Nonlinear and Threshold Responses to Environmental Stressors in Land-river Networks at Regional to Continental Scales

J. Melillo, B. Peterson, C.J. Vörösmarty, *with D. Kicklighter, W. Wollheim, B. Fekete, B. Felzer, P. Green*

EPA Program Review: Consequences of Global Climate Change: Water Quality Impacts, Ecological Impacts & Nonlinear Responses

Washington DC *21 September 2011*

Overall Goals

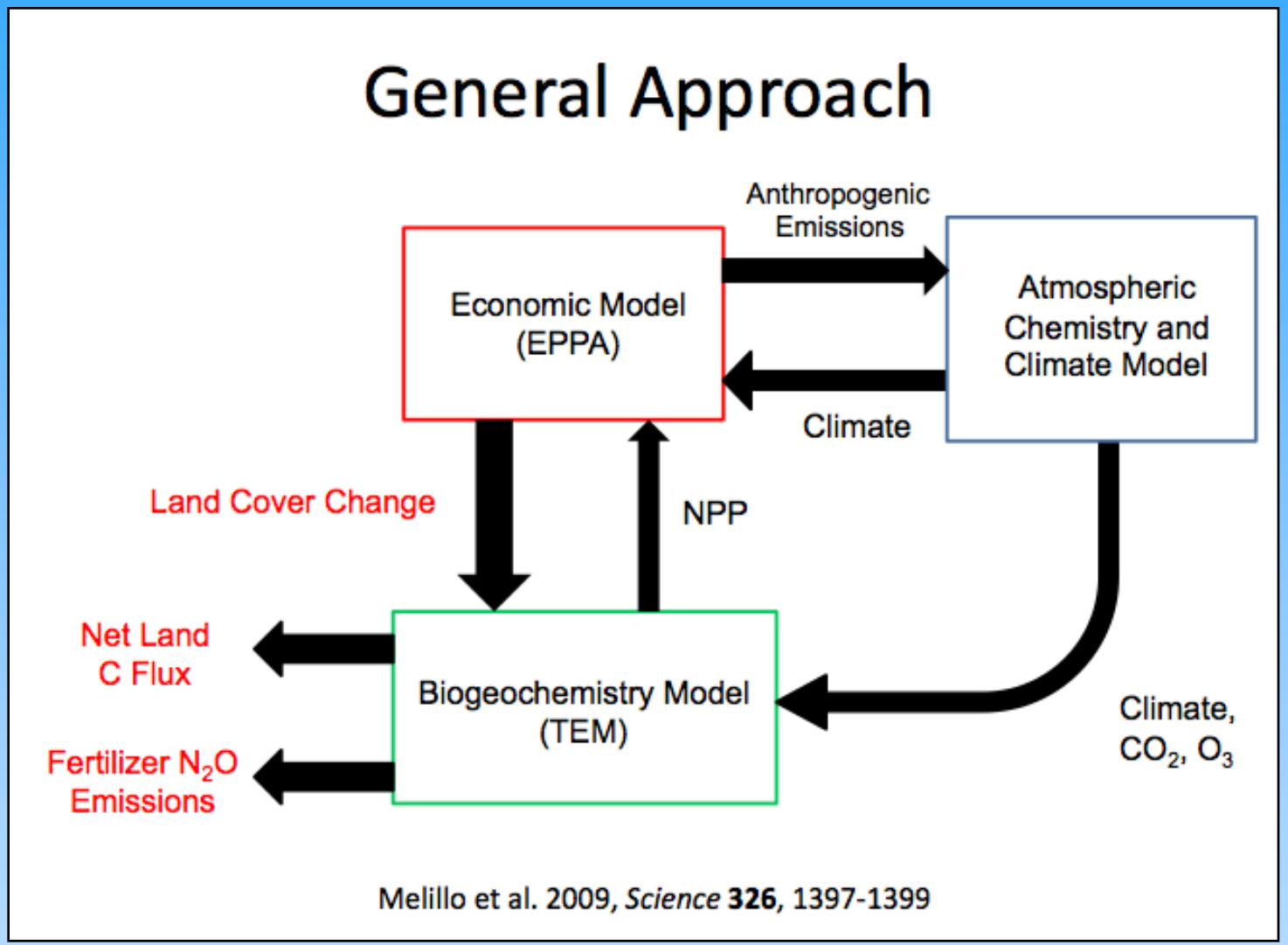
- To unite emerging models, integrative toolkits and data sets to explore multiple stressor impacts on regional-to-global landscapes, watersheds, and rivers
- Three examples
  - Biofuel strategies viewed thru lens of C-N interactions
  - Threats to human water security and biodiversity
  - Analysis of ecosystem services: Riverine N processing

Science
AAAS

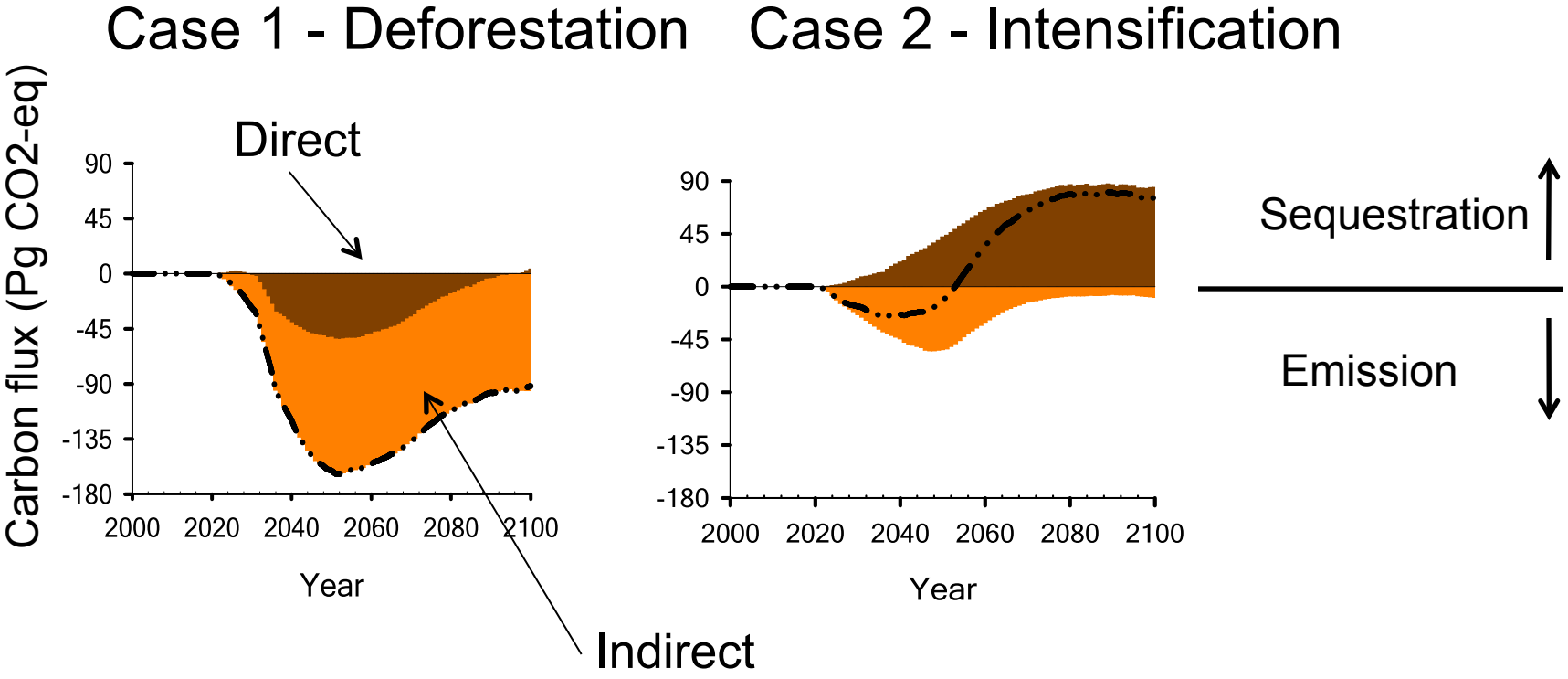
Indirect Emissions from Biofuels: How Important?

