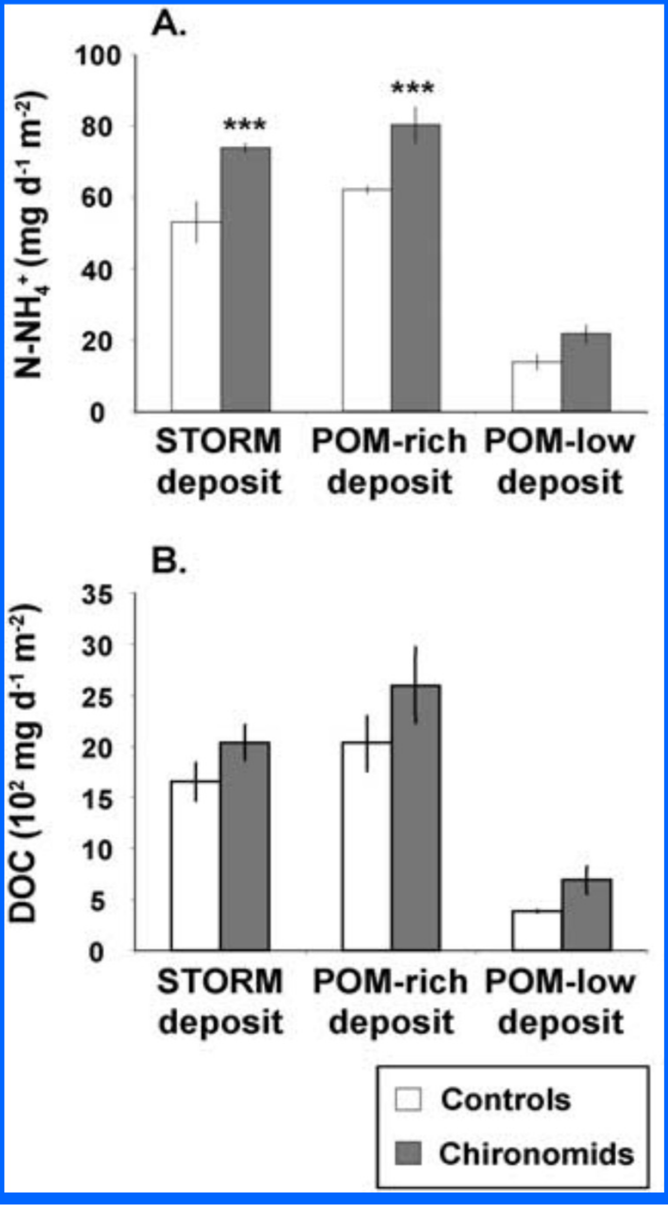
Organic Matter Processing and Benthic Biodiversity



Mixing of Surface Sediments



Nutrient Cycling By Chironomids

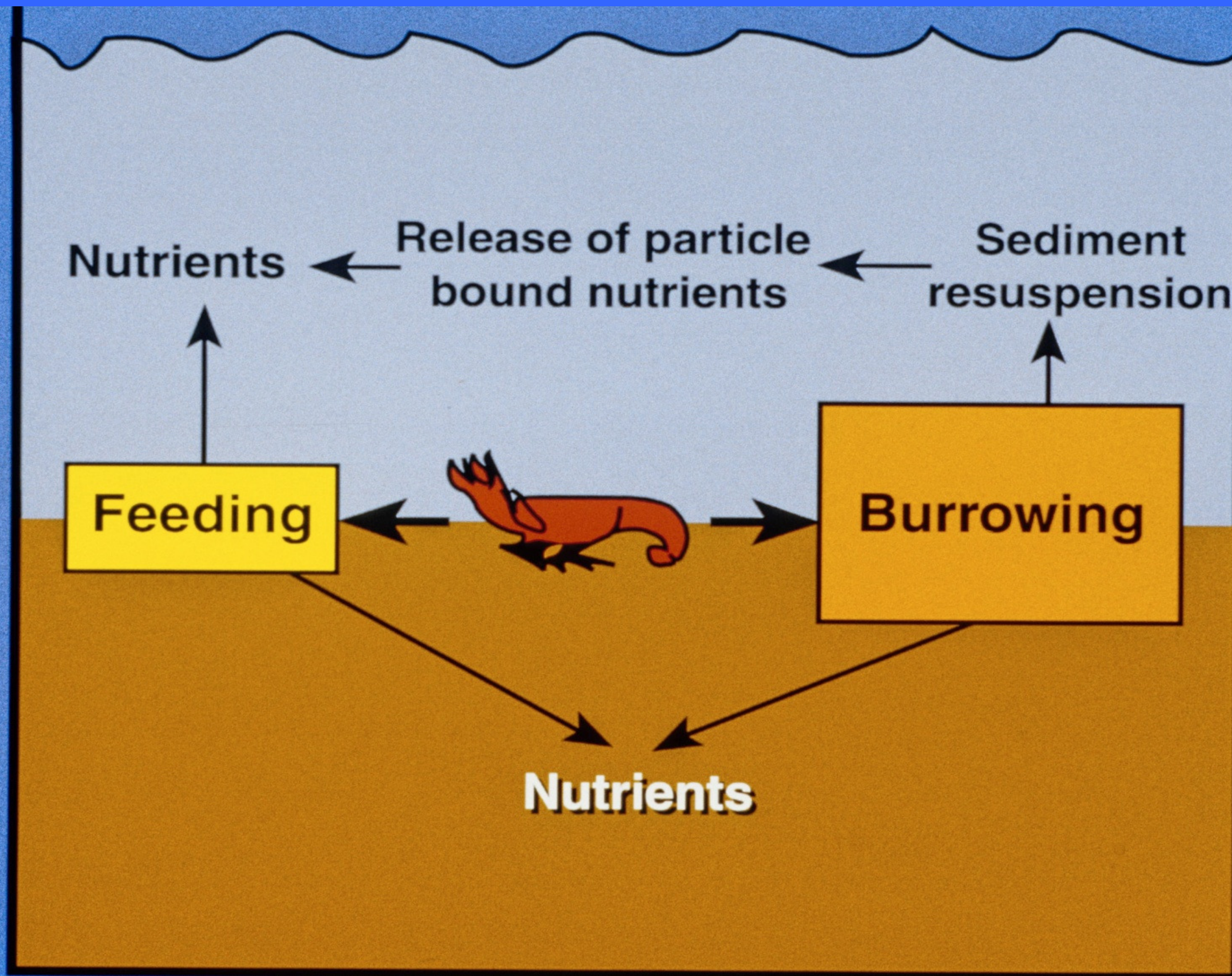


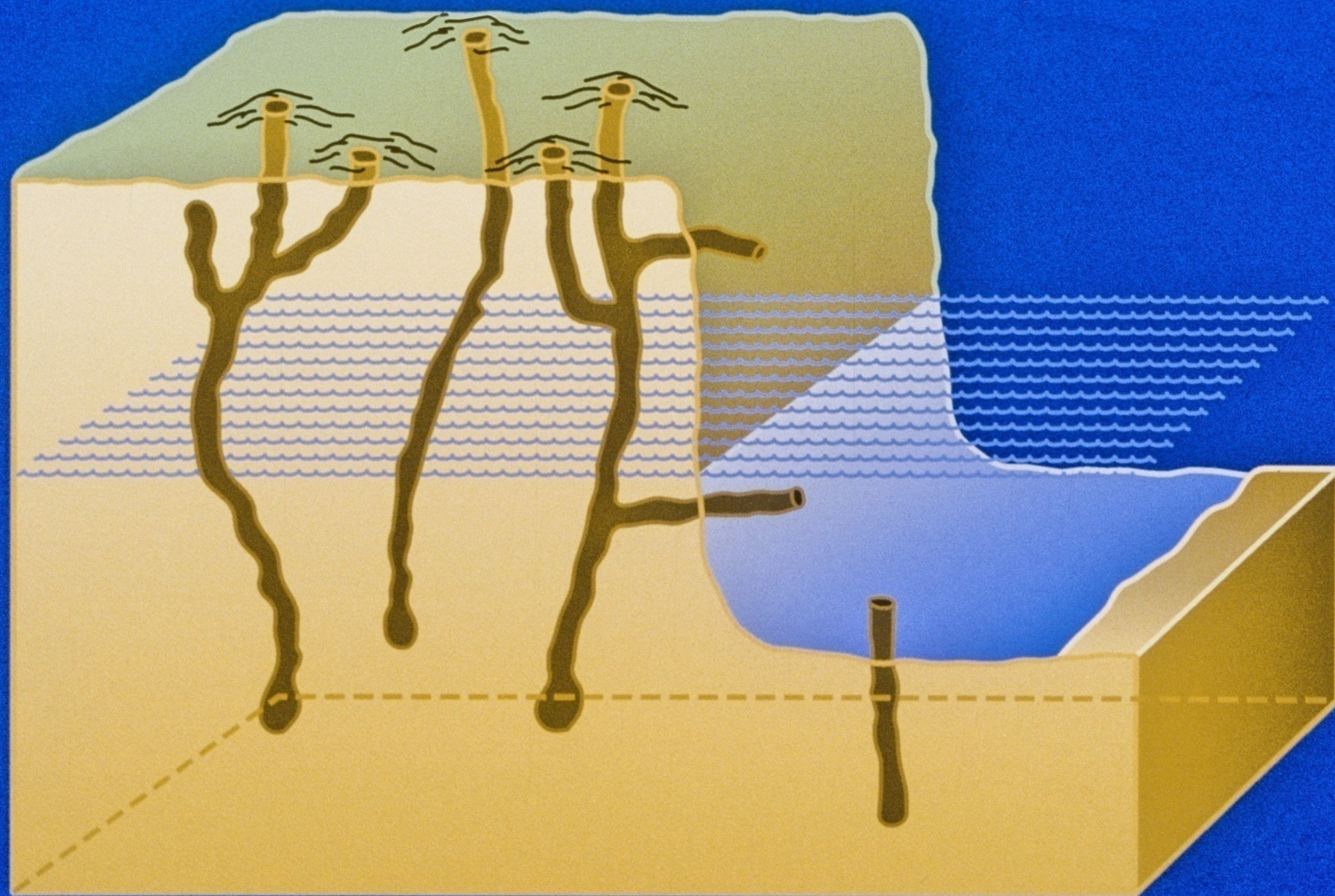
Mean release rates of (A) ammonium

(B) dissolved organic carbon (DOC) from days 1 to 20 (mean1 SD, n= 3)

Nogaro et al. 2008. Aquatic Sci. 70: 156-168

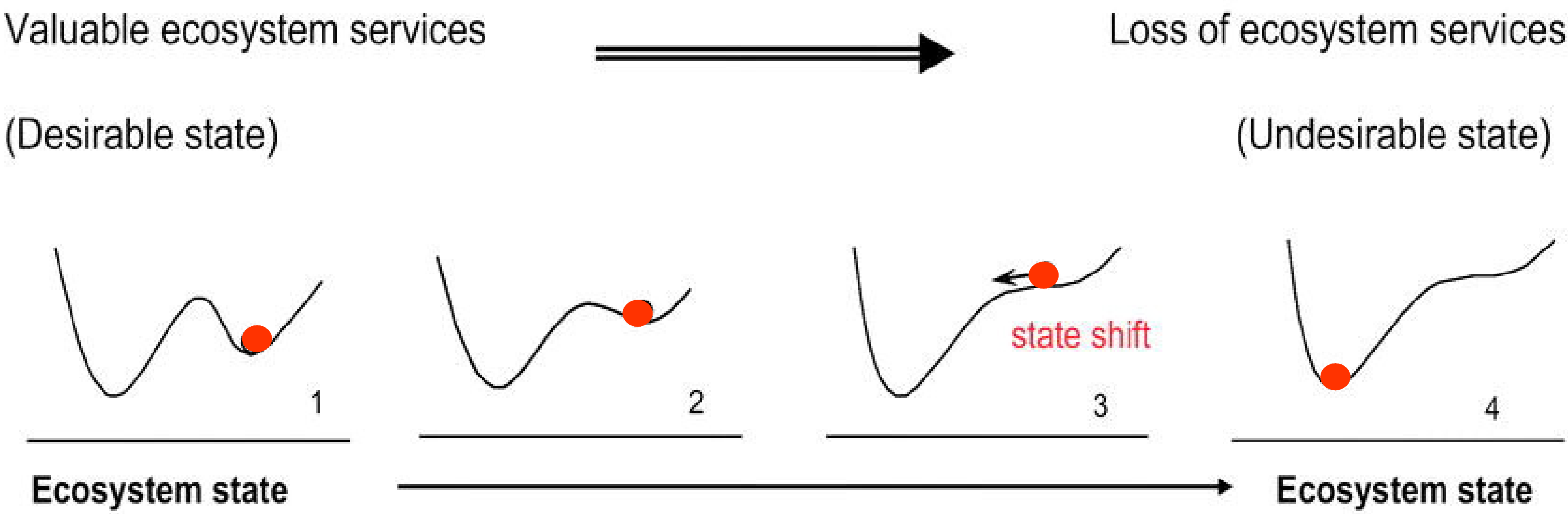
Infauna and Epifauna Mix Sediments and Recycle Nutrients





Modified from: Hobbs, 1981

Shifts in Benthic BioDiversity



How is Benthic Biodiversity Related to Breaking Down of Organic Matter and Cleaning Up Rivers, Lakes and Wetlands?

