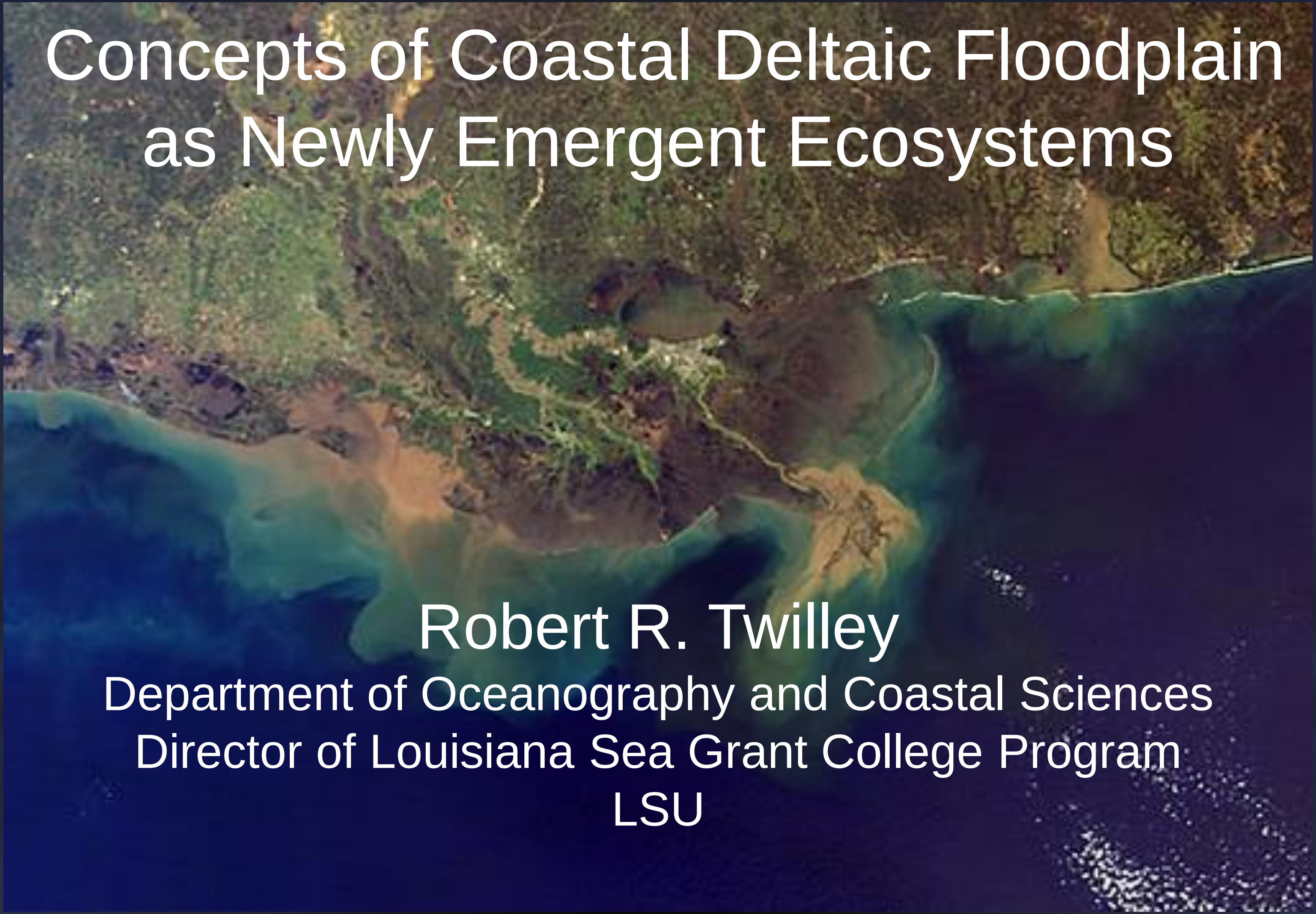

Concepts of Coastal Deltaic Floodplain as Newly Emergent Ecosystems

Robert R. Twilley
Department of Oceanography and Coastal Sciences
Director of Louisiana Sea Grant College Program
LSU

Ecosystems of Coastal Deltaic Floodplains

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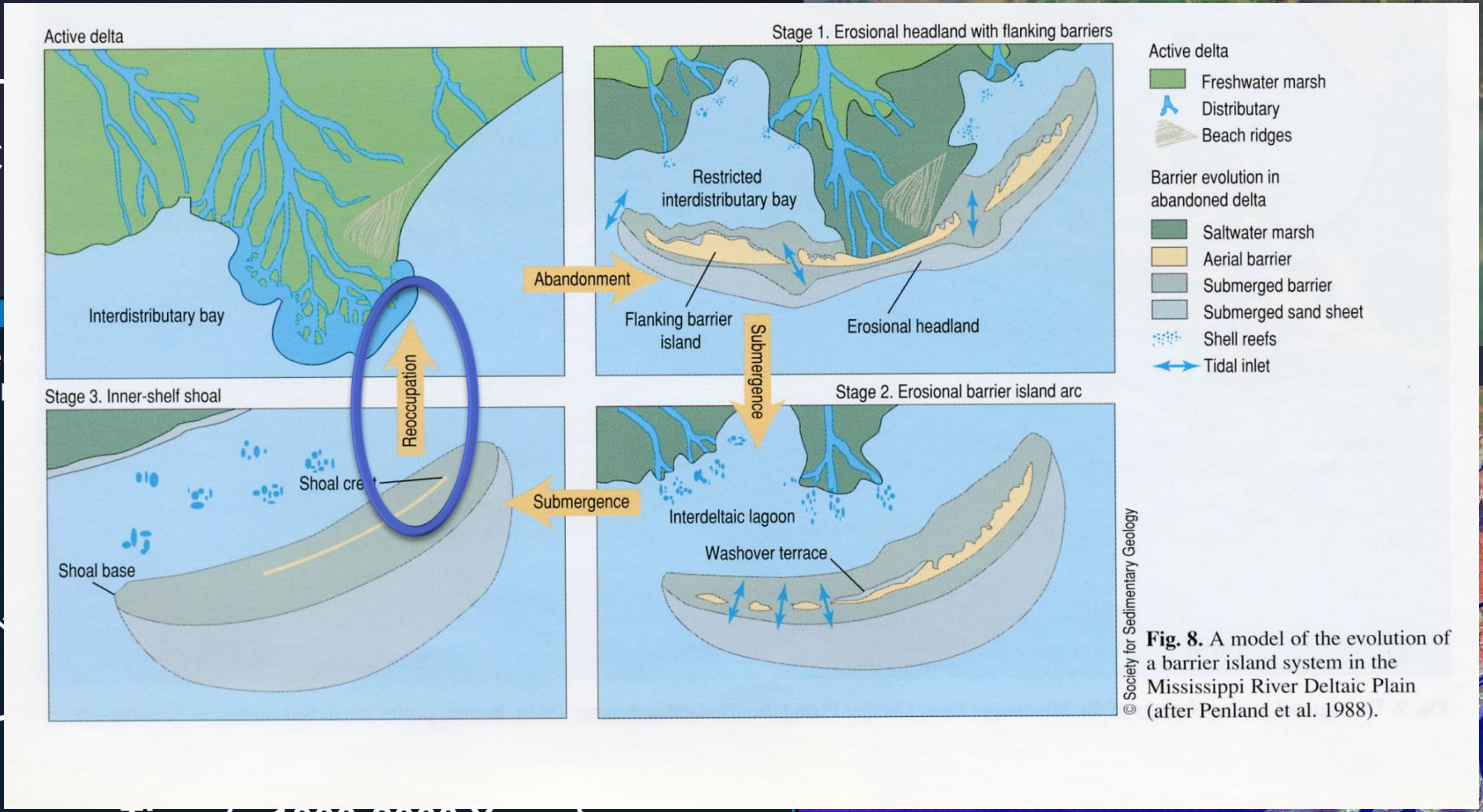

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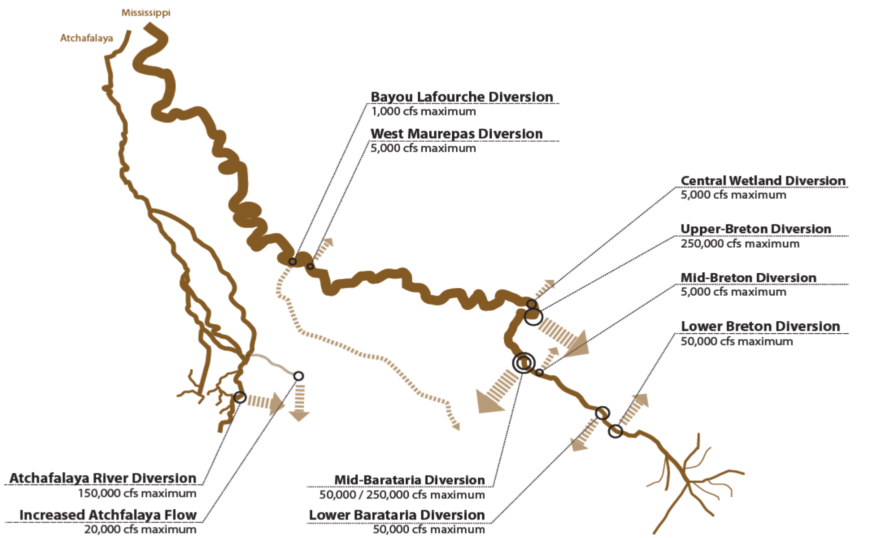
Fig. 8. A model of the evolution of a barrier island system in the Mississippi River Deltaic Plain (after Penland et al. 1988).

Louisiana’s 2012 Coastal Master Plan

- Sediment capture diversions for land building
- 10 diversions on Mississippi and Atchafalaya Rivers
- Wax Lake Outlet: 900 to 8800 $m^3 s^{-1}$
- Maximum discharge size categories:
    - $141.6\ m^3 s^{-1}$ (5,000 cfs)
    - $1416\ m^3 s^{-1}$ (50,000 cfs)
    - $7080\ m^3 s^{-1}$ (250,000 cfs)

Sediment Diversions in the Master Plan



▲ **Figure 5.15**
Sediment diversions depicted in the map above would be operated in coordination with high river events and seasonal flows. Operation at maximum capacity would occur only at targeted intervals for a fraction of time each year.

1: Concept of Emergent Ecosystems - Successional Chronosequences

- Types of deltaic floodplains that control ecosystem patterns change over time with terrestrial and lacustrine vs coastal influences.
- How do the concepts of emergent ecosystems in coastal deltaic floodplains follow the established concepts for emergent ecosystems (succession)

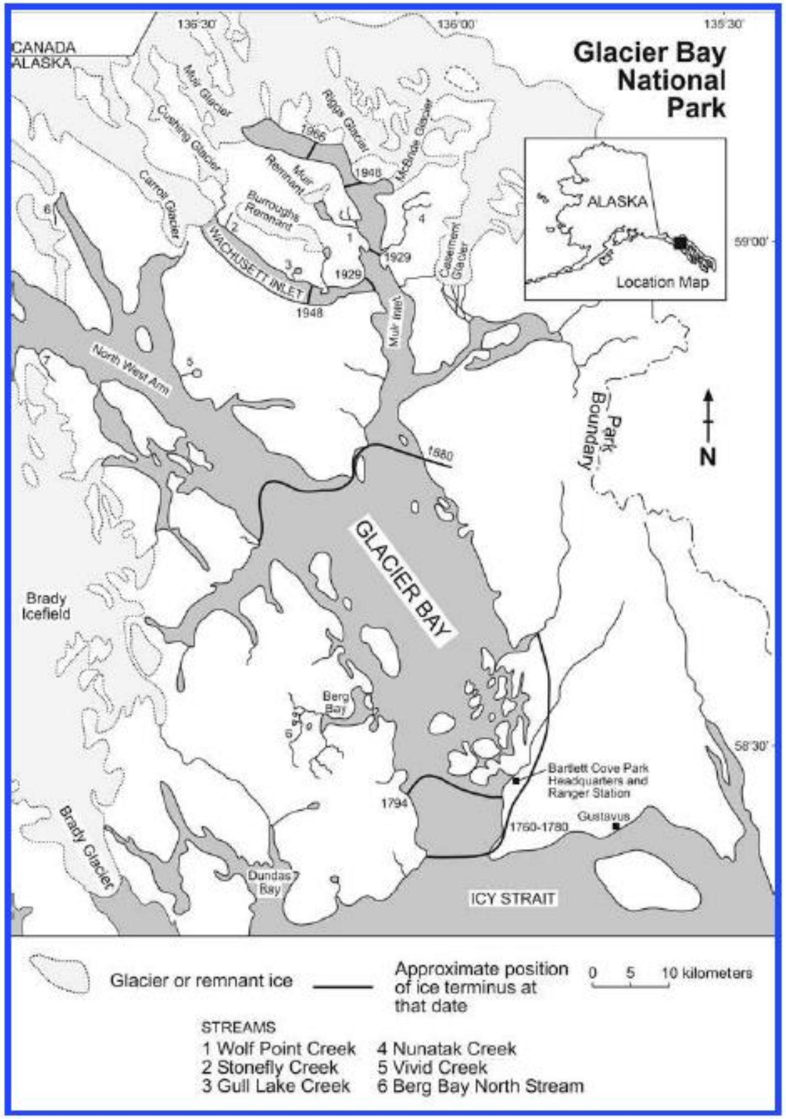
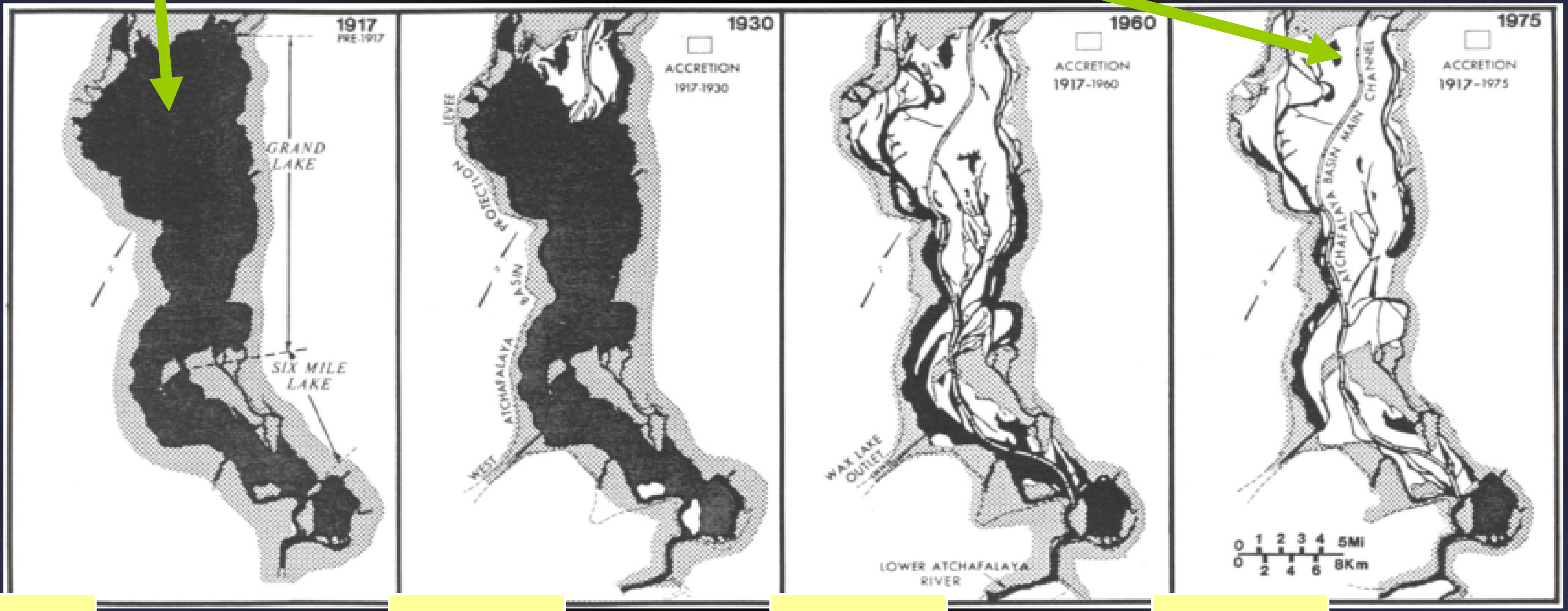