Jerry M. Melillo, *et al.*

Science **326**, 1397 (2009);
DOI: 10.1126/science.1180251

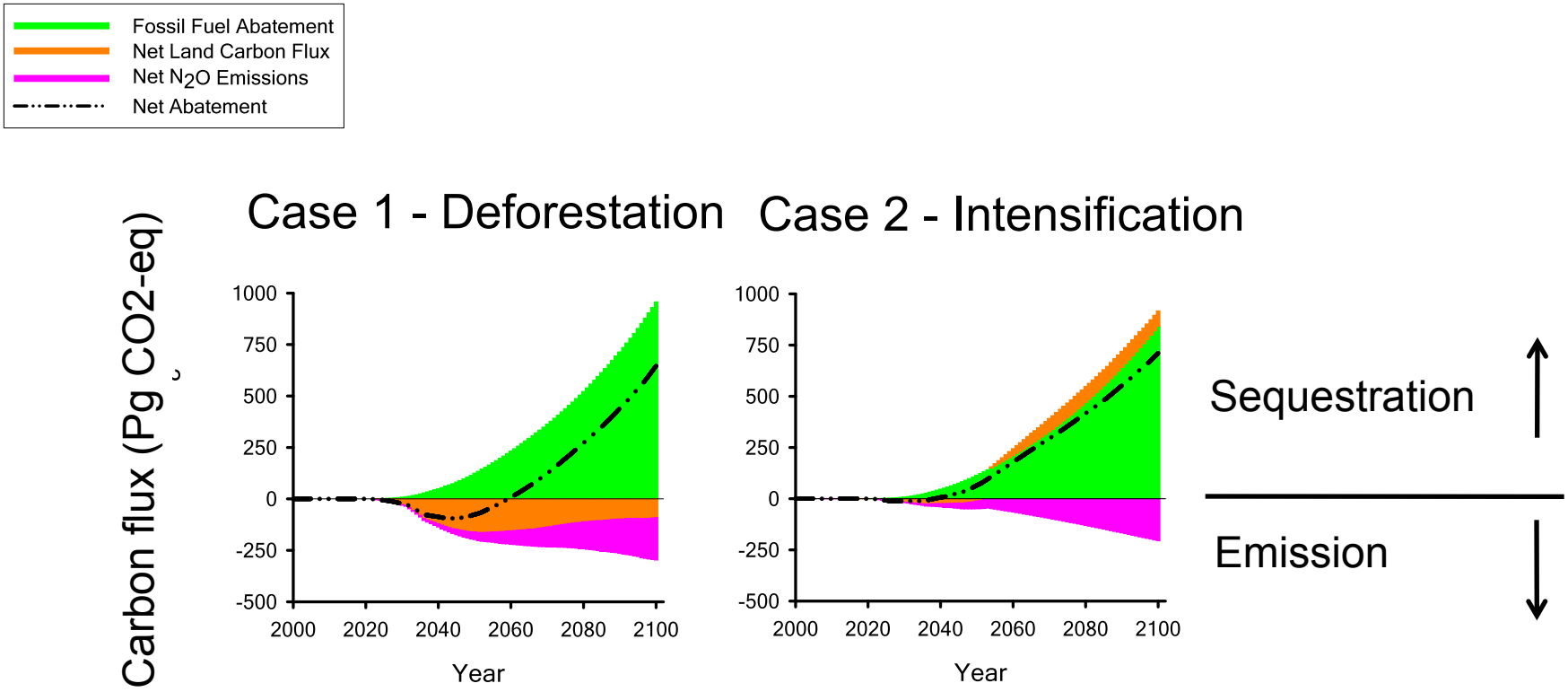


Effect of Biofuels on Cumulative Terrestrial Carbon Storage



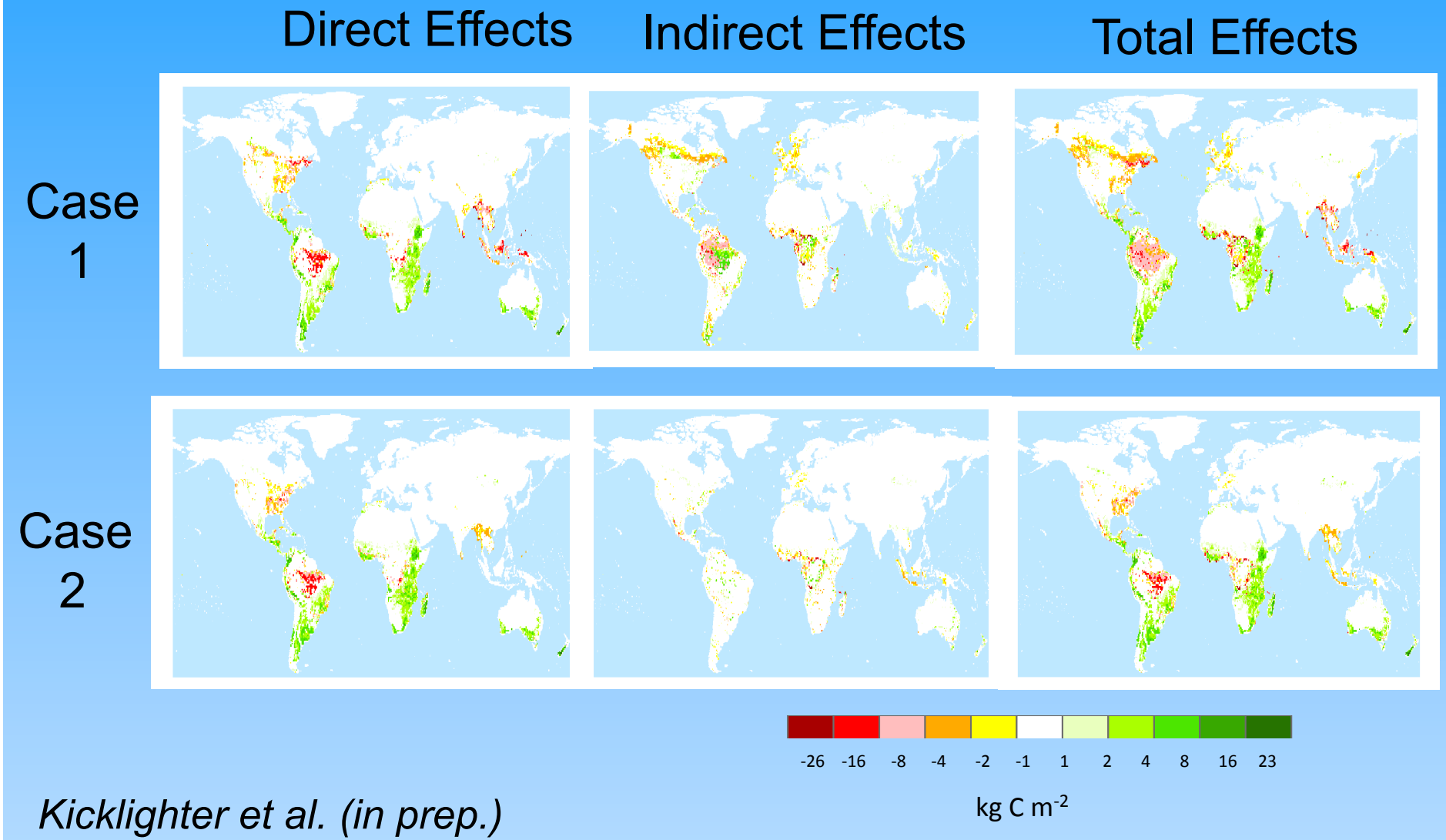
Melillo et al., 2009, *Science* **326**, 1397-1399

Effect of Cellulosic Biofuels Production on Net Greenhouse Gas Balance



Melillo et al., 2009, *Science* **326**, 1397-1399

Effects of Cellulosic Biofuels Production on Carbon Storage (2001-2100)



Kicklighter et al. (in prep.)

Nature: September 30 issue

Can we capture the **full dimensionality** of this issue & move from local to regional to a fully global perspective?

…and thus be on par with the global climate change question

Visit: *www.riverthreat.net*

Major Sources of Threat to Inland Waters: Four *Themes*

Watershed Disturbance

- *Cropland*
- *Imperviousness*
