Materials Transfer at the Continent-Ocean Interface under the Scenario of the Anthropocene

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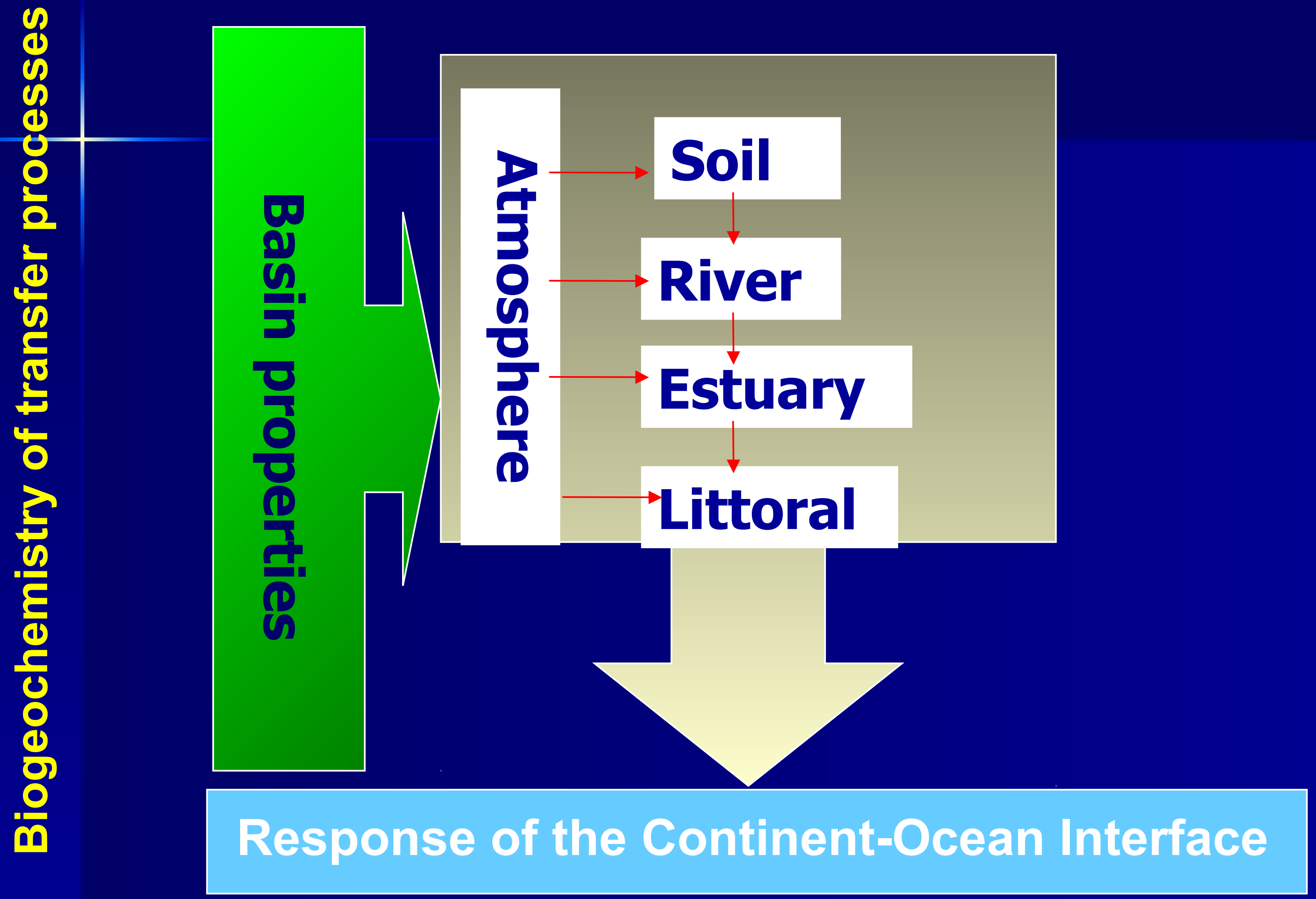
http://inct.cnpq.br/web/inct-tmcocean/home/

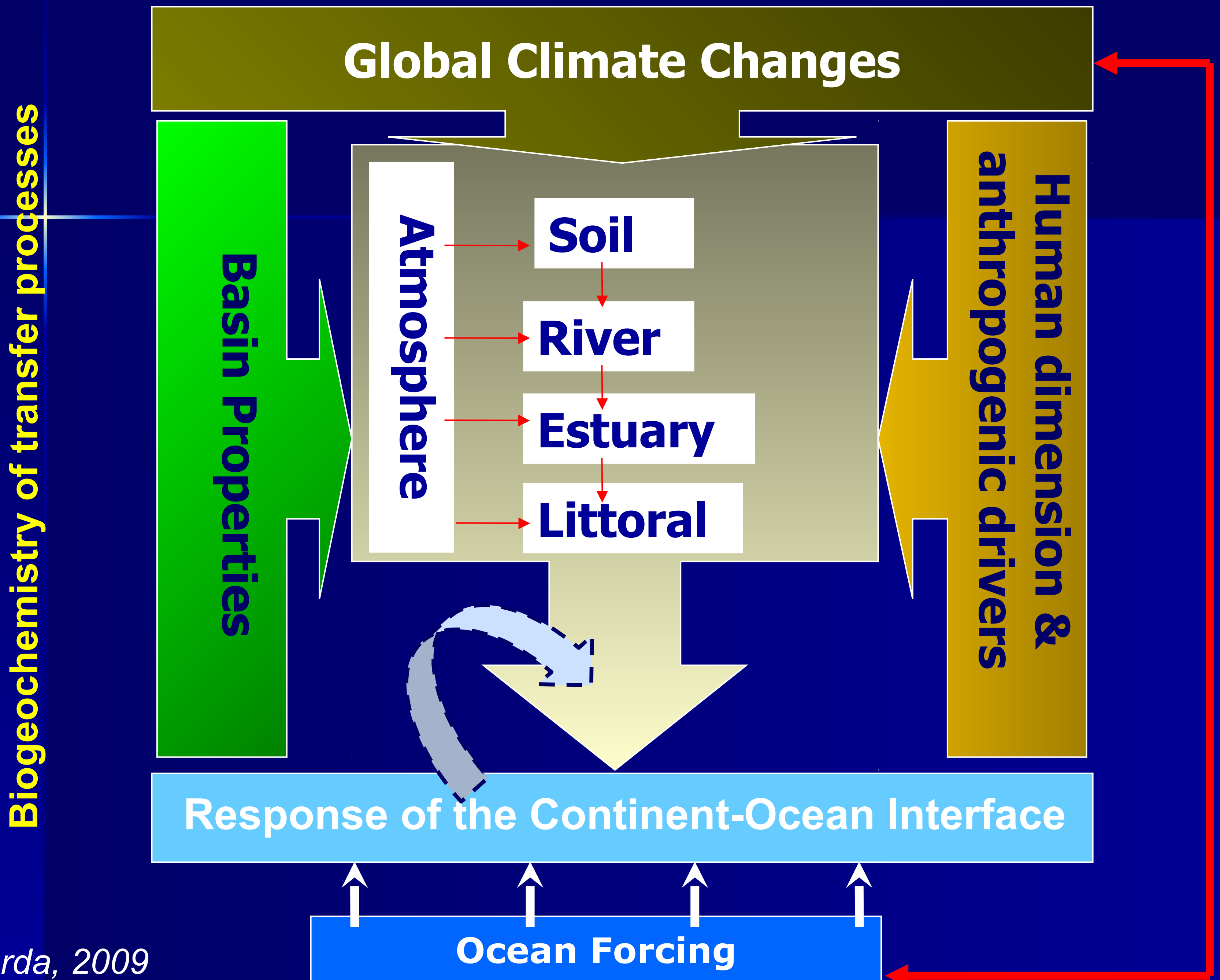
Continent-Ocean Transfer Processes *
(Concepcion at the end of the 20th century)



Lacerda, 2009

*Most legislation still based on it!

Present –day Continent-Ocean Transfer Processes *



Lacerda, 2009

Principals characteristics of the COI

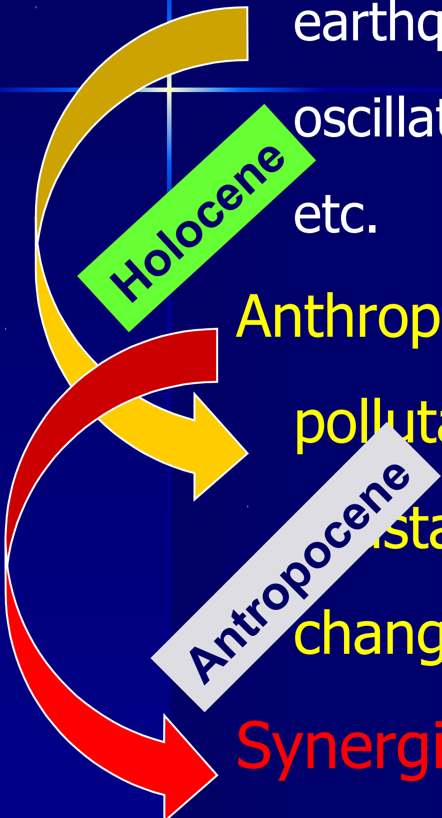
- **1 – T**ransfer of water, mass and energy occur through the continent-ocean interface at large spatial scale both in terrestrial and marine adjacent areas

- **2 - T**ransfer occurs simultaneously both at continent-ocean and ocean-continent directions at different temporal e spatial scales.

- **3 – T**ransfer is affected by natural and anthropogenic vectors.

c.f. Kjerfve, 2007

Vectors affecting the continent-ocean transport



Naturals: geotectonic (subsidence/elevation), wind, earthquakes, hurricanes, tsunamis, inundations, sea level oscillation, type and abundance of coastal vegetation, etc.

Anthropogenic: wastewaters, agriculture runoff, pollutant emissions and remobilization, conversion of coastal areas, engineering works, global climate changes.

Synergies: vectors act simultaneously and do affect each other, including through feedback mechanisms, in generally very poorly known.

c.f. Kjerfve, 2007

Major effects of anthropogenic vectors

(i) Human activities largely accelerate biogeochemical cycles and the transfer of materials at the planetary levels;

(ii) Natural fluvial filters have been constantly altered, particularly by the construction of dams and deforestation of gallery forests and conversion of coastal vegetation;

(iii) Fluvial discharges to the oceans are presently artificially controlled and reduced by engineering interventions (dams, diversion withdraw) and due to global climate change, at least in lower latitudes).