Decomposers and Dissolved Oxygen

Over 100 gigatons of terrestrial plant biomass are produced globally each year. Ninety percent of this biomass enters the sediments as dead organic matter. Together with aquatic-produced organic carbon, this detritus supports complex food webs that determine the critical balance of oxygen in organic-enriched sediments and the needs for respiration by benthic decomposers and other species.

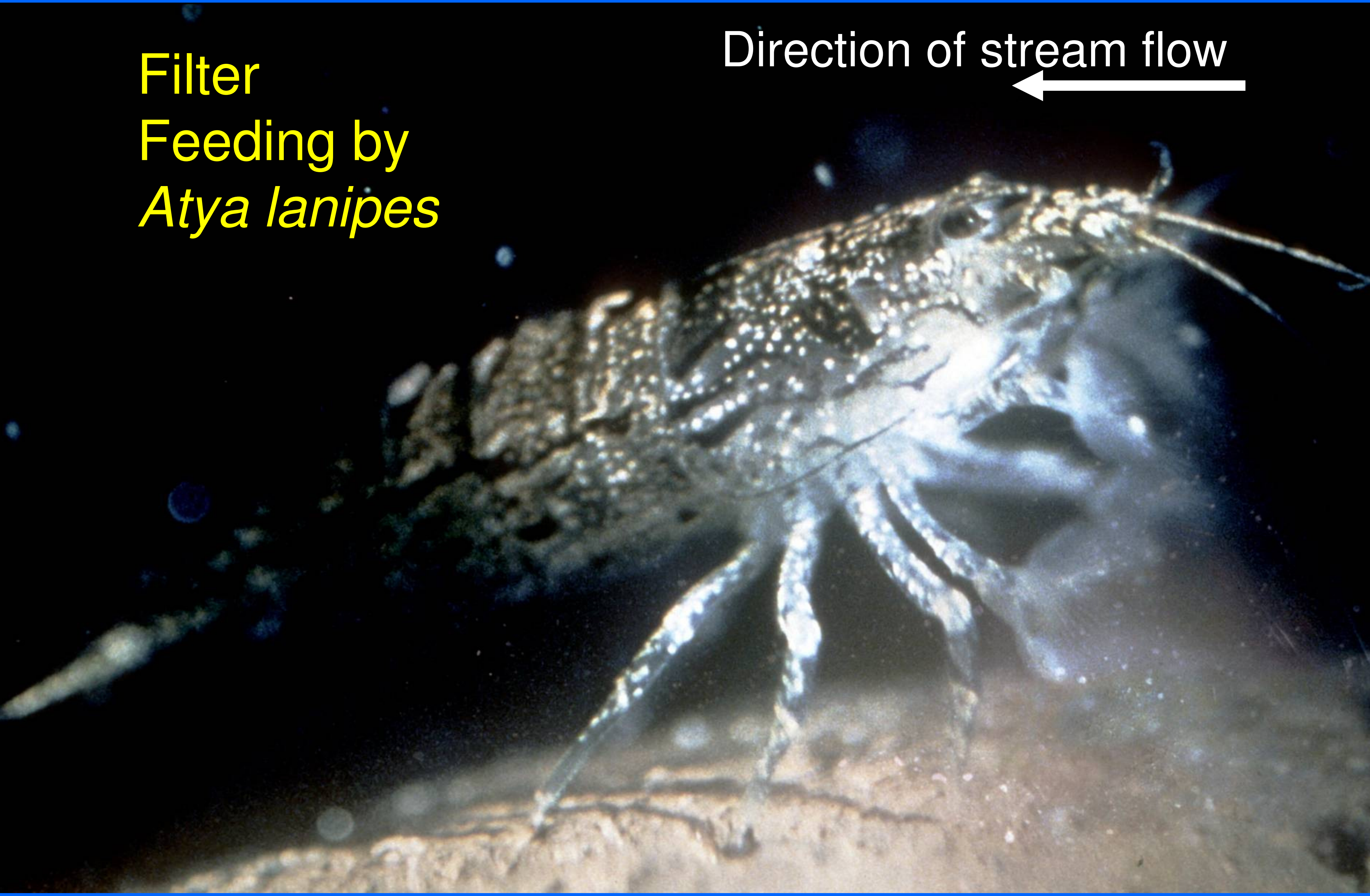
Habitat Coupling in Benthic Ecosystem Processing is Influenced by Fluid Dynamics

- Connections between sediments and the overlying and underlying waters are critical to species relationships.

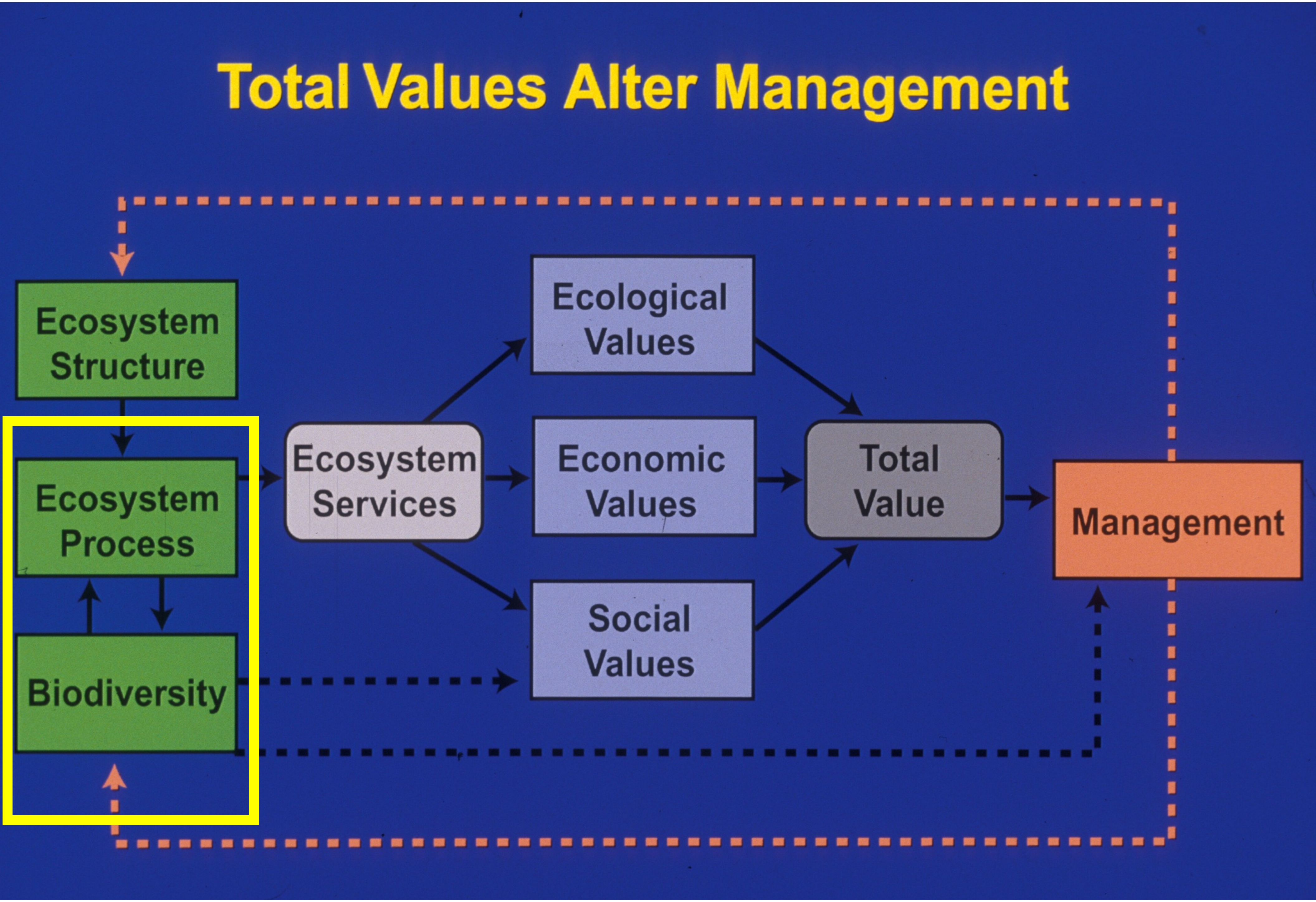
- Patch dynamics within sediments and coupling with the below-sediment surface waters can alter the rates of species interactions, nutrient cycling, and water quality.

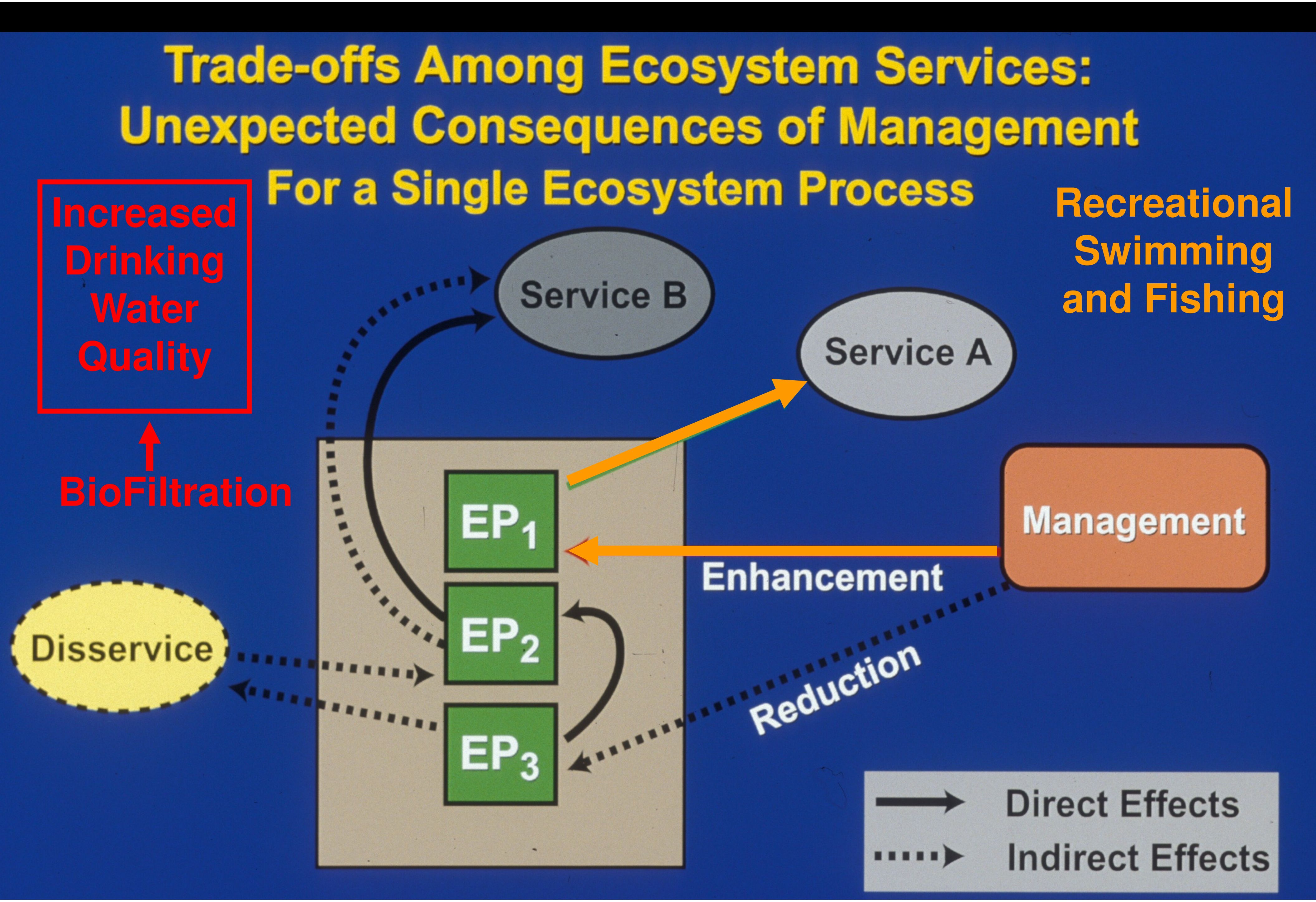
Loss of benthic species in the functional group with the fewest species is likely to lower rates of ecosystem processing such as breakdown of leaf litter.