- *Livestock density*
- *Wetland disconnectivity*

Pollutants

- *Soil salinization*
- *Nitrogen loads*
- *Phosphorus loads*
- *Mercury deposition*
- *Pesticide loads*
- *TSS loads*
- *Organic (BOD) loads*
- *Potential for acidification*
- *Thermal impacts*

Water Resource Development

- *Small dam density*
- *Large dam impacts (residency time Δ)*
- *River network fragmentation*
- *Consumptive use (loss/supply)*
- *Water crowding (population/supply)*
- *Cropland crowding (area/ supply)*

Biotic Threats

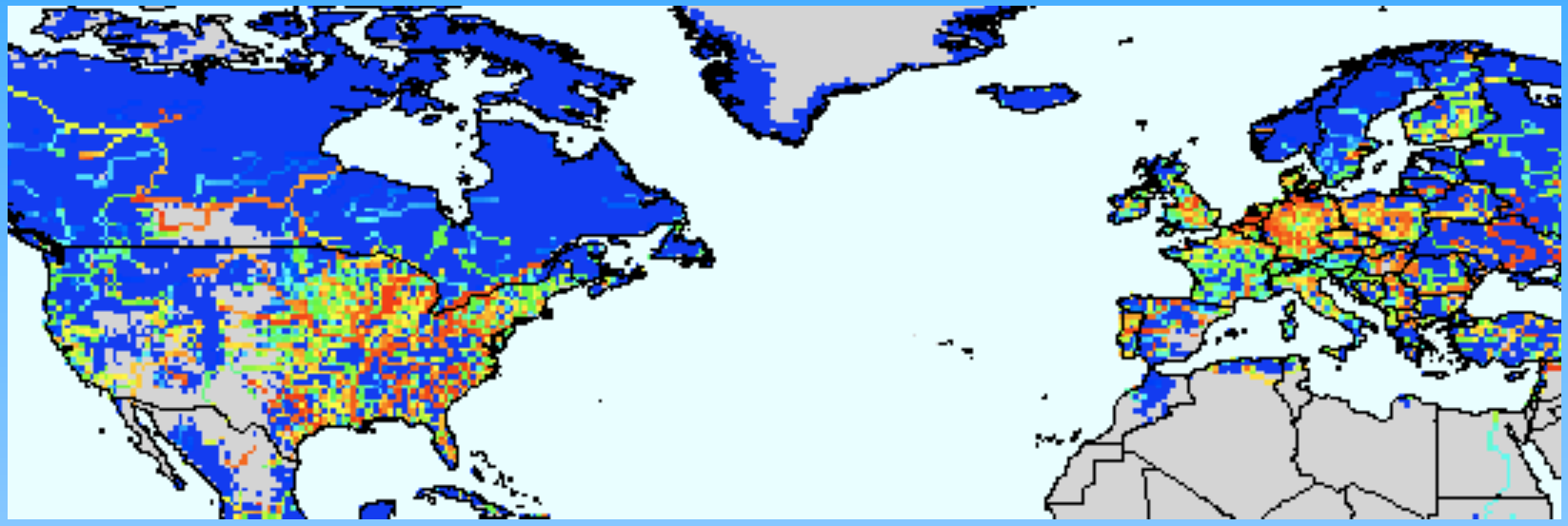
- *Invasion level (non-native fish)*
- *Non-native fish species richness*
- *Catch pressure*
- *Aquaculture*

N = 23 global data fields

One Example: Consequences of the Energy Mix

Heat Pollution from Thermoelectric Plants and Manufacturing

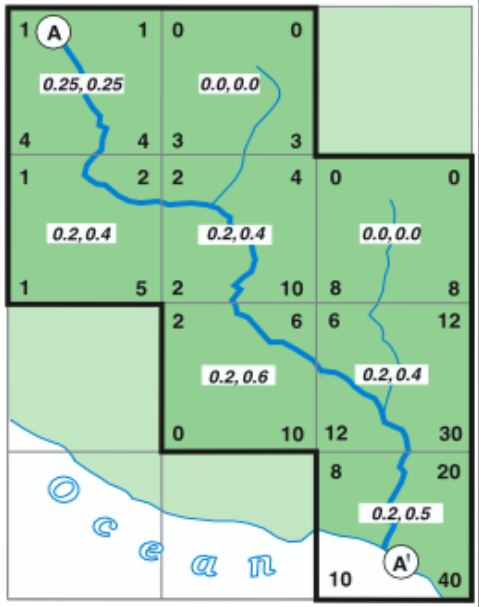
-- One of 23 Environmental Stress Agents Considered --