Figure 1. Glacier Bay National Park, showing the key ice recession dates.

1: The Atchafalaya Floodway represents major section of flood control system



1912

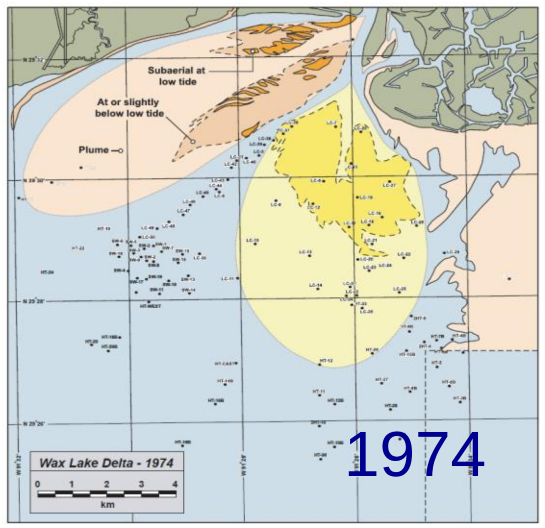
1930

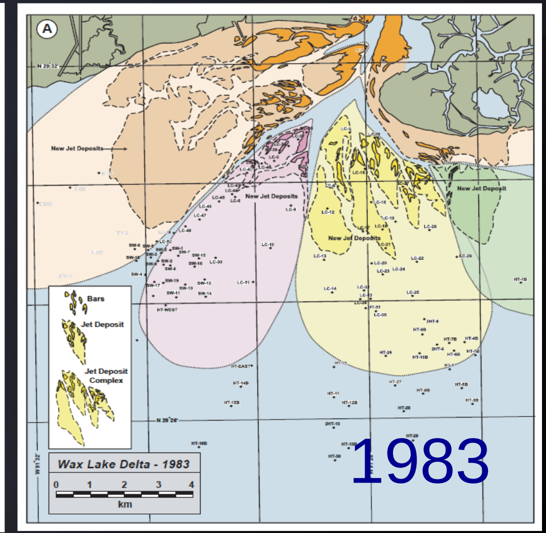
1960

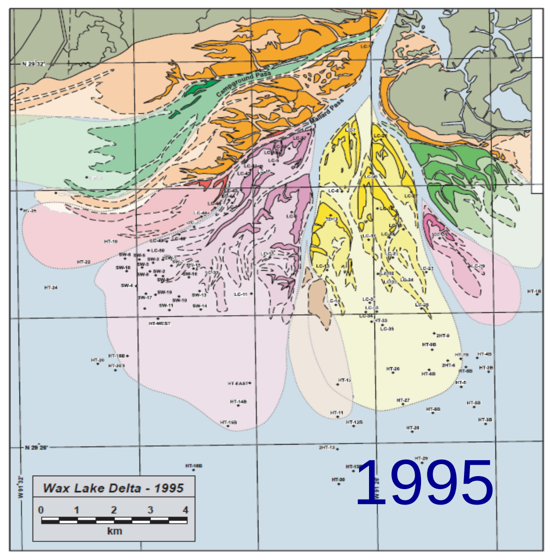
1975

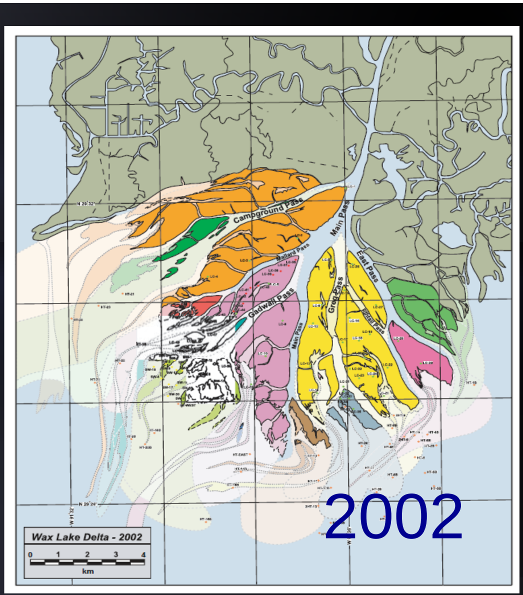
Roberts et al. 1997

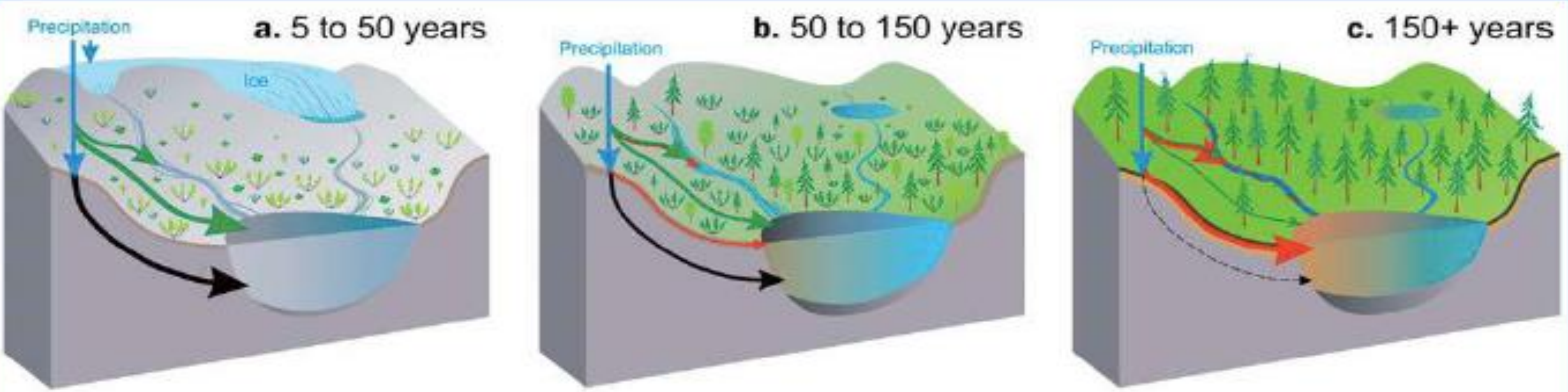
Coastal Deltaic Floodplain











a. 5 to 50 years

Soil
pH = 7-8, physical and chemical weathering, little OM, carbonate loss to groundwater, low N and C pools, high P pool

Vegetation
Black crust, *Dryas* and *Salix* shrubs, *Alnus* and *Populus* colonize, N limitation favors N fixers, conifer seed rain sparse

Streams
Bare soil and remnant ice in catchment result in unstable stream channels, high sediment load, low temperature, high TP, and low TN; chironomids abundant, salmonids colonize after 20 years

Lakes
Lakewater pH = ~8, TN low, abundant base cations brought by overland flow and groundwater flow, deep UV penetration, low diatom diversity

b. 50 to 150 years

Soil
pH = 6-7, rapidly accumulating C and N pools

Vegetation
Dense thickets of N-fixing *Alnus* shrubs, sparse *Populus* and *Picea* with high growth rates when emergent

Streams
Upstream lakes stabilize channels, POC input from riparian plants, EPT established

Lakes
TN and DOC increase as they are carried to lakes by streamflow, overland flow, and soil interflow; macrophyte communities develop; attached diatoms increase in abundance and diversity

c. 150+ years

Soil
pH = 4, fibrous O horizon, high C but low N and P pools, indurated B horizon begins to impede infiltration to groundwater

Vegetation
Dense forest of maturing *Picea* and *Tsuga*, trees have slow growth rate

Streams
High DOC and TN, low TP, unstable channels recruit CWD, which increases habitat heterogeneity and success of fish and macroinvertebrates (EPT are dominant), marine N and C imported by anadromous salmon may increase productivity

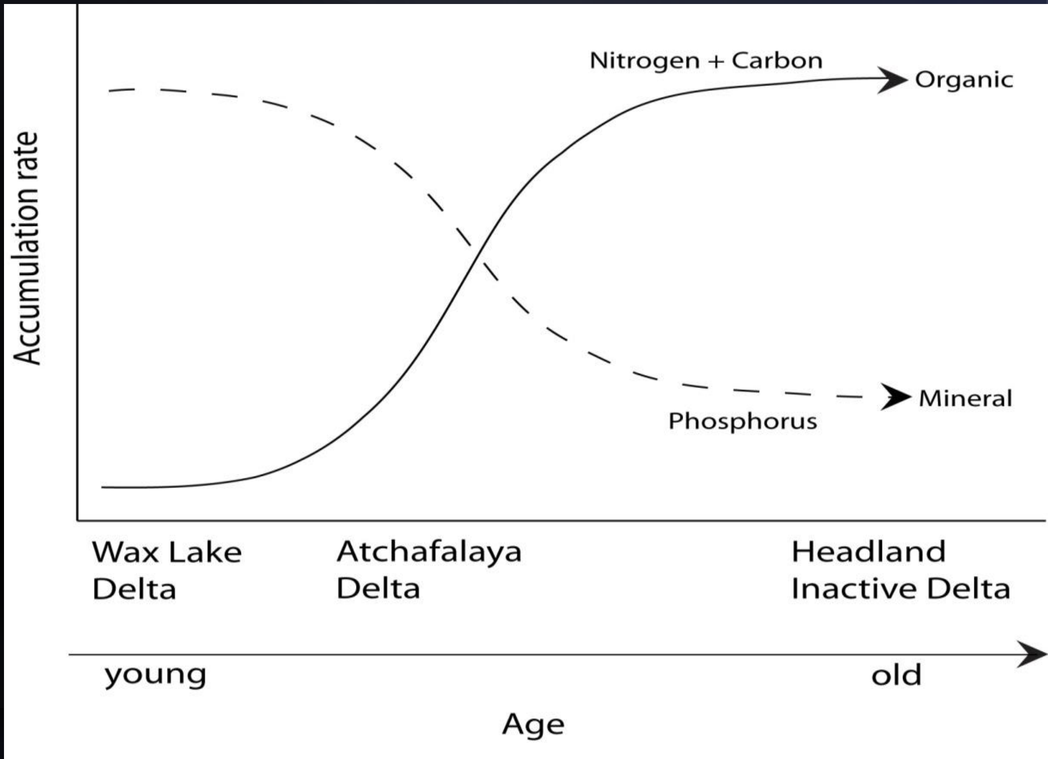
Lakes
Lower TN, pH, and base cations; high DOC absorbs UV; little input from deep groundwater; new suites of acid-tolerant diatoms and zooplankton

→ Precipitation
→ Overland flow
→ Soil interflow
→ Groundwater flow

Figure 3. Major features of terrestrial, stream, and lake environments at Glacier Bay at three time periods following glacial retreat. Arrow thickness represents relative contribution to stream and lake water from overland flow, soil interflow, and groundwater flow. The three panels represent different parts of the Glacier Bay landscape and do not constitute a sequence that has been followed at all sites. Abbreviations: C, carbon; CWD, coarse woody debris; DOC, dissolved organic carbon; EPT, Ephemeroptera, Plecoptera, and Trichoptera; N, nitrogen; OM, organic matter; P, phosphorus; POC, particulate organic carbon; TN, total nitrogen; TP, total phosphorus; UV, ultraviolet radiation.