Biodiversity in freshwaters provides synergism and "insurance" or "back up" among interacting species that break down and re-suspend organic matter in sediments and those that filter suspended particulates.


Filter
Feeding by
Atya lanipes
Direction of stream flow

Invasive Species Can Change the Ecosystem


Total Values Alter Management
Ecosystem Structure
Ecosystem Process
Biodiversity
Ecosystem Services
Ecological Values
Economic Values
Social Values
Total Value
Management


Trade-offs Among Ecosystem Services:
Unexpected Consequences of Management
For a Single Ecosystem Process
Increased Drinking Water Quality
BioFiltration
Recreational Swimming and Fishing
Service B
Service A
EP1
EP2
EP3
Management
Enhancement
Reduction
Disservice
Direct Effects
Indirect Effects

Conflicts Among Freshwater Ecosystem Services

"Misuse or overuse of one type of ecosystem service can lead to a negative effect on other important services and the biota that underpin them."

Covich et al. 2004. Sustaining Biodiversity and Ecosystem Services in Soils and Sediments. Island Press.

"Some species are drivers of ecosystems and others are passengers... and redundant"

B. H. Walker 1994

Asking what species do in ecosystems…forces increased integration of ecosystem and population ecology...”

J.H. Lawton 1994

Loss of key species with unique, highly specific traits (little or no niche overlap) have essential ecological roles in primary productivity.

Their loss will likely lower rates of ecosystem processing and may decrease ecosystem resilience and ecosystem services.

Several Hypotheses Regarding Species – Ecosystem Relationships

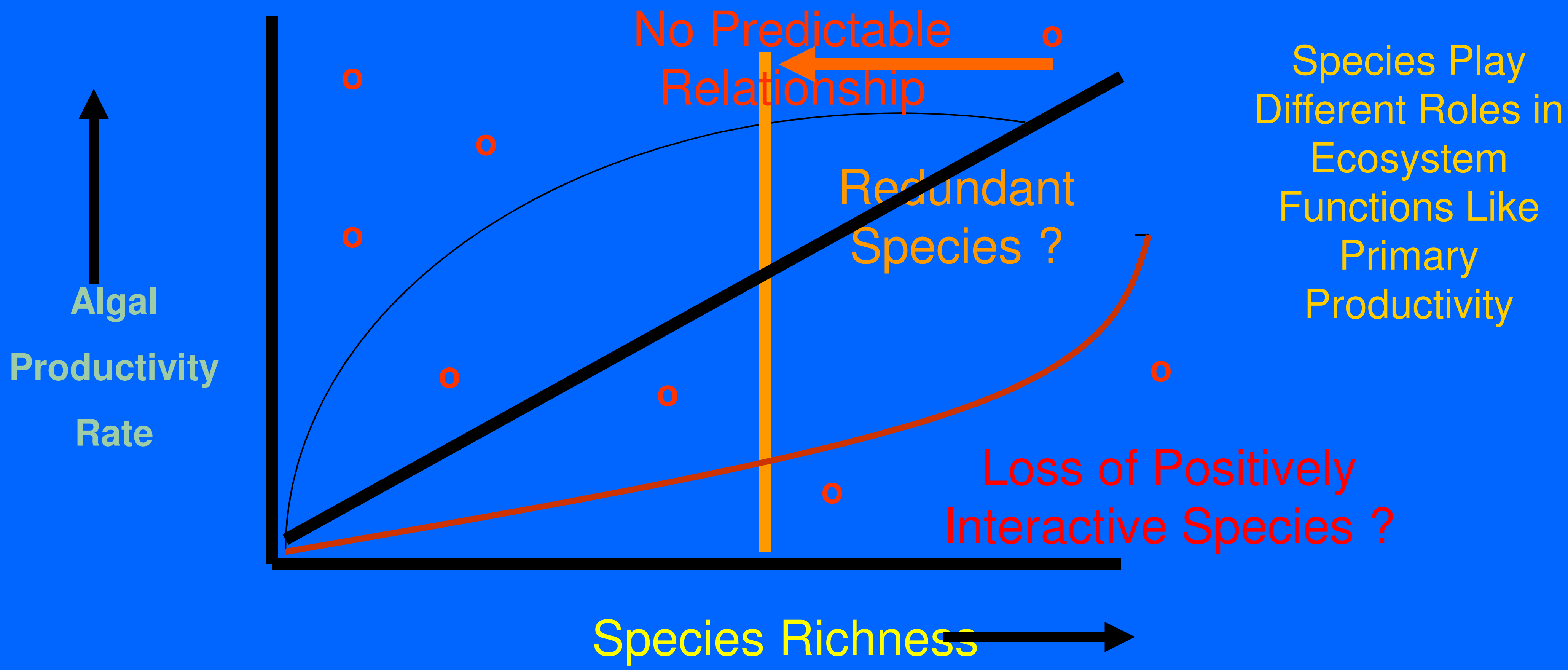
1. There is no relationship between species richness and ecosystem processes.

2. All species have an essential role.

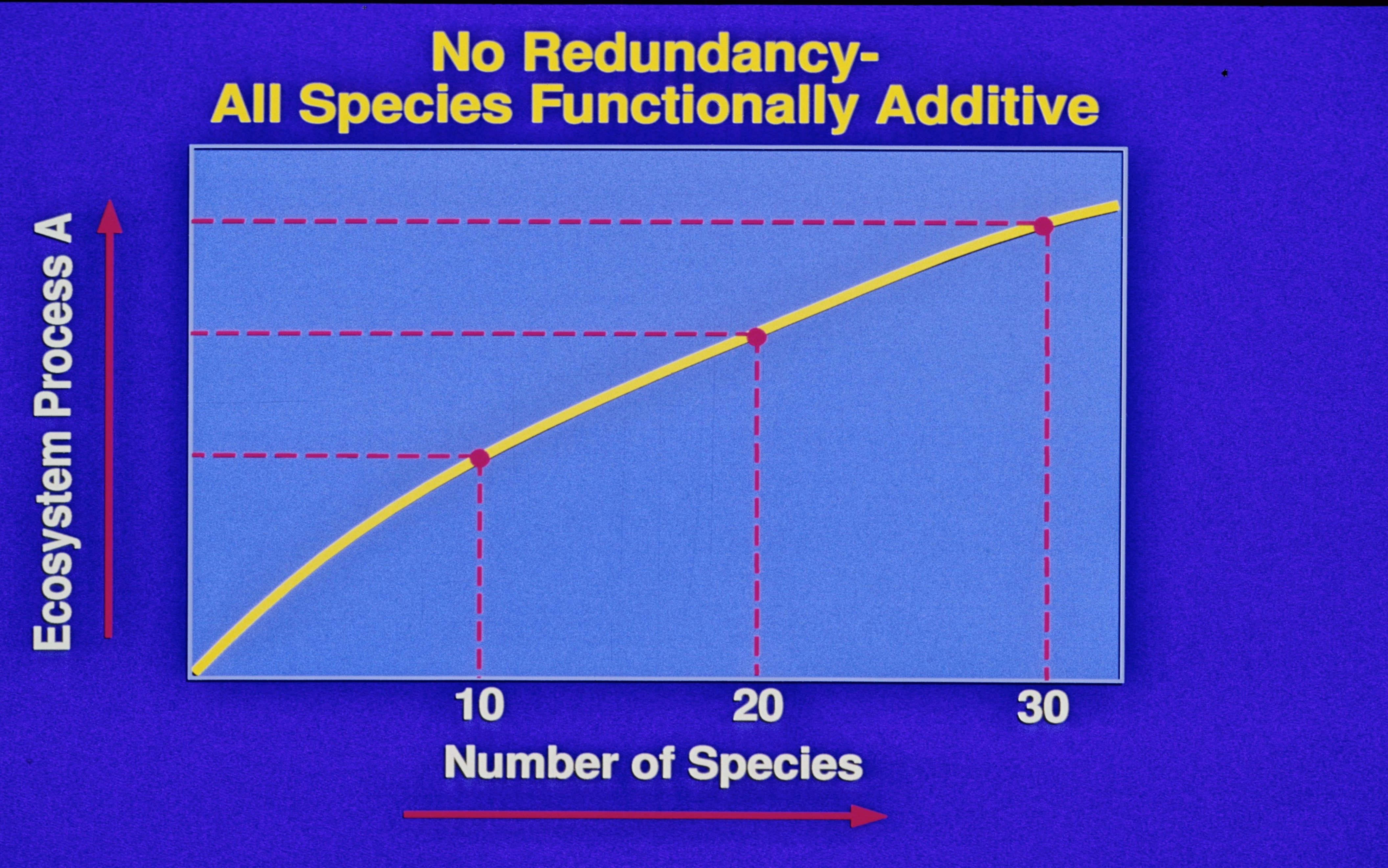
3. Some species have no essential role and are redundant.

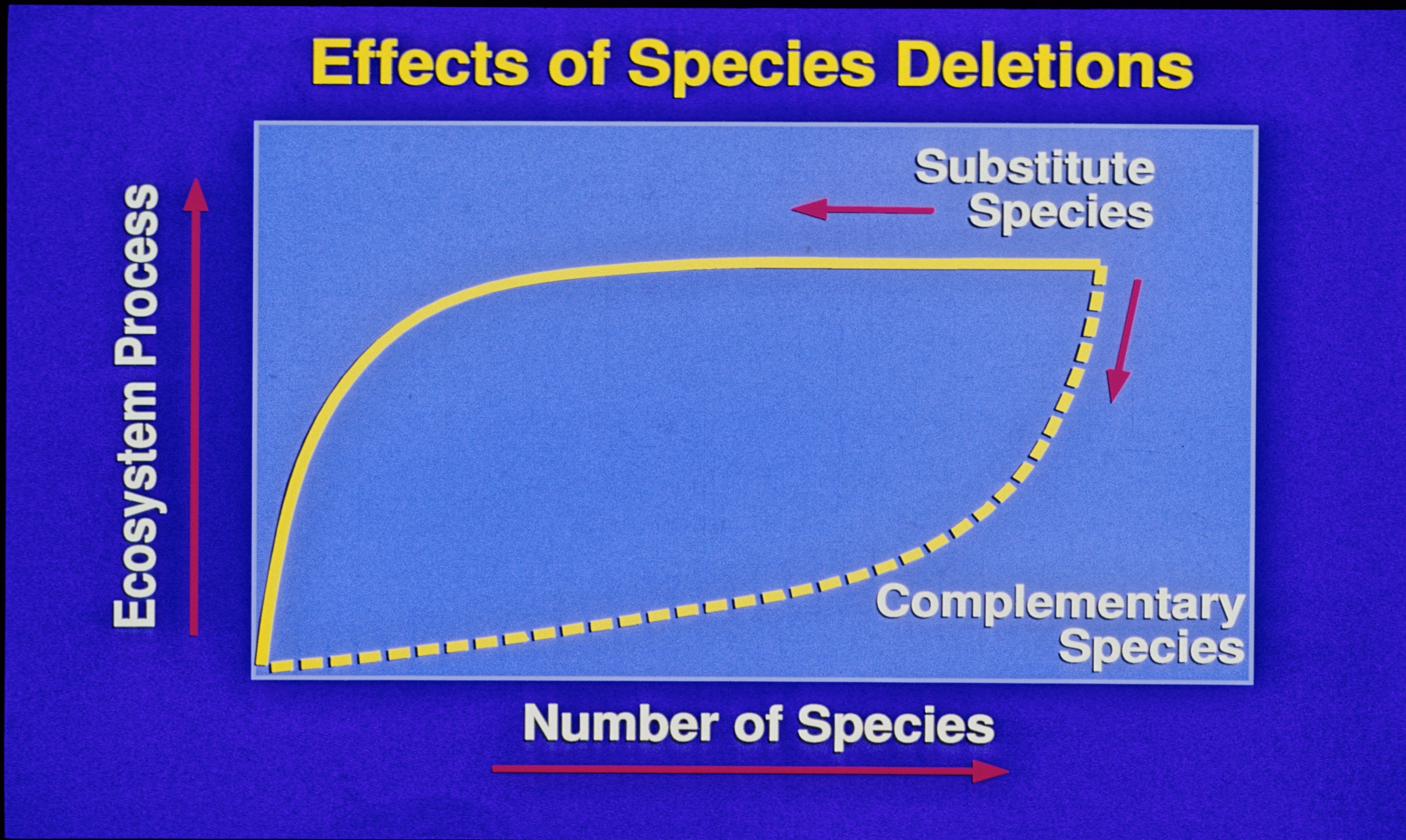
Conservation biologists hate this concept