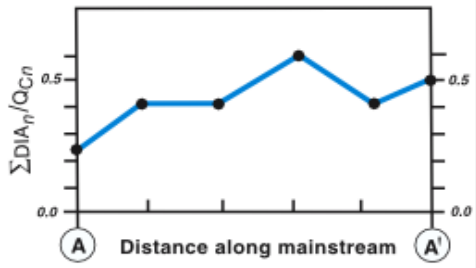


Normalized scores: based on Vassolo and Döll (2005)

Vörösmarty et al. 2010, Nature (vol. 467)

US EPA ARCHIVE DOCUMENT





CALCULATION OF KEY WATER INDICATORS

DIA_n = domestic, industrial, agricultural water use ($km^3\ yr^{-1}$) in cell n

$\sum DIA_n$ = DIA in cell n plus all upstream cells ($km^3\ yr^{-1}$)
$= \sum_{i=1}^{n} DIA_i$

R_n = locally-generated runoff (mm/yr)

A_n = area of cell n (km^2)

$Q_{Ln} = 10^6 * R_n * A_n$ = locally generated discharge ($km^3\ yr^{-1}$)

$Q_{Cn} = \sum_{i=1}^{n} Q_{L_i}$ = river corridor discharge ($km^3\ yr^{-1}$)

DIA_n/Q_{Cn} = local relative water use (unitless)

$\sum DIA_n/Q_{Cn}$ = water reuse index (unitless)

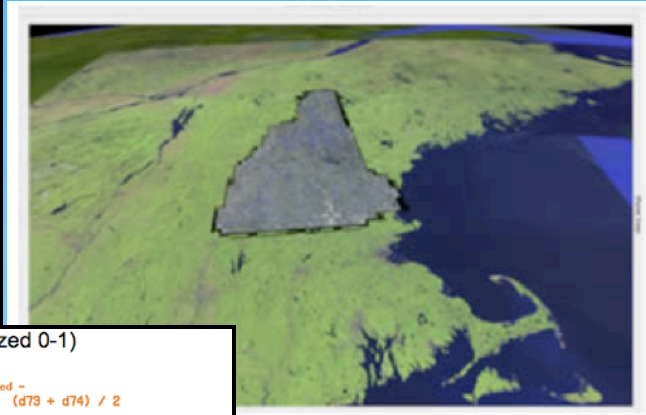
n = position of cell in river network
= total number of upstream cells plus cell in question

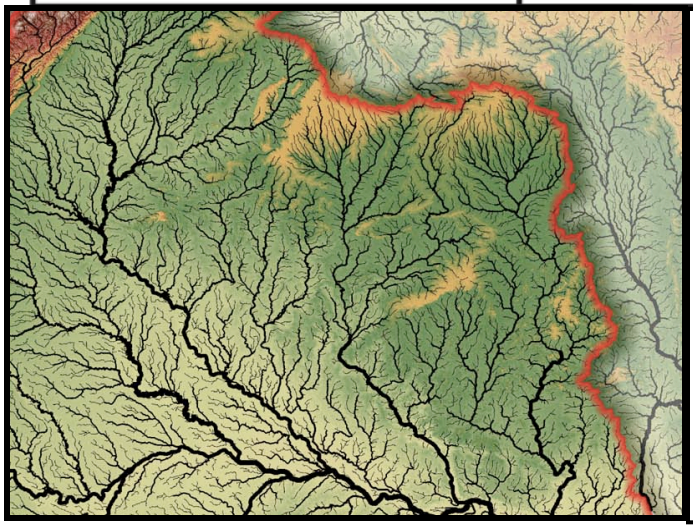
Key (cell n)

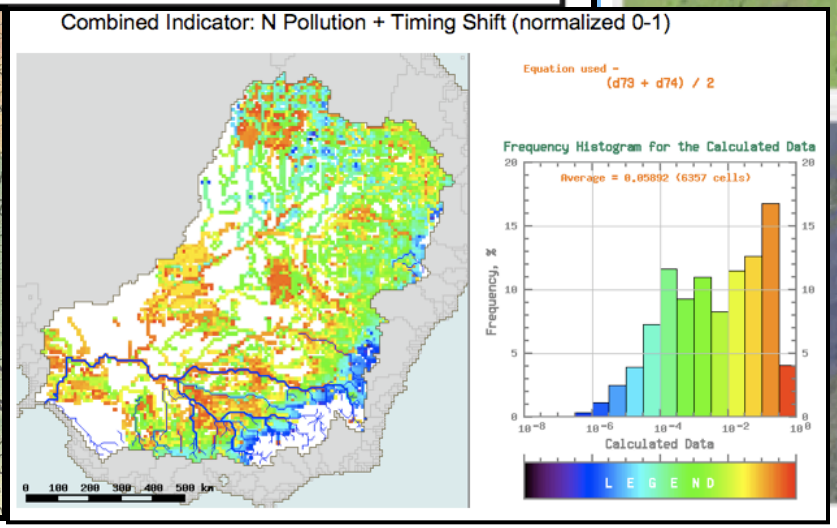
Global RIMS

Global Rapid Indicator Mapping System for Water Cycle & Water Resource Assessment

- *DEFINE WATERSHED STATE BASED ON LOCAL AND RECURSIVE INDICES*
- *GOOGLE AND OPEN MAP SERVERS*
- *MAP SYSTEM STATES OVER MULTI-SPACE & TIME SCALES*