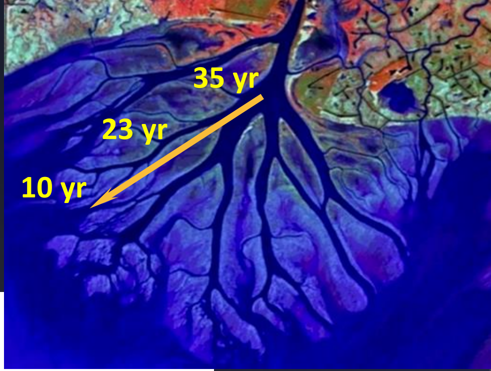
2: Chronosequence of soil development in deltaic lobes of coastal deltaic floodplain

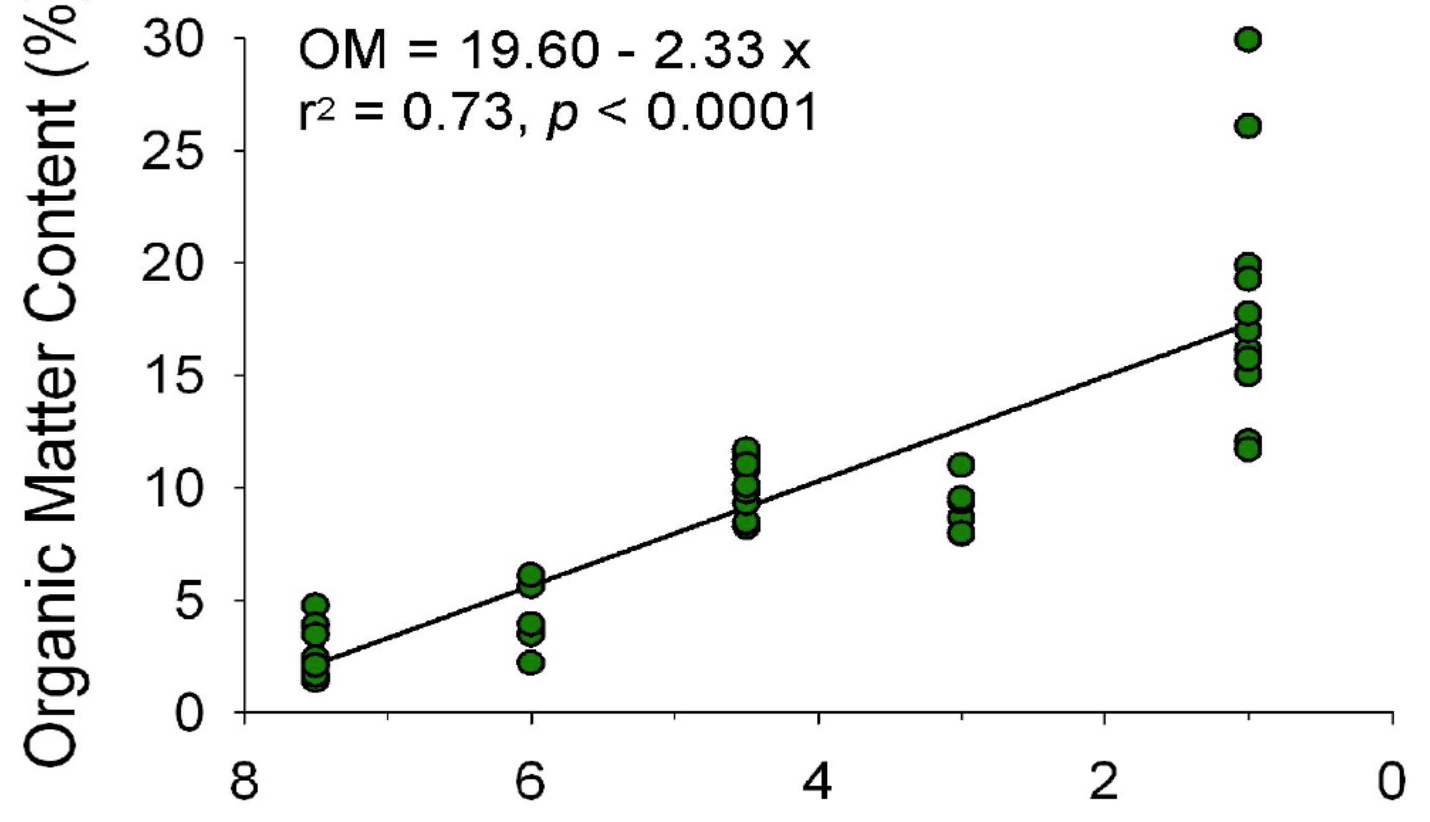
- Chronosequence soil characteristics
  - Organic Matter
  - Total Nitrogen
  - Total Phosphorus
- Limitations of growth



Soil organic matter content with substrate age

- *Distance from head of WLD used as a proxy for age*





Distance (km)

10
Young

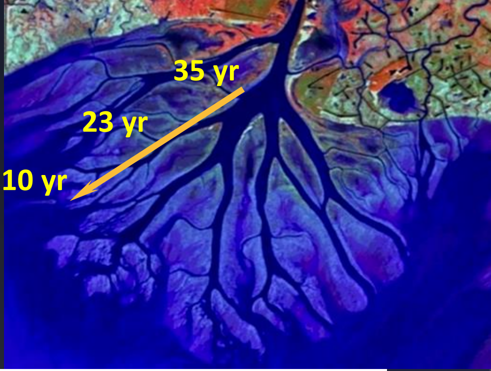
35
Older

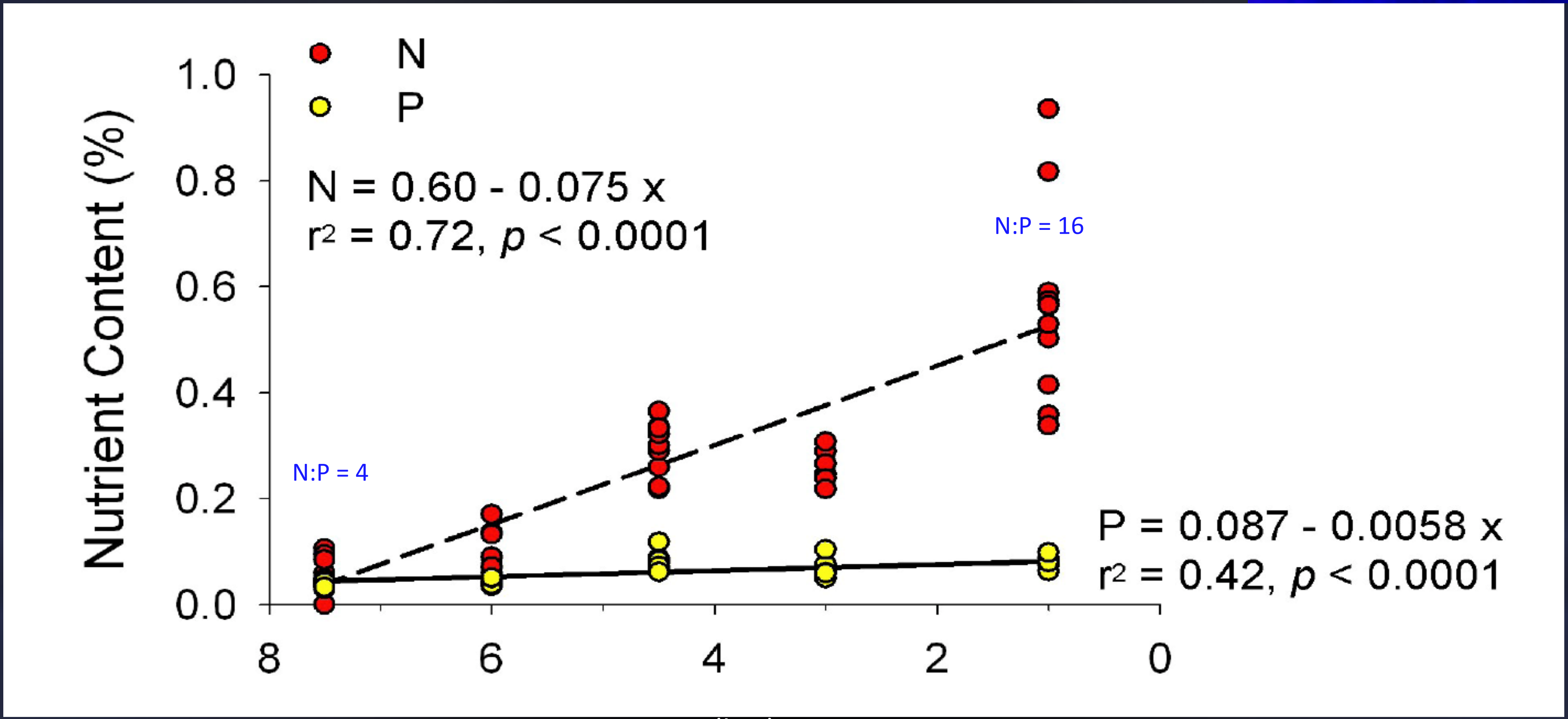
Age (yr)

Henry and Twilley 2013. Ecosystems

Soil N and P content with substrate age

- *Distance from head of WLD used as a proxy for age*





10
Young

Age (yr)

35
Older

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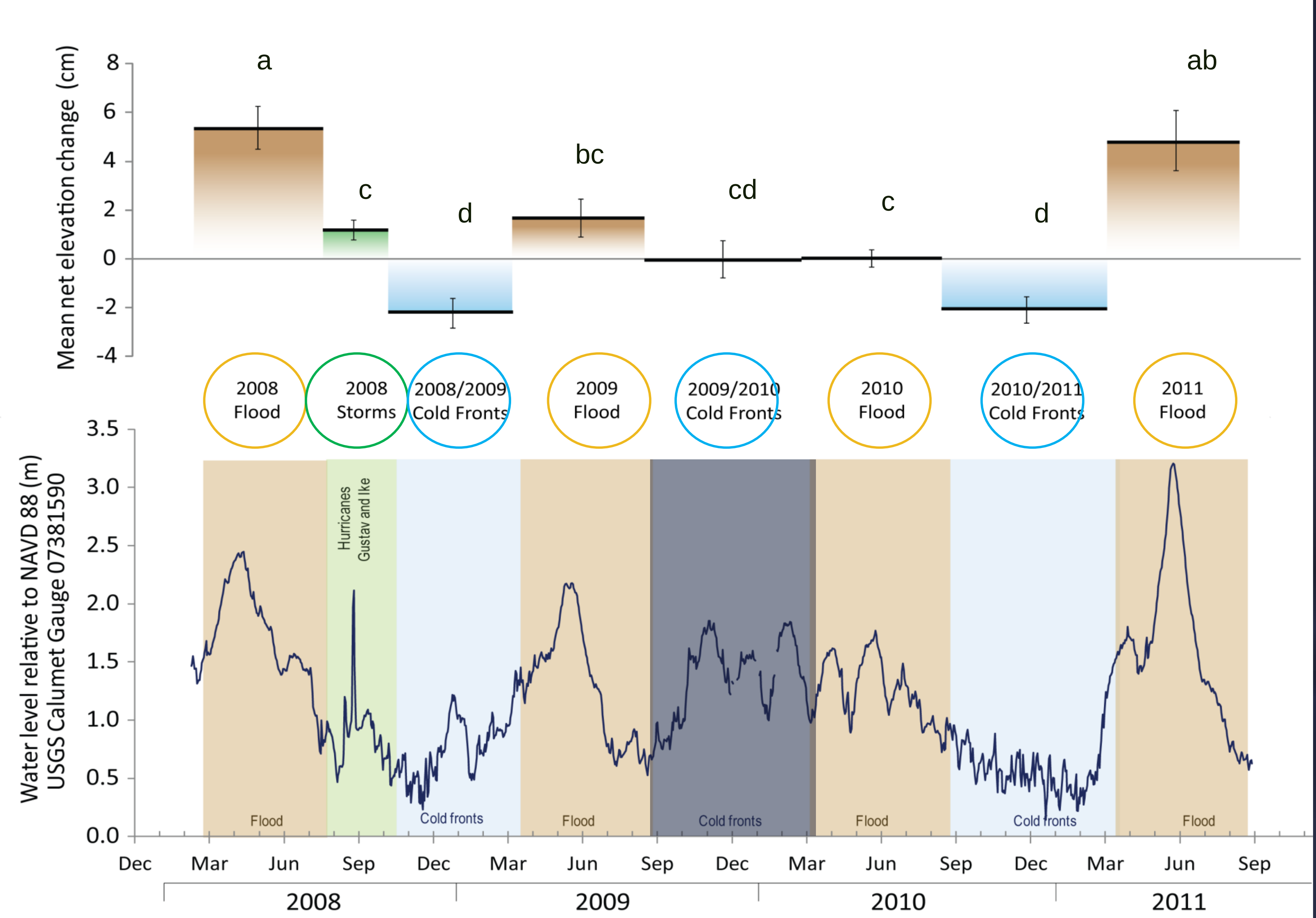
3: Soil composition as part of Deltaic Floodplain Successional Chronosequences

- Soil extremes in composition from inorganic to organic dominated (IS:OM ratio) reflects delta cycle.
- Abandonment and reoccupation control the IS:OM ratio; and the compsition of deltaic soils.

Growth = River

Maintenance = Plants

Seasonal event net elevation change



4: Plant communities contribute to the topography of coastal deltaic floodplains during delta development

- Plants respond to elevation gradients – step functions during extreme storm events?.
- Plants increase deposition and sediment storage on delta top and thus change elevation gradients and channels?.

