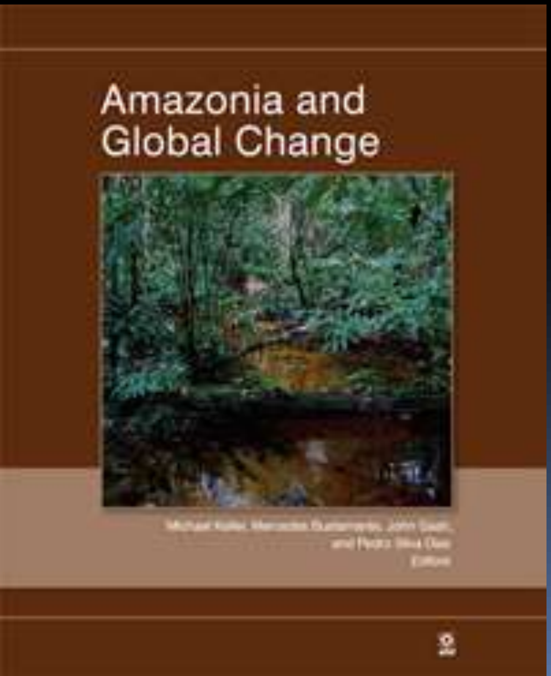
River Corridors of the Amazon Basin and their Response to Anthropogenic Change: A look back and a glimpse forward.

- Daniel Markewitz, University of Georgia
- Michael Coe, The Woods Hole Research Center
- Ricardo de O Figueiredo, Embrapa Amazonia Oriental
- John Melack, University of California Santa Barbara
- Evelyn Novo, University of Sao Paulo
- Jeff Richey, University of Washington
- Javier Tomasella, *INPE*



LBA Science Plan

- "The Amazon still persists as one of the few remaining basins where the watercourses and nearby land have not yet undergone overwhelming human modification."
  - Richey et al., 1997

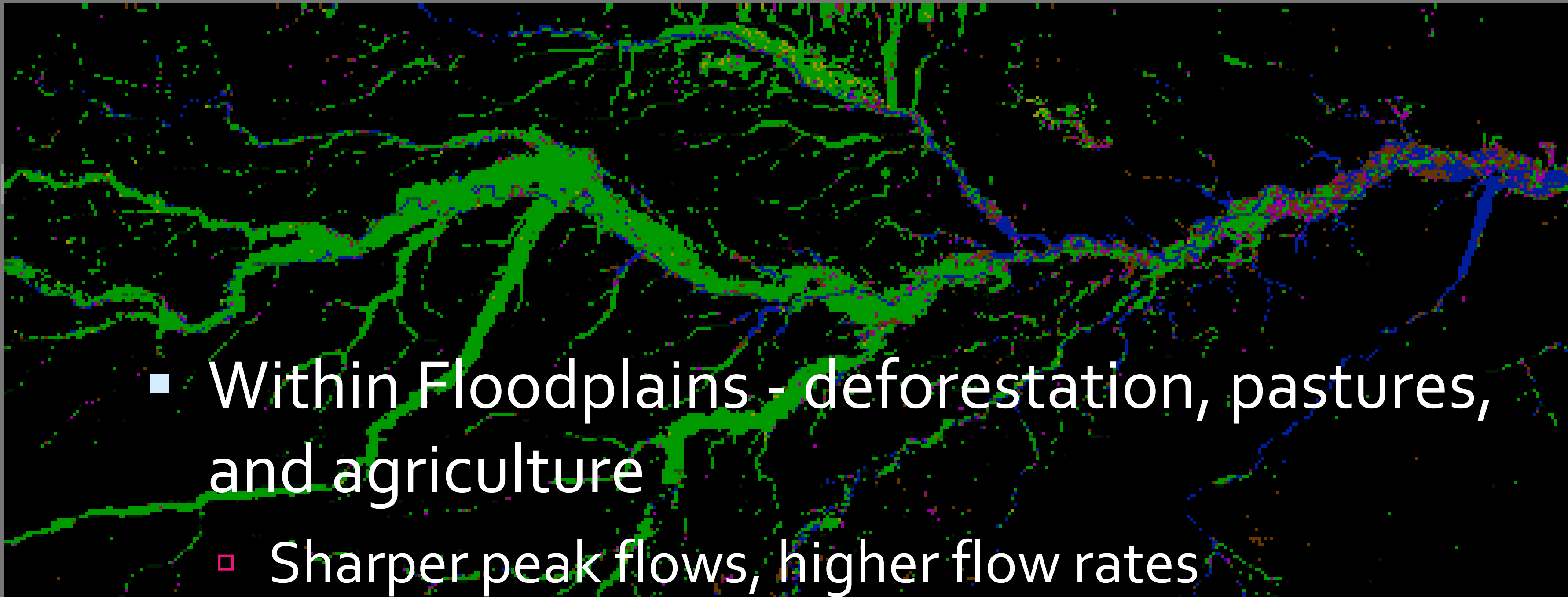
- How do the pathways and fluxes of organic matter, nutrients and associated elements through river corridors (riparian, floodplain, channels, and wetlands) change as a function of land cover?"

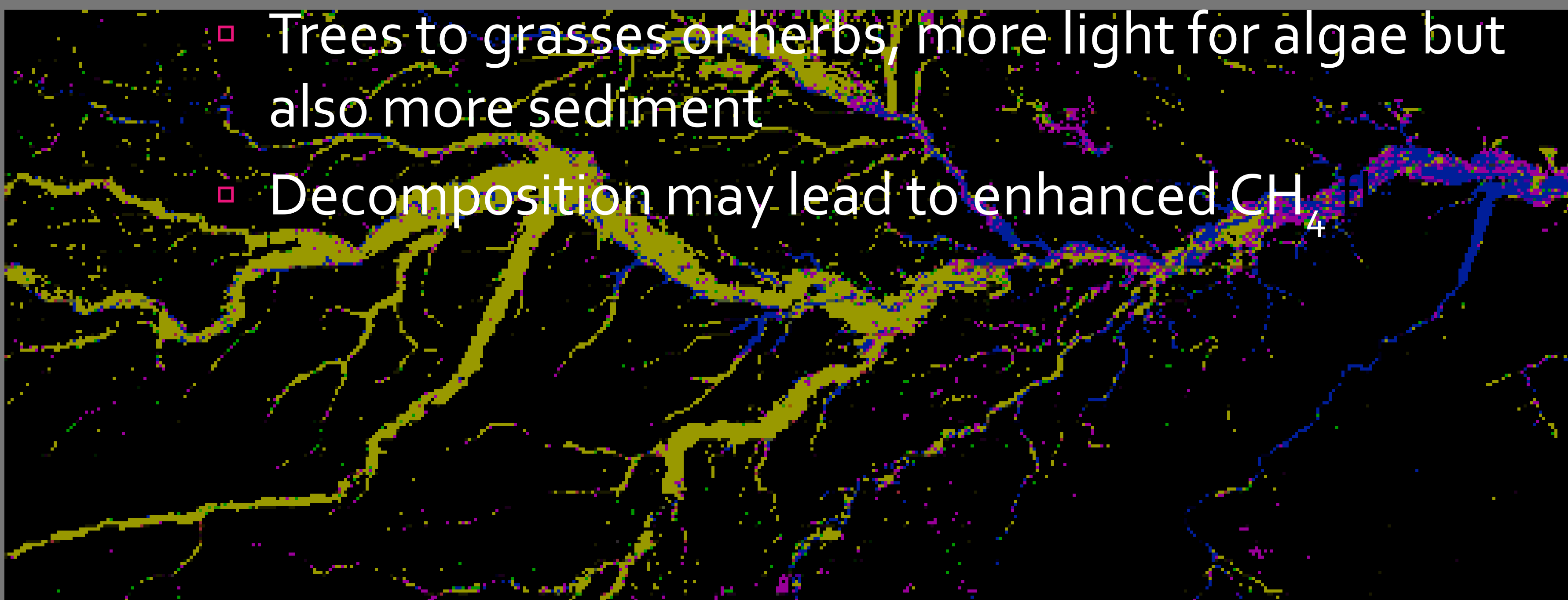
River Function

- Interaction of hydrology, floodplains, and the land surface, specifically removing excess water
  - 160,000 m^3/sec discharge, 3 month lag from north to south
- Transport of dissolved and particulate materials, fueling biological activity
  - 30 Tg ton C/yr, FPOC long MRT, DOC close to modern
- Trees, macrophytes, phytoplankton, attached algae, vascular vegetation , and annual herbaceous vegetation may all achieve peak production at different stages of the hydrograph
- Organic matter consumption and oxygen depletion drive the relative production of CO_2, CH_4, and N trace gases
  - Floodplains as much as 5-10% of global CH_4 flux

Impacts of Anthropogenic Change

- At small scale upland clearing increases stream runoff
  - lost ET, decreased infiltration, decreased WHC
  - Enhanced sediment and nutrient flow (3-50x for N)
  - Expected response strong for small streams, mitigated by riparian zones, but riparian zones may also change with increased sediment input, water table rise, and vegetation change





- Within Floodplains - deforestation, pastures, and agriculture
  - Sharper peak flows, higher flow rates
  - Trees to grasses or herbs, more light for algae but also more sediment
  - Decomposition may lead to enhanced CH_4

At the Basin Scale

- Will the Amazon come to resemble many of the world's large river basins
  - Channelized and cut off from floodplains
  - Agricultural lands "reclaimed" from wetlands
  - Large loads of fertilizers and anthropogenic chemicals
  - Industrial and domestic wastes
  - Dams on all major tributaries

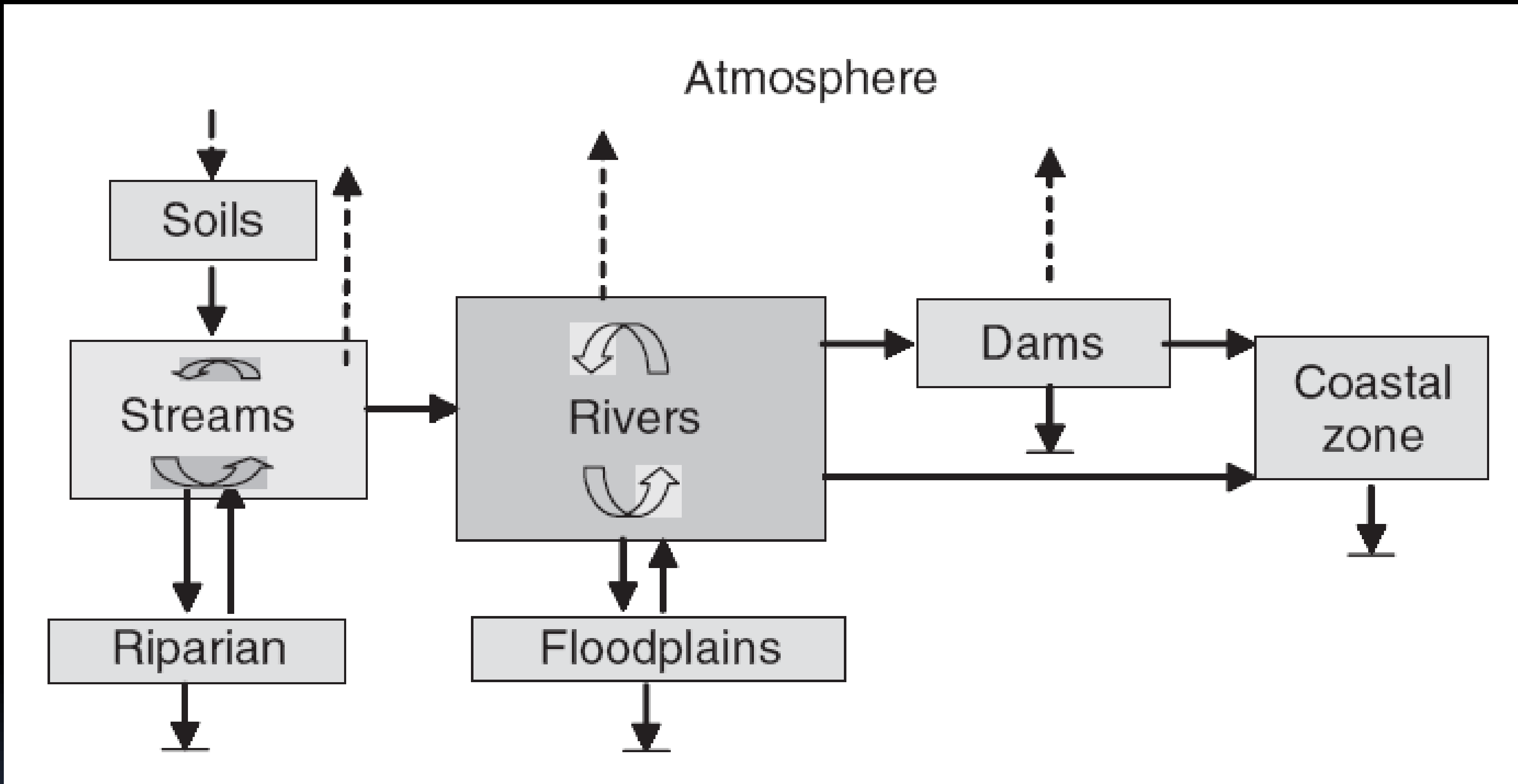
Fundamental Questions for River Corridors during LBA

- What are the changes in the pathways, fluxes and processing of organic matter and nutrients through river corridors?
- How can these changes be described as a function of original landscape characteristics and imposed land use?
- How much change is required to create a signal larger than natural variability at various scales, and how far downstream will disturbance signals persist?