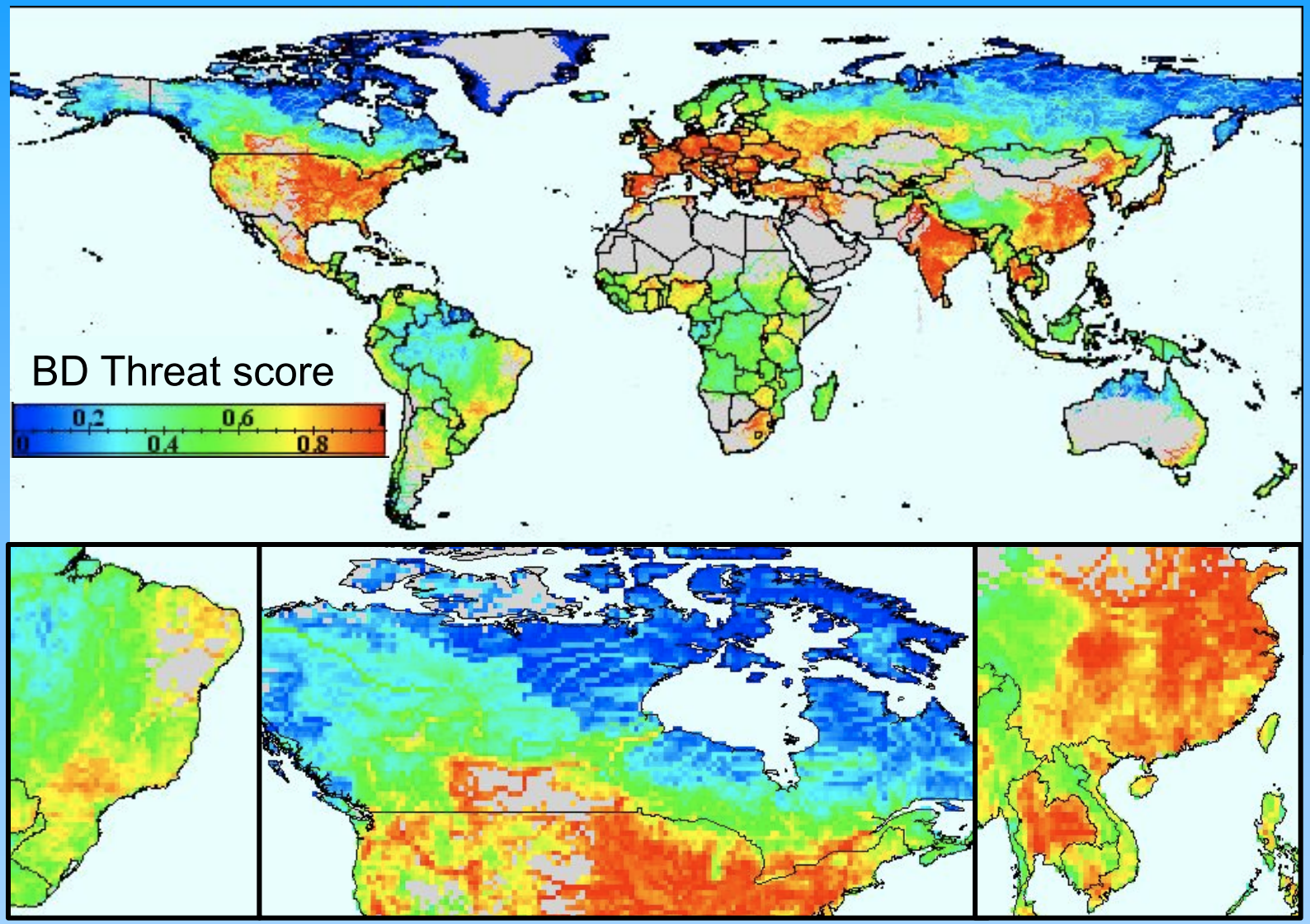




GWSP Global Water System Project

DIVERSITAS

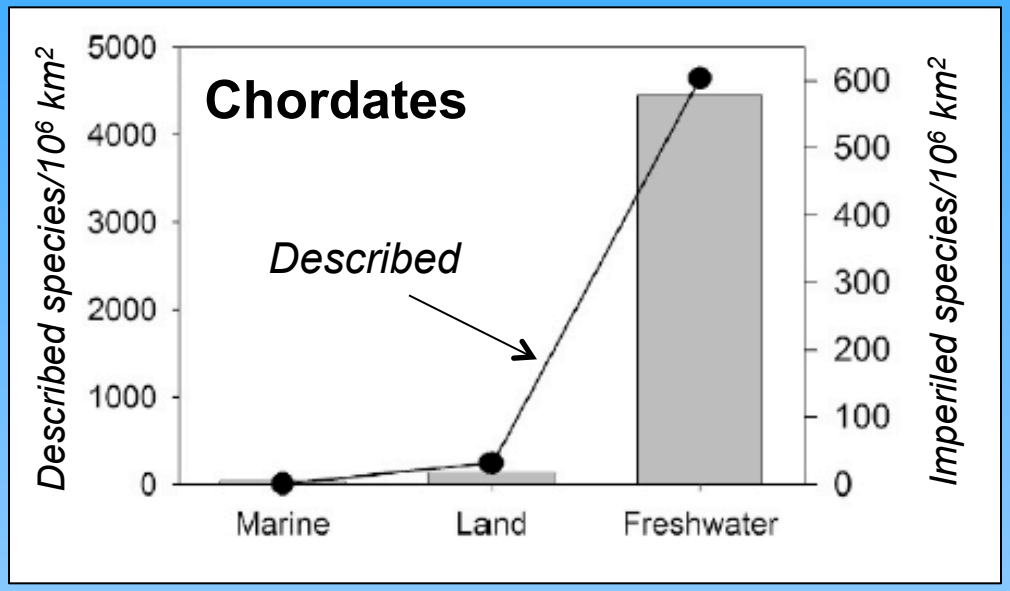
Threat to Biodiversity



- Pandemic
- Generally correlated to population, agriculture, development
- Transboundary: Atmospheric transport & river network legacies

An Underpinning / Corroboration of BD Loss?