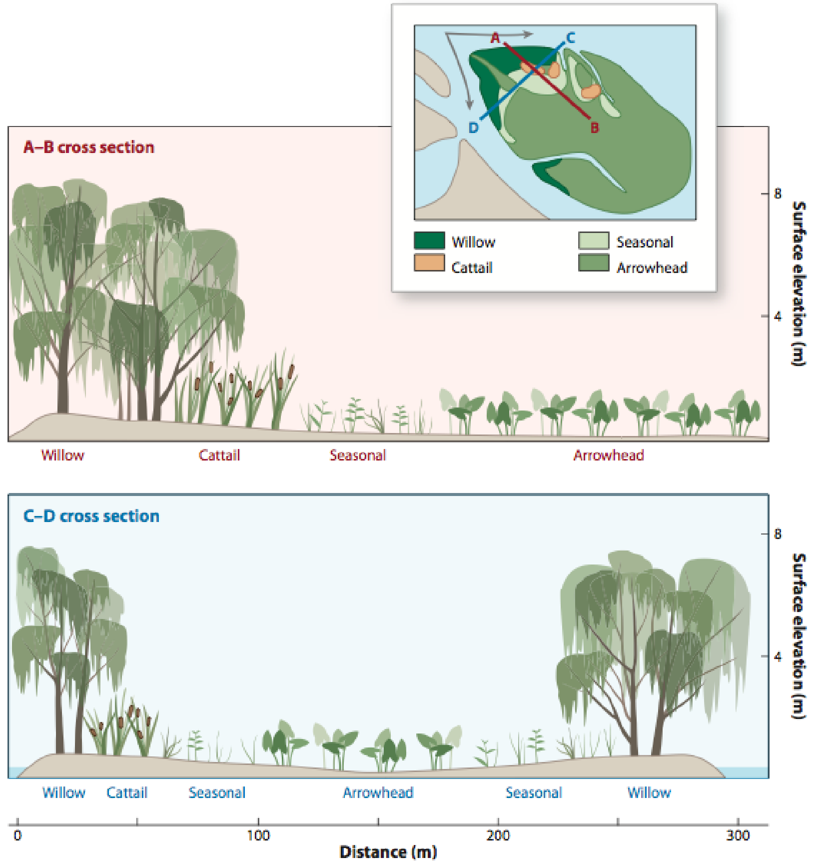
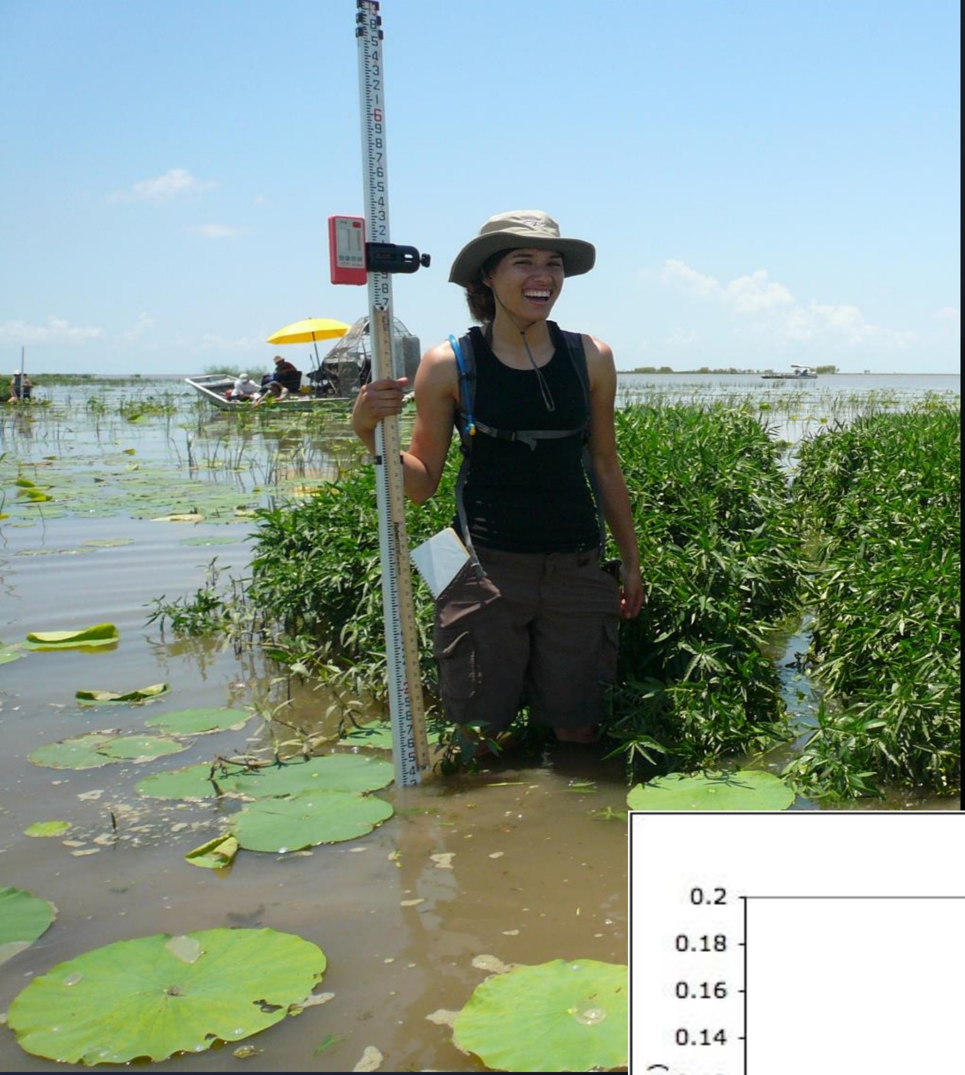


Figure 8

Control of delta vegetation by bed elevation in longitudinal (*upper panel*) and transverse (*lower panel*) directions on a growing mouth-bar island, Atchafalaya River Delta (Johnson et al. 1985). Willow: *Salix*; Cattails: *Typha*; Arrowhead: *Sagittaria*.



Plant – Sediment Interactions

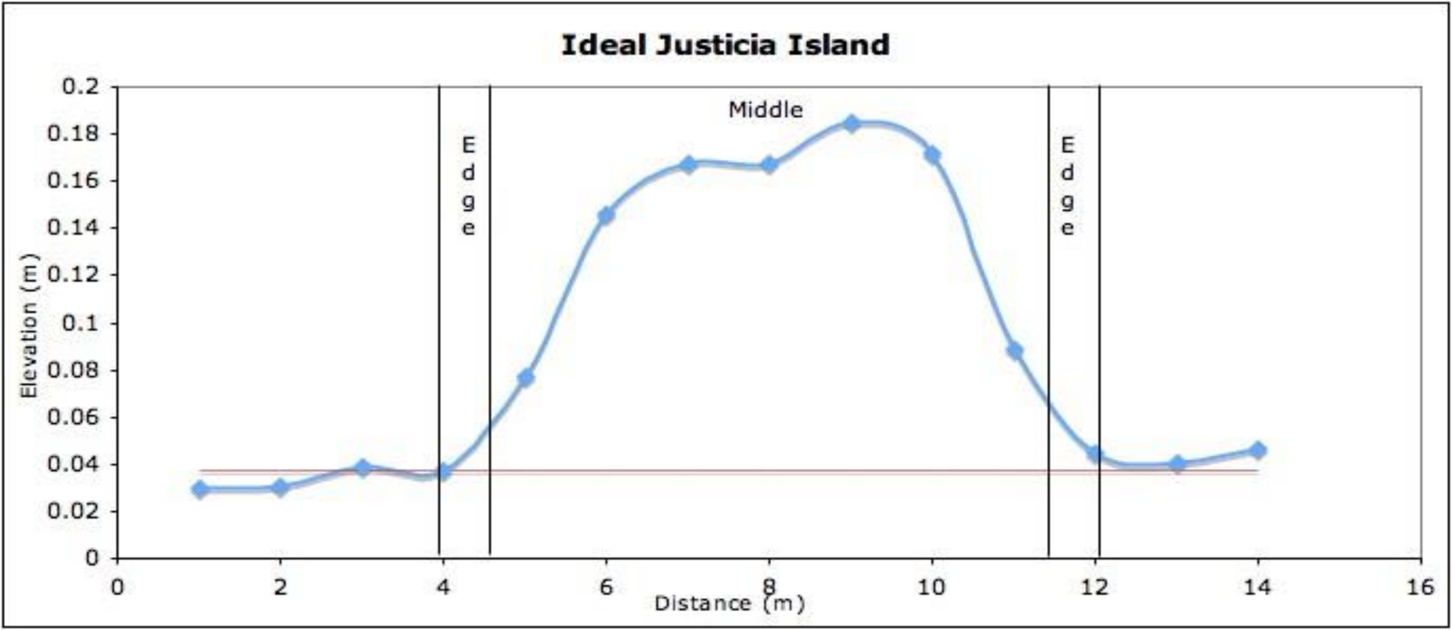
Justicia, Phragmites, Polygonum

Elevation

⇑ 15-20 cm

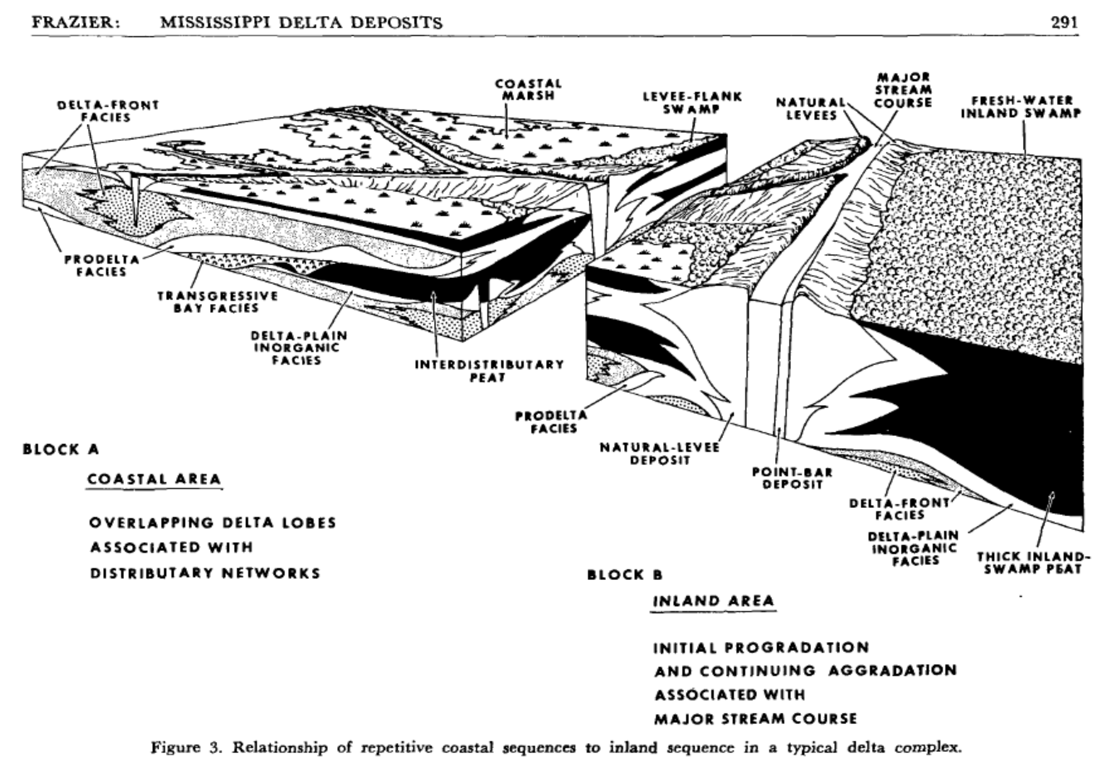
Mass

⇑ ~20 kg m^{-2}



5: Carbon accumulation of Coastal Deltaic Floodplains contribute to the elevation of emergent deltas

- Ecosystems provide biomass production and organic matter accumulation – balance of production, respiration and export.
- Does this organic matter accumulation contribute to elevation of delta top



FRAZIER: MISSISSIPPI DELTA DEPOSITS 291

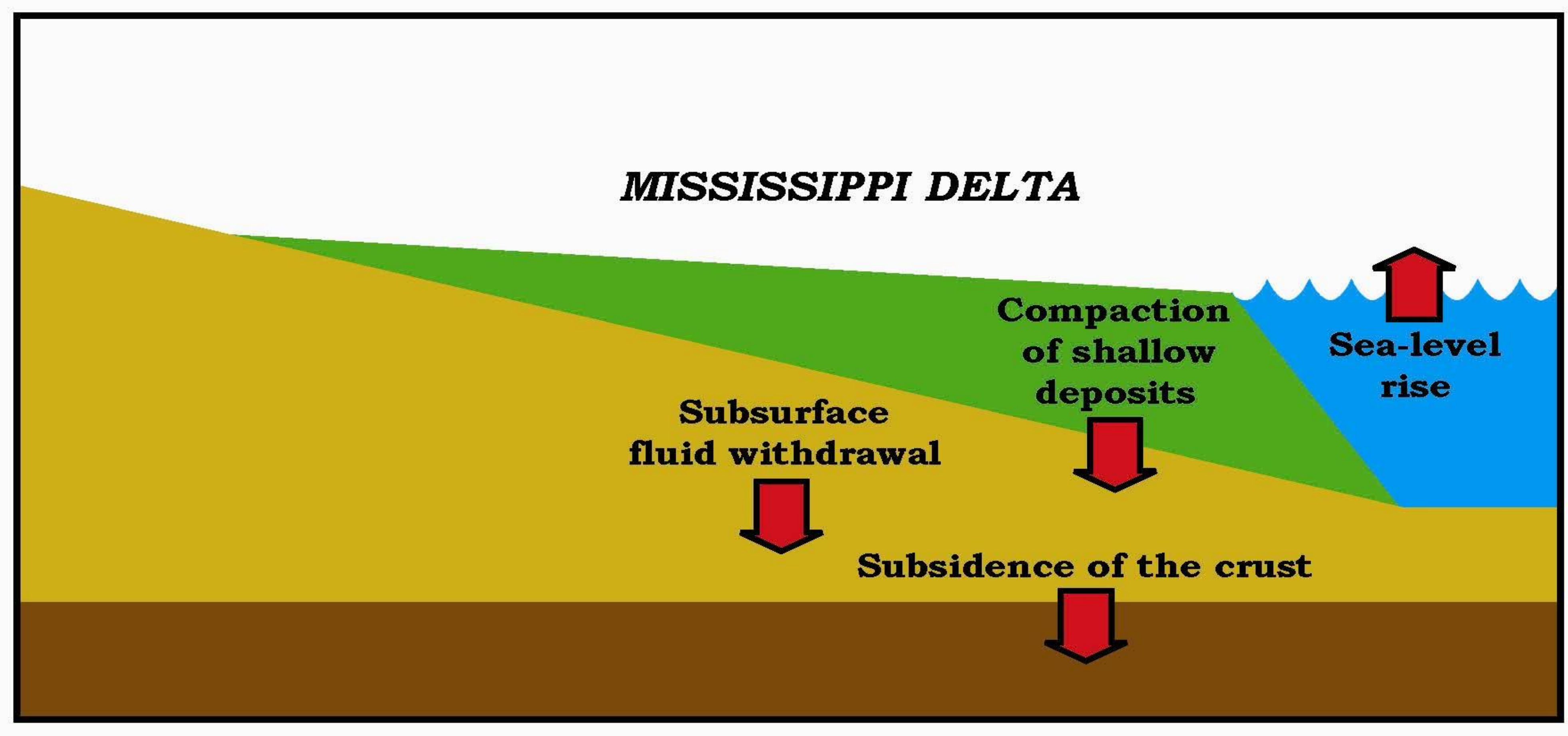
Figure 3. Relationship of repetitive coastal sequences to inland sequence in a typical delta complex.