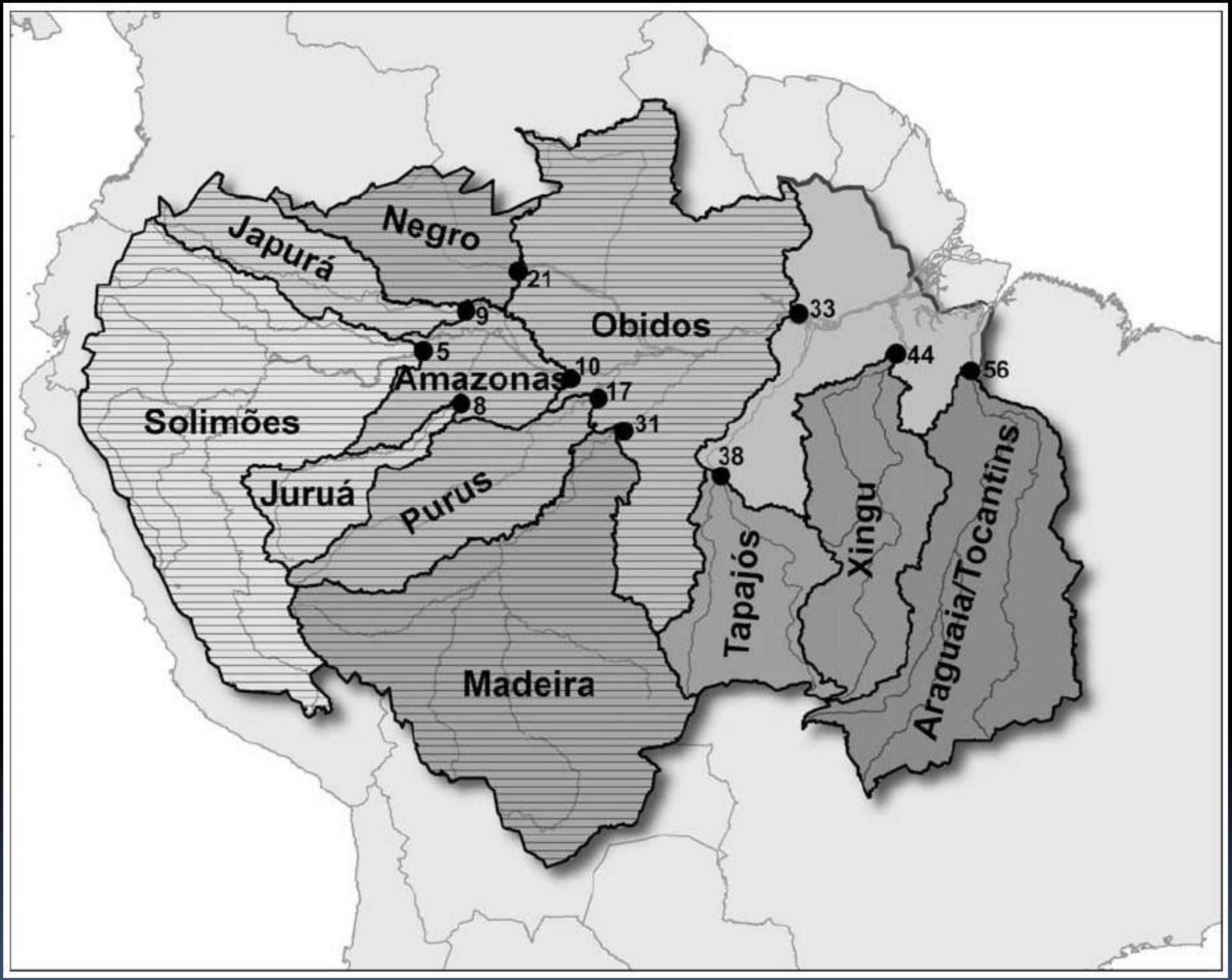
Science Plan

- Rivers should respond with differing magnitudes and lags to perturbations depending on the processes involved and the downstream transfer rates of their characteristic products, as such it is critical to work at multiple scales
  - Small watershed (<10 km^2)
    - Paired, process level
  - Mesoscale (~10,000 km^2)
    - Regions of intensive study
  - Whole Basin (7×10^6 km^2)
    - Remote sensing products, tested against hydrologic outputs from large tributaries

  - Nested within each other, and within a background of natural variability,
  - Seeking a process-based understanding, with a particular interest in processes of organic matter movement and transformation


Atmosphere
Soils
Streams
Rivers
Dams
Coastal zone
Riparian
Floodplains

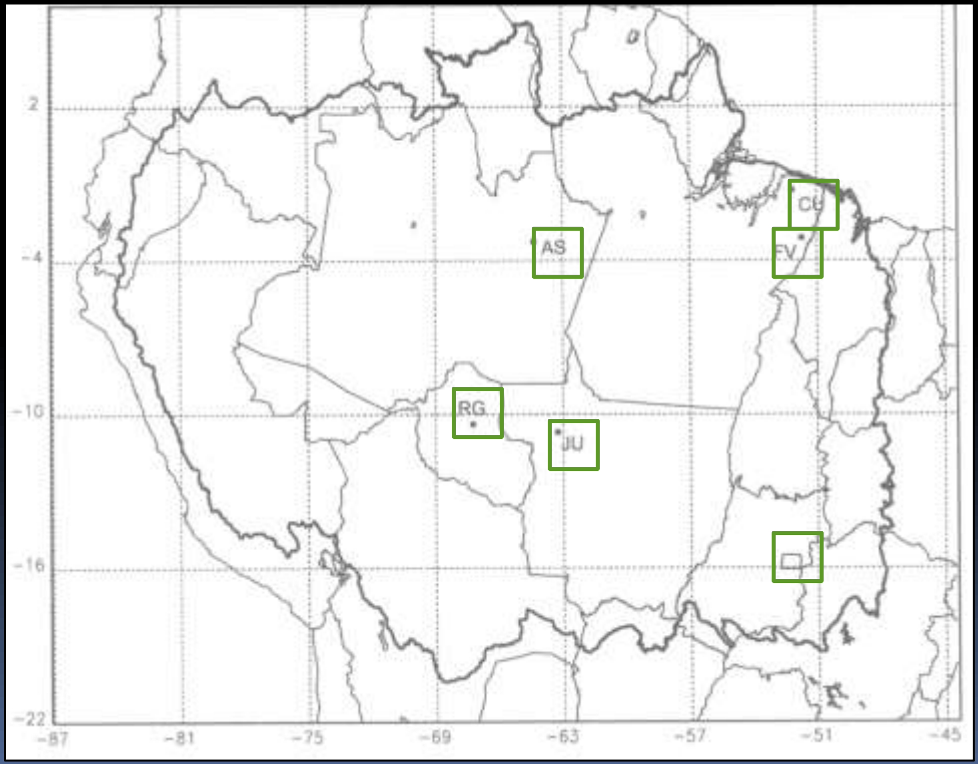
Richey, 2004



Coe et al., 2009

The Catchment Scale

- Before LBA few experimental sites (Barro Branco, Lake Calado, Roraima)
- During LBA the number of sites increased with each having unique site characteristics



Modified from Tomasella et al., 2010

Hydrologic flow

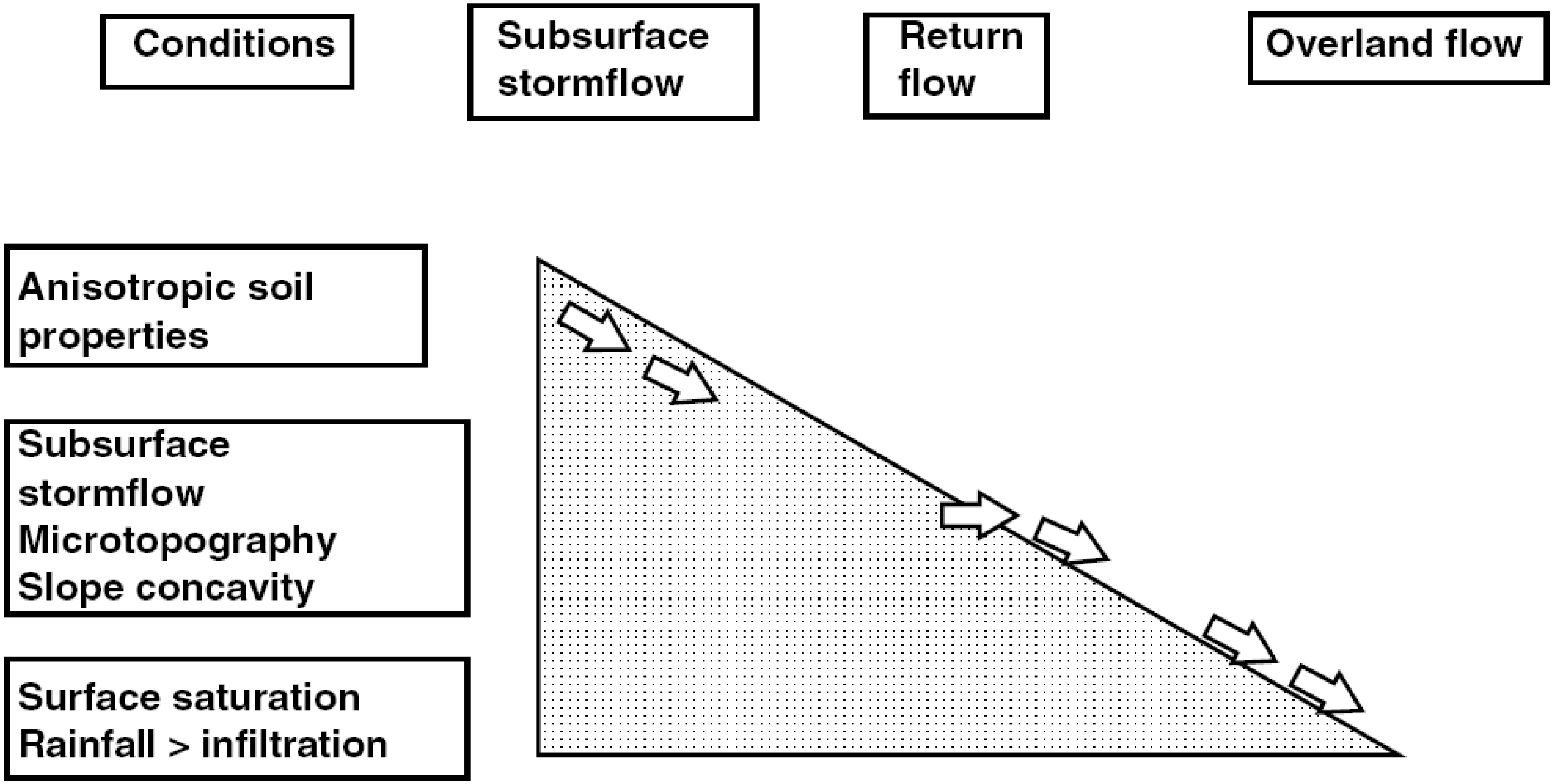
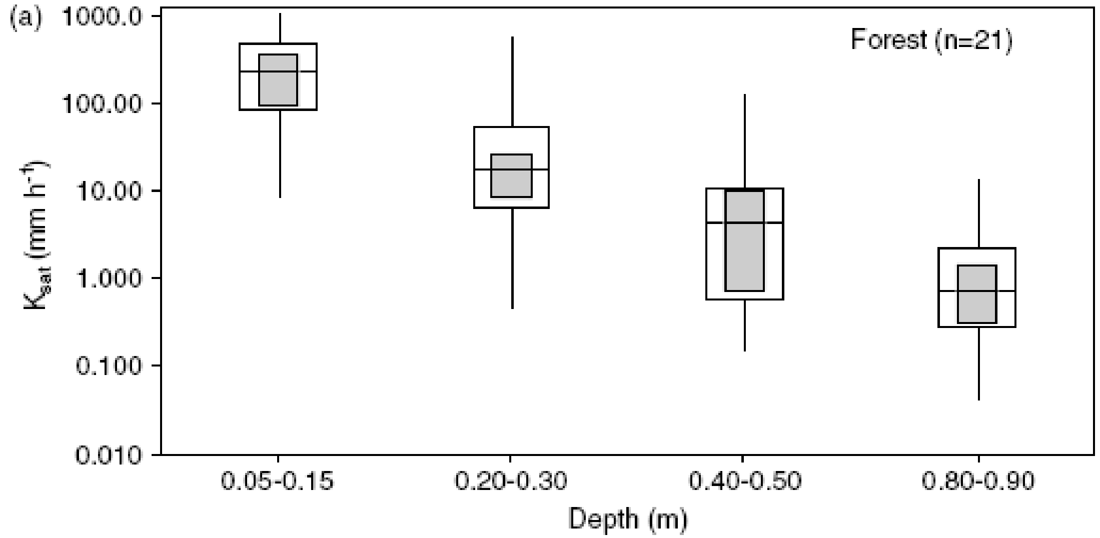
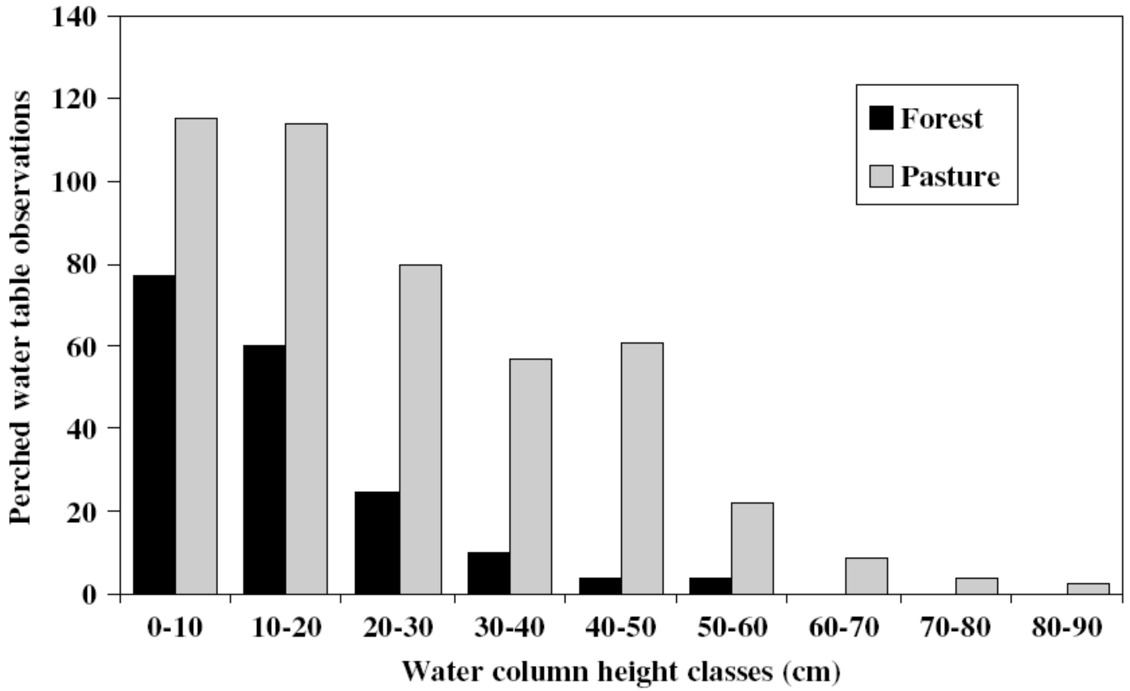