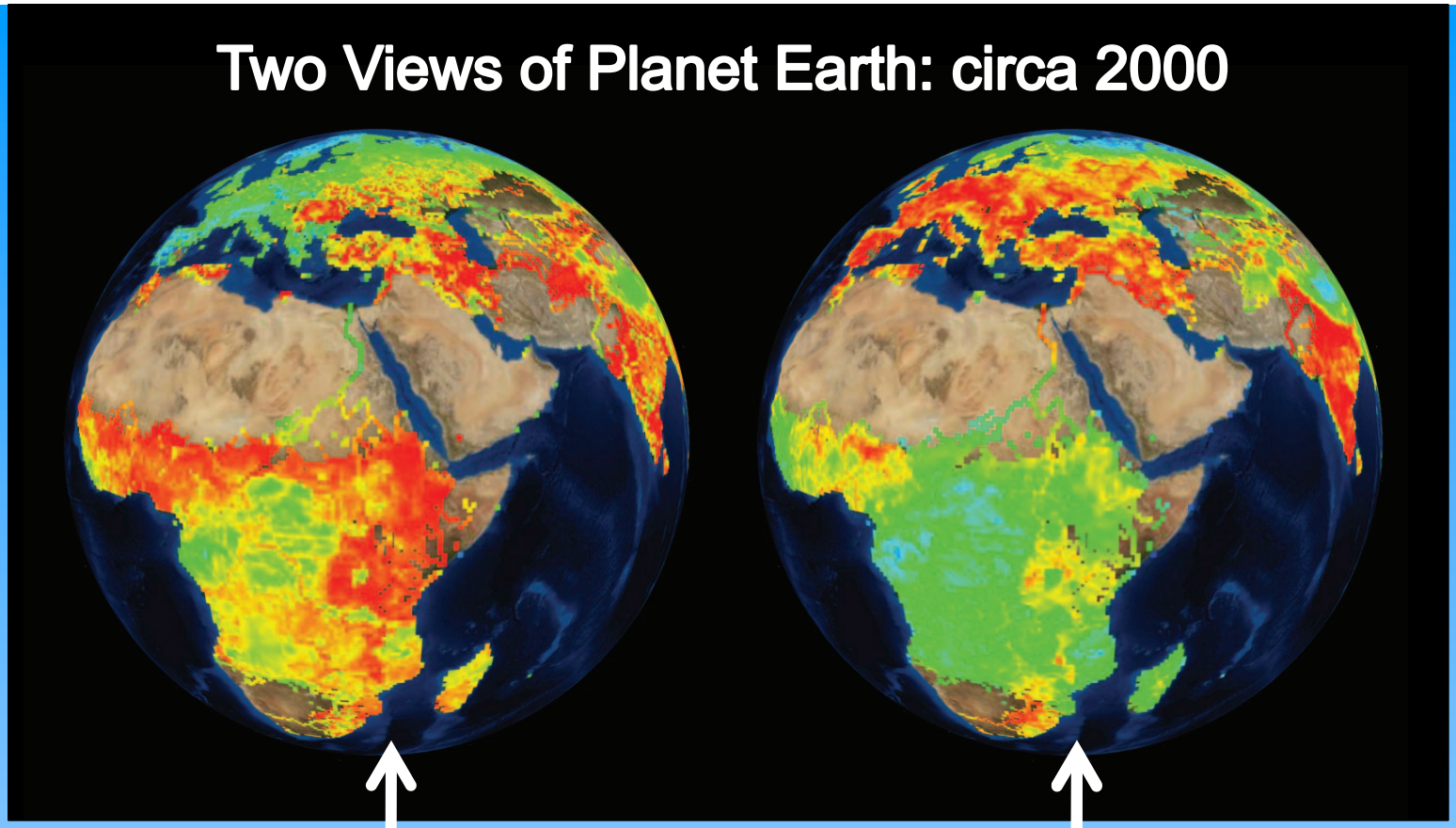
- Unusually high concentration of biodiversity: ~125,000 freshwater species described (~10% of known animal species) despite inland waters <1% of the Earth's area; high endemism…high risk

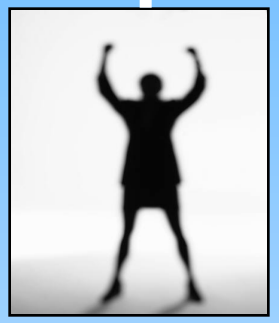


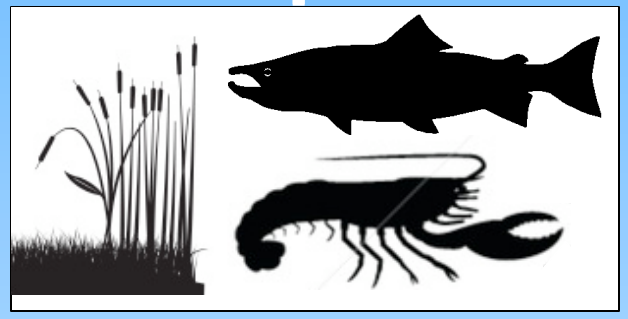
From: Strayer and Dudgeon (2010), J-NABS

- Globally 10,000-20,000 freshwater species are extinct or imperiled
- Have FW systems moved from the Holocene into the Anthropocene?