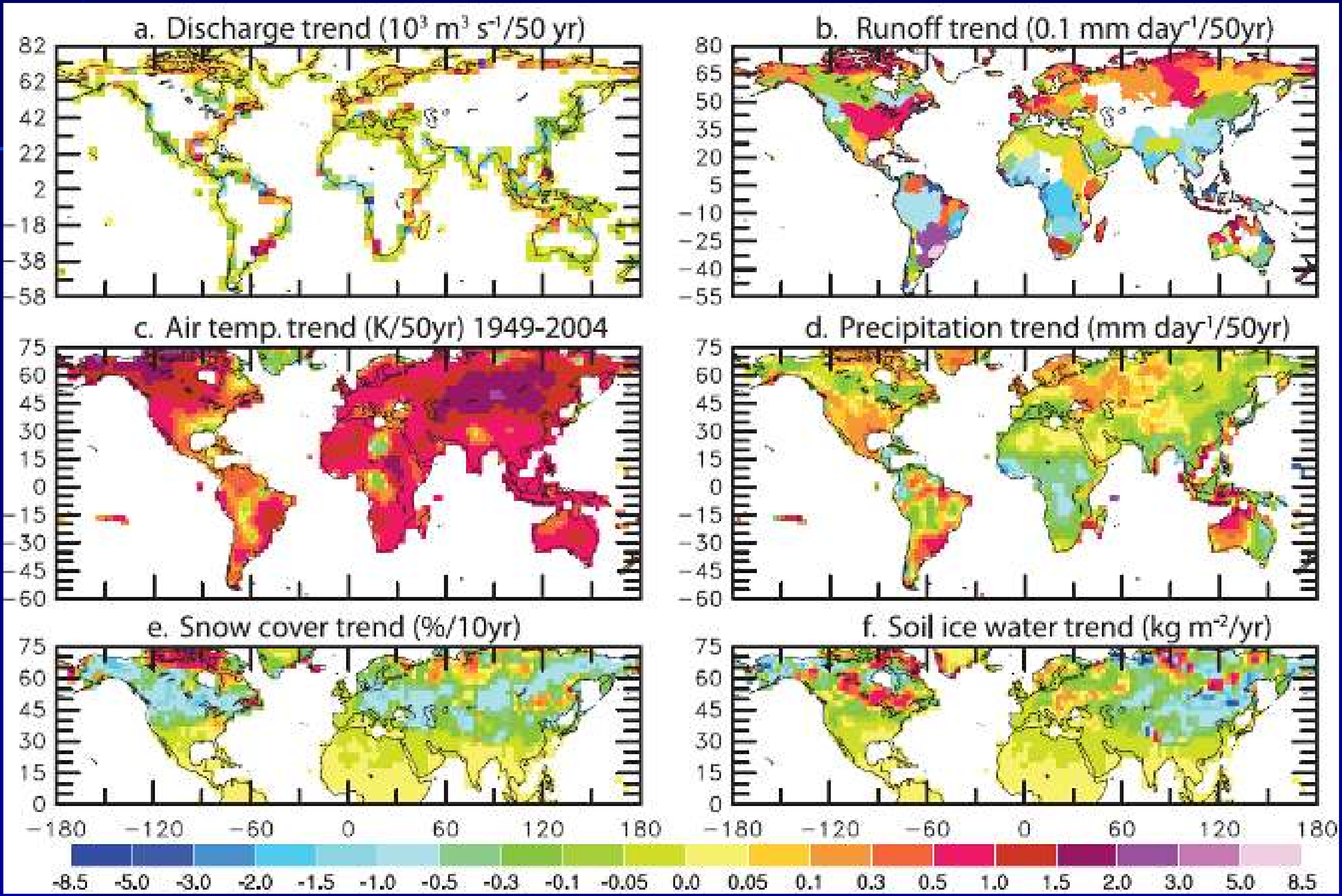
Meybeck a & Vörösmarty (2005)

Principals classes of anthropogenic vectors affecting the transport of materials at the continent-ocean interface

Vectors	Pressure	Impact
Agribusiness/ Aquaculture	Increasing loads of sediments, nutrients and contaminants, permeability of surfaces, decreasing water availability	Sedimentation Eutrophication
Urbanization / Industrialization		Sedimentation Eutrophication Contamination
Dams	Retention of sediments and nutrients Regularization of the fluvial flux	Sedimentation Erosion Oligotrophy
Global climate change	Sea level rise, alteration of the rainfall regime	Sedimentation Erosion

Marins et al. (2002)

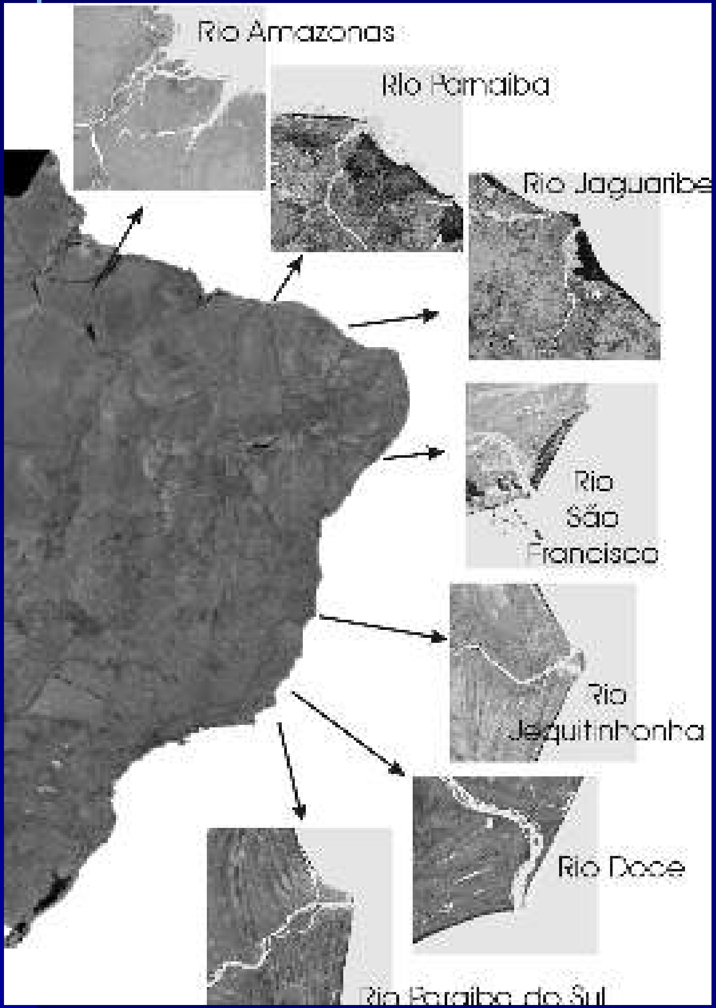
Global changes augment continental runoff in high latitudes, and decrease in lower latitudes and in semiarid regions in particular (Dai et al., 2009).



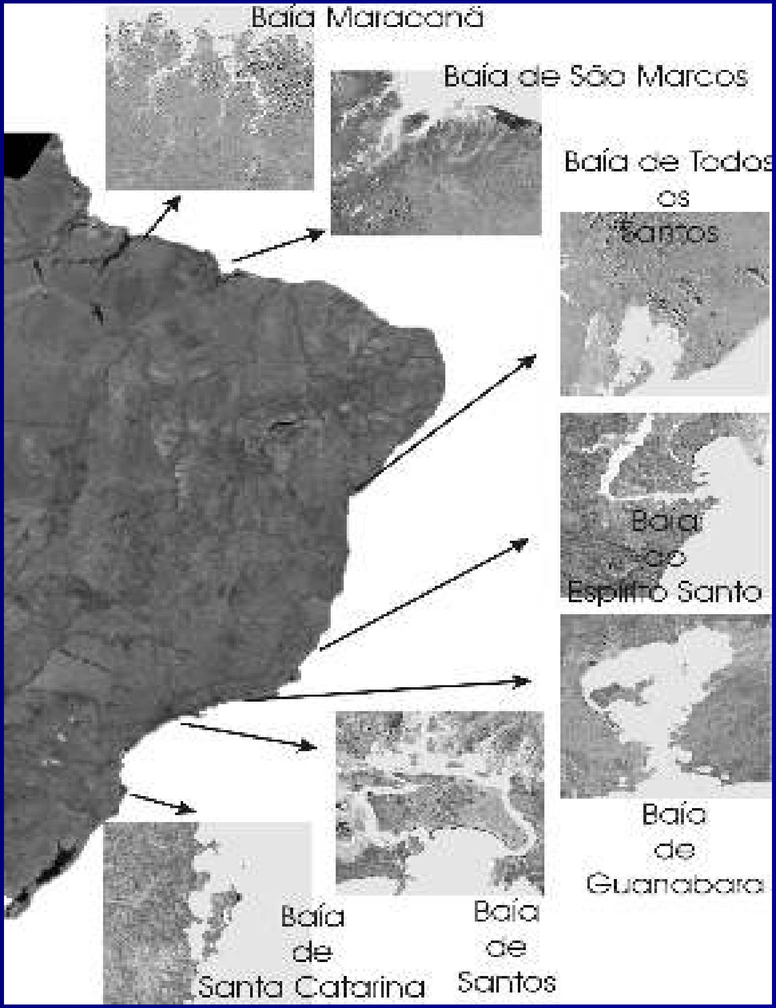
Clases of interface systems in Brazil (Knoppers *et al*., 2009).