Figure 1. A conceptual framework of hillslope runoff-generating mechanisms

Elsenbeer 2001



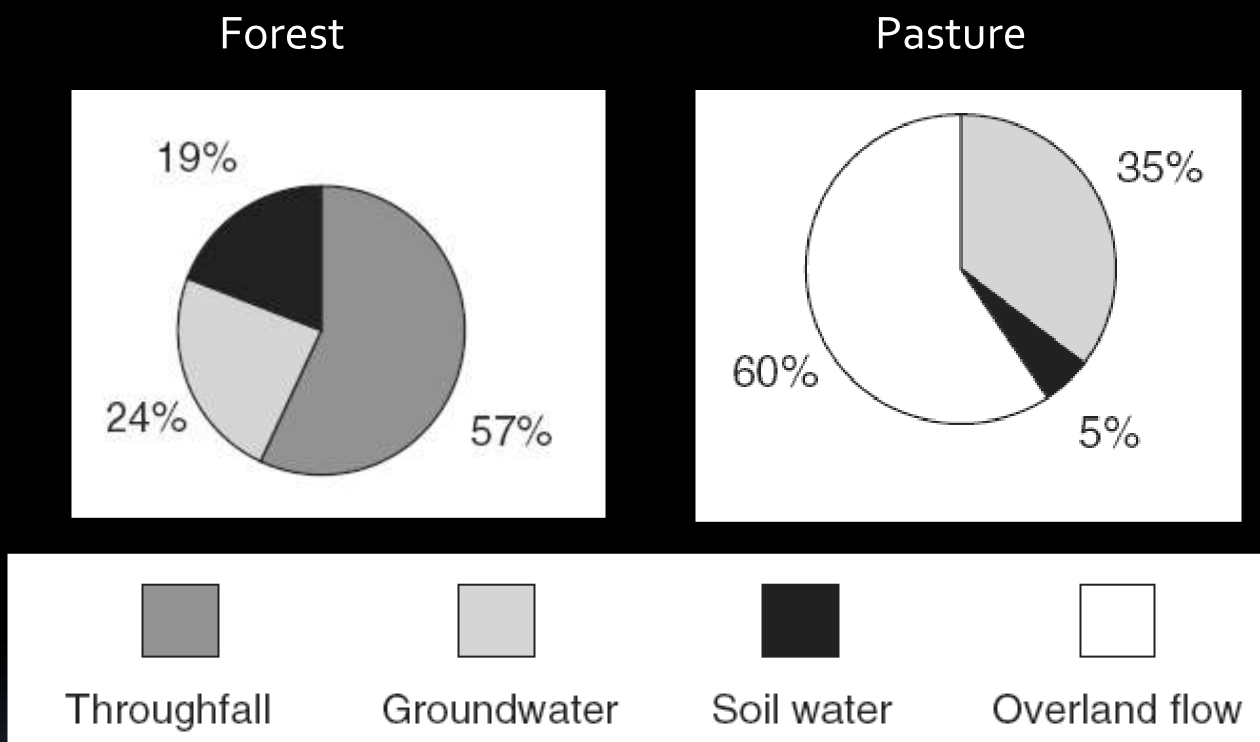
Saturated Hydraulic Conductivity (Ksat) as a function of depth under forest Eastern Amazon



Number of perched water table observations per class of water column height (cm) from the bottom of 1-m depth wells

Moraes et al 2006

Land Use Impacts at the Catchment Scale



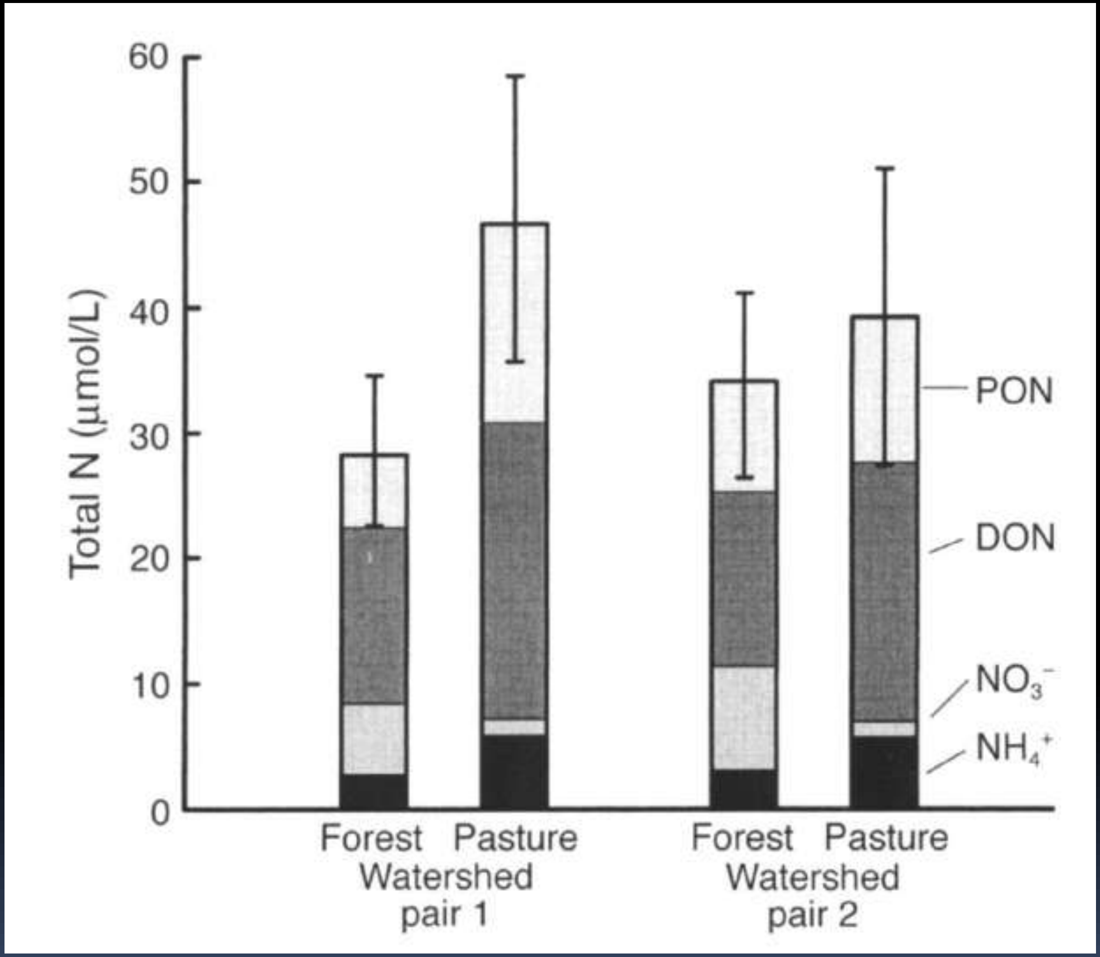
Relative proportion of sources contributing to channel flow for the entire rainy season , Rancho Grande

Modified from Chavez et al., 2009

Basin	Area (km^2)	Location	Land Cover	Runoff Coef (%)	Source
Fazenda Vitoria	0.0072	E. Amazon	Pasture	17.3	Moraes et al., 2006
Cumaru WS3	0.122	E. Amazon	Fallow Veg-Ag	38.0	Wickel et al., 2004,2008
Cumaru WS1	0.358	E. Amazon	Falow Veg-Ag	40.9	
Colosso	1.22	C. Amazon	Pasture	43.0	Trancoso 2006
Nosso Senhora	14.5	SW Amazon	Pasture	40.8	Biggs et al., 2006
Rancho Grande	0.0073	SW Amazon	Pasture	17.3	Chaves et al., 2008
Fazenda Vitoria	0.0033	E. Amazon	Forest	3.2	Moraes et al., 2006
Asu Mirin	1.26	C. Amazon	Forest	1.26	Trancoso 2006
Asu	6.56	C. Amazon	Forest	42.6	Hodnett et al., 2009
Rancho Grande	0.0137	SW Amazon	Forest	0.8	Chaves et al., 2008

Modified from Tomasella et al 2010

Changes in flow are associated with changes in nutrient concentration and flux



Stream water concentration in Fazenda Nova Vida

Neill et al., 2001

Total annual DOC fluxes and net flux of carbon out of Igarapé Asu catchment in 2003

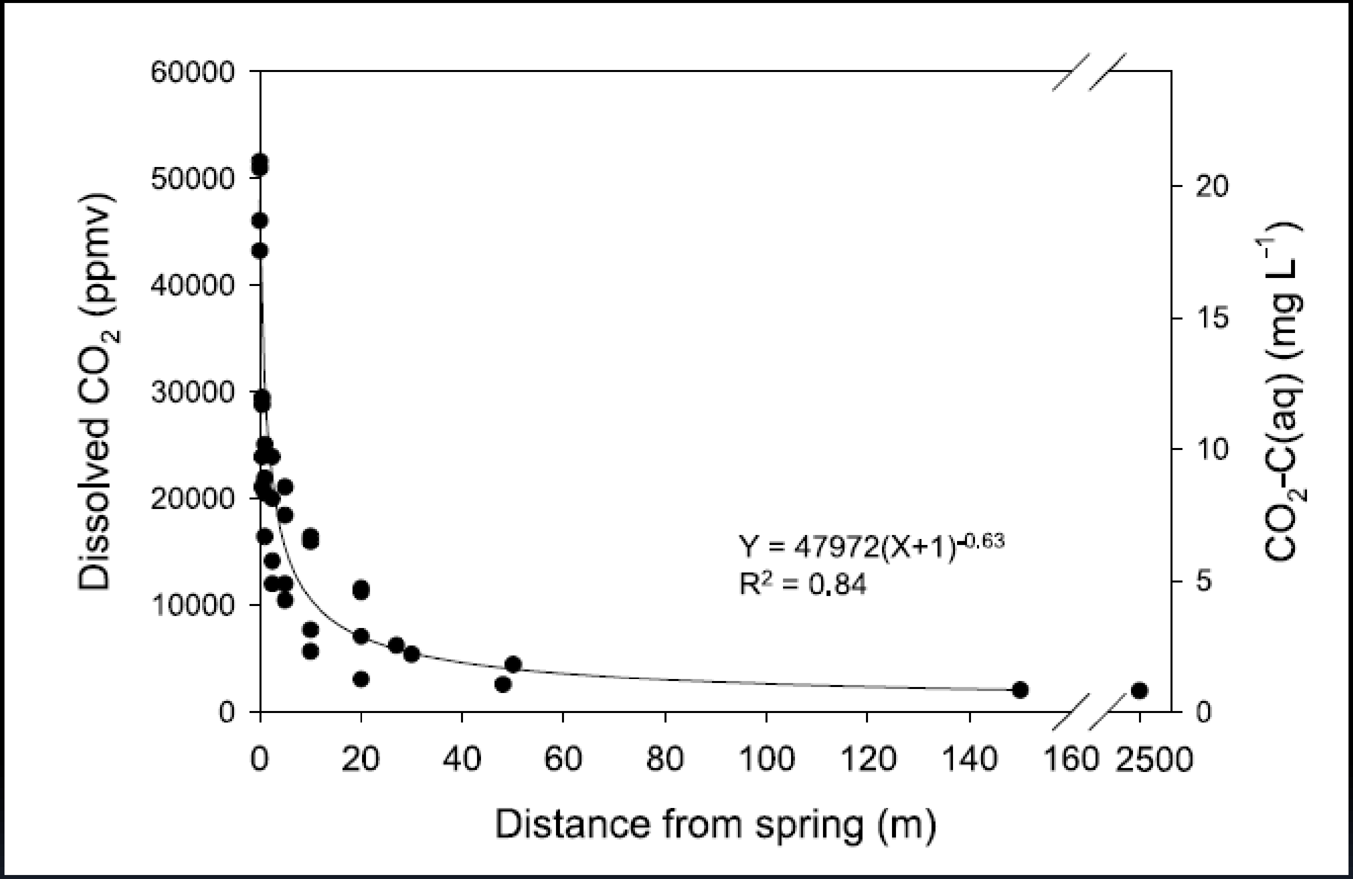
Component	Carbon Flux (g m^{-2})
Precipitation	
DOC flux	2.44
Discharge	
DOC flux	10.83
FPOC flux	0.89
Net total	9.27

Modified from Waterloo et al 2006

Carbon Form	Concentration
DOC	(mg/L)
Throughfall	14.1±4.0
Overland flow	10.7±1.6
Subsurface flow	7.5±1.1
Deep Groundwater	1.0±0.2
Emergent Groundwater	0.51
CO_2-C	
Emergent Groundwater	20.5±1.4

Modified from Johnson et al., 2006

Dissolved CO_2 as a function of distance downstream from groundwater springs.