Some Positively Interactive Species Play Important Roles in Primary Productivity

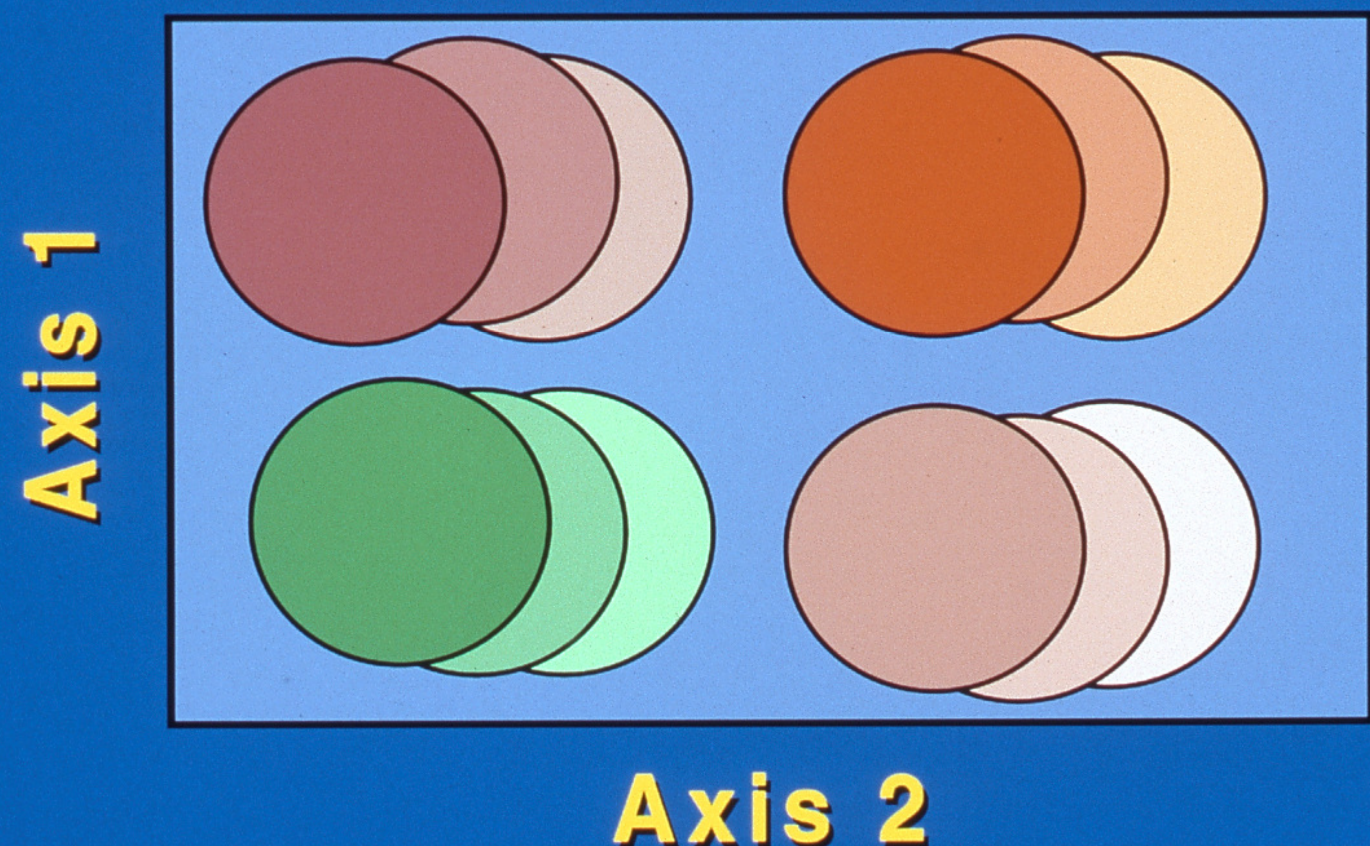


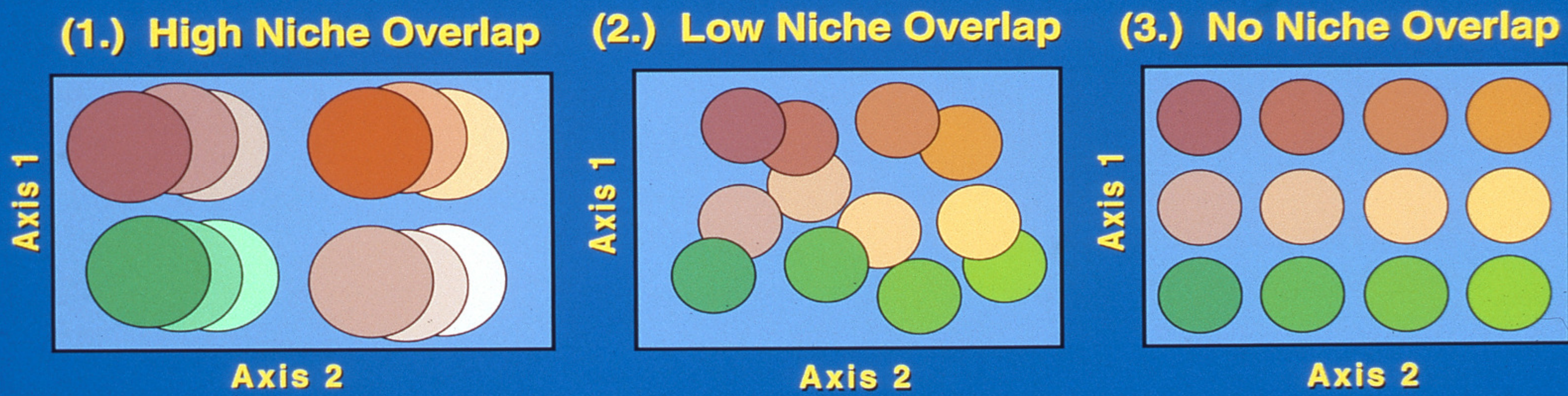
Can We Distinguish Between "Redundant" and Positively Interactive Species?


No Redundancy-
All Species Functionally Additive
Ecosystem Process A
10
20
30
Number of Species


Effects of Species Deletions
Substitute Species
Complementary Species
Ecosystem Process
Number of Species