1. Spatial Scale

Exporters / Accumulators



Accumulators/ Exporters



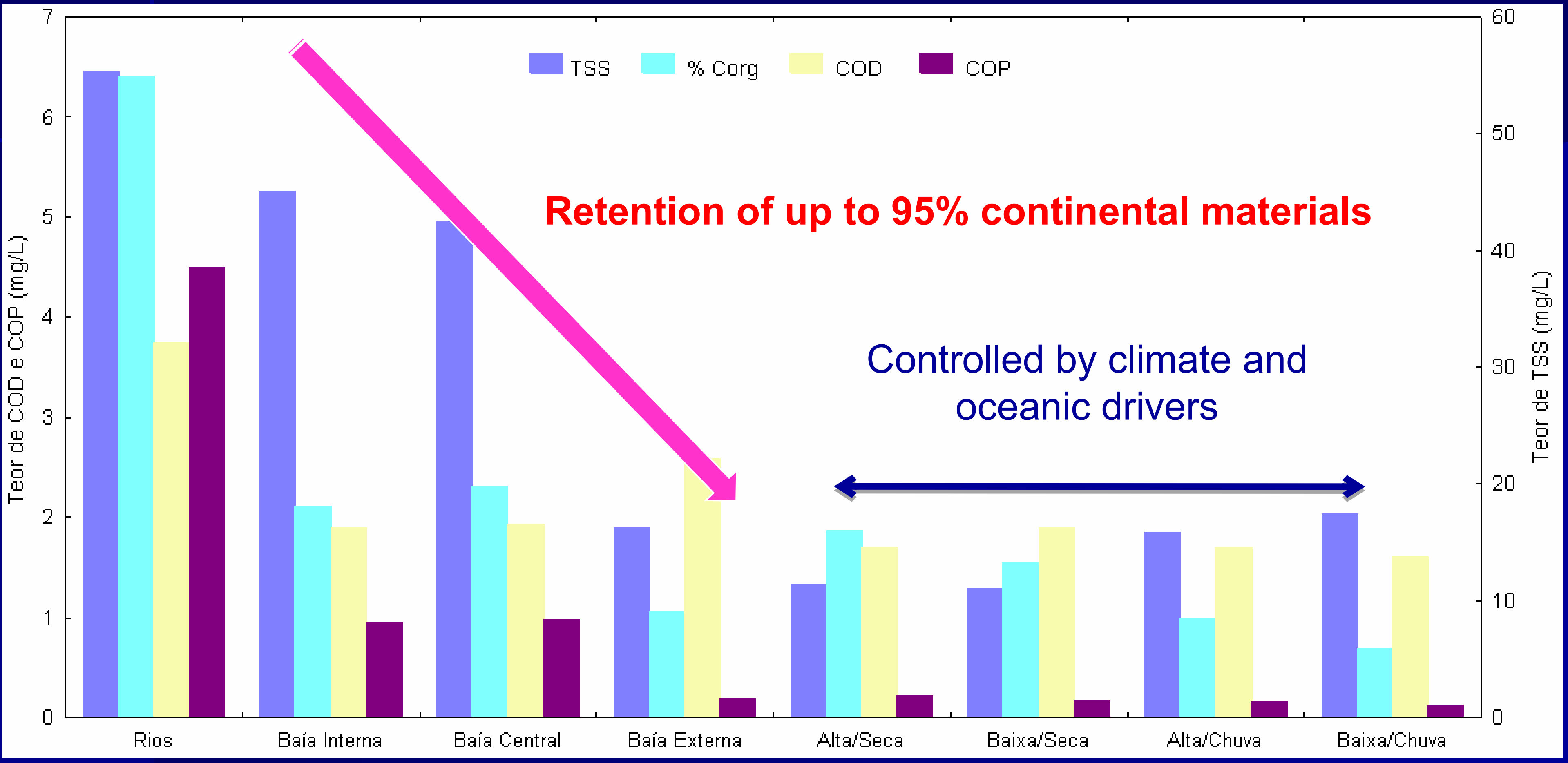
Typical exporting systems form fluvial plumes over continental shelves, but may display seasonality

1. Spatial scale

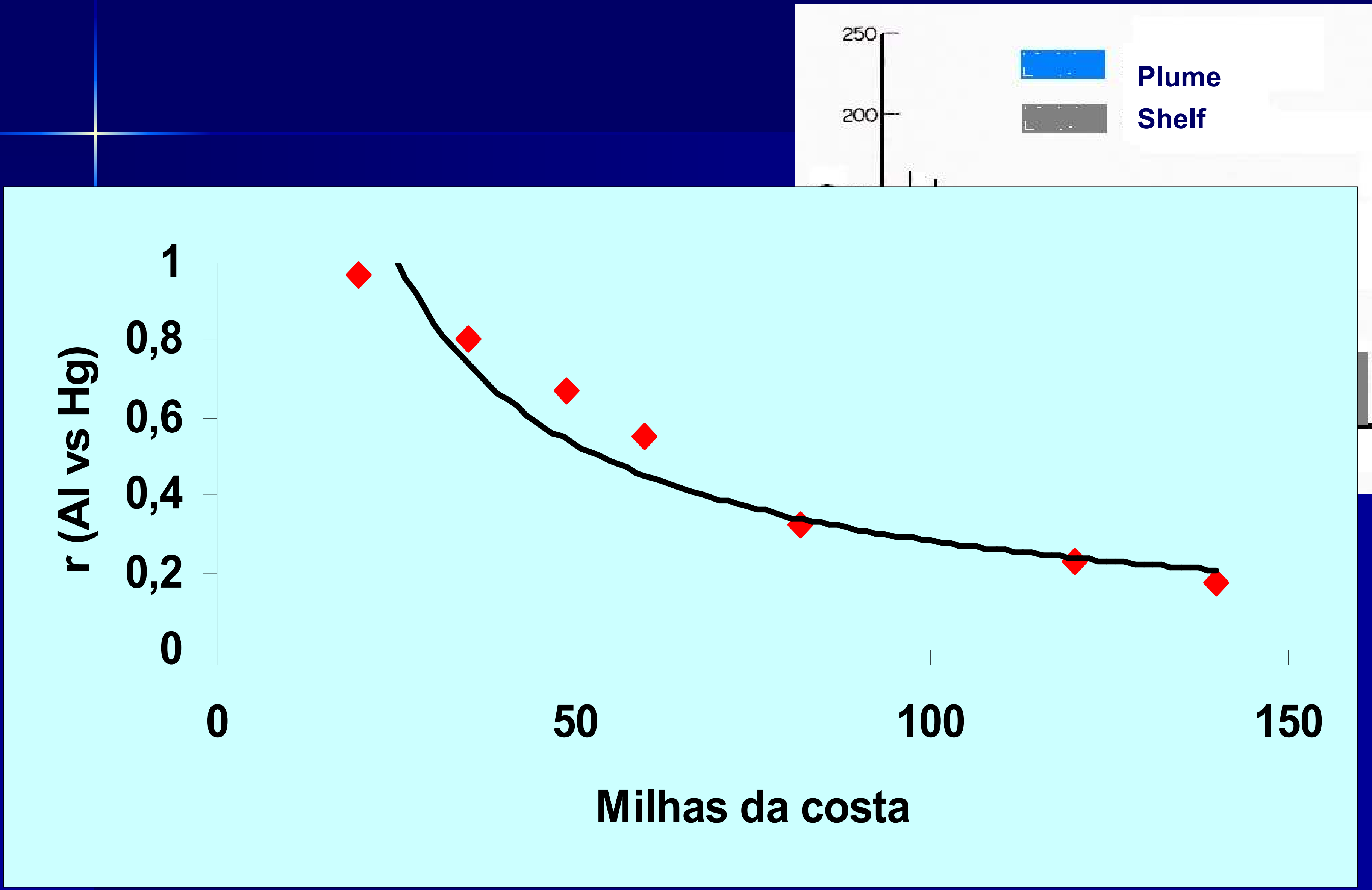
Typical retainer systems forms sedimentary environments in the estuarine zone

1. Spatial scale

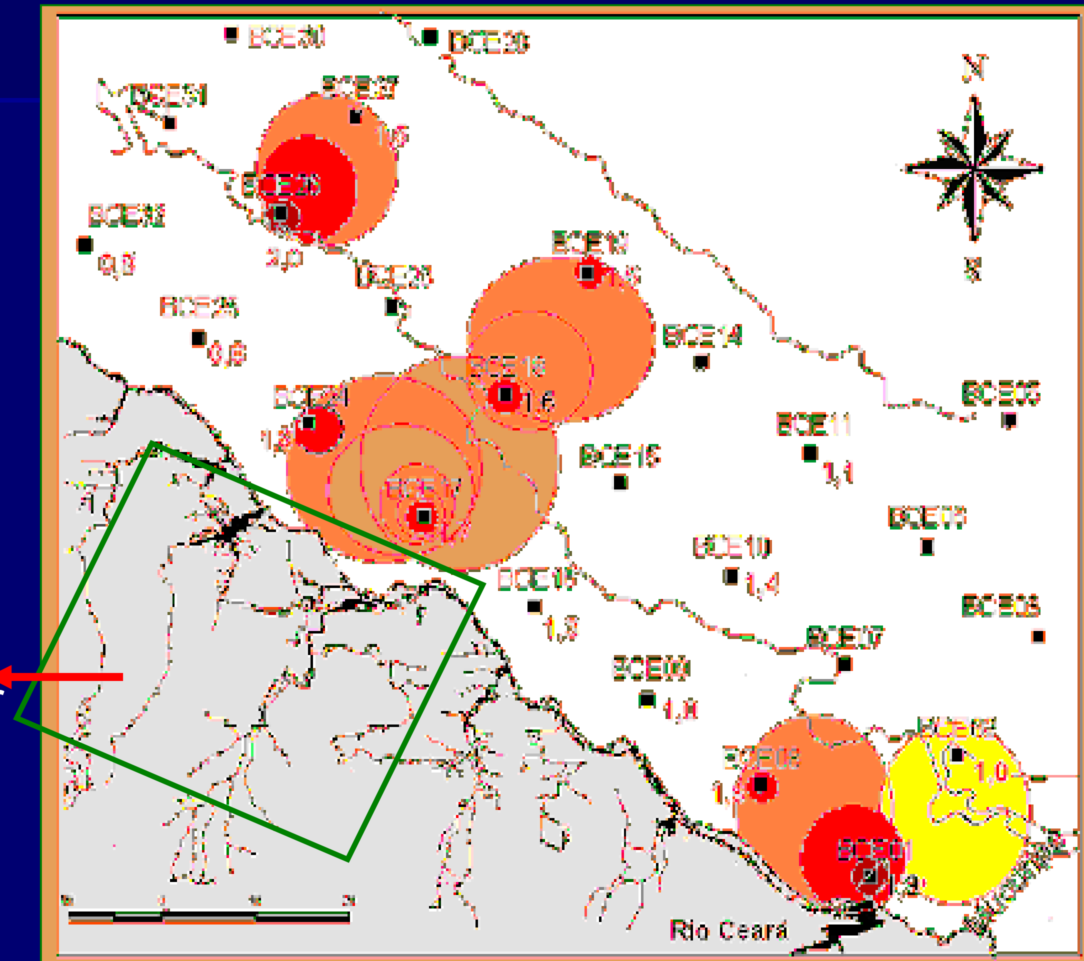
Concentration changes of COD, COP e TSS along Sepetiba Bay, SE Brazil



Hg *vs* Al in sediments along the continental shelf in SE Brazil



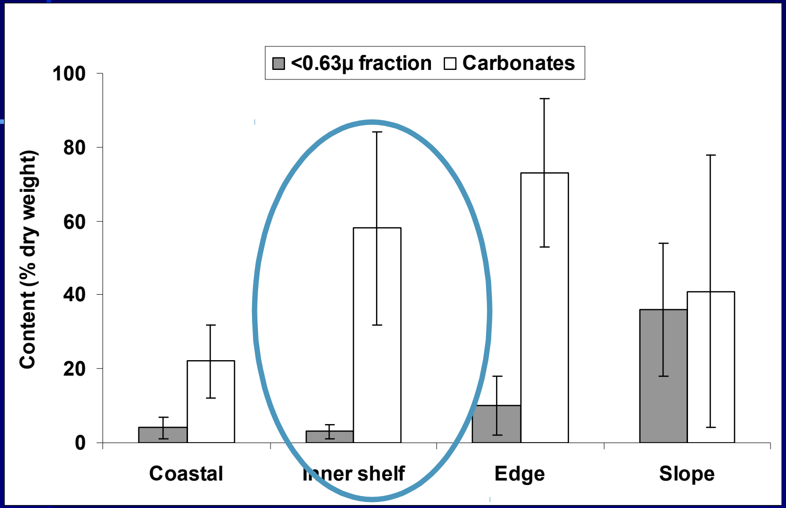
Al distribution in shelf sediments from NE Brazil