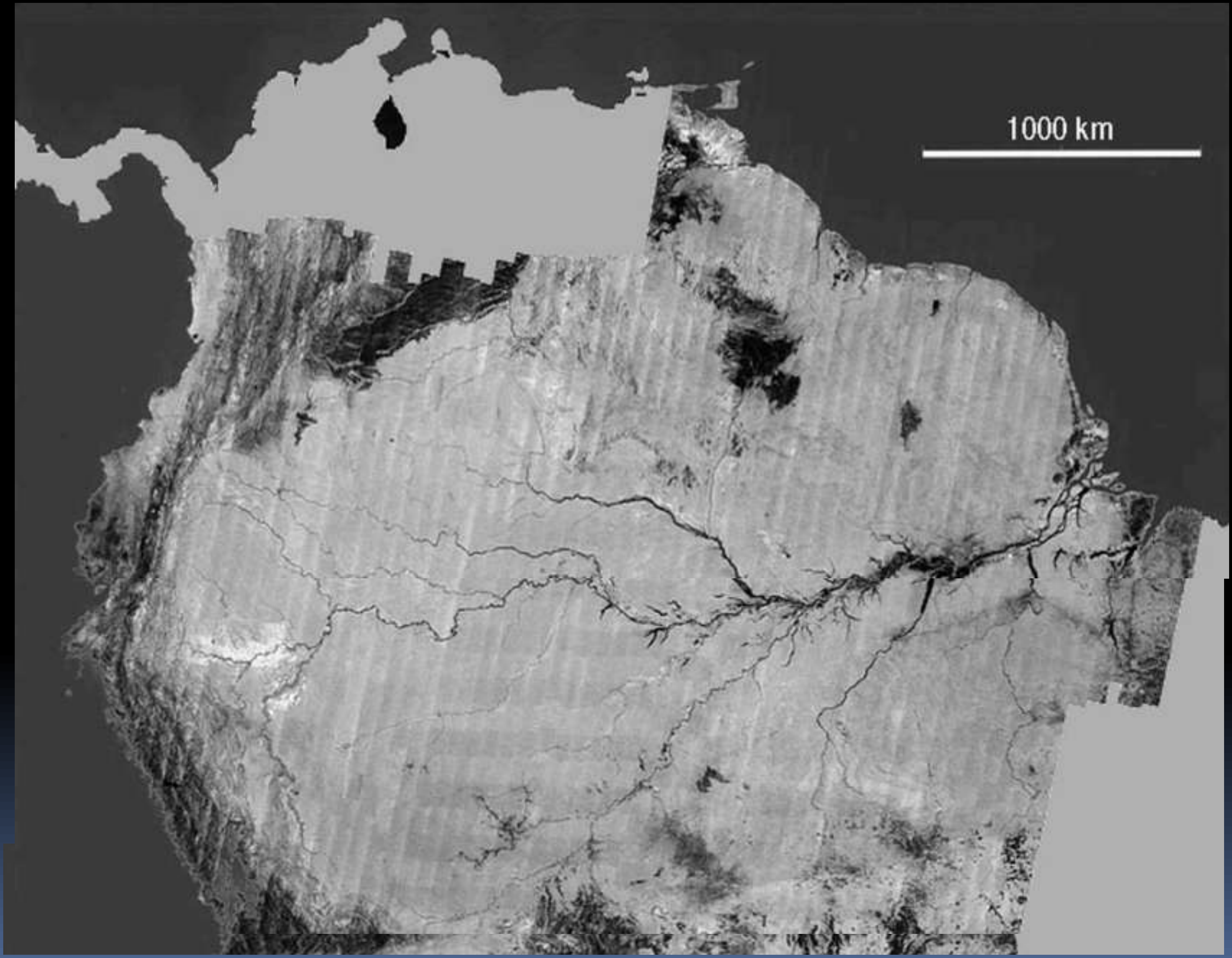
Johnson et al., 2009

Summary

- Greatly expanded network of investigated locations, improve d appreciation for soil and landscape variance
- New insight into mechanisms of runoff generation
  - Most streamflow is baseflow, which reduces gradually with scale.
  - Most stormflow is saturation overland flow but return flow can be crucial
- Clear short term release in N but remaining question of mechanism of N removal
- Novel results regarding potential for C flux through CO_2 outgassing.

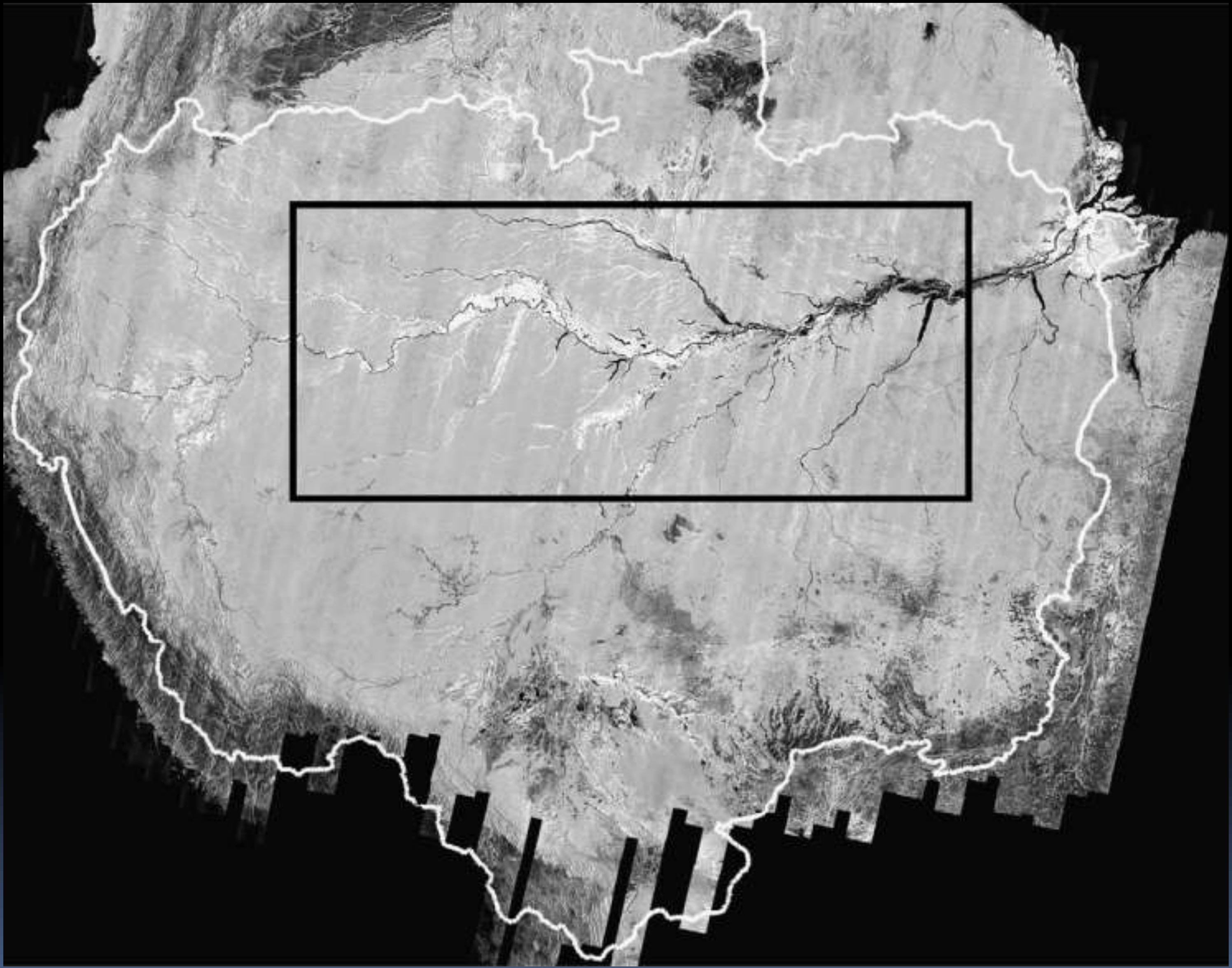
Floodplain Ecosystem Processes

- Comprised of thousands of lakes and wetlands linked to one another and to the many streams and rivers
- Modify hydrology, influence carbon and nutrient biogeochemistry, emit CO_2 and CH_4, and support highly diverse ecosystems and productive fisheries
- 1 million square kilometers