Two Views of Planet Earth: circa 2000





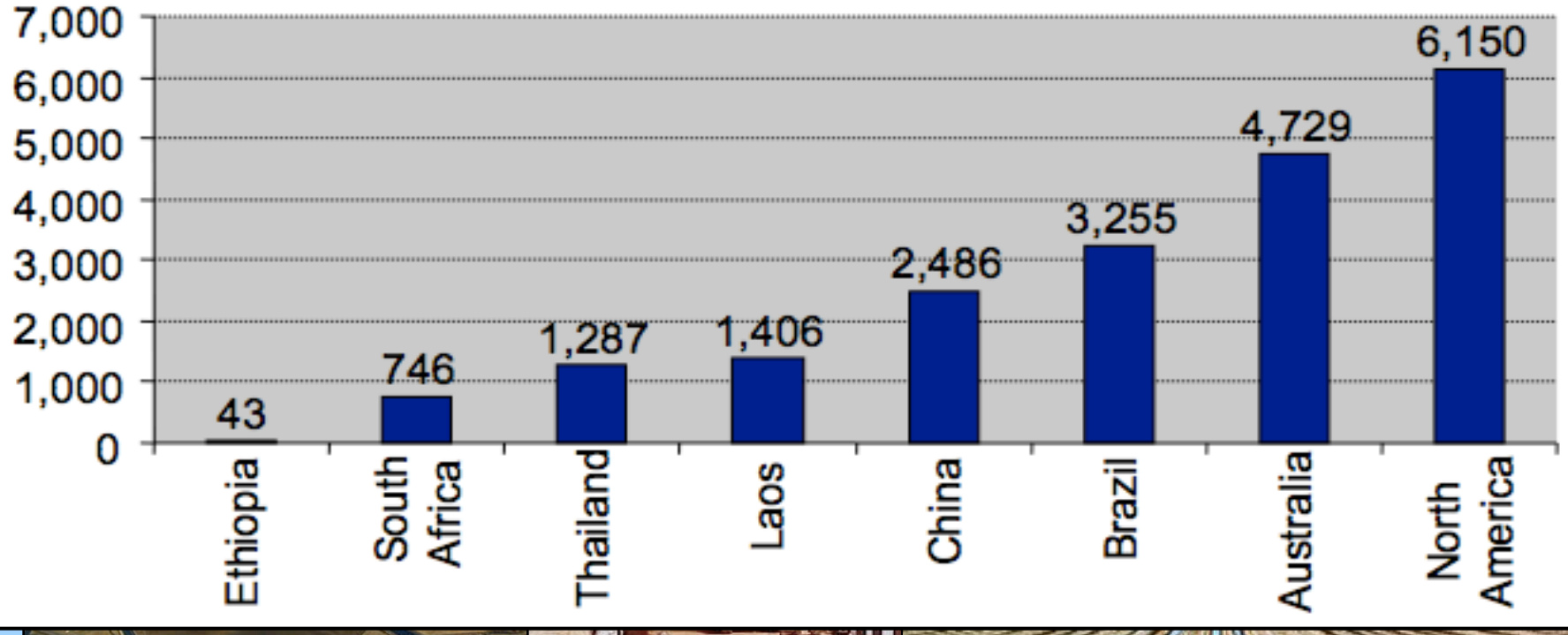


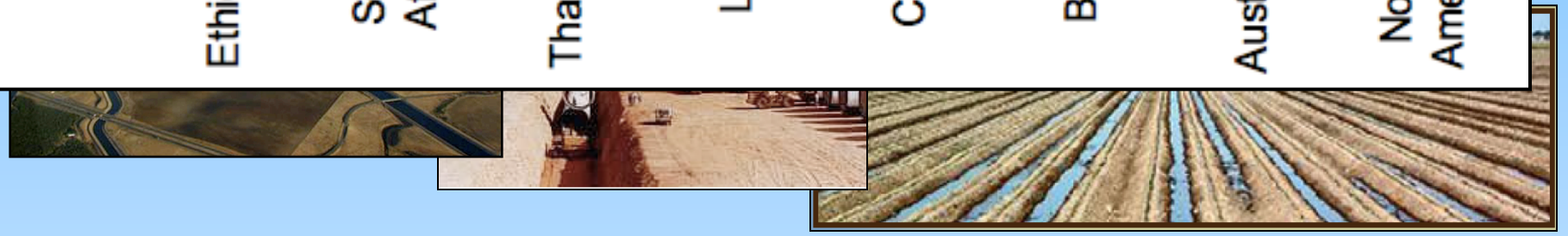
Why so different?

Water Management: Engineering, Human Use/Overuse: Core Element of the Contemporary Earth System

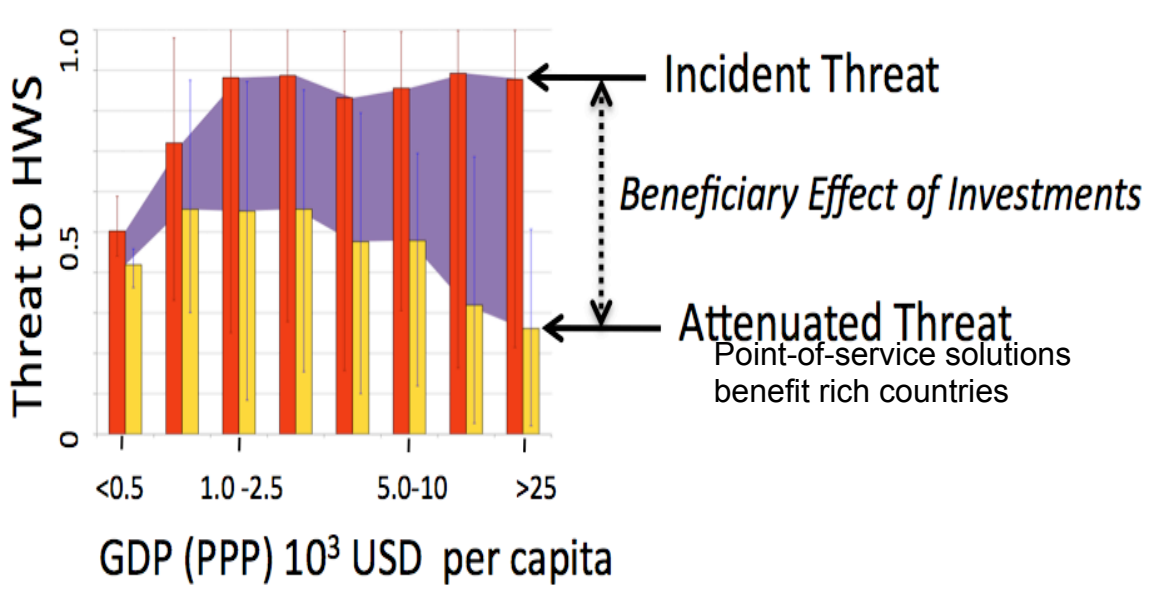
Infrastructure gap: Reservoir water storage

Haves and Have-Nots: Water storage per person (m3)