Carbon contribution to $A_{top} = r_{org}$

$$\left(\dot{H}+\sigma\right)A_{top} = f_r Q_s + r_{org} A_{top}$$

W. Kim, G. Parker, C. Paola, D. Mohrig, R. Twilley, EOS 2009

6: There are thresholds of relative sea level rise that will result in the collaspe of coastal deltaic floodplains



Kirwan et al. 2010

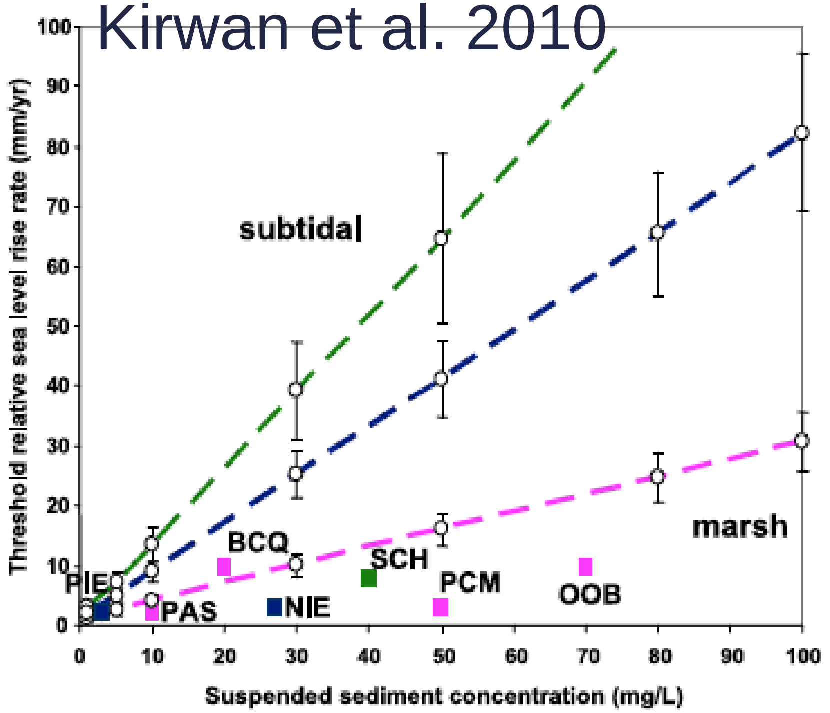
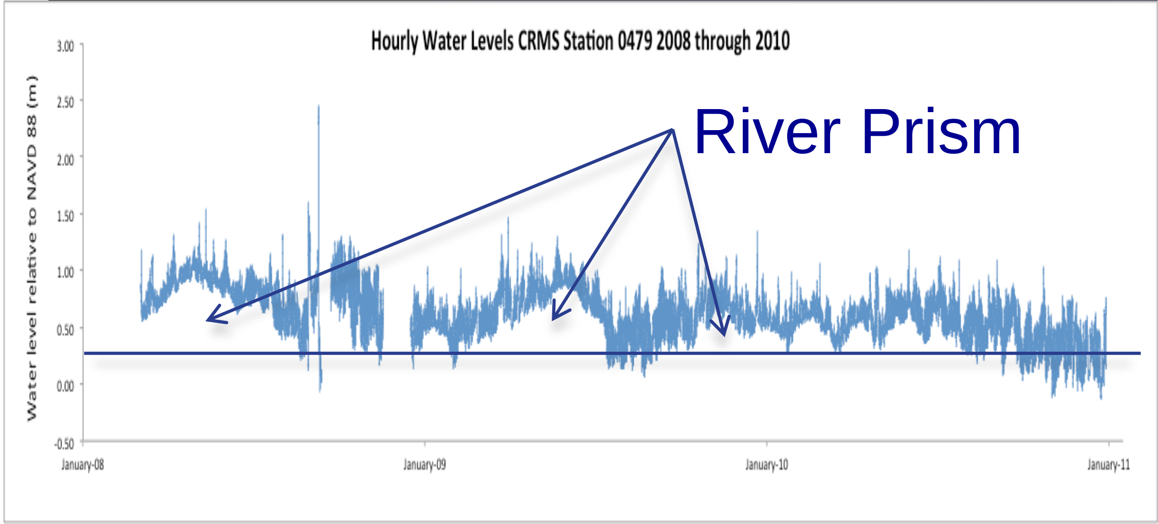
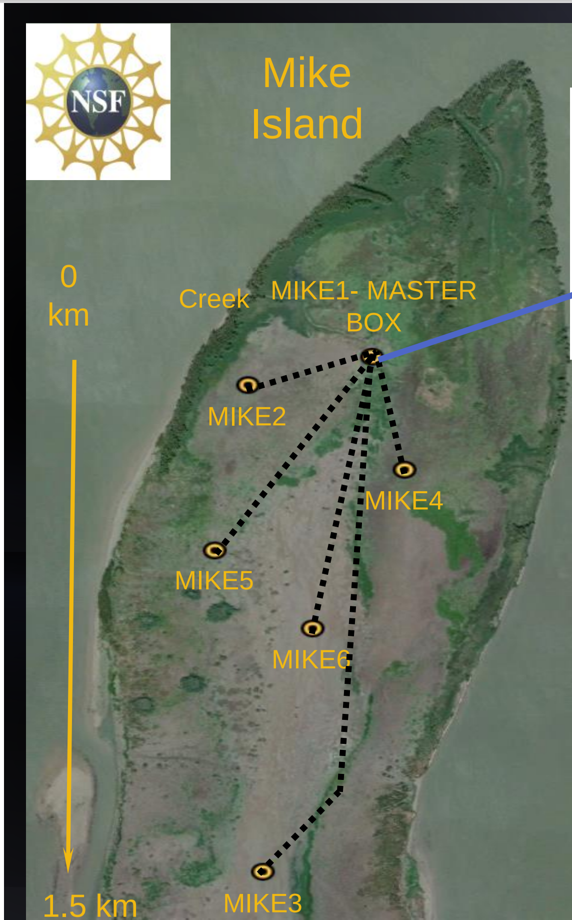
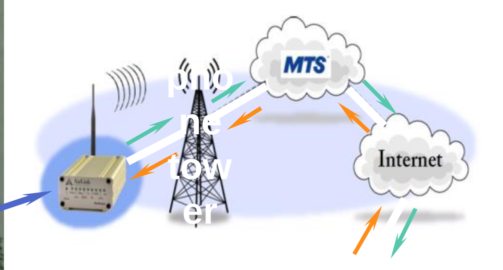


Figure 3. Predicted threshold rates of sea-level rise, above which marshes are replaced by subtidal environments as the stable ecosystem. Each line represents the mean threshold rate (±1 SE) predicted by 5 models as a function of suspended sediment concentration and spring tidal range. Pink line denotes thresholds for marshes modeled under a 1 m tidal range, blue line denotes 3 m tidal range, and green line denotes 5 m tidal range. For reference, we have included examples (denoted with square markers) of marshes worldwide in estuaries with different rates of historical sea-level rise, sediment concentration, and tidal range. (Abbreviations: PIE = Plum Island Estuary, Massachusetts; PAS = Pamlico Sound, North Carolina; BCQ = Bayou Chitique, Louisiana; NIE = North Inlet Estuary, South Carolina; SCH = Scheldte Estuary, Netherlands; PCM = Phillips Creek Marsh, Virginia; OOB = Old Oyster Bayou, Louisiana).



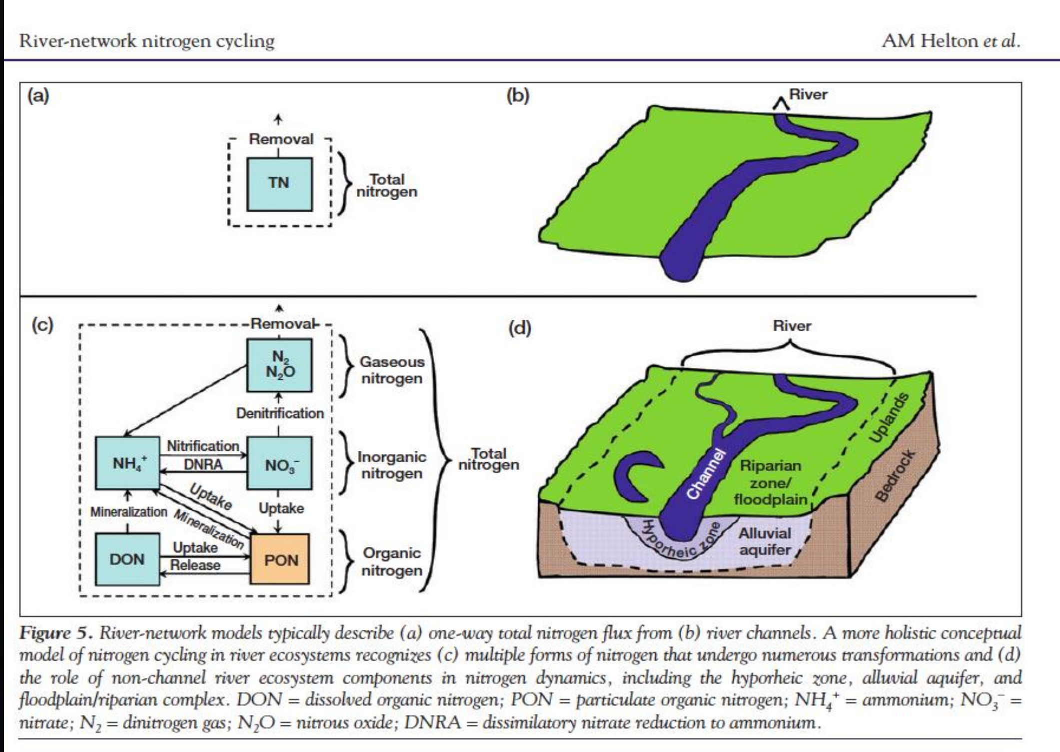
River Prism





7: Ecosystem service as reduction of nitrate from riverine source to shelf hypoxia.

- How do nutrient fluxes vary with age of delta lobe development
- How do nutrient fluxes vary with the elevation and vegetation types
- What are the seasonal fluxes of nutrients
- Focus on the fate of nitrate as flows across delta lobe



River-network nitrogen cycling

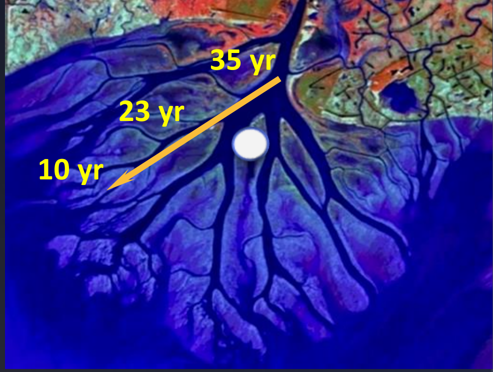
AM Helton *et al.*

Figure 5. *River-network models typically describe (a) one-way total nitrogen flux from (b) river channels. A more holistic conceptual model of nitrogen cycling in river ecosystems recognizes (c) multiple forms of nitrogen that undergo numerous transformations and (d) the role of non-channel river ecosystem components in nitrogen dynamics, including the hyporheic zone, alluvial aquifer, and floodplain/riparian complex. DON = dissolved organic nitrogen; PON = particulate organic nitrogen; NH_4^+ = ammonium; NO_3^- = nitrate; N_2 = dinitrogen gas; N_2O = nitrous oxide; DNRA = dissimilatory nitrate reduction to ammonium.*

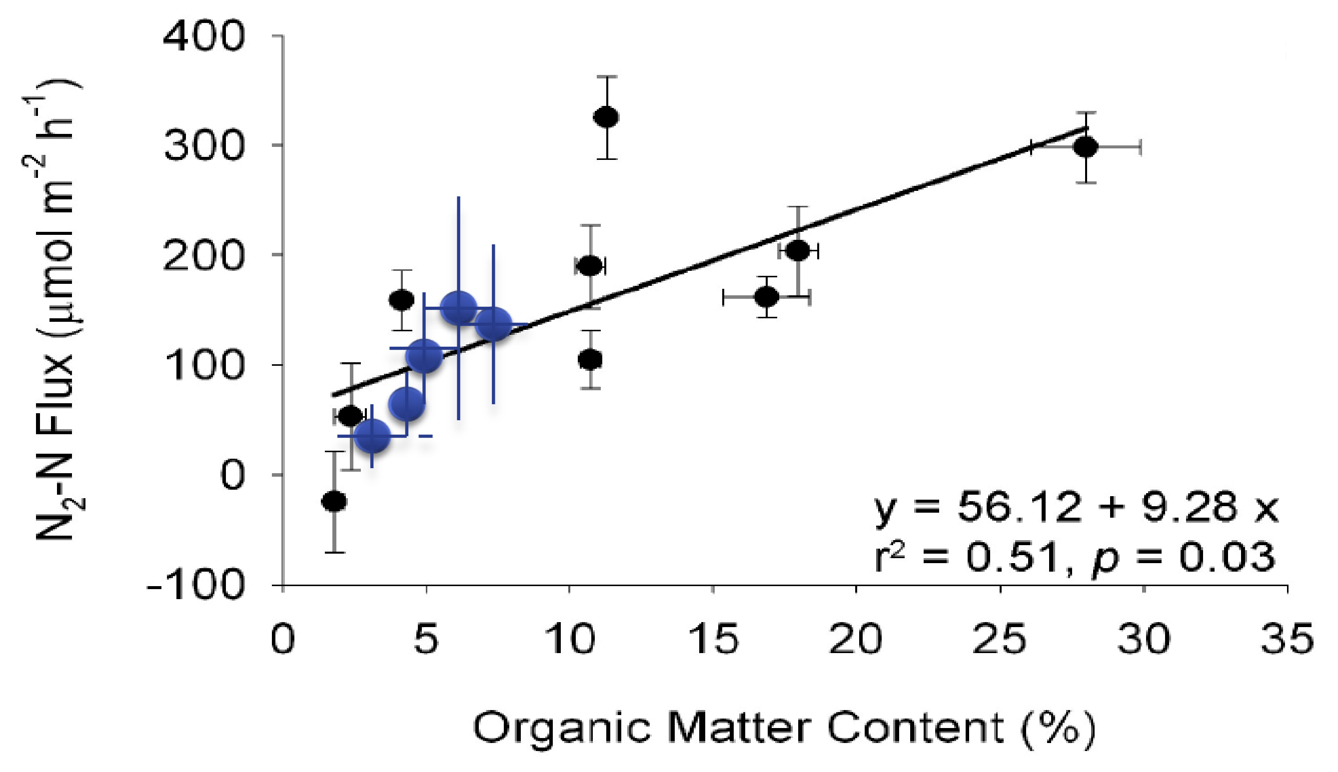
N_2-N Fluxes as a Function of Organic Matter Content