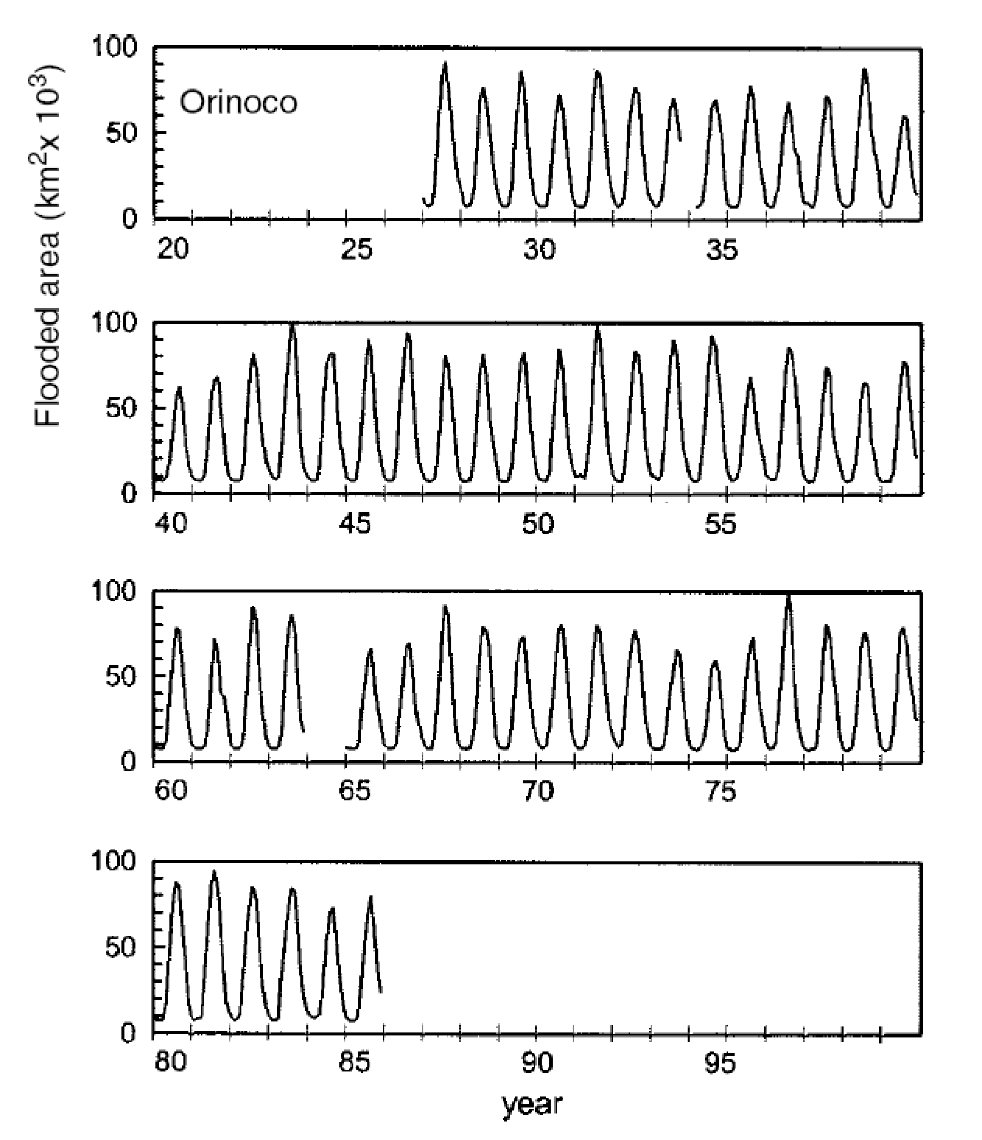
Rosenqvist et al 2000

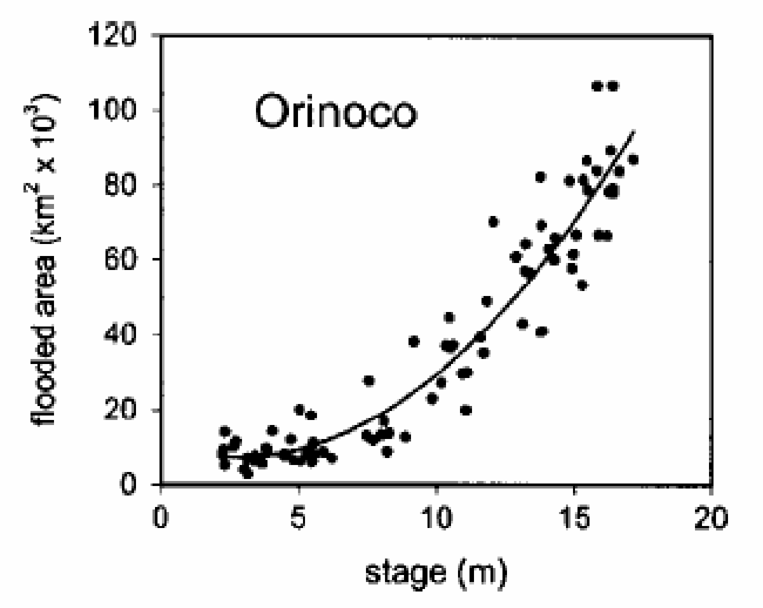
Regional extent of floodplains



Hess et al., 2003

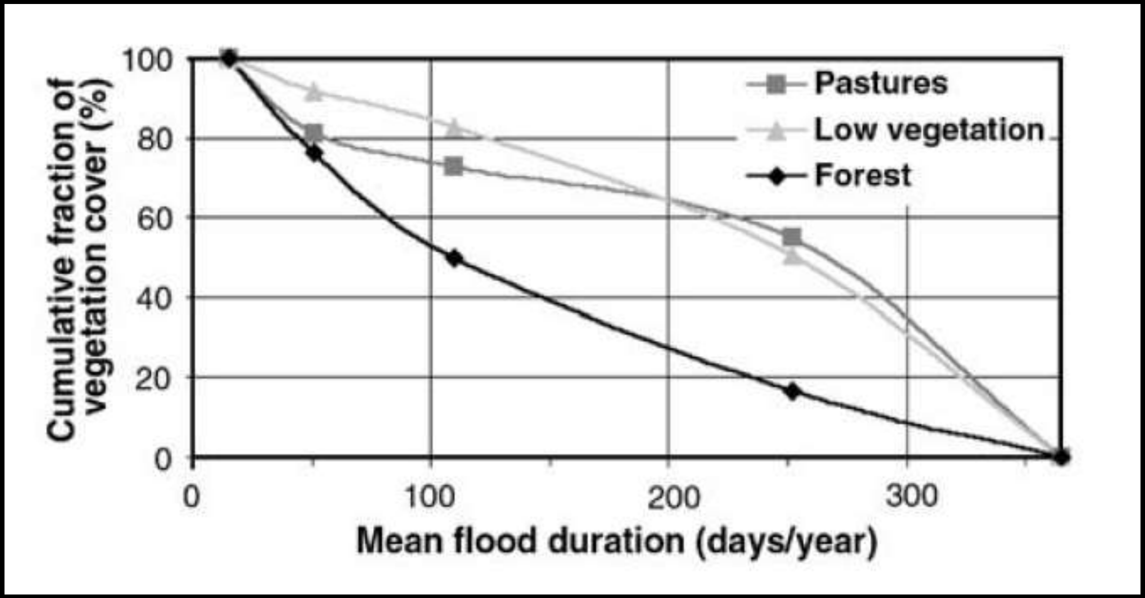
Extension of the inundation record using records of river stage



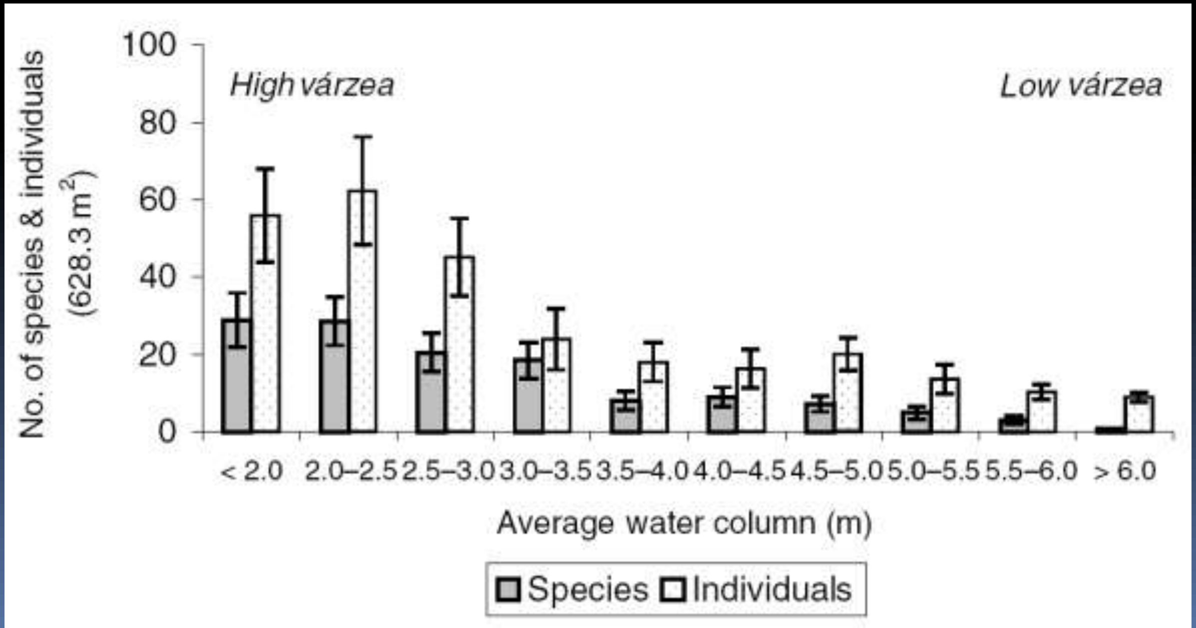


Hamilton et al., 2004

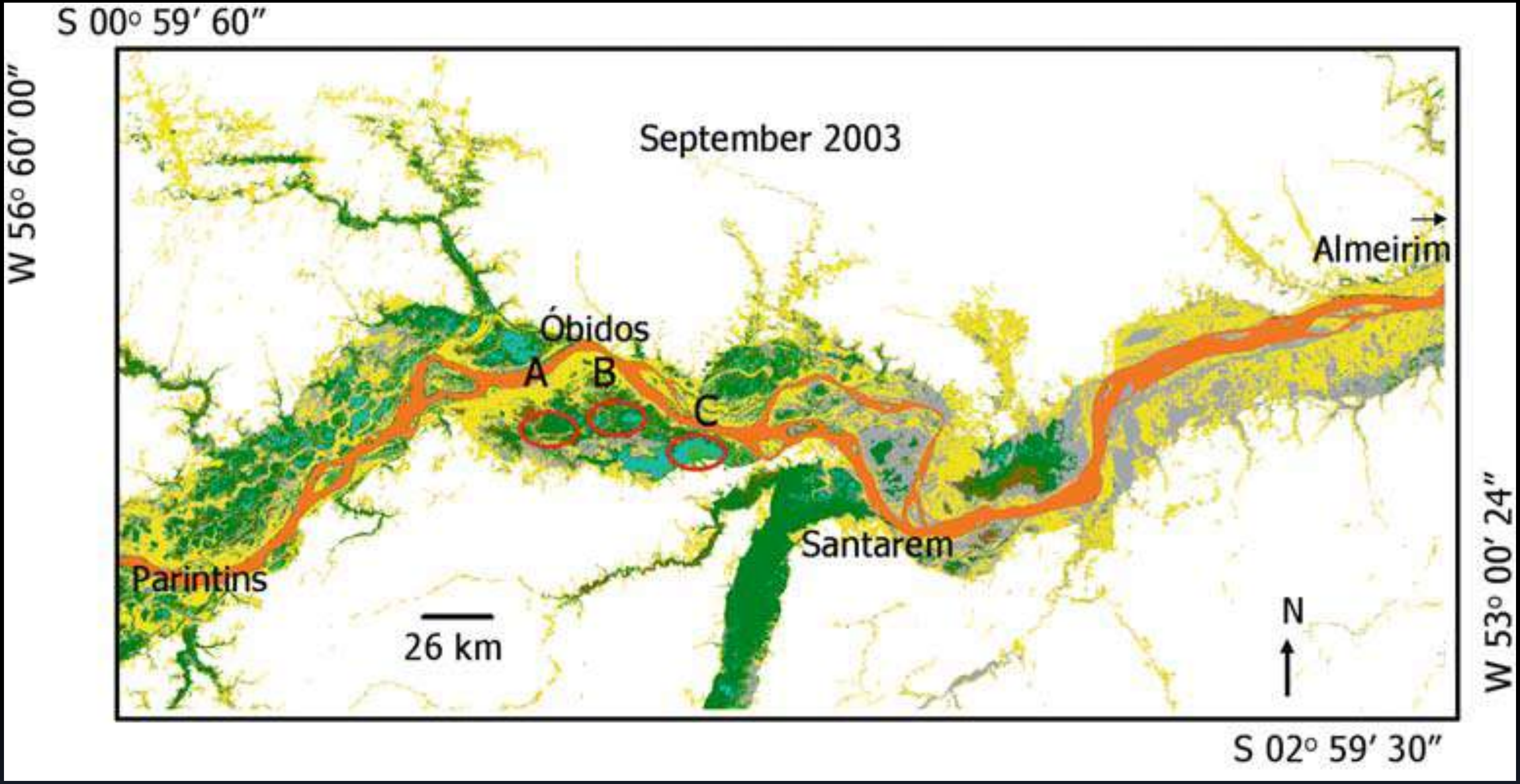
Relation between inundation and floodplain vegetation



Martinez and Toan, 2007



Wittmann et al., 2003

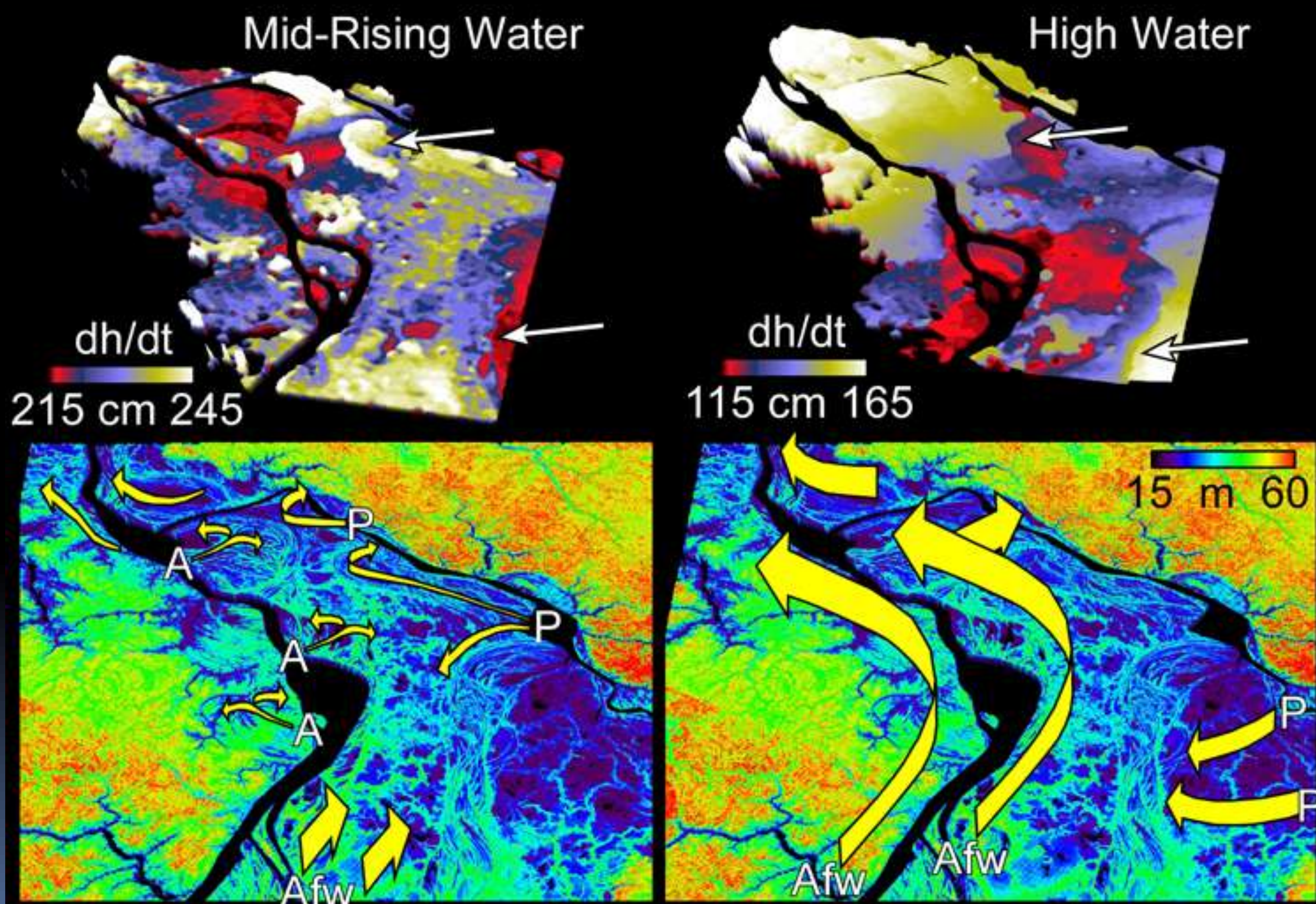


Novo et al., 2006

Inundation Hydrology

Component	Calado (Lesack and Melack, 1993, 1995)	Curuai (Maurice Bourgoin et al., 2007, Bonnet et al., 2008)
Runoff	57	10
River inflow	21	77
Rainfall	11	9
Adjacent lake	6	
Seepage	4	4
CA/FA	7	2

Changes in water levels (top) and floodplain topography (bottom)
Arrows show changes in water levels aindicating flow