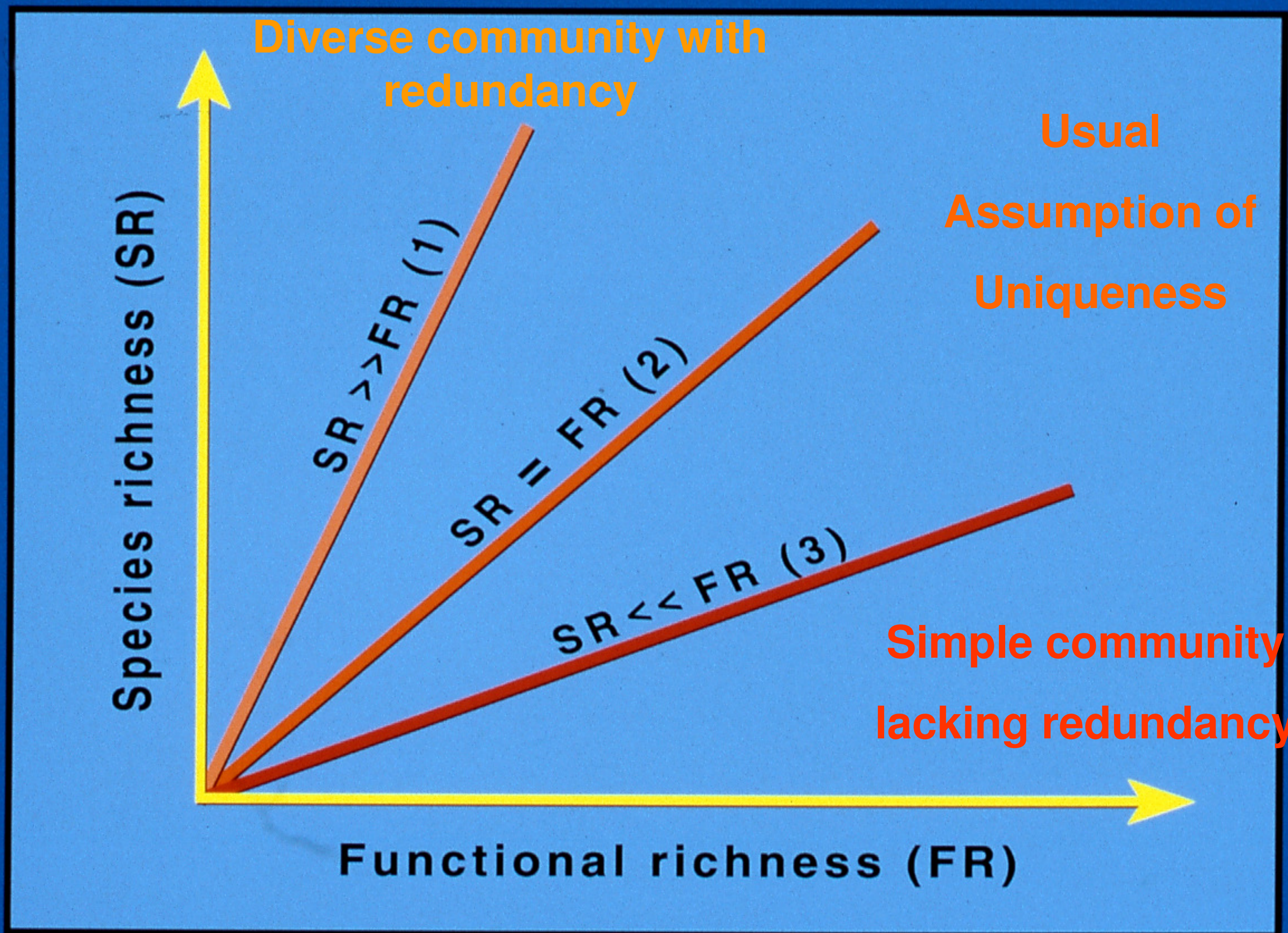
(1.) High Niche Overlap



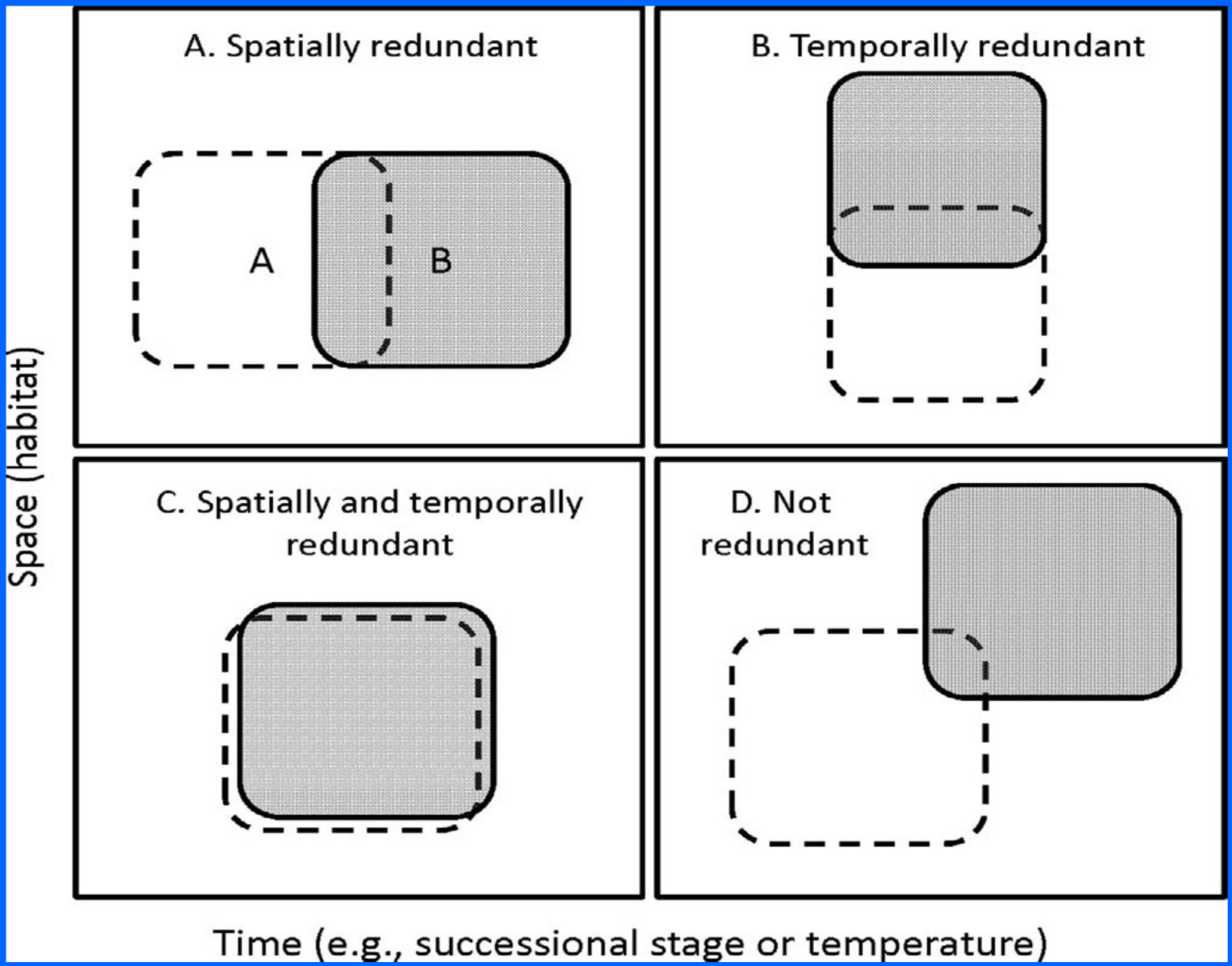


(1.) High Niche Overlap
Axis 1
Axis 2
(2.) Low Niche Overlap
Axis 1
Axis 2
(3.) No Niche Overlap
Axis 1
Axis 2

Functional Diversity in Ecosystem Processes



From: Sandra Diaz and Marcelo Cabido 2001



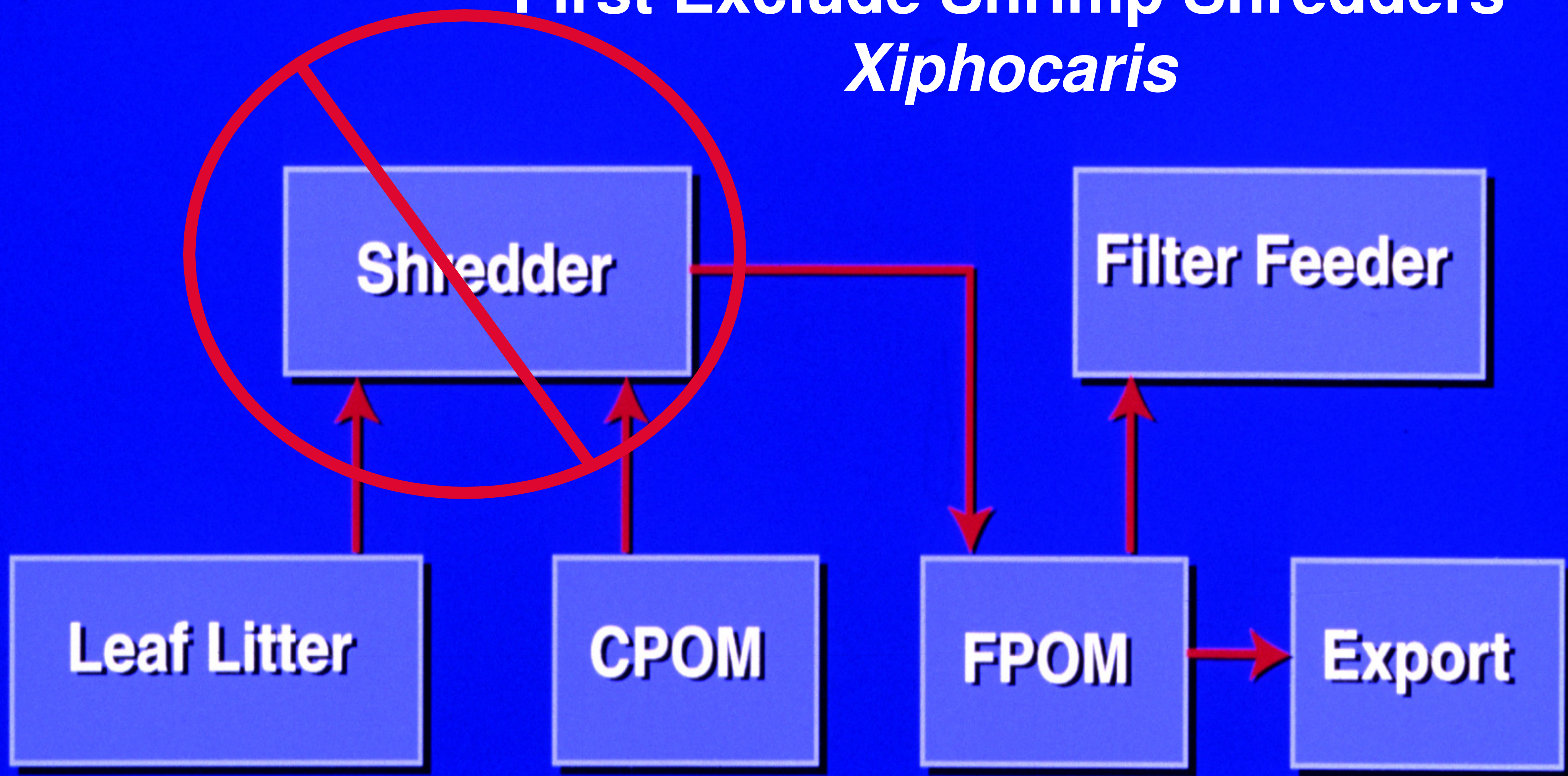
Conceptual diagram illustrating the potential overlap in ecosystem effects of spatially redundant (A), temporally redundant (B), spatially and temporally redundant (C), and not redundant (D) species within functional groups across space and time. The loss of a species whose effects on ecosystem properties overlap with those of other species over space and time (i.e., C) is predicted not to alter ecosystem properties.

Functional Diversity

The effects of losing aquatic species on ecosystem function are difficult to predict because of the diverse forms of organisms and complex interactions among species. The ecosystem effects of many species might be predicted by grouping species into functional groups (e.g., trophic levels or feeding guilds) and assuming that all species within functional groups have similar effects. Such groupings imply that loss of a species within a functional group should have little effect on an ecosystem because other members of the group can compensate for the loss (i.e., species are redundant within groups; Lawton and Brown 1993).

Field Experiments Simplify Processing Chain

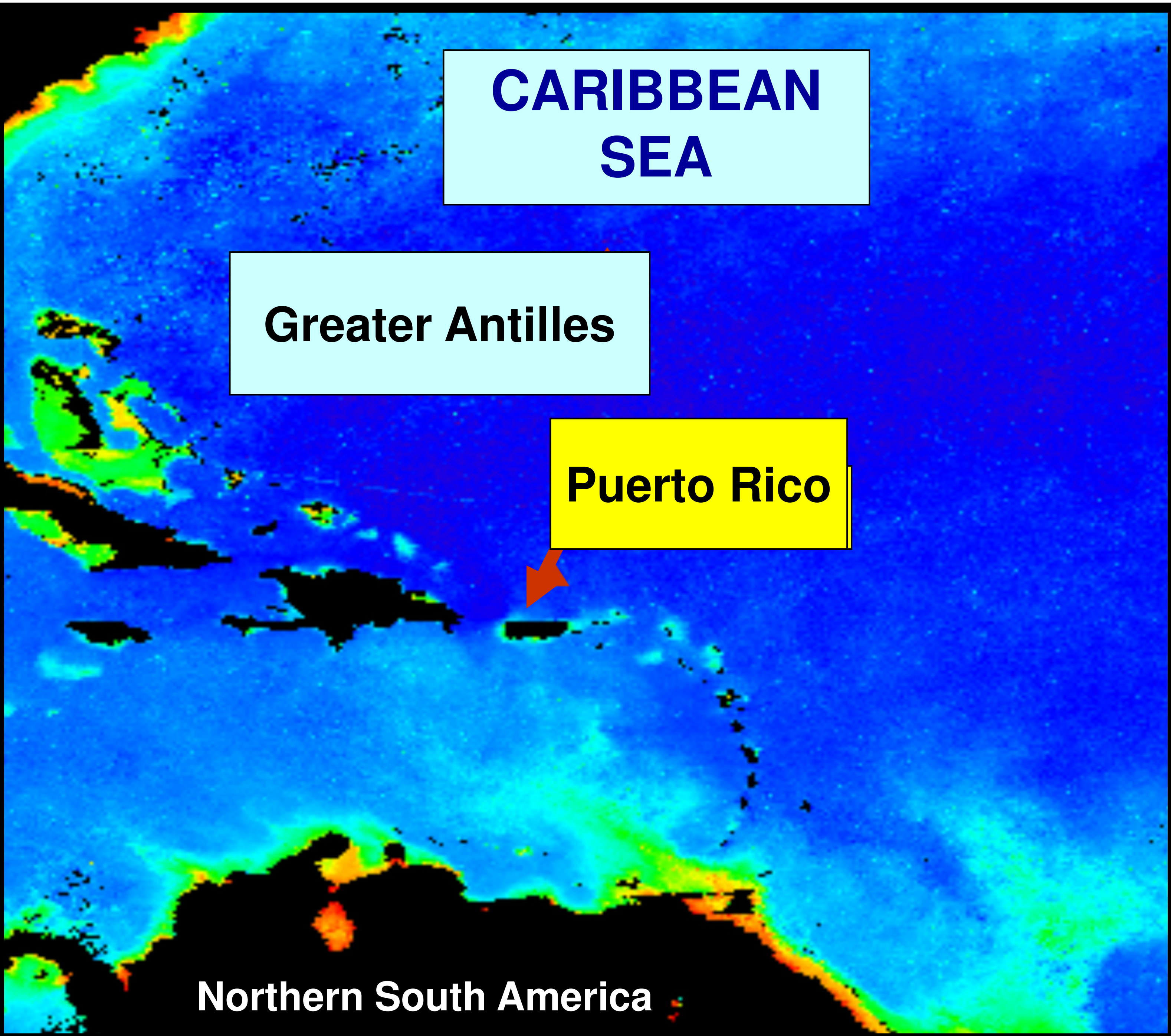
First Exclude Shrimp Shredders
Xiphocaris



Functional Diversity

Individual species can facilitate resource use among species within functional groups or species might partition resources over space or time . Thus, each species in a functional group might provide a unique contribution to the functioning of an ecosystem. The roles of individual species and functional groups and the context within which species in a community alter ecosystems must be characterized to understand fully the consequences of biodiversity losses

Studies in Puerto Rican streams provide a case study of biodiversity that sustains ecosystem processes and clean water following changes in stream drainage network locations and disturbances such as hurricanes, floods and droughts.