Henry and Twilley 2013. Ecosystems

DOI: 10.1007/s10021-013-9727-3



WLD Chronosequence

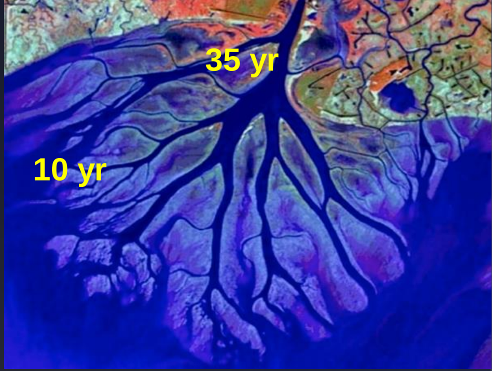


10
Young

35
Older

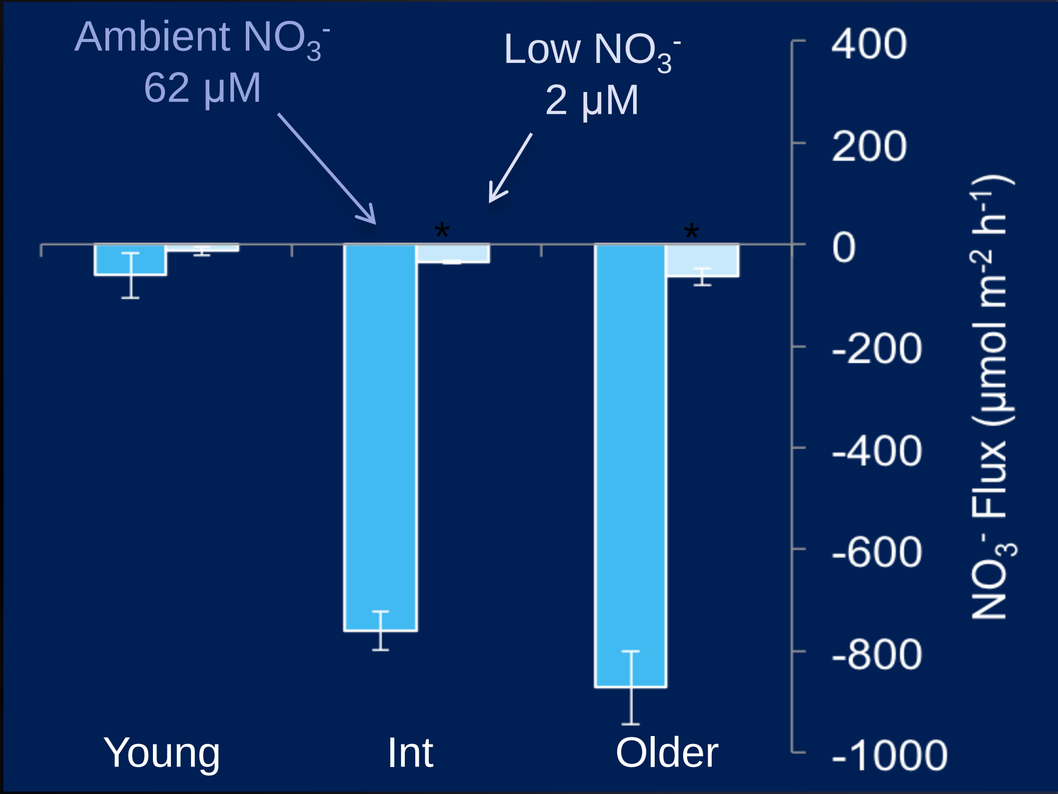
Age (yr)

Net N_2 and Nitrate Fluxes in Marshes of WLD – Effects of Nitrate Enrichment (nitrate removal experiments)



Experiment: Summer (May) 2011, 25 ° C, <1.0 ‰

* *



3% OM → Site → 18% OM

N_2 positive fluxes = net denitrification
N_2 negative fluxes = net N fixation

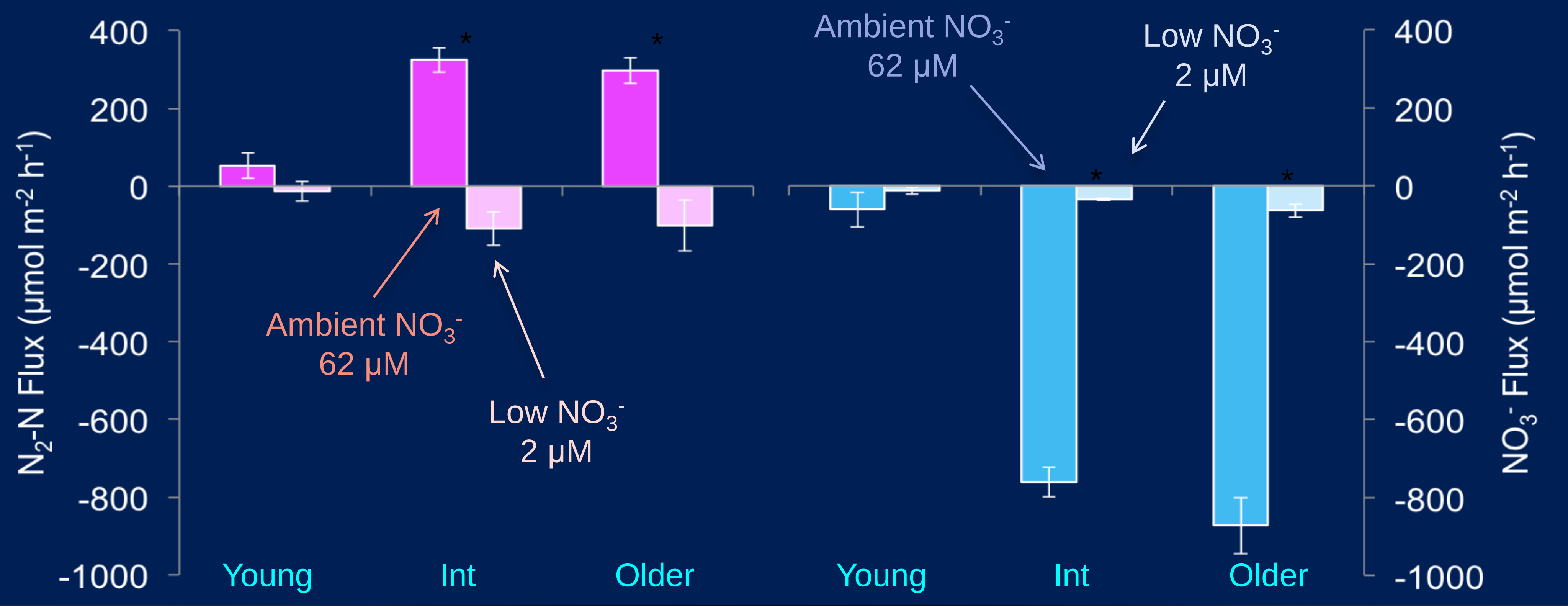
Henry and Twilley 2013. Ecosystems

DOI: 10.1007/s10021-013-9727-3

Net N_2 and Nitrate Fluxes in Marshes of WLD

Positive fluxes = soil production or release
Negative fluxes = soil consumption and uptake

Experiment: Summer (May) 2011, 25 ° C, <1.0 ‰



3% OM $\xrightarrow{\text{Site}}$ 18% OM

3% OM $\xrightarrow{\text{Site}}$ 18% OM

N_2 positive fluxes = net denitrification
N_2 negative fluxes = net N fixation

Henry and Twilley 2013. Ecosystems

DOI: 10.1007/s10021-013-9727-3

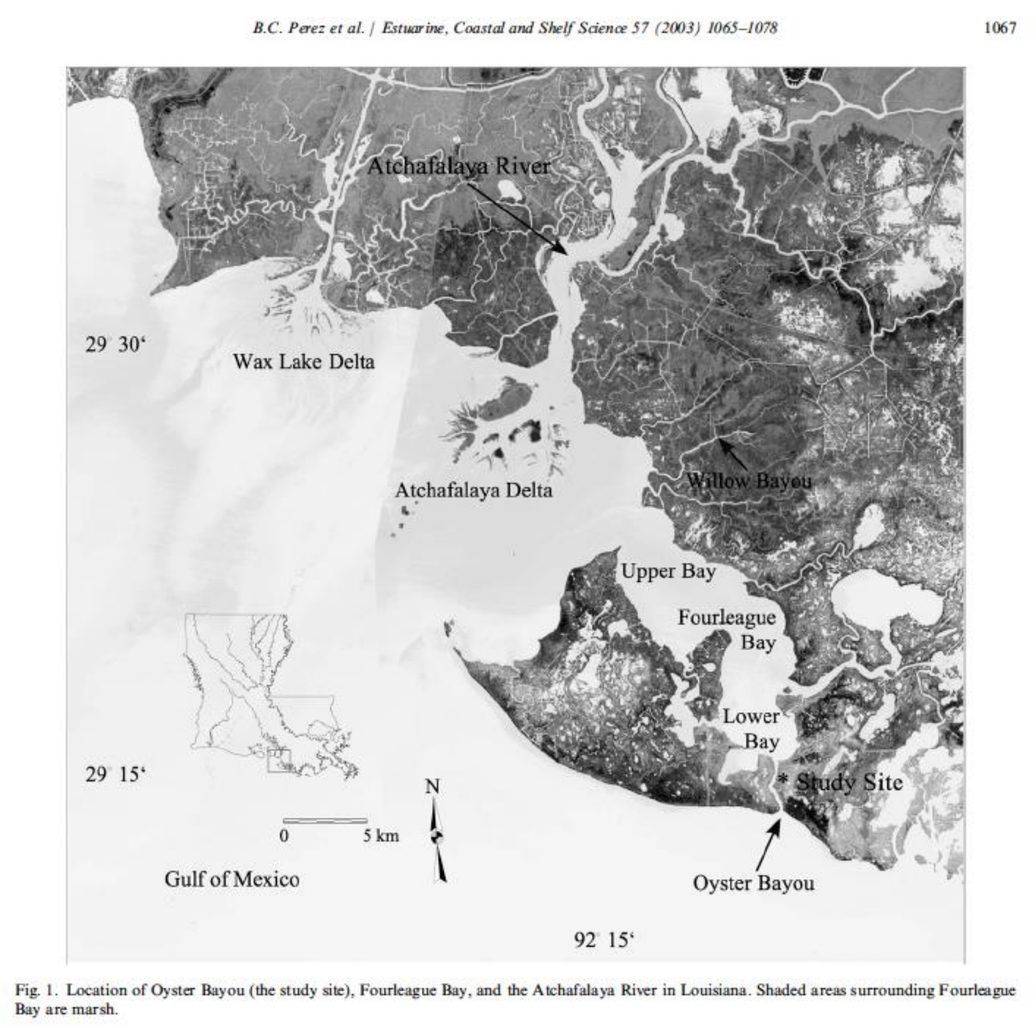
8: Coastal Deltaic Floodplains succession varies with nature of disturbance from biological and physical factors

9: Coastal Deltaic Floodplains are linked to productive estuaries with fisheries value

Fourleague Bay is at the mouth of Atchafalaya River. It has historically received about 3% of river discharge.

Has productive oyster leases in lower bay; 50% nutrient reduction; stable wetlands.

Is also site of extensive shrimp harvest. Thus is coastal basin with river occupation and ecosystem services.



B.C. Perez et al. / Estuarine, Coastal and Shelf Science 57 (2003) 1065–1078 1067

Fig. 1. Location of Oyster Bayou (the study site), Fourleague Bay, and the Atchafalaya River in Louisiana. Shaded areas surrounding Fourleague Bay are marsh.

Fourleague Bay: Note upper right panel that shoses the salinity variation with high flow discharge of Atch River – decreases to <2 ppt, but then recovers to 20 ppt is short time frame. Residence time of freshwater is about 0.25 to 0.5 months during high discharge (bottom right panel).