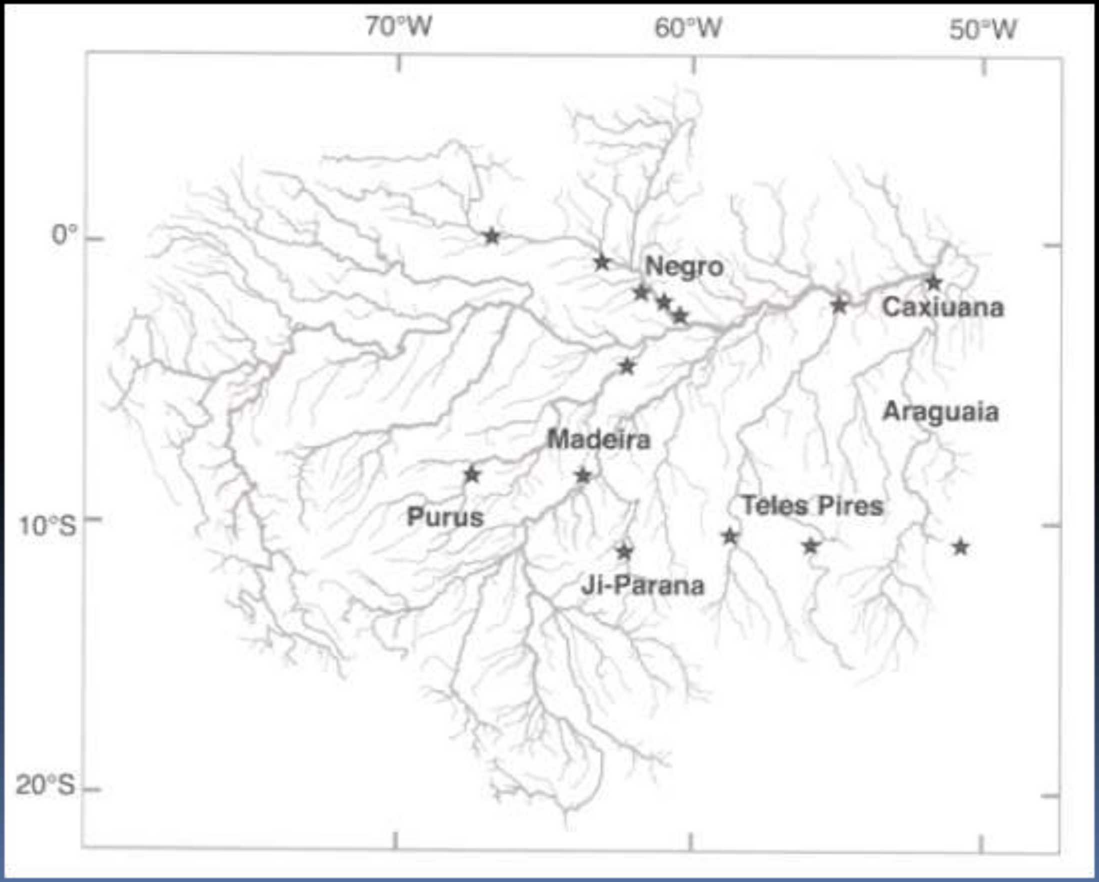
Alsdorf et al., 2007

Summary

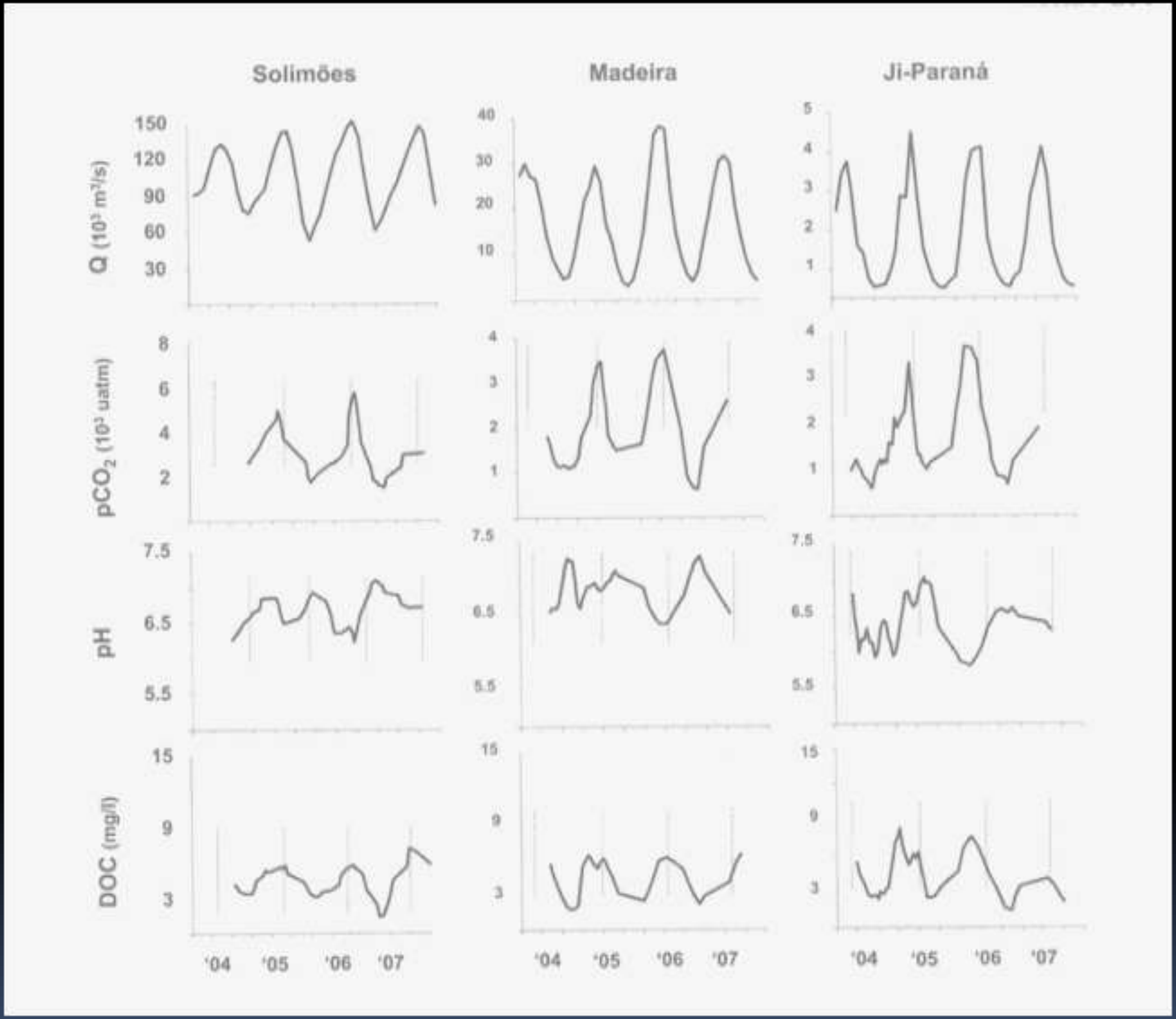
- Tremendous advances in measuring and mapping extent of inundation
- Dramatic new insight into hydrology of floodplains and mechanistic modeling of these flows
- Refined understanding of vegetation communities with flooding
- Improved forest, macrophyte, and phytoplankton production estimates.

The Regional to Basin Scale
Rede Beija Rio

- How do the inputs from small streams and in floodplains translate downstream?

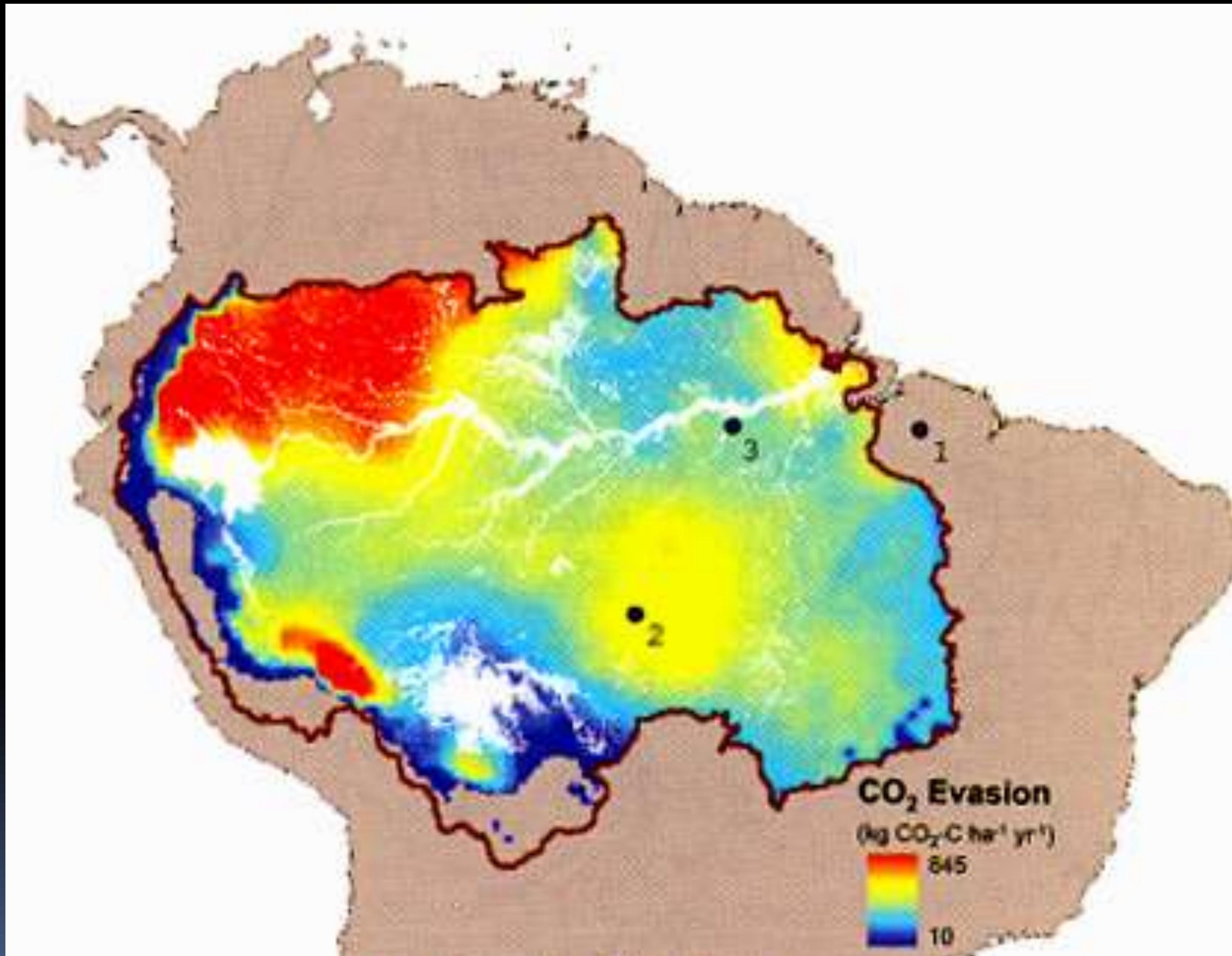


Richey et al., 2010



Richey et al., 2010

CO_2 evasion estimated at 114 10 x 10^{12} g-C yr^{-1}



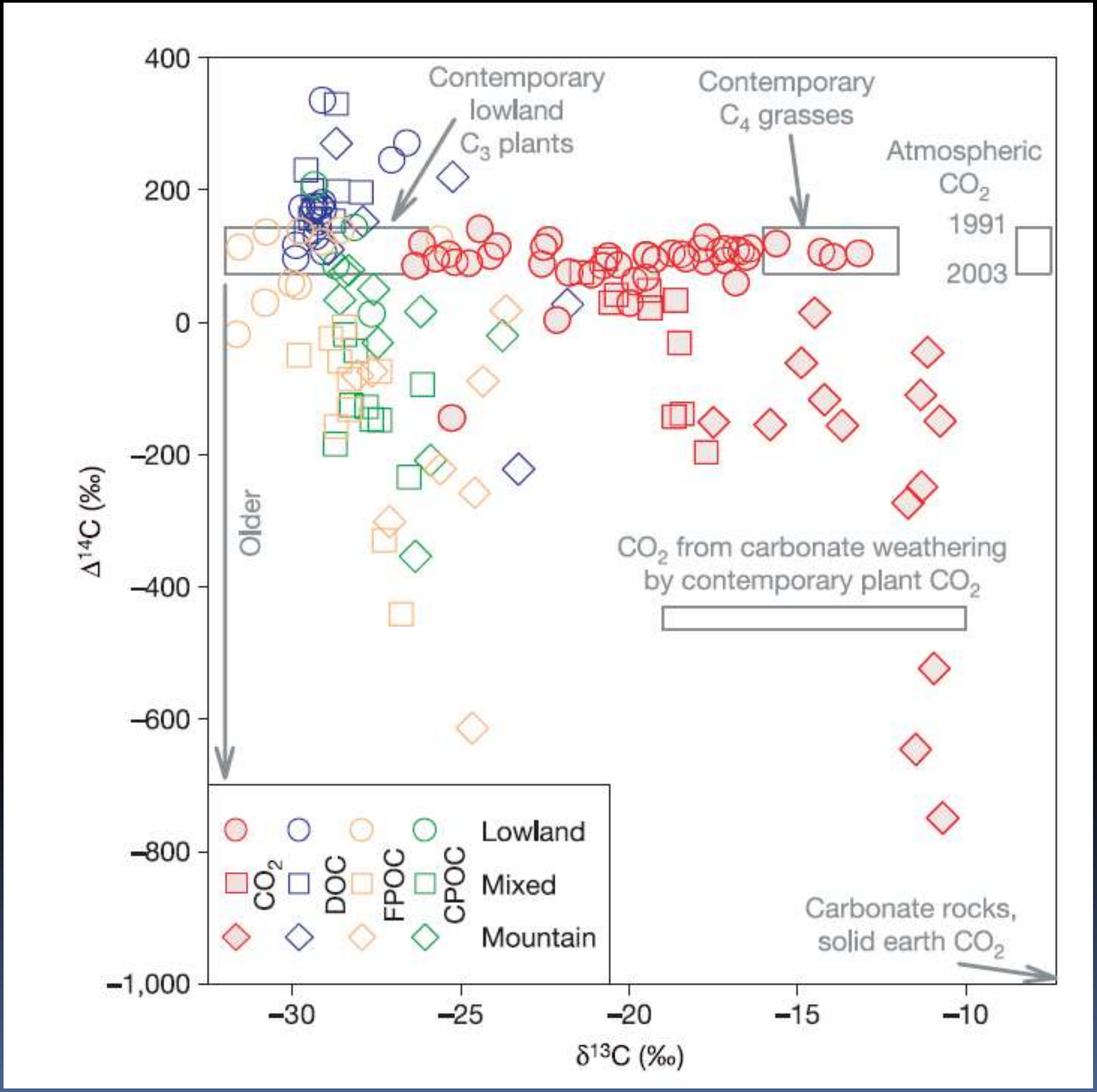
Richey et al., 2010 modified from Johnson et al., 2009

What is the source of carbon driving this CO_2 efflux?