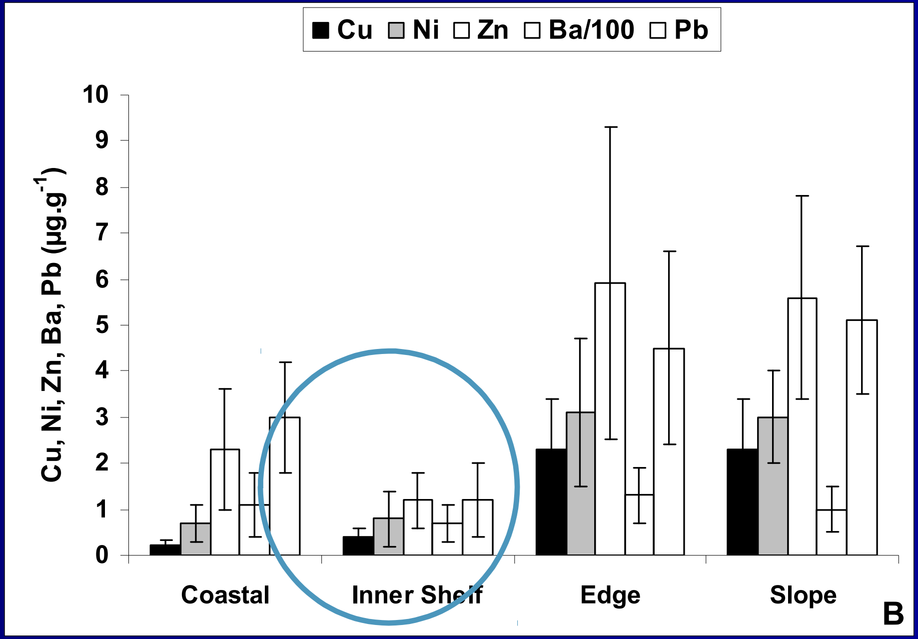
Irrigated perimeter

1. Spatial scale

Trace metals in shelf sediments ina offshore oil and gas exploration area in NE Brazil (Lacerda et al., 2013)



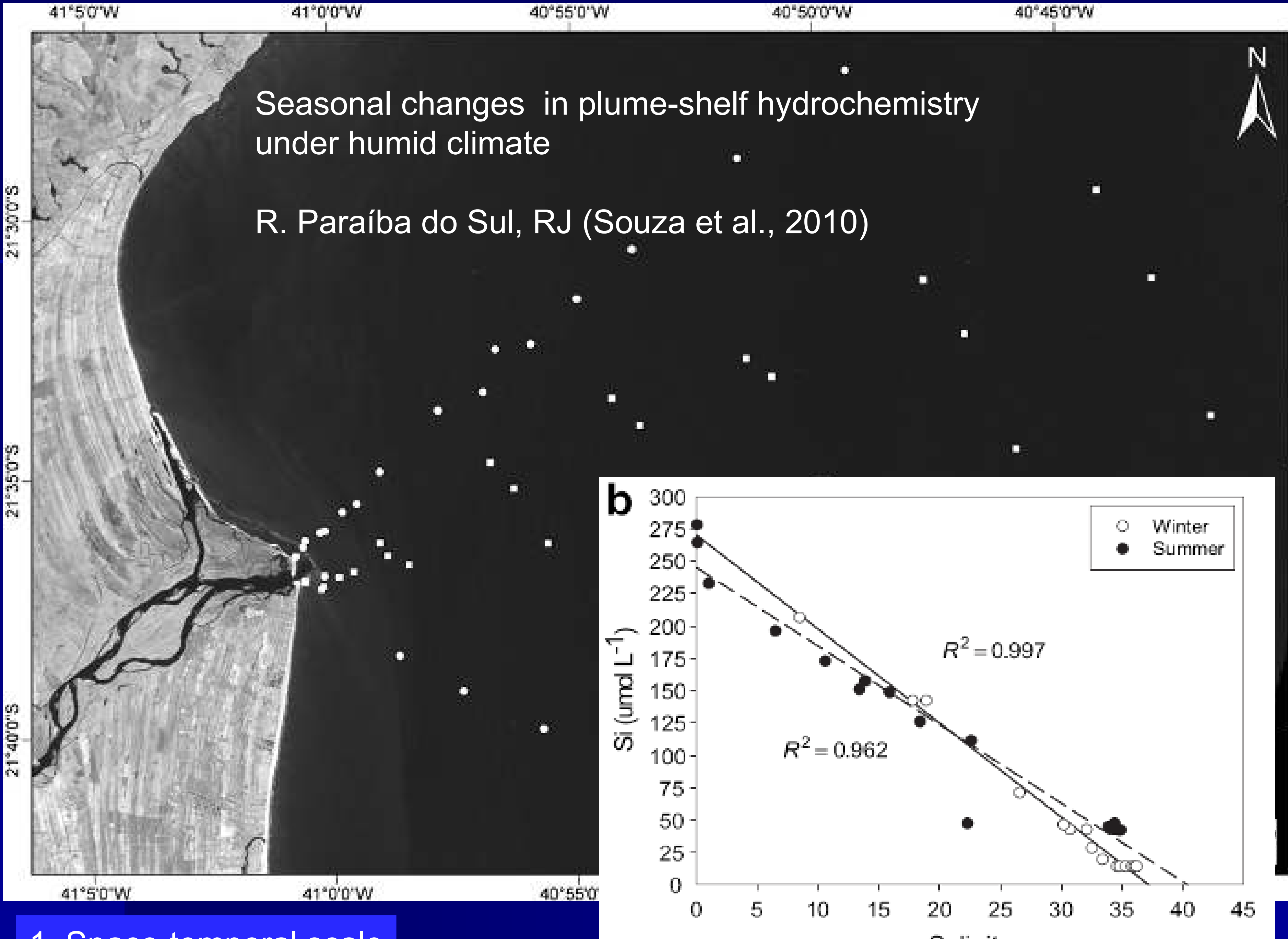
Potiguar Basin, RN



1. Spatial scale

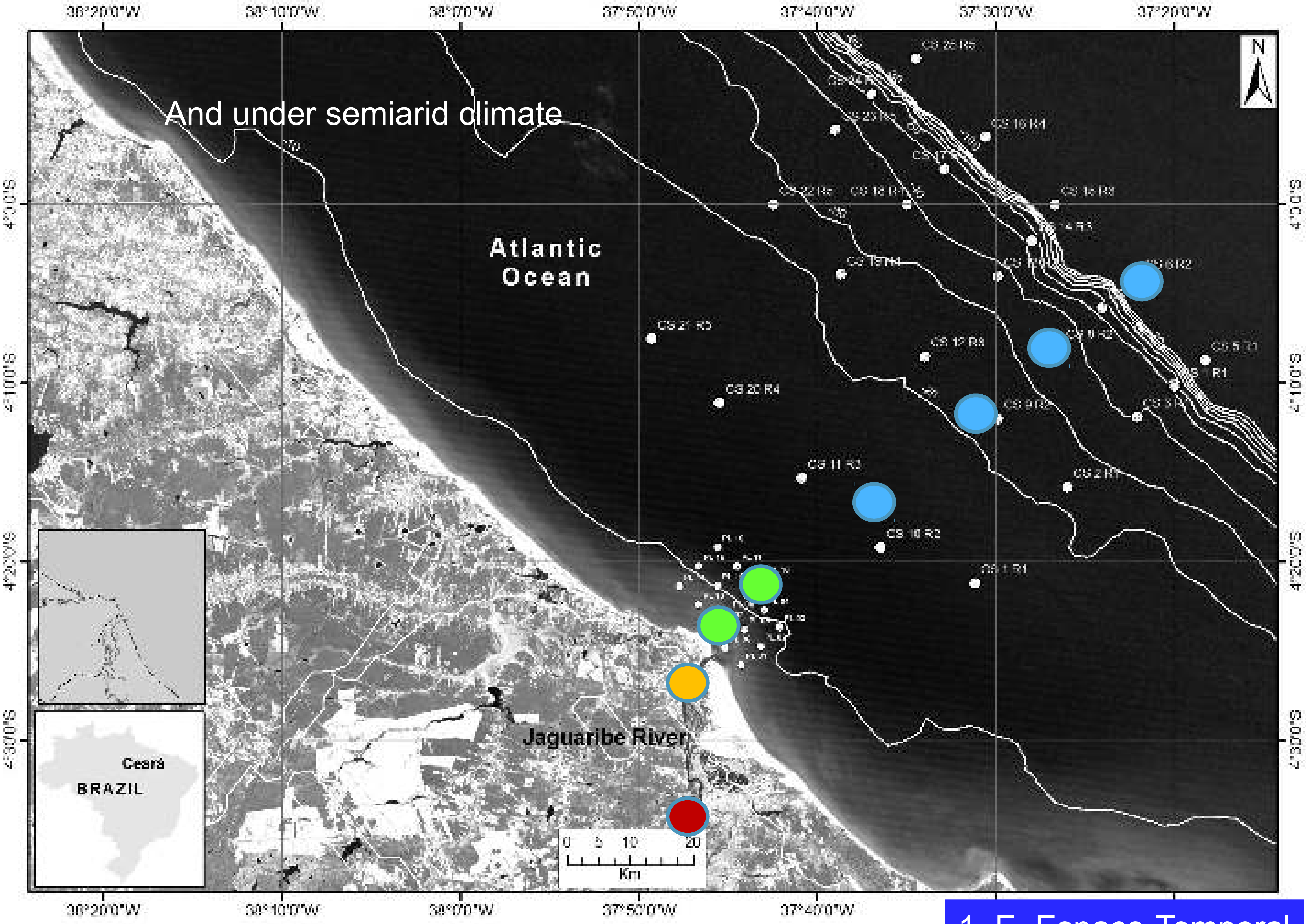
Seasonal changes in plume-shelf hydrochemistry under humid climate