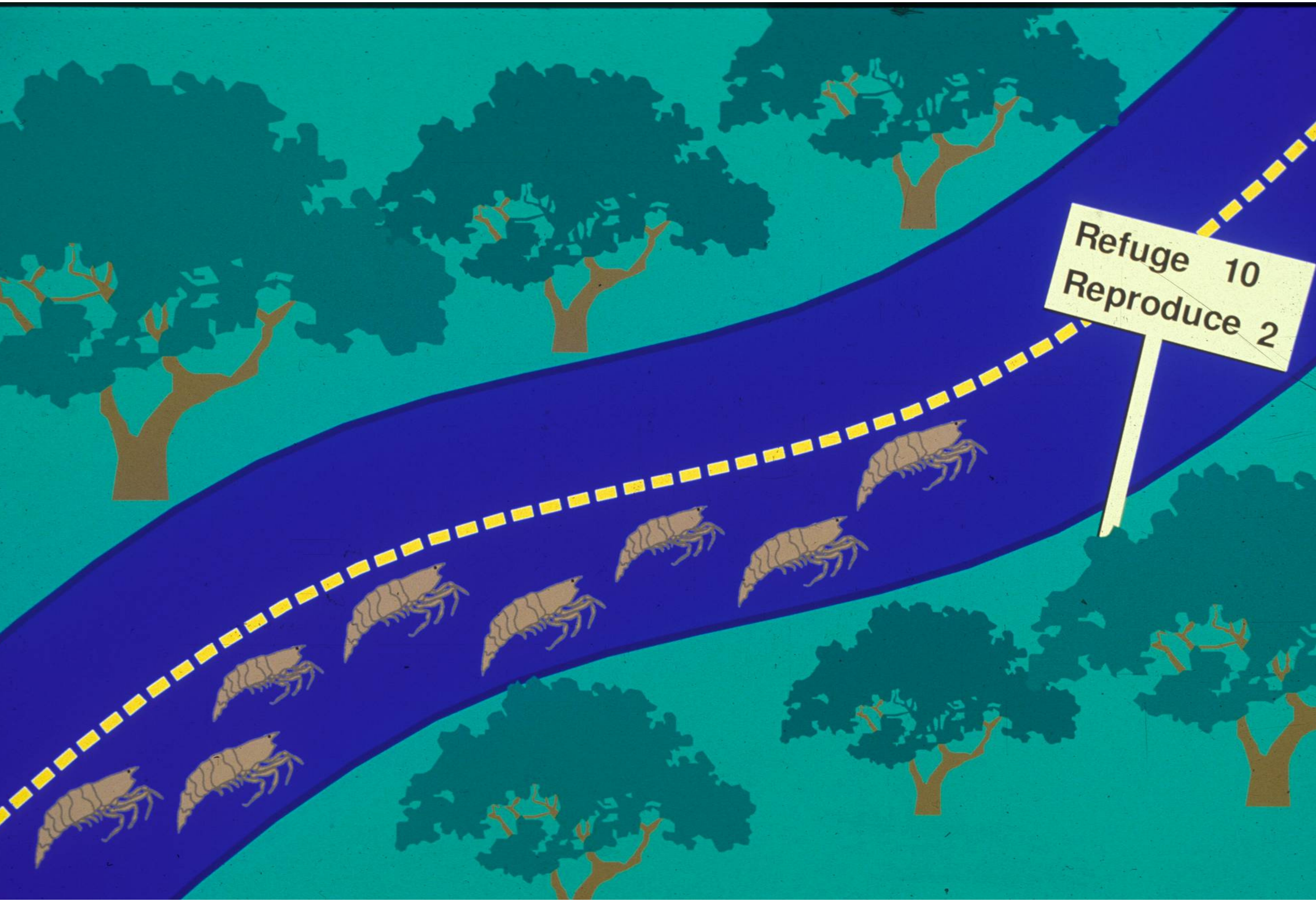

CARIBBEAN
SEA
Greater Antilles
Puerto Rico
Northern South America


El Yunque
National Forest
Puerto Rico
5 meters of
annual rainfall


Headwater streams drain steep tropical forests in the Luquillo Mountains and flow over numerous waterfalls

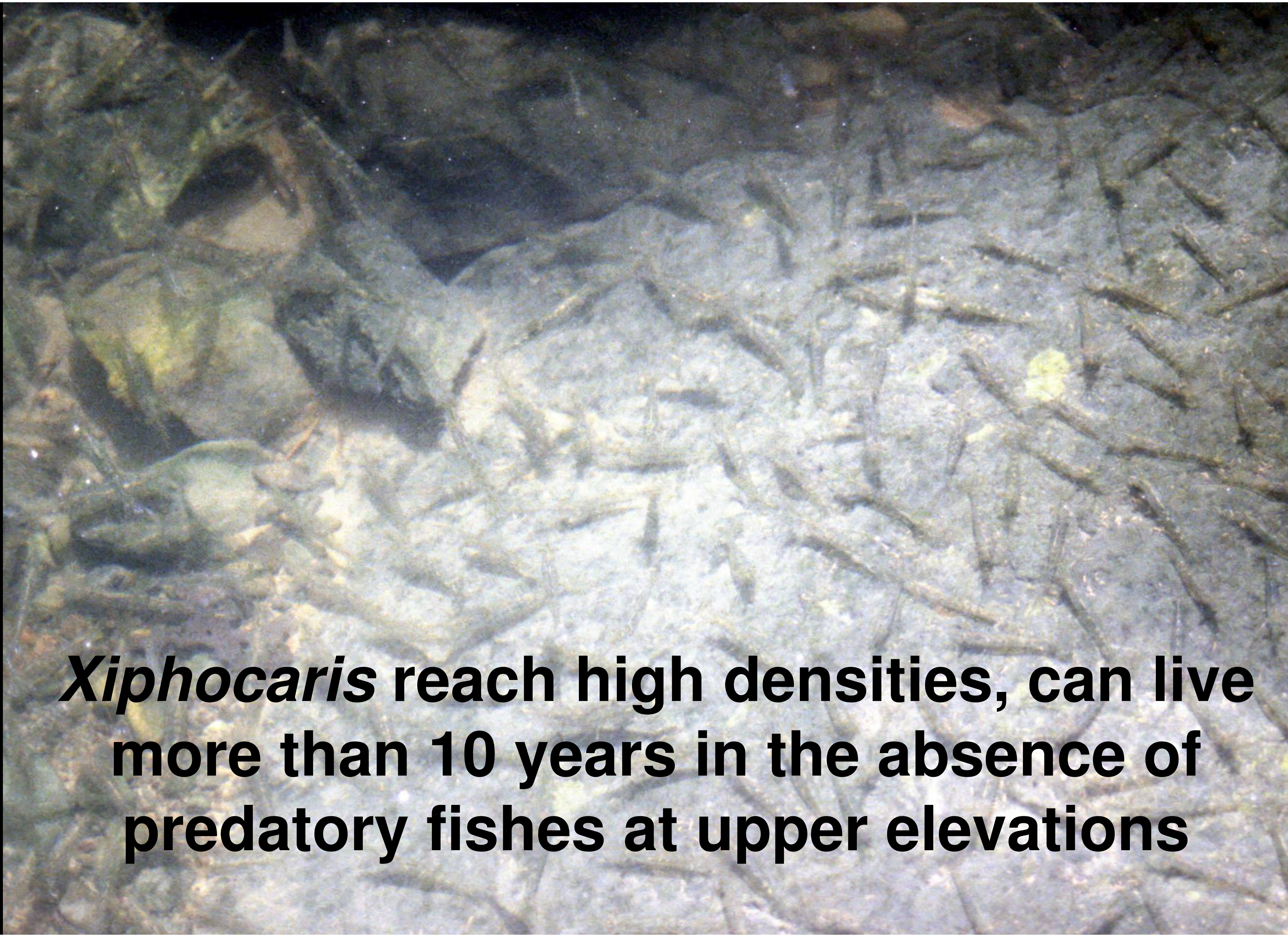

Tropical Streams
Provide Water for Cities
and Recreation for
Local Residents and
Visitors.


Shrimp migrate upstream from pool to pool into headwater streams from estuaries


Refuge 10
Reproduce 2

Shrimp larvae drift downstream to estuaries and develop into post -larval juveniles

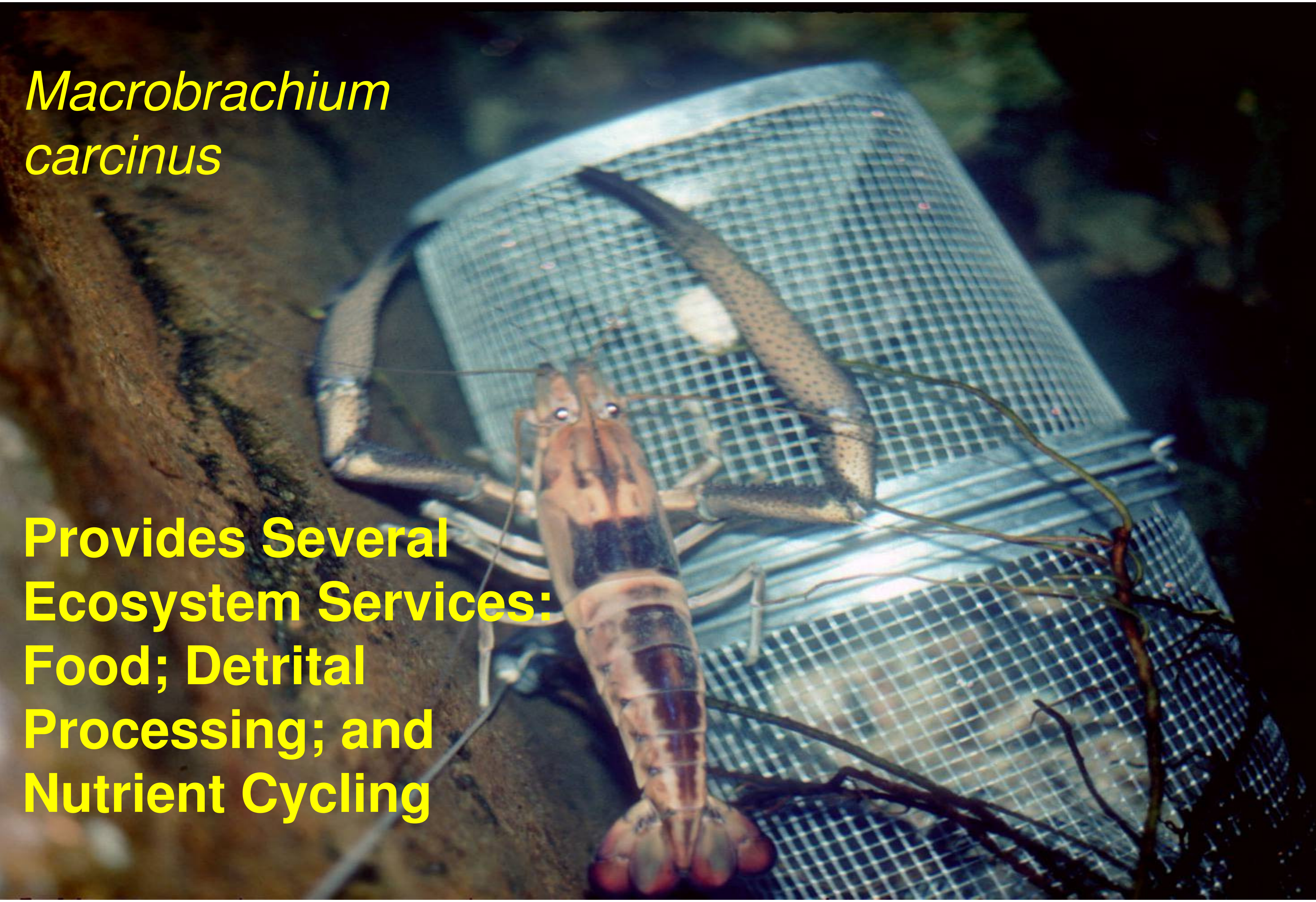

Post - larval shrimp migrate upstream
from estuaries to feed, grow, and
reproduce and to avoid predatory fishes.