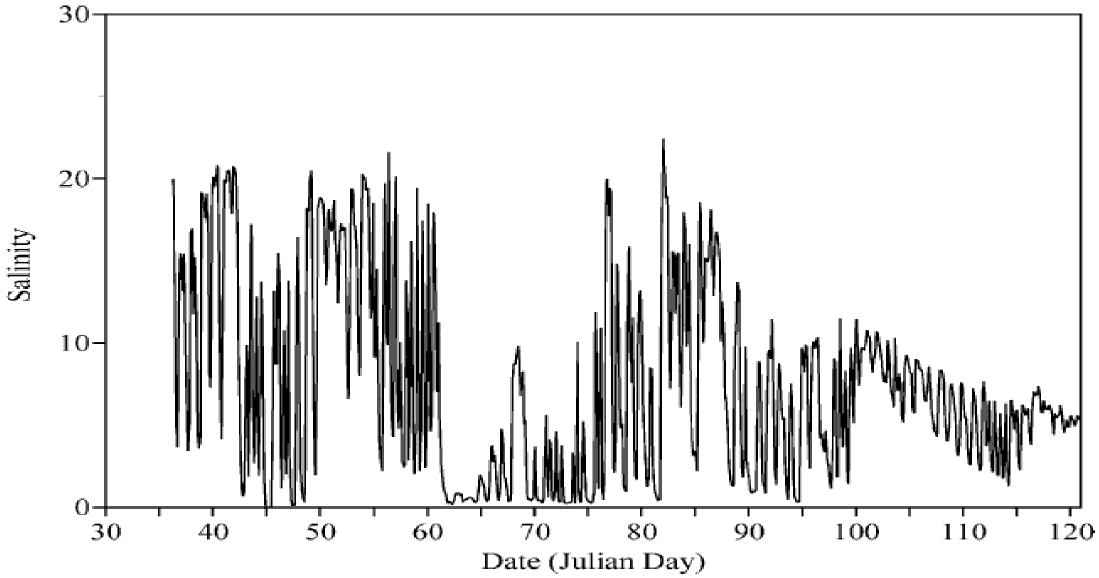


Fig. 5. Salinity measured in Oyster Bayou.

Sediment transport

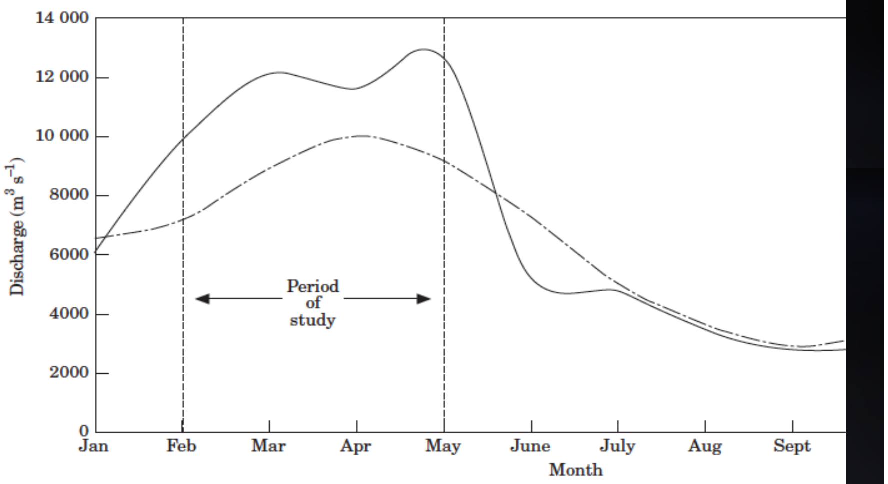
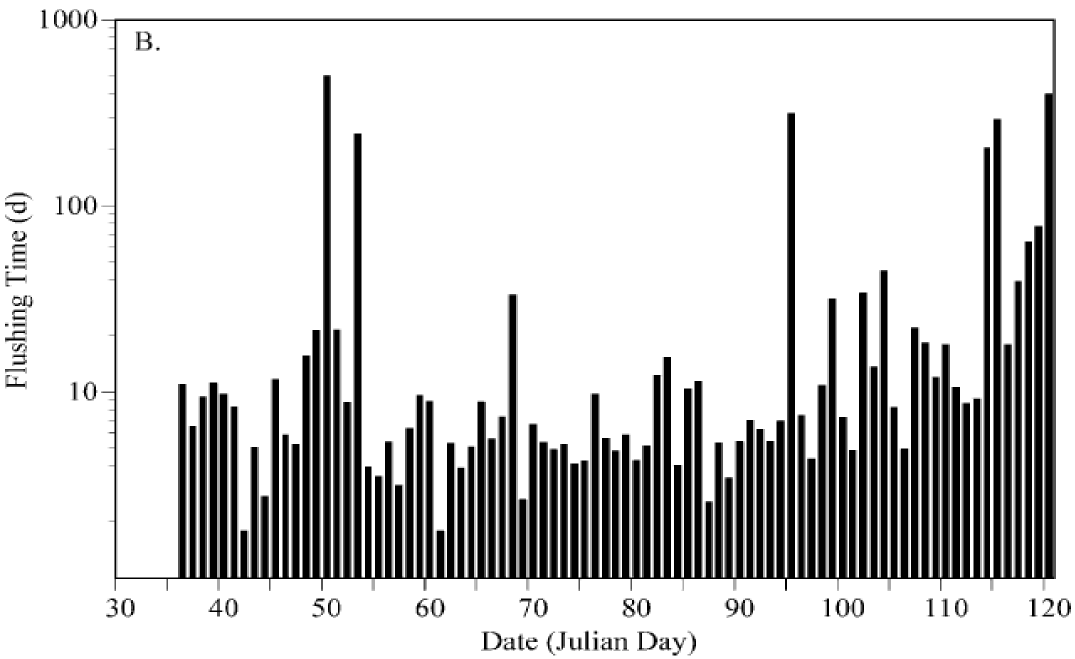


FIGURE 5. Atchafalaya River discharge at Simmesport, Louisiana. Study dates are indicated
——, 1994; – · –, 40-year mean.



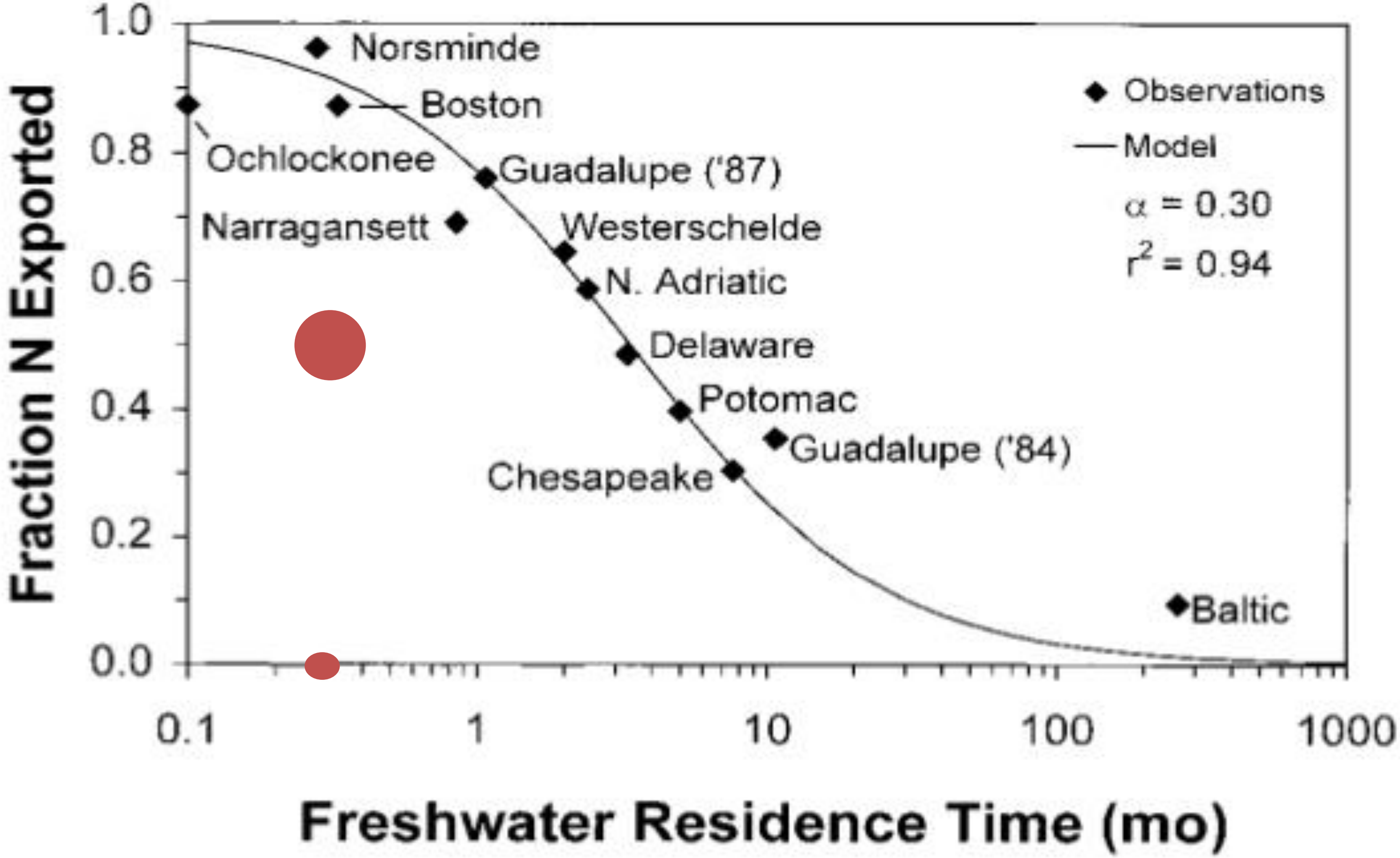


Fig. 2. The fraction of upland nitrogen input that is exported from 11 estuaries versus freshwater residence time (logarithmic time scale).

Very important finding – that normalized for depth, shallow coastal systems of deltaic coasts have nutrient removal rate of about 50 m/yr;

which is the coefficient similar to most wetland dominated systems.

Thus there is a very high nutrient removal capacity of shallow coastal systems.

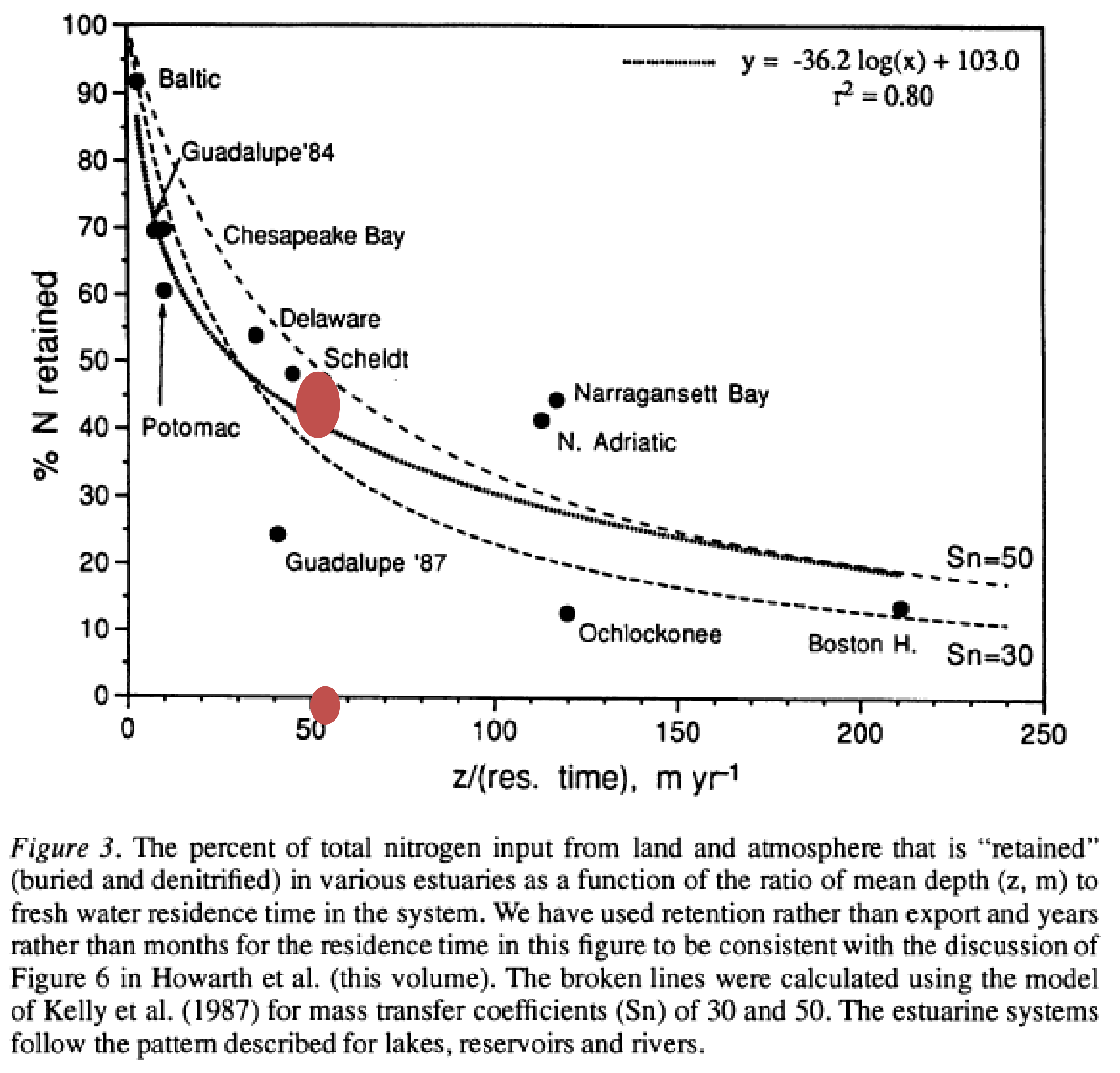
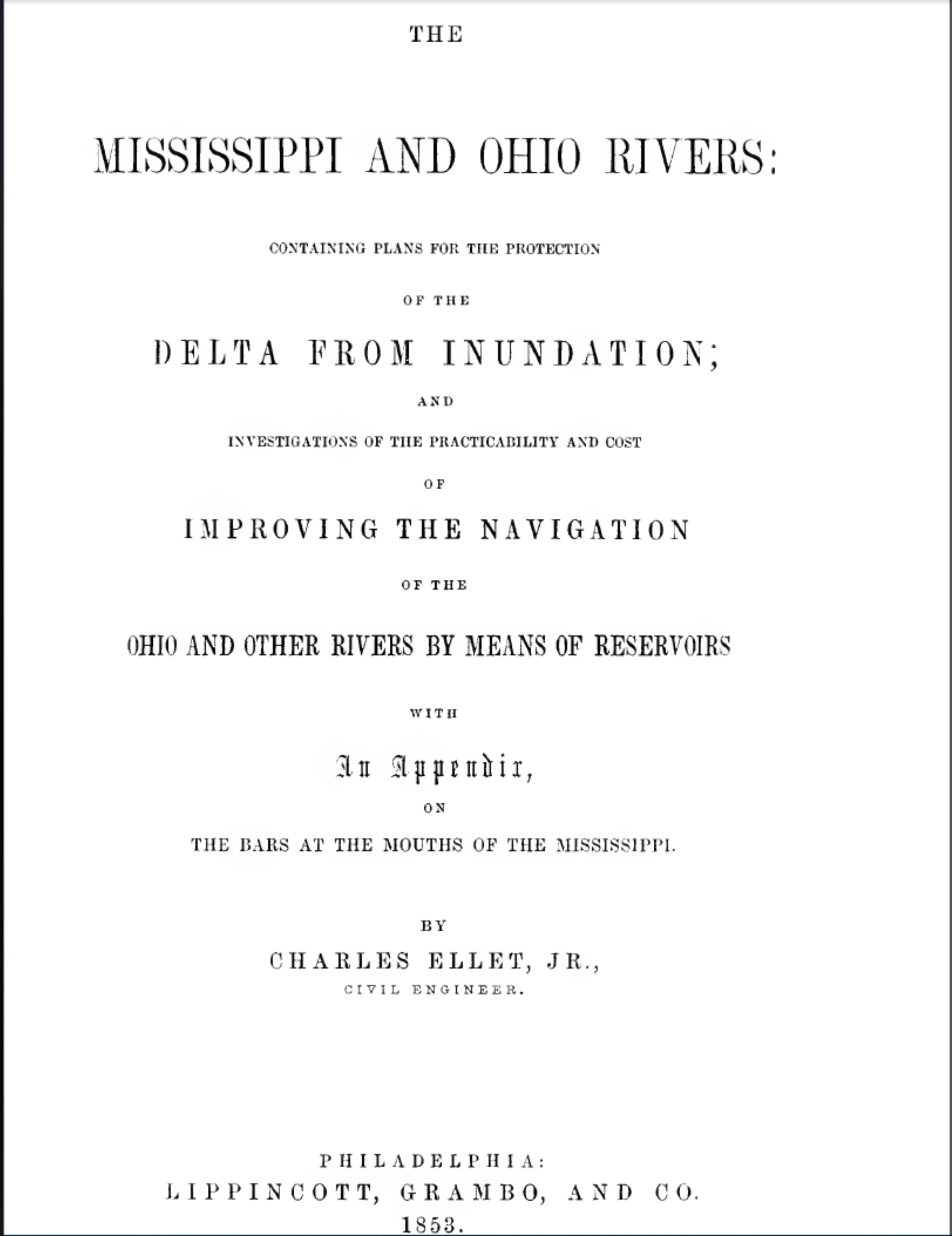