R. Paraíba do Sul, RJ (Souza et al., 2010)



1. Space-temporal scale

And under semiarid climate

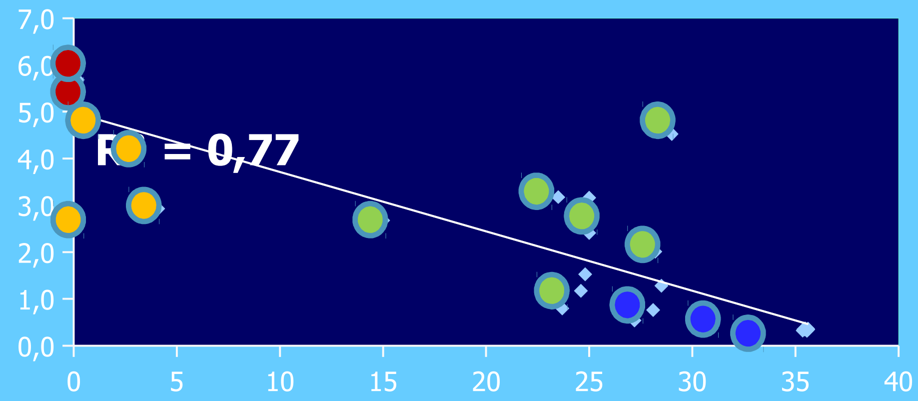


1. E. Espaço-Temporal

Seasonality under semiarid climate

R. Jaguaribe, CE (Lacerda et al., 2010)

Si vs Salinidade, Período Chuvoso



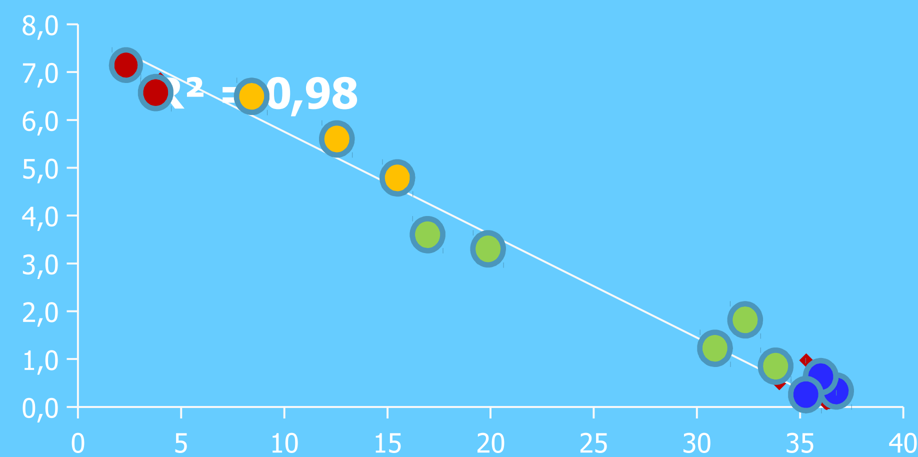
Shelf

Plume

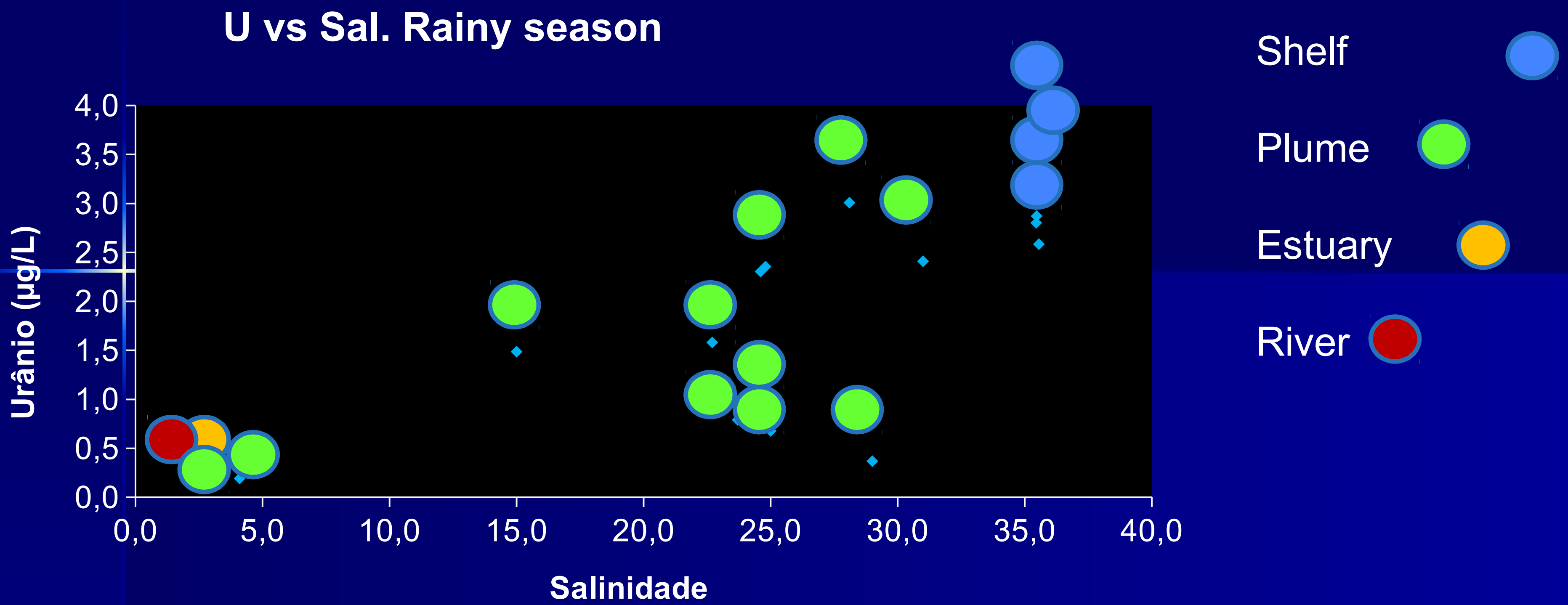
Estuary

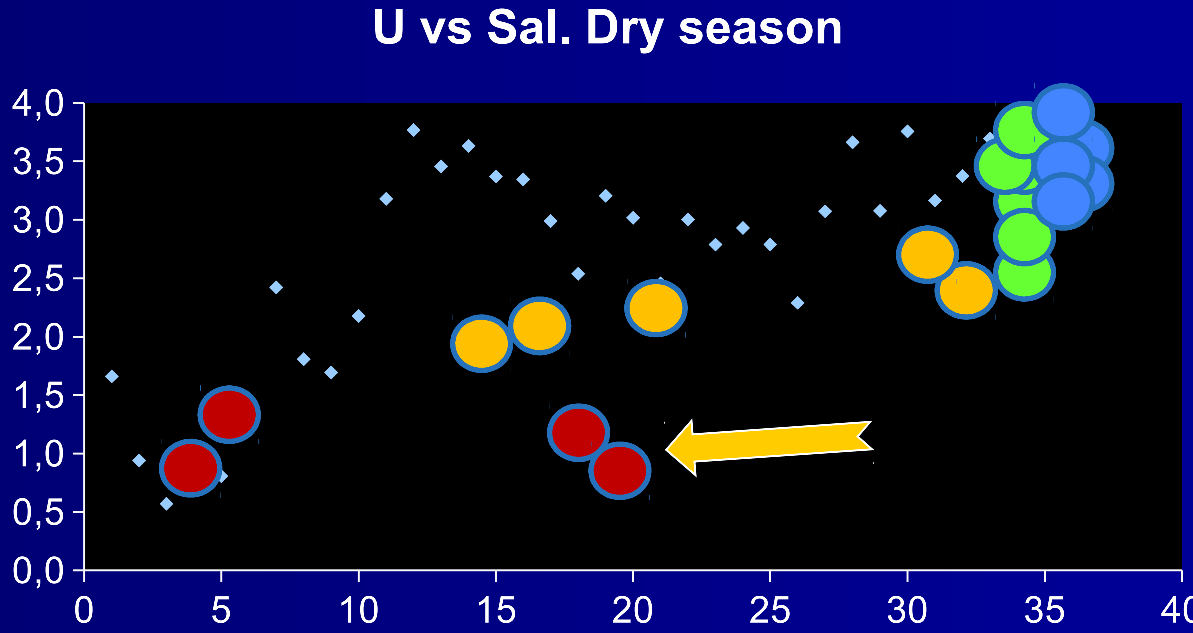