- Where does the carbon come from that ultimately is evaded?

- Problem: respiration rates are sufficiently large to recycle all carbon in a parcel of water but yet concentrations do not change downstream?
- In other words, water column respiration exceeds planktonic photosynthesis; hence DO is undersaturated and CO_2 supersaturated

Insitu processing



Mayorga et al., 2005

Gas Exchange

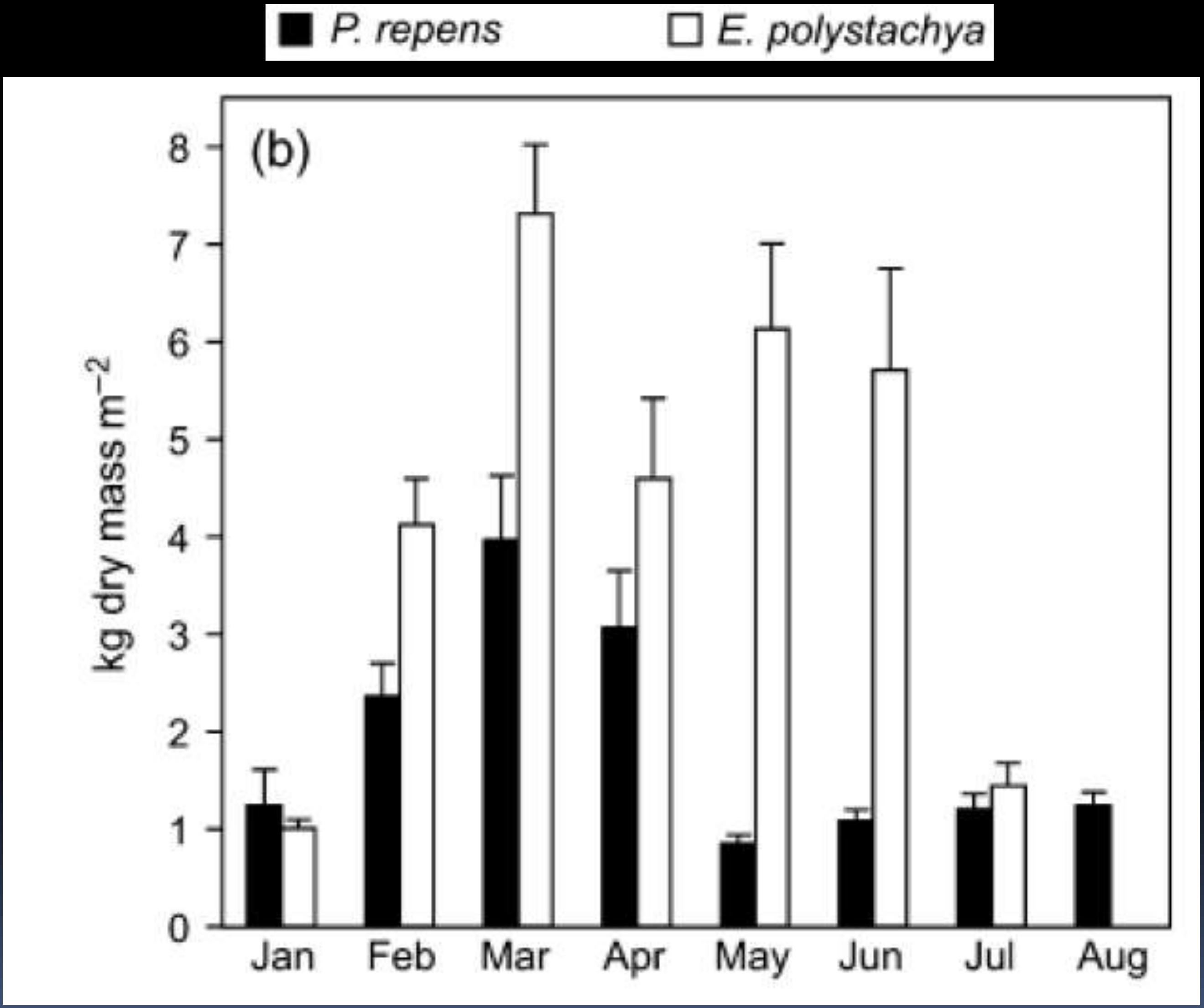
Location	Stage	Source	δ ^{13}C
Rio Negro/ Shaded streams		C_3 plants	-28.3 to -30.1
Shallow Purus Tributaries		Algae/C_3 plants	-33.2 to -31.2
Solimoes	Falling water	Algae/C_3 plants	-32.6
	Early rising water	C_4 macrophytes/ C_3 plants	-22.9

Ellis el al. submitted

Aquatic Vegetation	Areal NPP (Mg C/km²/a)	High-Water Area (km²)	Total NPP (Tg C/a)
Flooded forest	1150	160,000	184
Macrophytes	2500	40,000	100
Phytoplankton	200	20,000	4
Periphyton (forest)	100	160,000	8
Periphyton (macrophytes)	111	40,000	2
	Total		298

Melack et al., 2010

Regionalization of Carbon Biogeochemistry

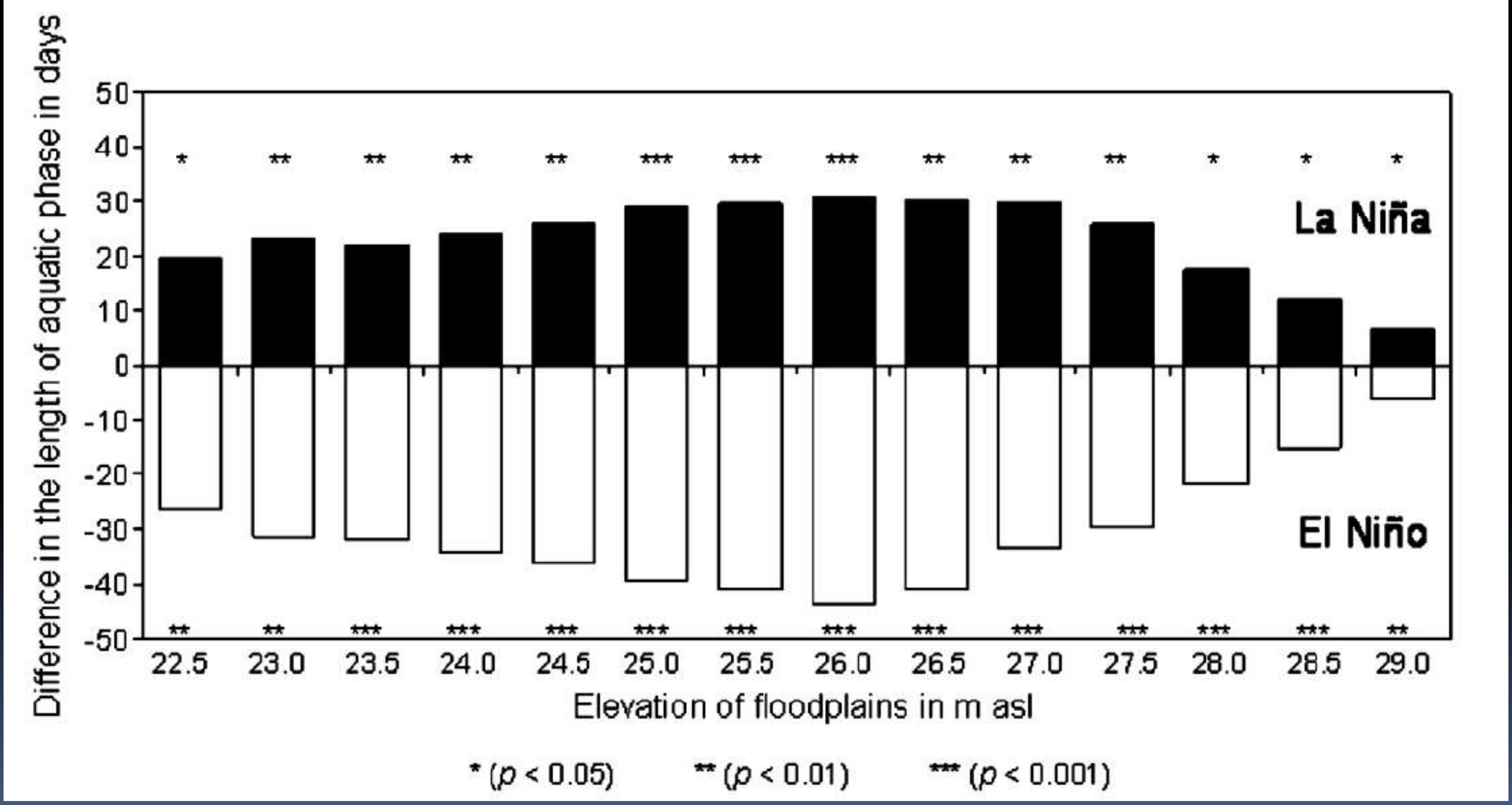


Engle et al., 2008

- NPP 300 Tg C/a
  - 62% Flooded Forest
  - 34% aquatic macrophytes
  - 4% periphyton and phytoplankton
- Enough to account for CO_2 efflux
  - 10% export of organic carbon
  - 2.5% export as CH_4
  - Remainder ≈degassing of 210±60 Tg C/a