Xiphocaris reach high densities, can live more than 10 years in the absence of predatory fishes at upper elevations

Xiphocaris elongata **are leaf-litter shredders. Their feeding creates suspended organic particulates consumed by filter-feeding Atyid freshwater shrimps.**

Atya lanipes filter feed on suspended particles

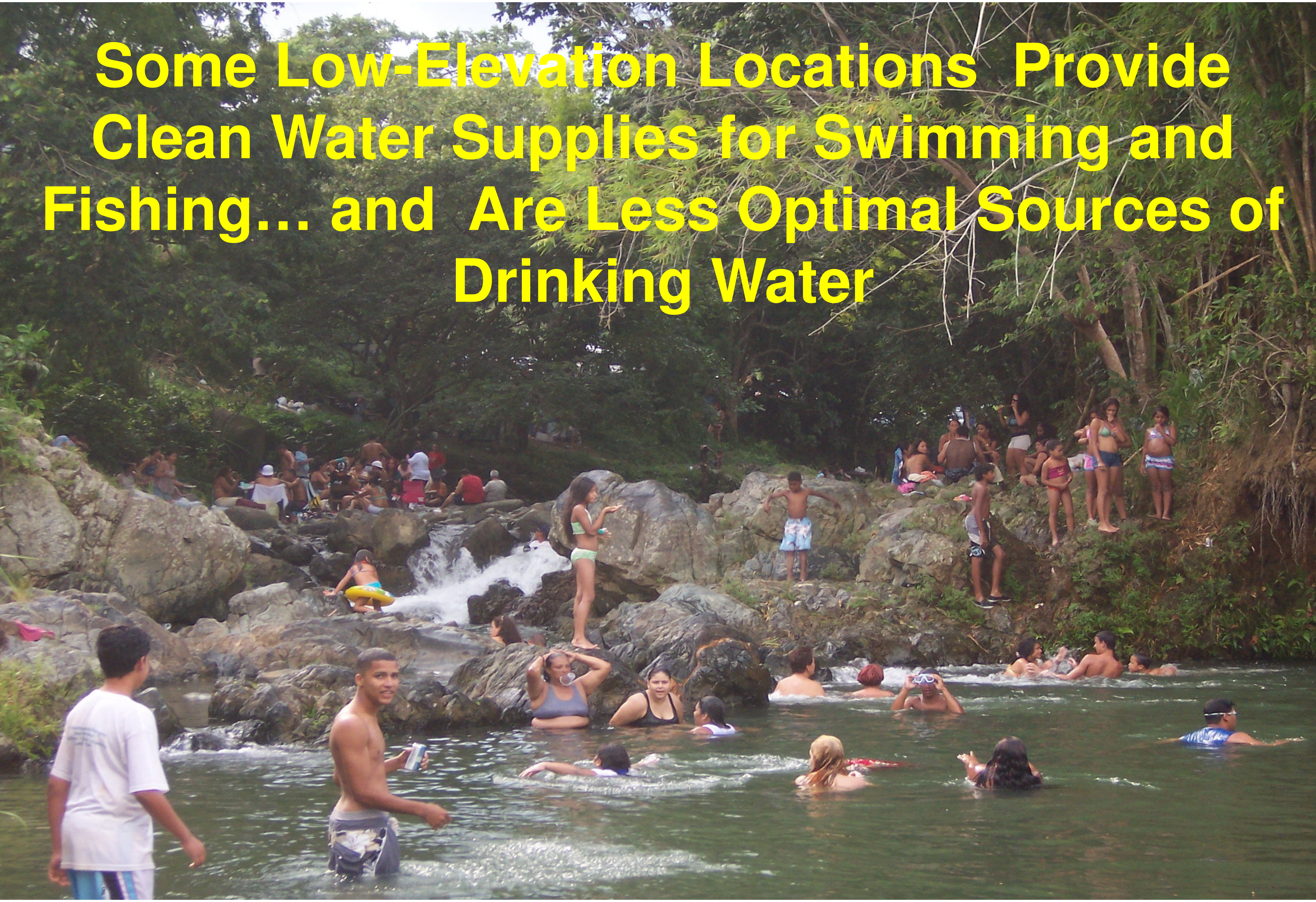

Atya Line Up to Filter Feed
Day and Night
Marked individuals remain in the same pool
for more than 8 years

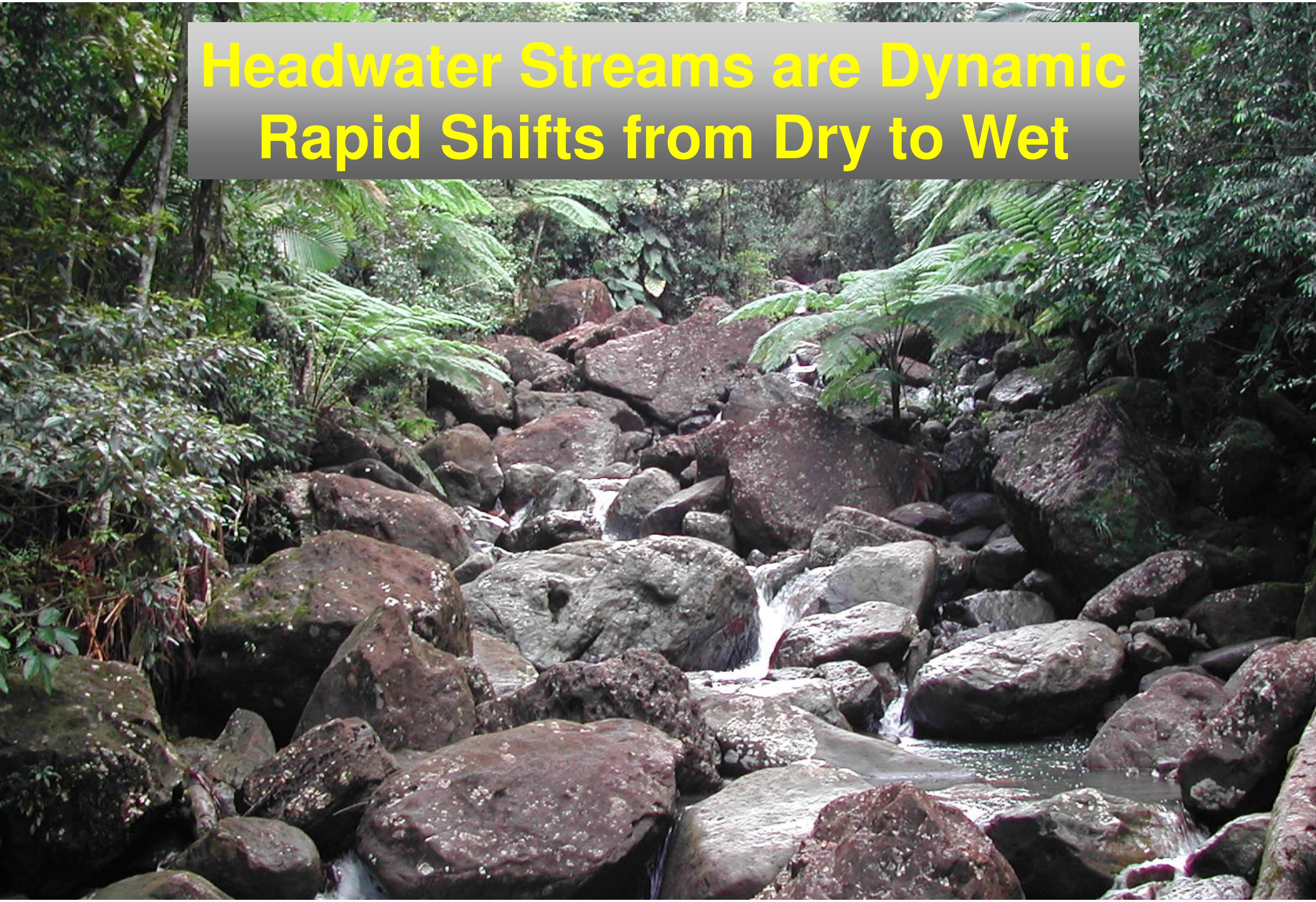

Macrobrachium carcinus
Provides Several Ecosystem Services: Food; Detrital Processing; and Nutrient Cycling

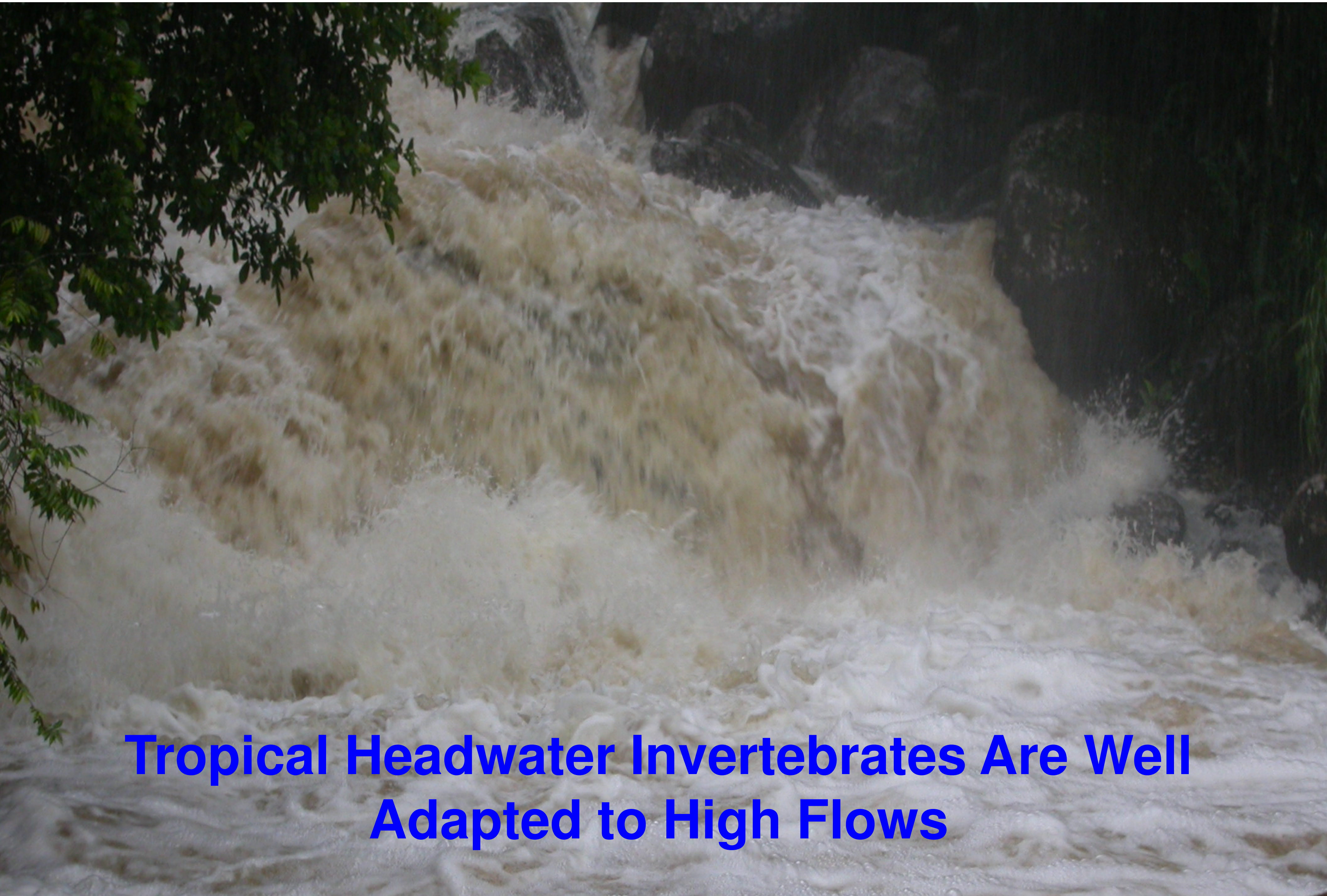

Freshwaters Provide Shellfish


Recreational Fishing Requires Clean Water


Clean Water for Recreation and Drinking?
Can Both Ecosystem Services Be Managed in the Same Streams?
Reserve High-Elevation Sources for Drinking Water Supplies


Some Low-Elevation Locations Provide
Clean Water Supplies for Swimming and
Fishing… and Are Less Optimal Sources of
Drinking Water