River

Si vs Salinidade, Estação Seca

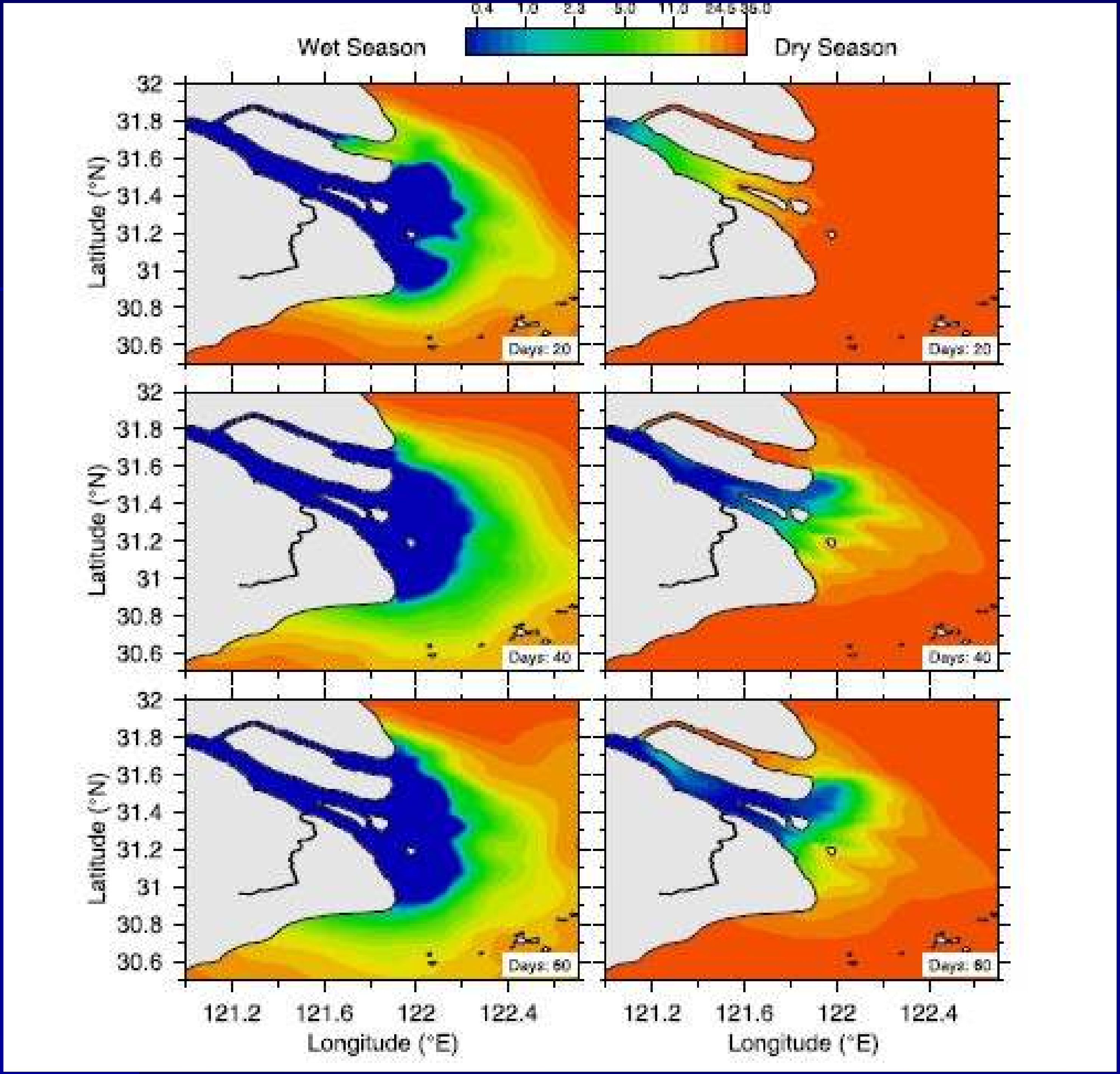


1. Space-temporal scale





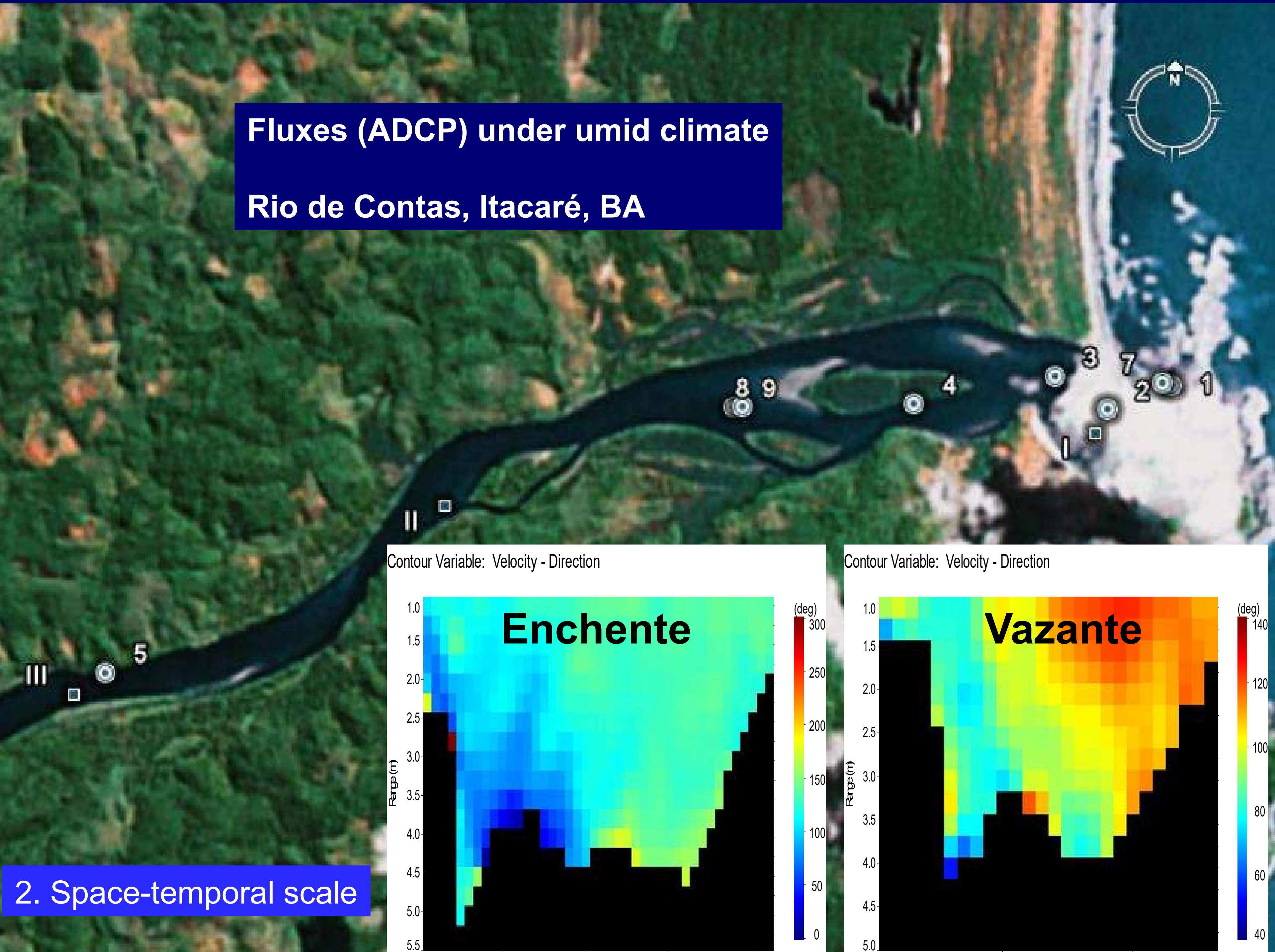
2. Space-temporal scale



Salt intrusion at the Yangtze, China
c.f. LOICZ (2010)

Fluxes (ADCP) under umid climate

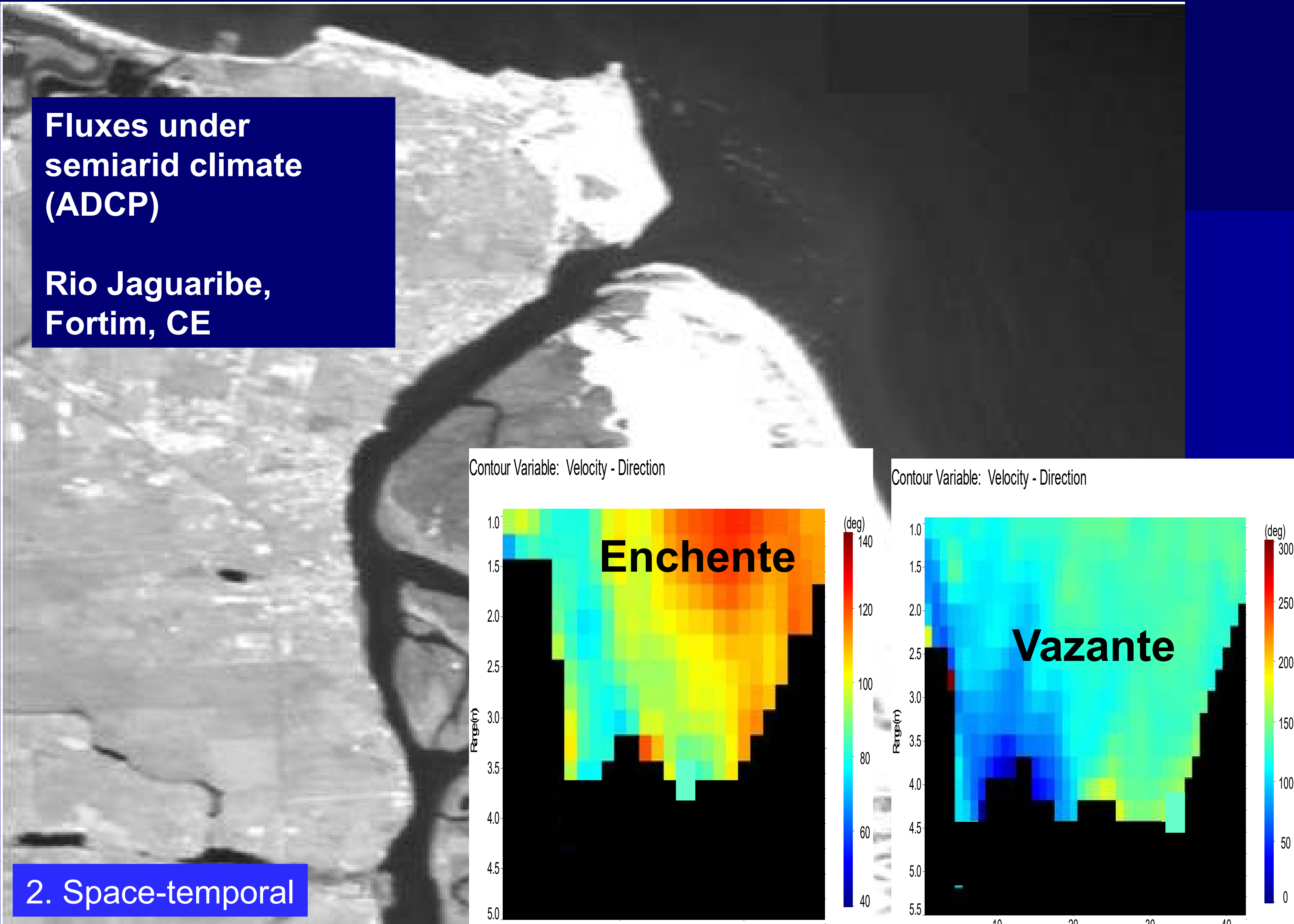
Rio de Contas, Itacaré, BA



2. Space-temporal scale

Fluxes under semiarid climate (ADCP)