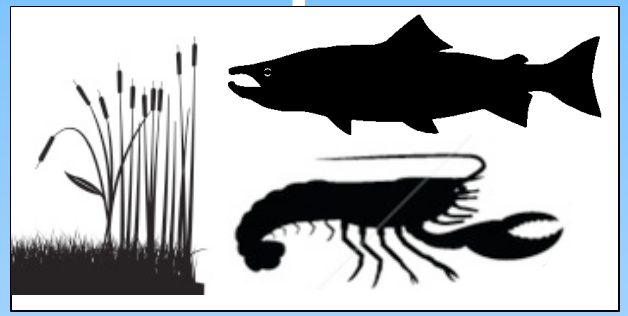
Human Water Security



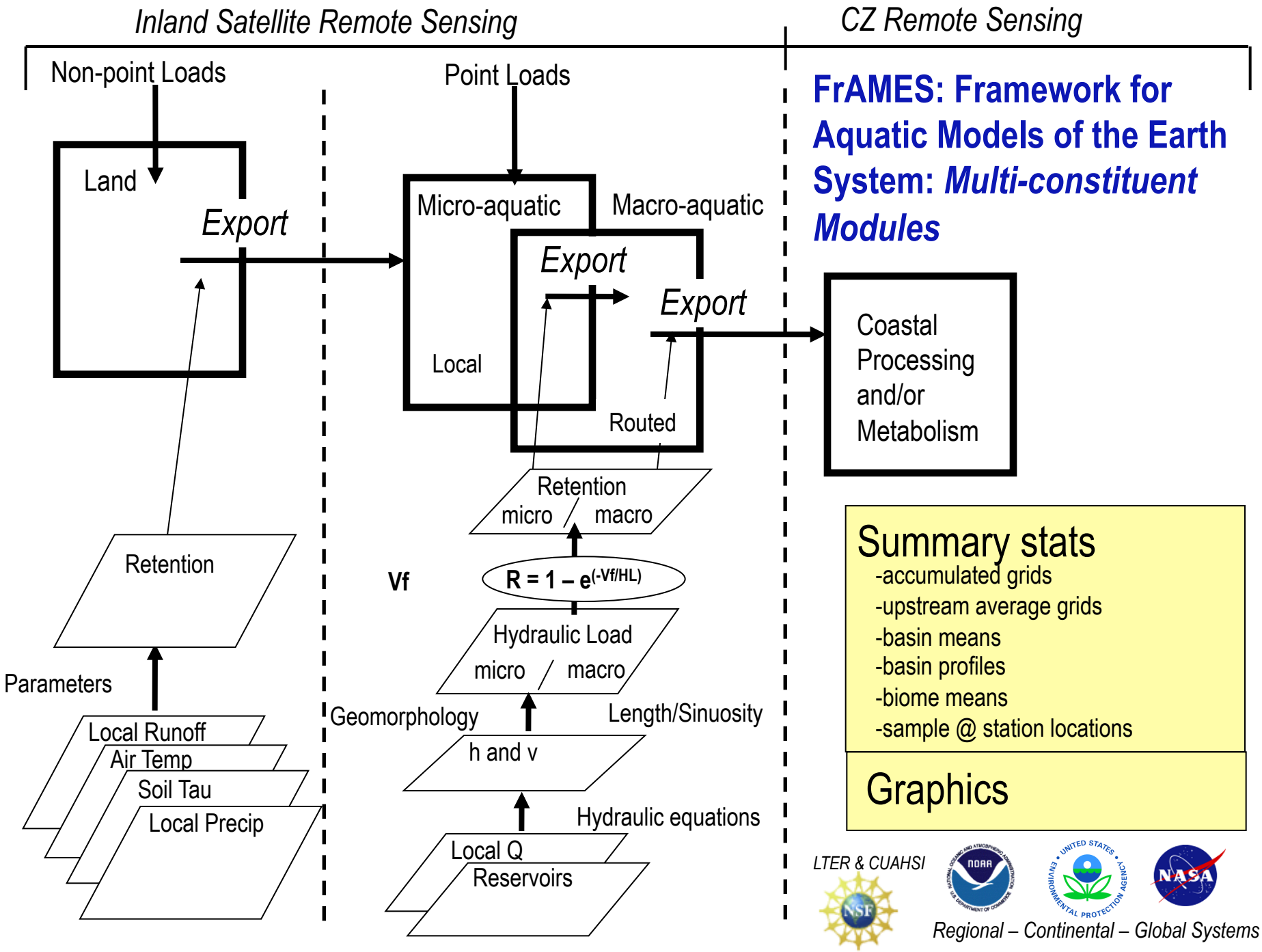
Large $$ & Energy Costs

- Treat symptoms rather than causes
- Strand poor & BD under high levels of threat
- Water management impacts (like from dams) impair BD and Ecosystem Services

Infrastructure investments are huge: $0.75Trillion/yr for OECD & BRIC alone by 2015



Why so different?



FrAMES: Framework for Aquatic Models of the Earth System: *Multi-constituent Modules*

Summary stats

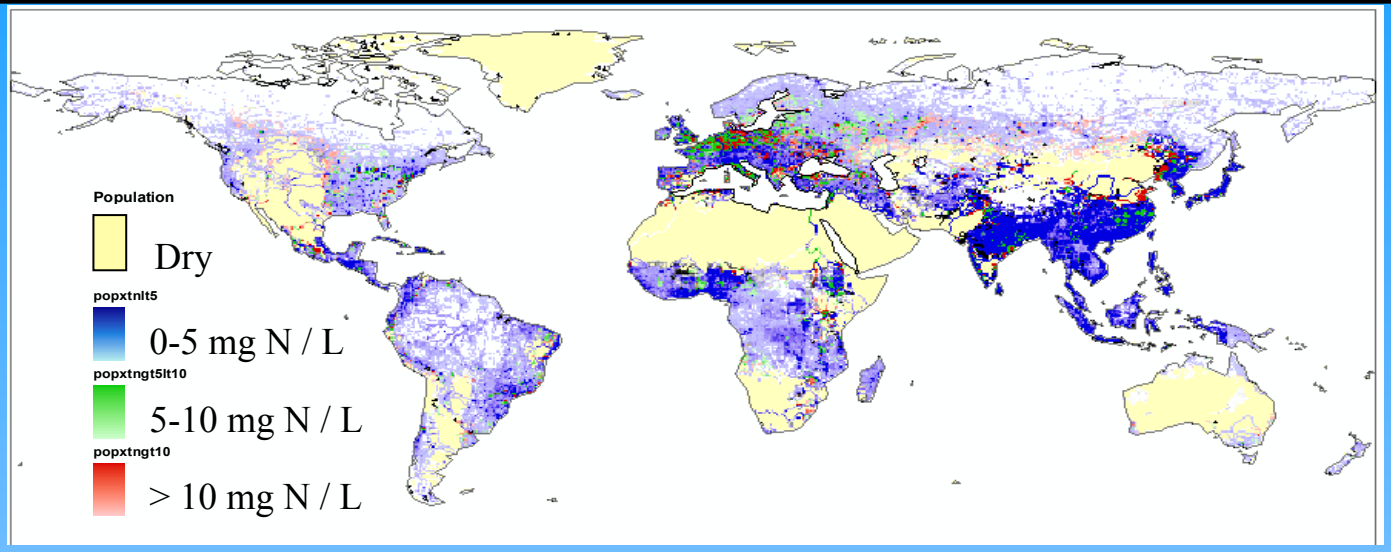
- -accumulated grids
- -upstream average grids
- -basin means
- -basin profiles
- -biome means
- -sample @ station locations

Graphics

LTER & CUAHSI

Regional – Continental – Global Systems

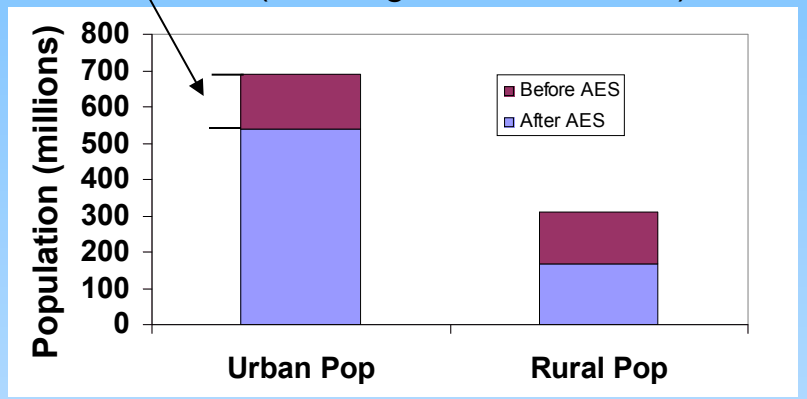
Population Density Exposed to Impaired Water Quality and the Role of Aquatic Ecosystems Services



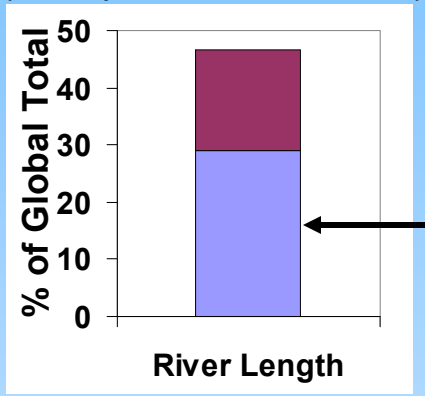
Impact of Aquatic Processing

Exposure to:

> 10 mg N/L
(Drinking Water Standard)



> 2 mg N /L
(Eutrophication Standard)



Overshooting of Self-Purification Capacity

Courtesy: Wollheim, Vörösmarty

In Conclusion

- Well-intentioned global C management thru biofuels convolved with unintended consequences thru N cycle
- Pandemic fingerprint of human-induced impacts on water systems…multi-stressors… *local effects move to regional and global syndromes*
- Viewed as an ecosystem service, beneficial N pollution processing by natural systems is "overshot" by human impacts—affecting ~1Bn
- Overall: Coupled processes and multi-stressors require integrated frameworks

Some Add'l References

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