Figure 3. The percent of total nitrogen input from land and atmosphere that is "retained" (buried and denitrified) in various estuaries as a function of the ratio of mean depth (z, m) to fresh water residence time in the system. We have used retention rather than export and years rather than months for the residence time in this figure to be consistent with the discussion of Figure 6 in Howarth et al. (this volume). The broken lines were calculated using the model of Kelly et al. (1987) for mass transfer coefficients (Sn) of 30 and 50. The estuarine systems follow the pattern described for lakes, reservoirs and rivers.

Questions?

First exercise is to frame some evidence of how large was a flood-pulse of the Mississippi River during a major flood before the federal levee system was installed and restricted inundation of coastal basins.

An analysis by Charles Ellet Jr. published in 1853 gives provides some evidence of how large a flood-pulse event during the 1851 flood.



THE

MISSISSIPPI AND OHIO RIVERS:

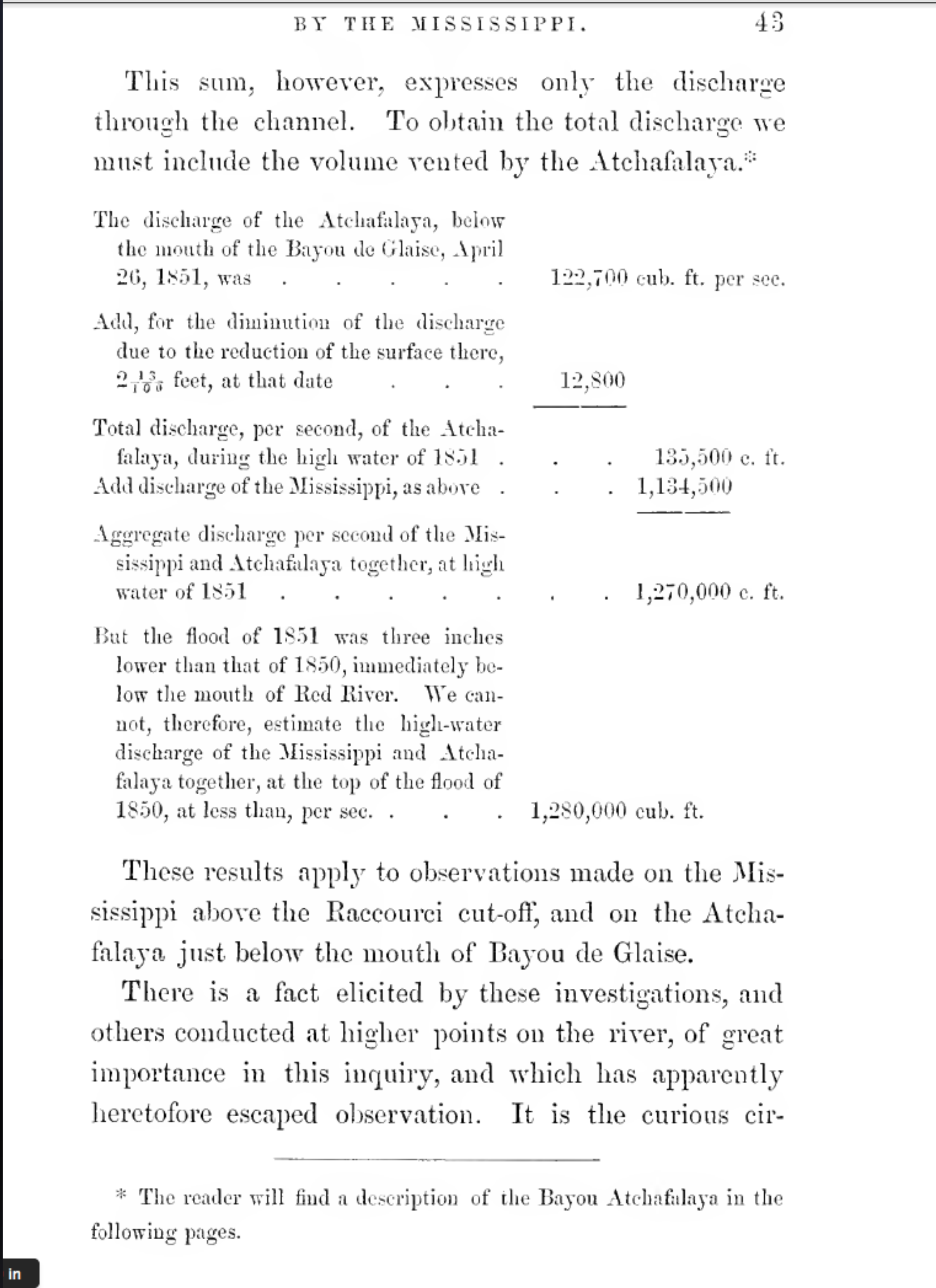
CONTAINING PLANS FOR THE PROTECTION
OF THE
DELTA FROM INUNDATION;
AND
INVESTIGATIONS OF THE PRACTICABILITY AND COST
OF
IMPROVING THE NAVIGATION
OF THE
OHIO AND OTHER RIVERS BY MEANS OF RESERVOIRS
WITH
An Appendix,
ON
THE BARS AT THE MOUTHS OF THE MISSISSIPPI.

BY
CHARLES ELLET, JR.,
CIVIL ENGINEER.

PHILADELPHIA:
LIPPINCOTT, GRAMBO, AND CO.
1853.

Estimate that the discharge of the 1851 flood – about 1.28 million cfs.

The next slide will show an estimate of how much of that flood emptied into the adjacent floodplain by creating crevasses along the river.



BY THE MISSISSIPPI. 43

This sum, however, expresses only the discharge through the channel. To obtain the total discharge we must include the volume vented by the Atchafalaya.*

The discharge of the Atchafalaya, below the mouth of the Bayou de Glaise, April 26, 1851, was	122,700 cub. ft. per sec.	
Add, for the diminution of the discharge due to the reduction of the surface there, $2\frac{13}{100}$ feet, at that date . . .	12,800	
Total discharge, per second, of the Atchafalaya, during the high water of 1851 . . .		135,500 c. ft.
Add discharge of the Mississippi, as above . . .		1,134,500
Aggregate discharge per second of the Mississippi and Atchafalaya together, at high water of 1851		1,270,000 c. ft.
But the flood of 1851 was three inches lower than that of 1850, immediately below the mouth of Red River. We cannot, therefore, estimate the high-water discharge of the Mississippi and Atchafalaya together, at the top of the flood of 1850, at less than, per sec. . . .	1,280,000 cub. ft.	

These results apply to observations made on the Mississippi above the Raccourci cut-off, and on the Atchafalaya just below the mouth of Bayou de Glaise.

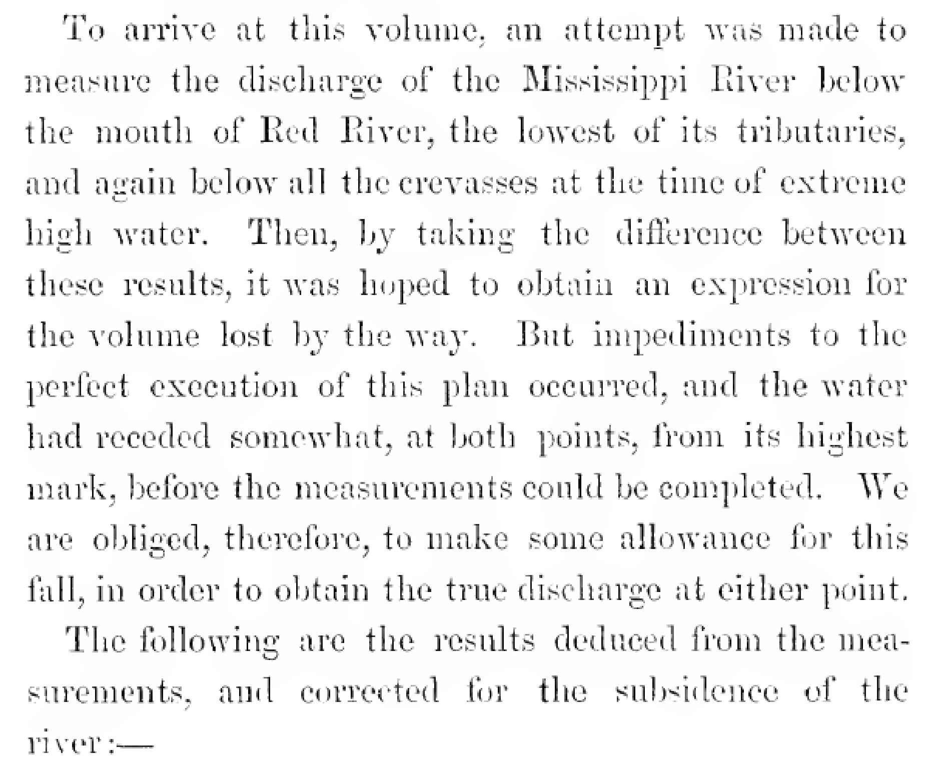
There is a fact elicited by these investigations, and others conducted at higher points on the river, of great importance in this inquiry, and which has apparently heretofore escaped observation. It is the curious cir-

---

* The reader will find a description of the Bayou Atchafalaya in the following pages.

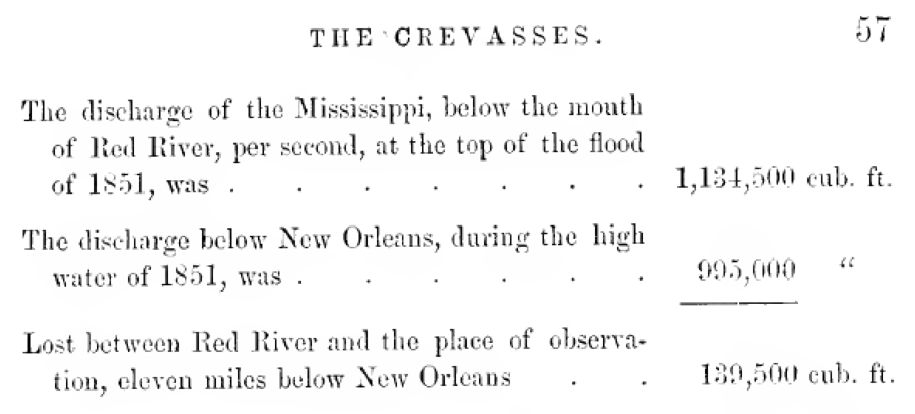
Estimate that the total loss of river flow during 1851 flood between point of present Old River Control structure and below New Orleans (english turn) is about 139,500 cfs.

This is flood pulse volume during 1851 flood that connected river to floodplain.



To arrive at this volume, an attempt was made to measure the discharge of the Mississippi River below the mouth of Red River, the lowest of its tributaries, and again below all the crevasses at the time of extreme high water. Then, by taking the difference between these results, it was hoped to obtain an expression for the volume lost by the way. But impediments to the perfect execution of this plan occurred, and the water had receded somewhat, at both points, from its highest mark, before the measurements could be completed. We are obliged, therefore, to make some allowance for this fall, in order to obtain the true discharge at either point.

The following are the results deduced from the measurements, and corrected for the subsidence of the river:—



THE CREVASSES. 57

The discharge of the Mississippi, below the mouth of Red River, per second, at the top of the flood of 1851, was	1,134,500 cub. ft.
The discharge below New Orleans, during the high water of 1851, was	995,000 "
Lost between Red River and the place of observation, eleven miles below New Orleans . .	139,500 cub. ft.