Rio Jaguaribe, Fortim, CE



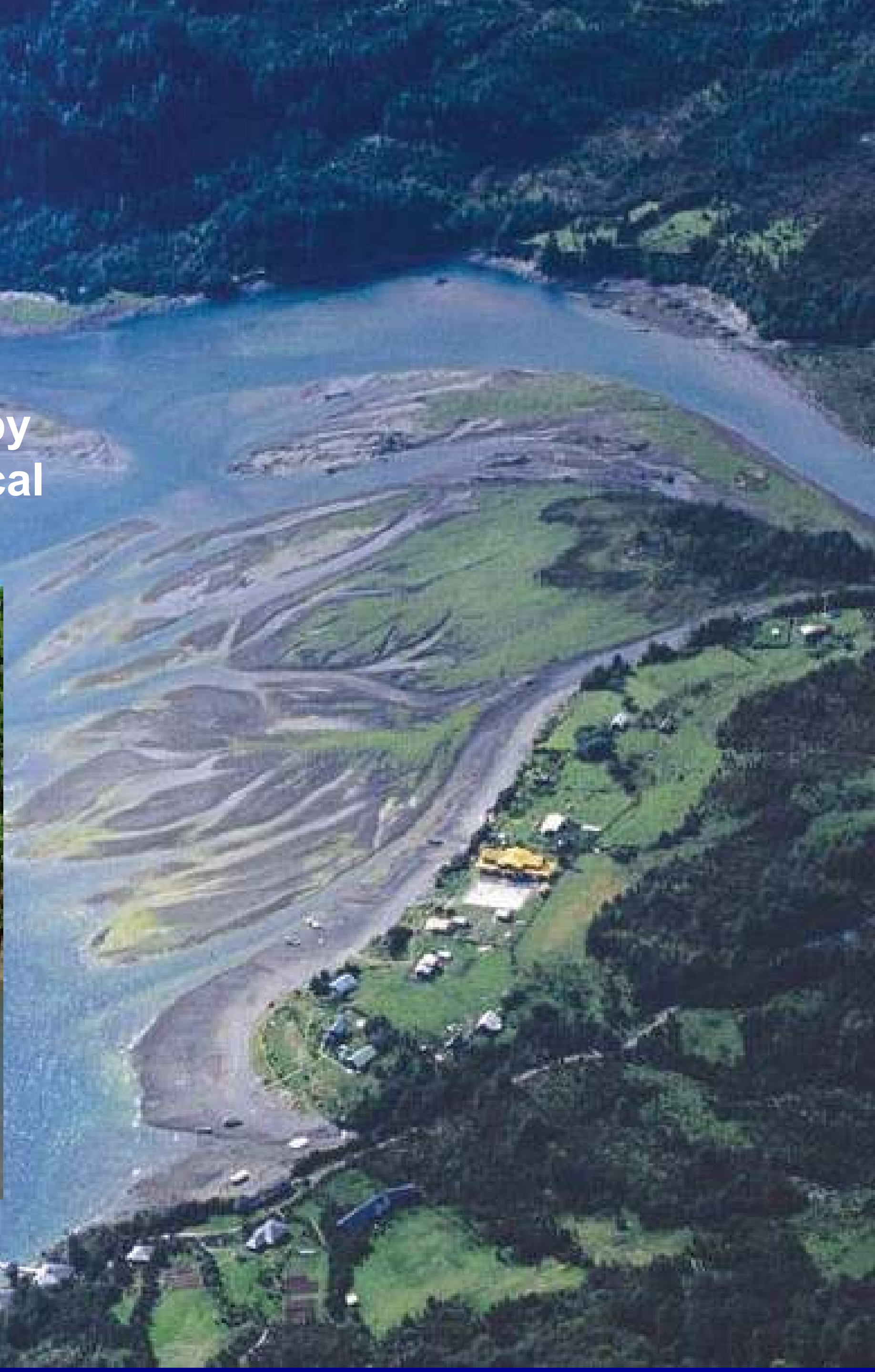
2. Space-temporal

Globally, about 40% of traported materials from continental origin by rivers are trapped in estuarine and deltaic sediments.

Materials passing through the estuarine-deltaic filter are deposited in the continental shelf according to shelf characteristics.

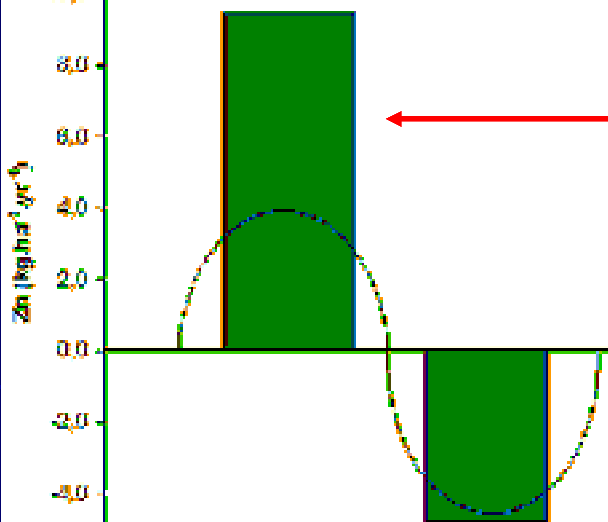
Less than 10% is eventually exported to the deep ocean

Post-depositional colonization of estuarine and deltaic sediments by plants changes the biogeochemical nature of the environment



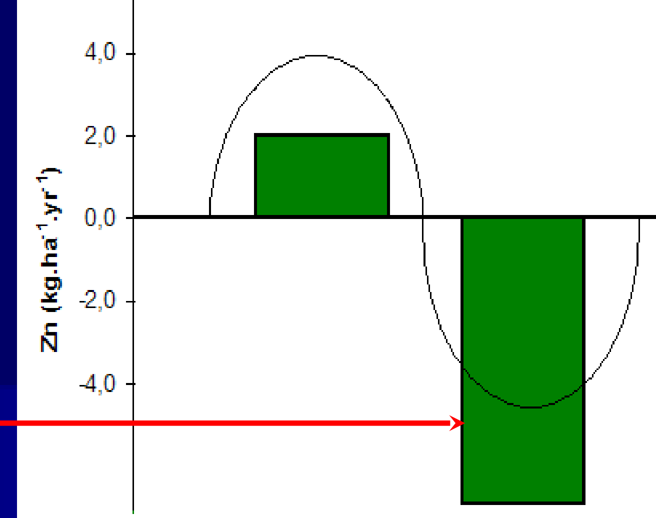
e.g. Impact from mangrove colonization of significance to estuarine ecology and sustainable use

- Augment of the deposition of fine sediments and sedimentation rates
- Decreasing aeration of sediments
- Increasing organic matter deposition and preservation in sediemts
- Increasing consumpion of dissolved oxygen
- Anoxia & sulfate reduction