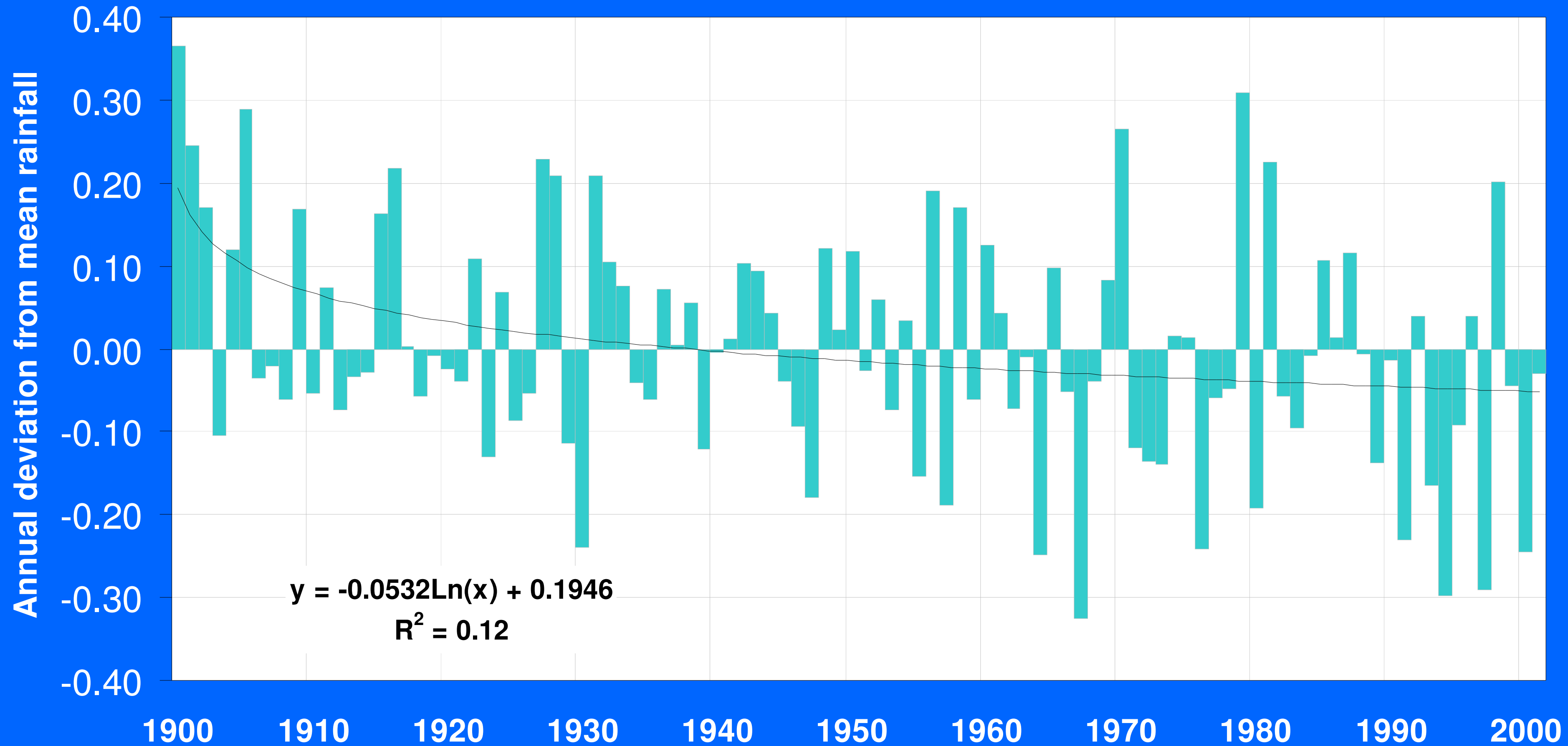

Headwater Streams are Dynamic
Rapid Shifts from Dry to Wet



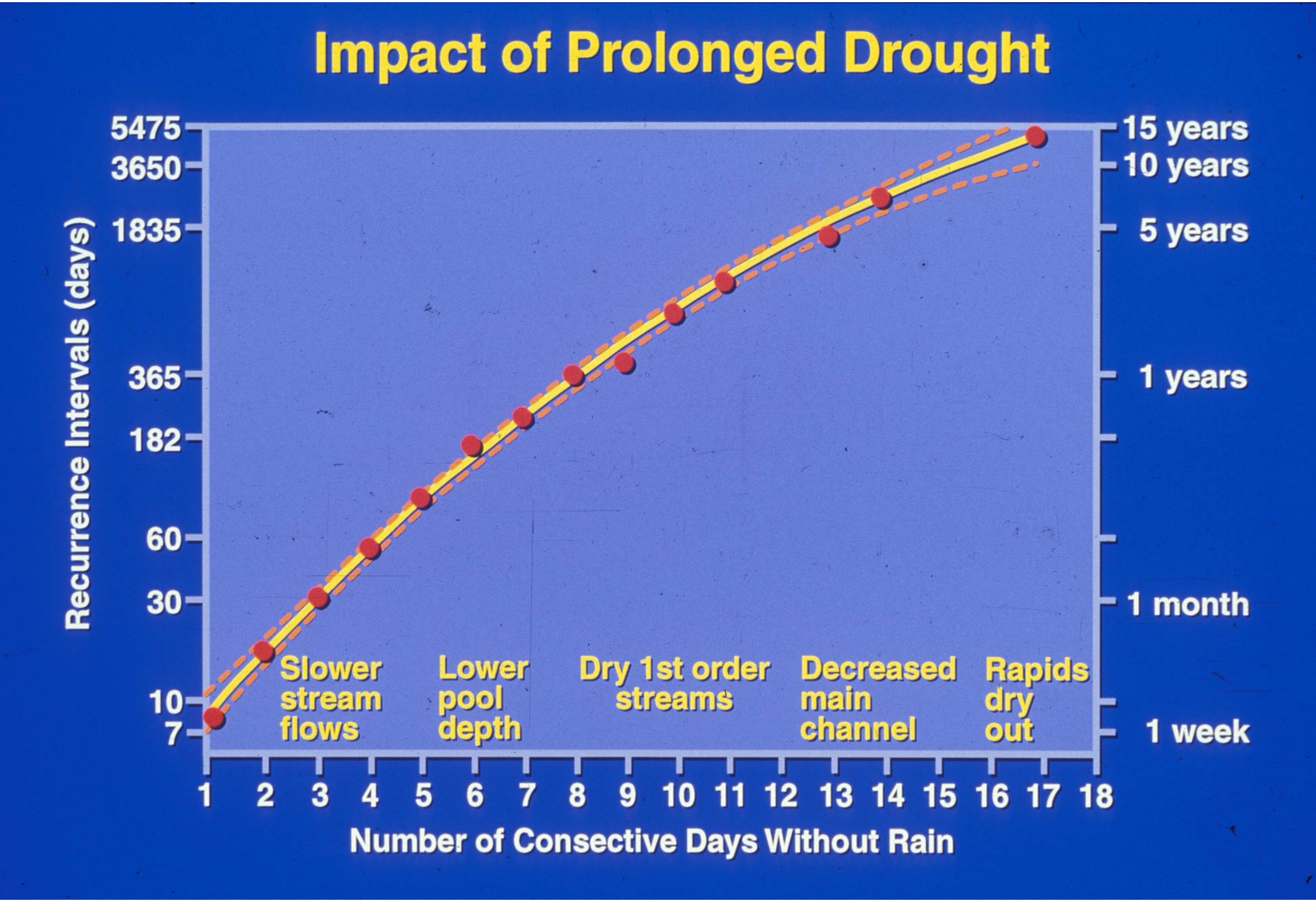
Tropical Headwater Invertebrates Are Well Adapted to High Flows

Increased variability in stream flows and more frequent very dry conditions will likely decrease biodiversity and a tipping point in reliability of ecosystem services will result.

Puerto Rican 100 year departures from mean annual rainfall 10 stations



Droughts are increasing in frequency



Impact of Prolonged Drought
Recurrence Intervals (days)
5475
3650
1835
365
182
60
30
10
7
15 years
10 years
5 years
1 years
1 month
1 week
Slower stream flows
Lower pool depth
Dry 1st order streams
Decreased main channel
Rapids dry out
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Number of Consective Days Without Rain

Droughts Are Increasing on Caribbean Islands

171

The San Juan Star

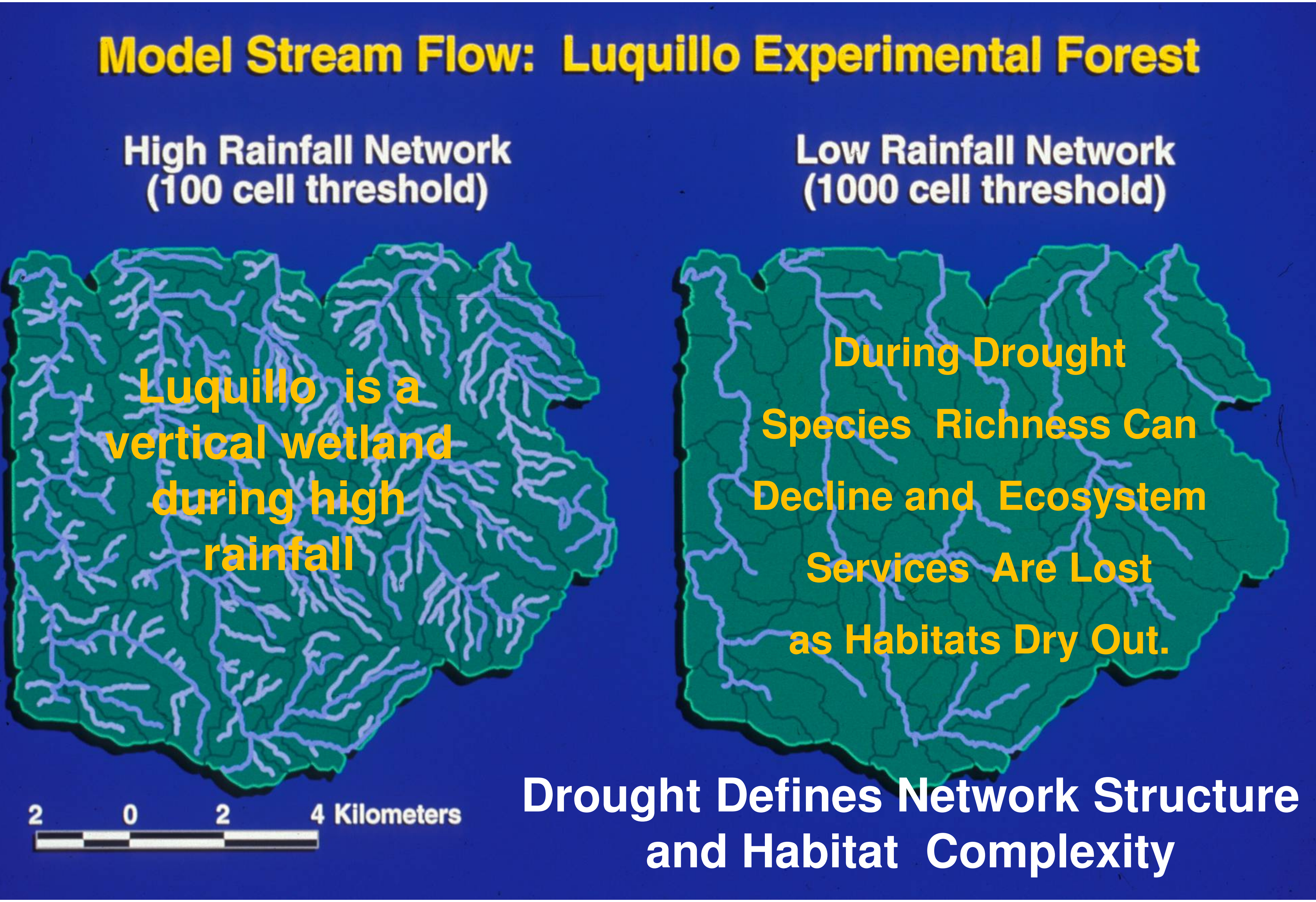
Virgin Islands 80¢ | Friday, May 6, 1994 | Puerto Rico 30¢

Water taps start drying up

ASA begins indefinite rationing that may spread islandwide. Page 3

Conservation being urged on the job and at home until Carraizo Lake level rises.
Page 2

Aqueduct and Sewer Authority officials wish they had a reason for standing under an umbrella but Thursday's short-lived drizzle did nothing to replenish the severely depleted Carraizo Lake, the source of water for


Model Stream Flow: Luquillo Experimental Forest
High Rainfall Network
(100 cell threshold)
Low Rainfall Network
(1000 cell threshold)
Luquillo is a vertical wetland during high rainfall
During Drought Species Richness Can Decline and Ecosystem Services Are Lost as Habitats Dry Out.
2 0 2 4 Kilometers
Drought Defines Network Structure and Habitat Complexity

Post- Larval Shrimp Migrate Upstream and Avoid Predatory Mountain Mullet Below Waterfall Barriers

Complex Processing Chains

With Long - Lived Species

Different Ages and Species Have Complementary Roles

Organic Matter Processing Rates Depend on Species Behavioral Interactions, Sizes, and Ages as Well as Species Richness.