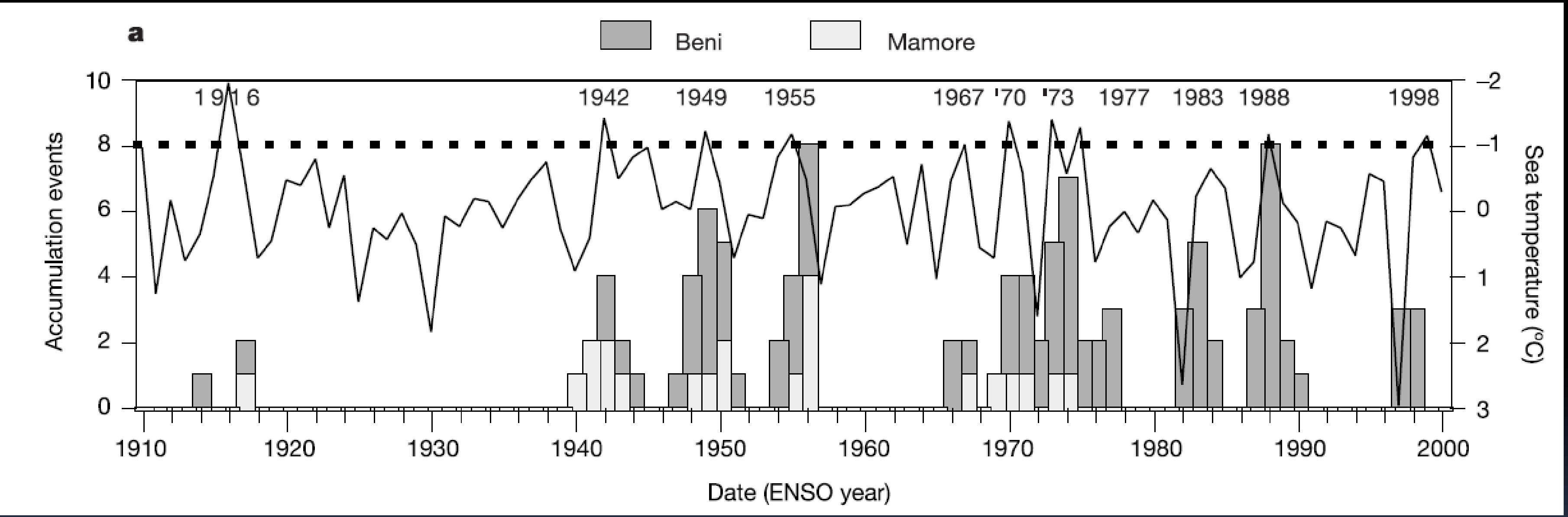
Basin Scale Surface Water Regimes

- Rainfall records to 1940, flow to 1903

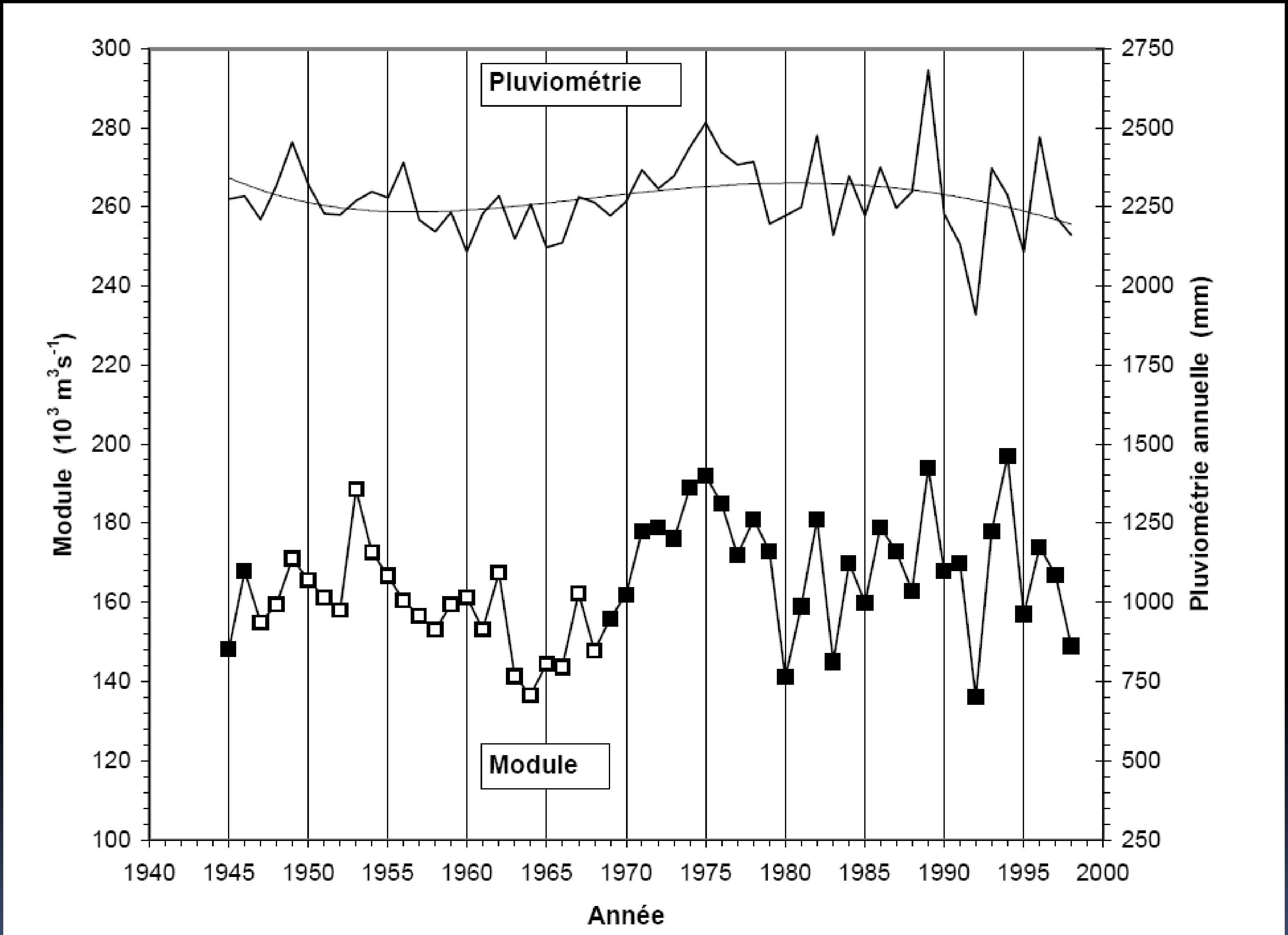


Schogart and Junk, 2007

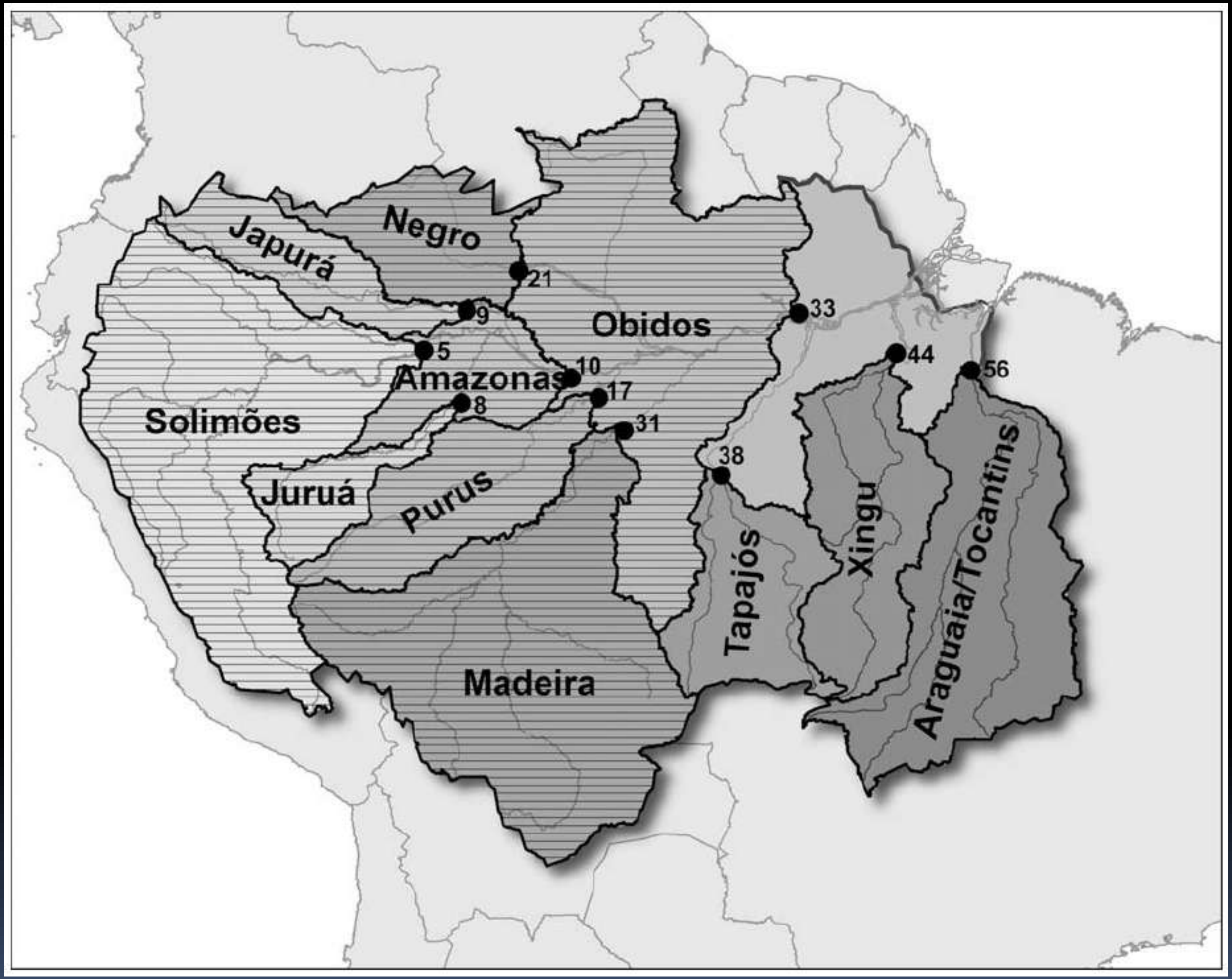
Episodic events



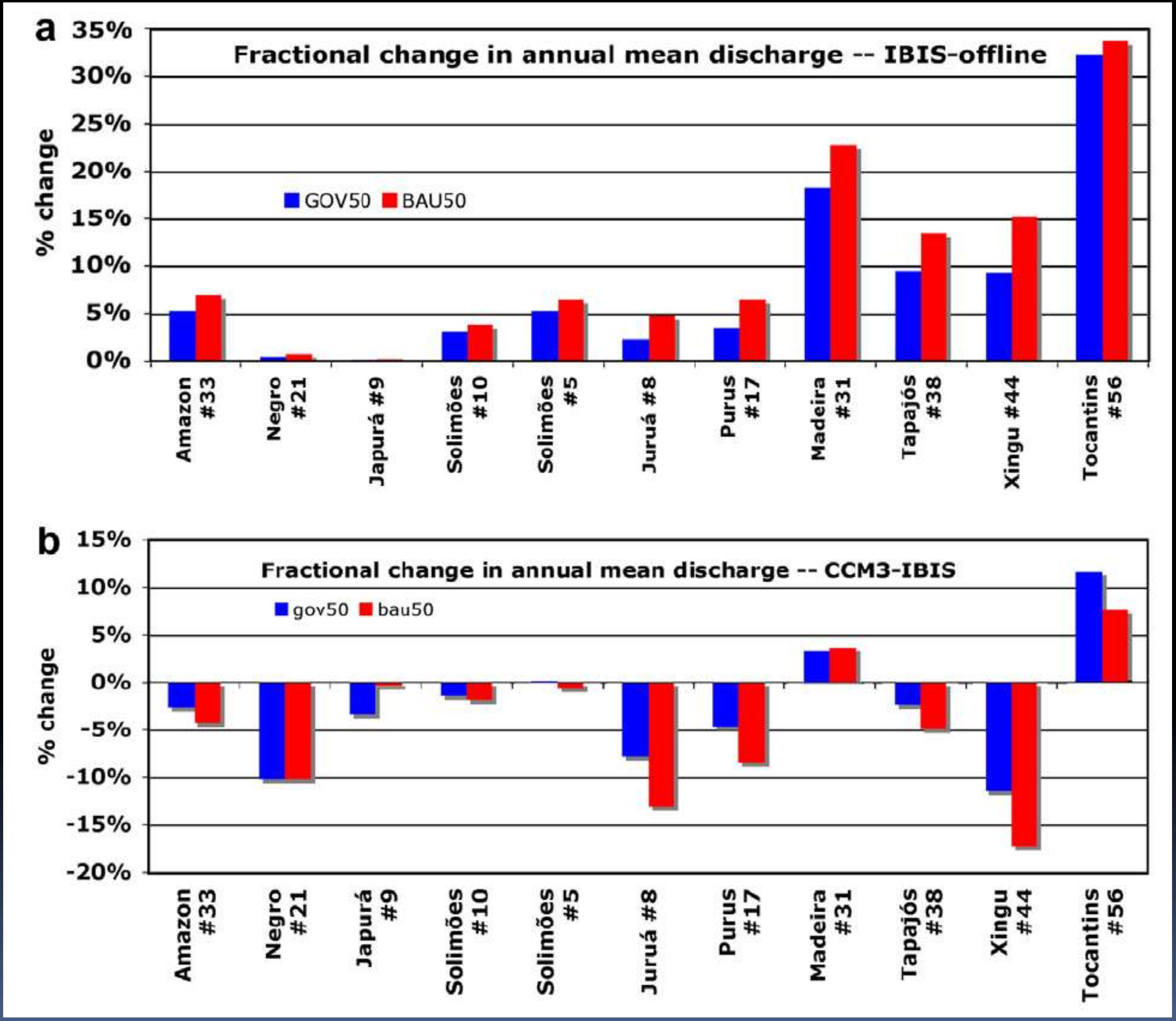
Aalto et al., 2003



Callède et al 2004



Negro
Japurá
21
9
Obidos
33
5
44
56
Amazonas
10
17
8
Solimões
31
38
Juruá
Purus
Araguaia/Tocantins
Xingu
Tapajós
Madeira


a
Fractional change in annual mean discharge -- IBIS-offline
GOV50
BAU50
% change
35%
30%
25%
20%
15%
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5%
0%
Amazon #33
Negro #21
Japurá #9
Solimões #10
Solimões #5
Juruá #8
Purus #17
Madeira #31
Tapajós #38
Xingu #44
Tocantins #56
b
Fractional change in annual mean discharge -- CCM3-IBIS
gov50
bau50
% change
15%
10%
5%
0%
-5%
-10%
-15%
-20%
Amazon #33
Negro #21
Japurá #9
Solimões #10
Solimões #5
Juruá #8
Purus #17
Madeira #31
Tapajós #38
Xingu #44
Tocantins #56

Summary

- The role of large rivers in the carbon economy of the Amazon seem unequivocal.
- A similarity in discharge-concentration relationships is striking and suggests a potential constancy in process
- But Inputs and water column processing indicate changing sources of carbon in space and time
- Short and long-term modes of variability are evident in historic flow, although flows appear to be changing

Did LBA meet is scientific goals?

- What are the changes in the pathways, fluxes and processing of organic matter and nutrients through river corridors?

- How can these changes be described as a function of original landscape characteristics and imposed land use?

- How much change is required to create a signal larger than natural variability at various scales, and how far downstream will disturbance signals persist?

Did LBA meet is scientific goals?

- Great strides have been made in understanding pathways and flows of carbon and nutrients through river corridors

- Greatly improved appreciation of landscape variance and thus quantitative modeling of changing processes relative to land use

- How much change is required remains unresolved.
  - Some evidence of changing flows
  - But downstream signature still seems like forest

Future needs

- Small Watershed
  - The influence of the degree of fragmentation on meteorological (evaporation) and hydrological (surface runoff) processes
  - The influence of flow paths on nitrogen and nutrient exports
  - Improved upland DOC , DIC, and POC inputs

- Floodplains
  - Improved topography and bathymetry
  - Precisely leveled gauges in floodplains
  - Measurements of water velocities in floodplain channels
  - Improved LISFLOOD model

- Basin Scale Rivers
  - Close carbon budget
  - Improve models and new methodologies for upscaling local to macroscale