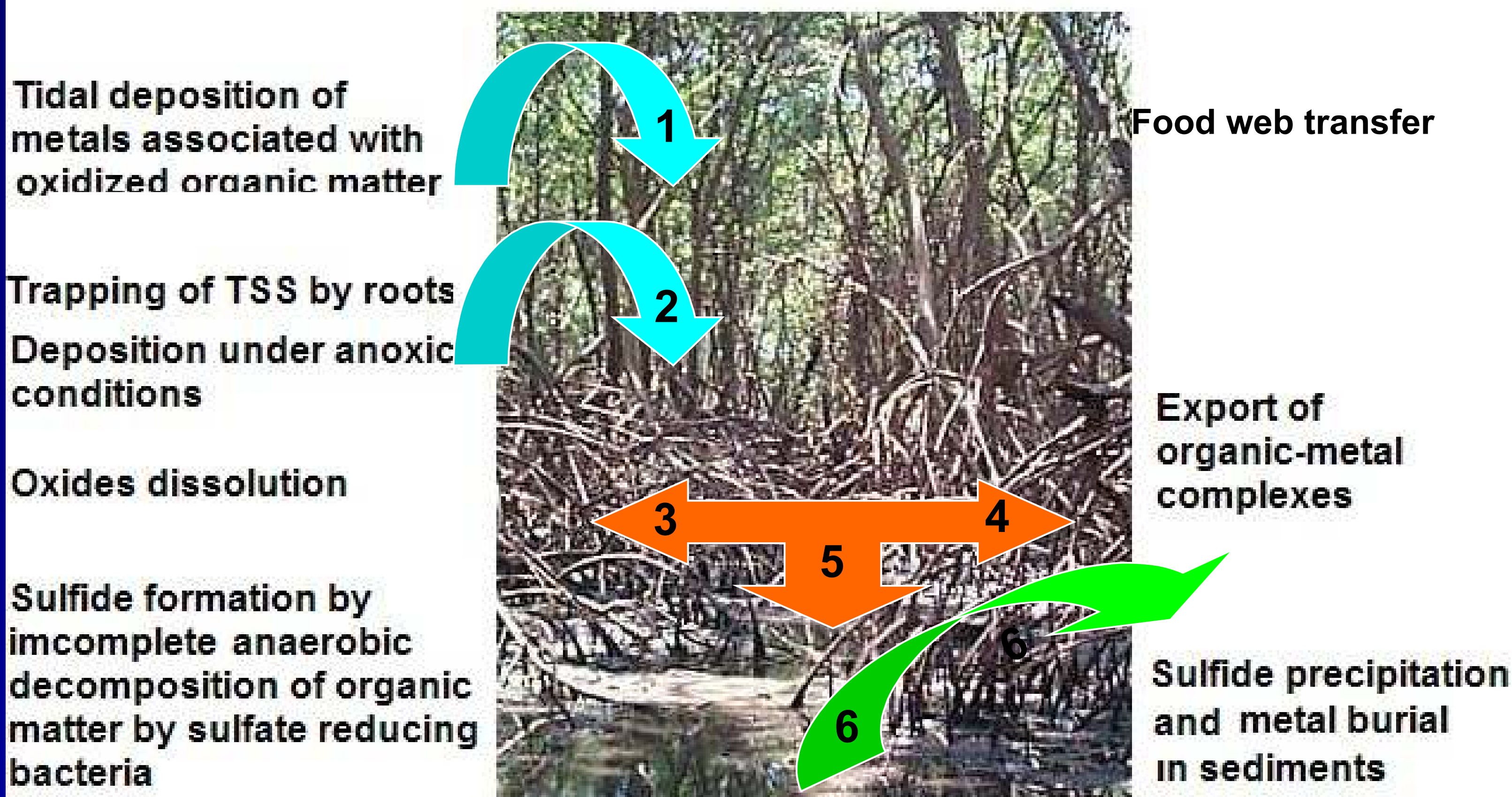


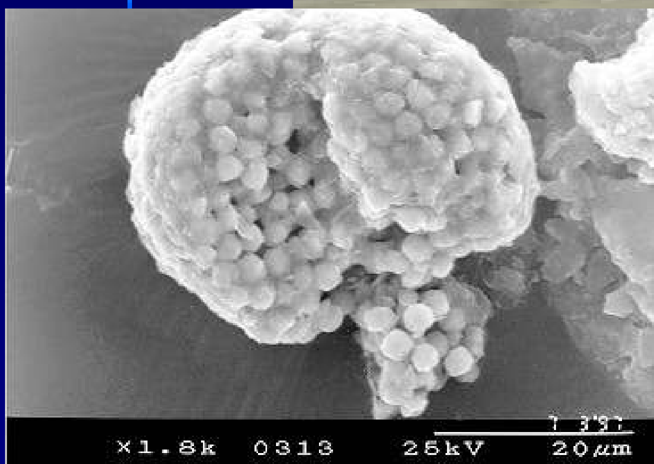
Accumulation of Zn in neap tides

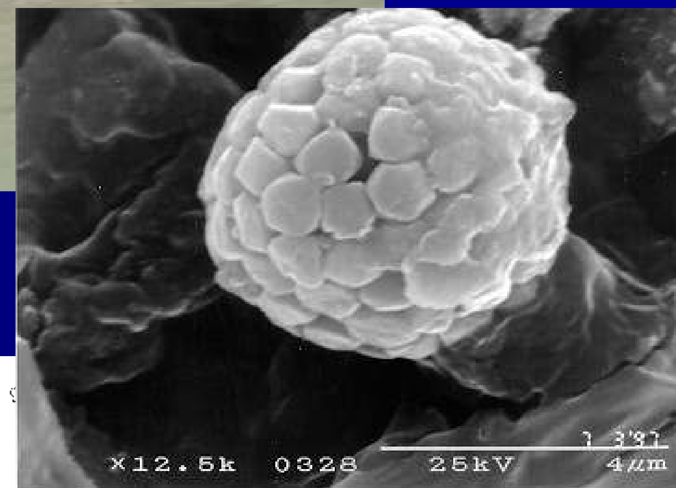
Export of Zn in spring tides

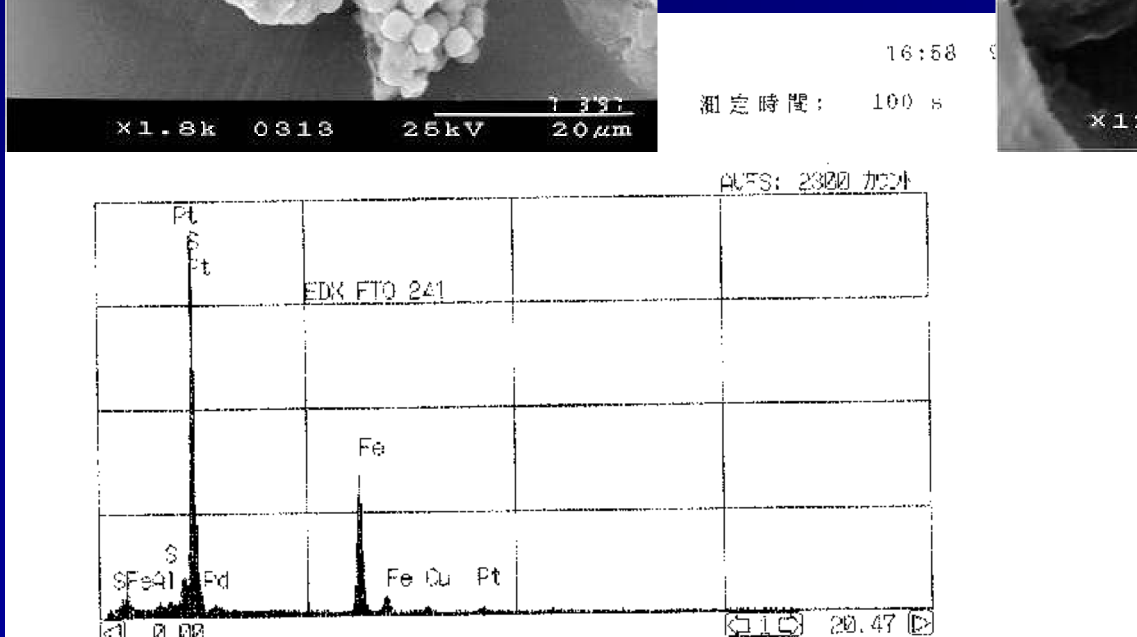


Lacerda (1998)





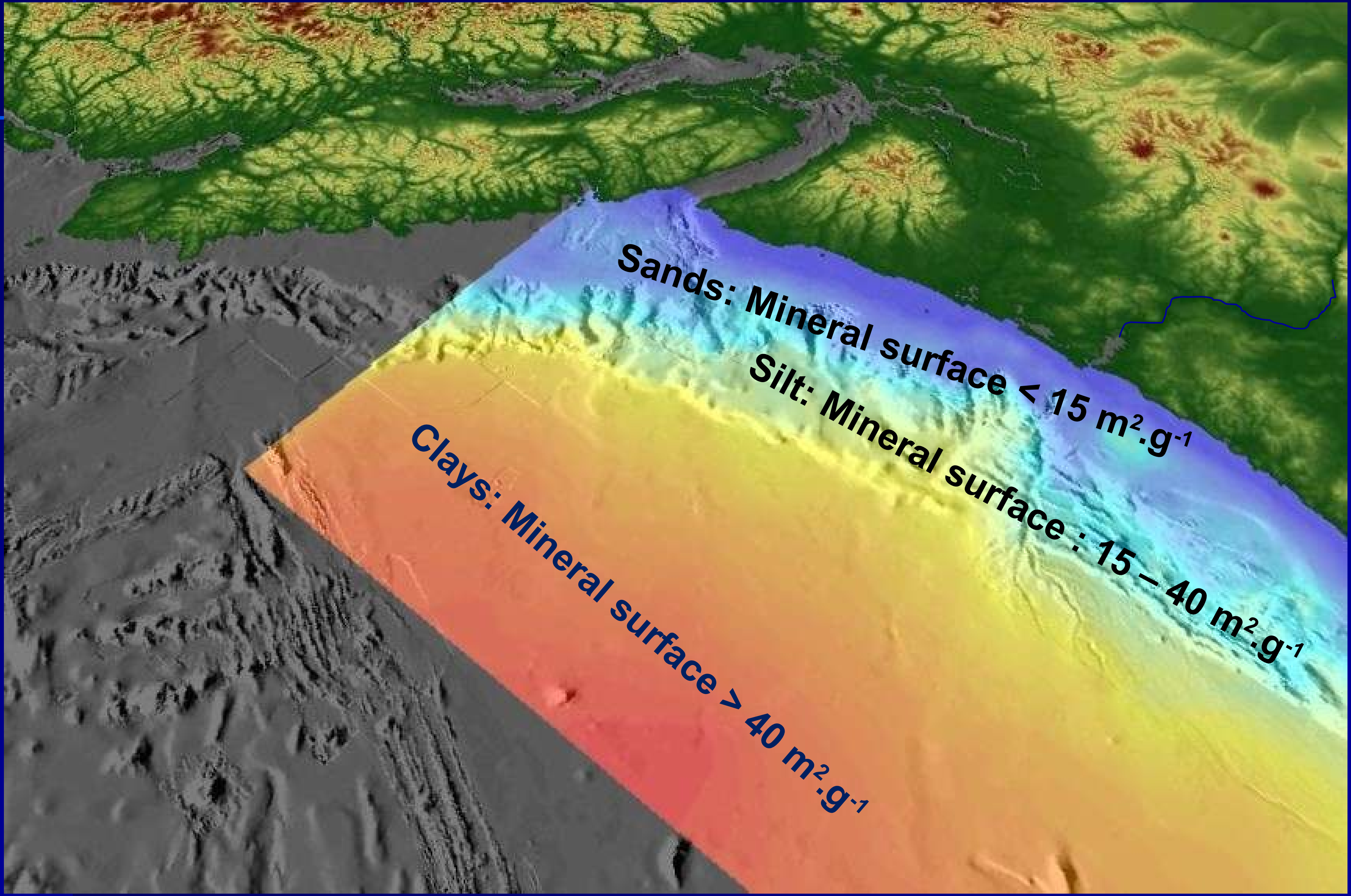


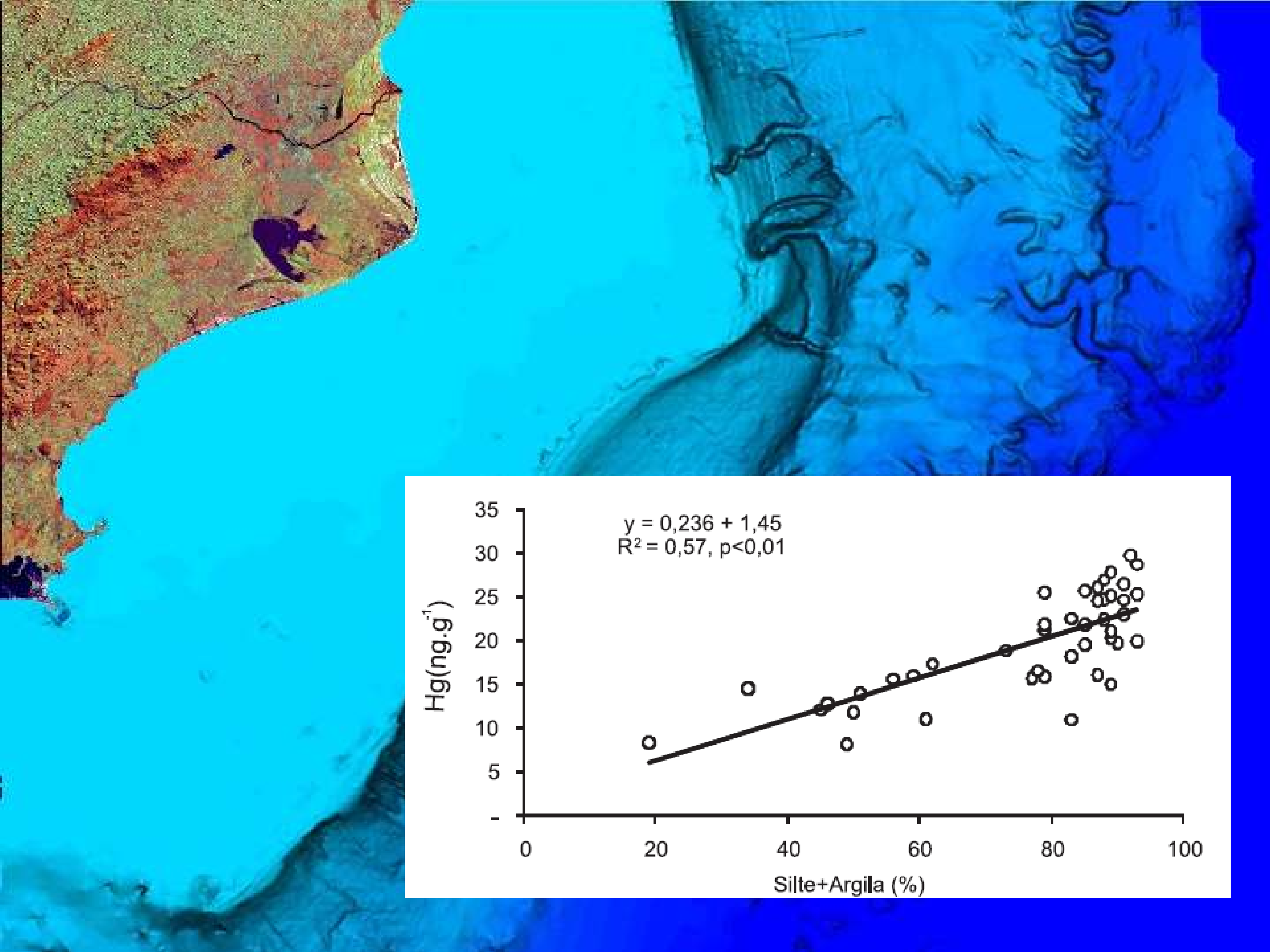


Framboids of pyrites that release metals upon oxidation due to erosion and sea level rise or decreasing fluvial sediment transport

Pires & Lacerda (2007)

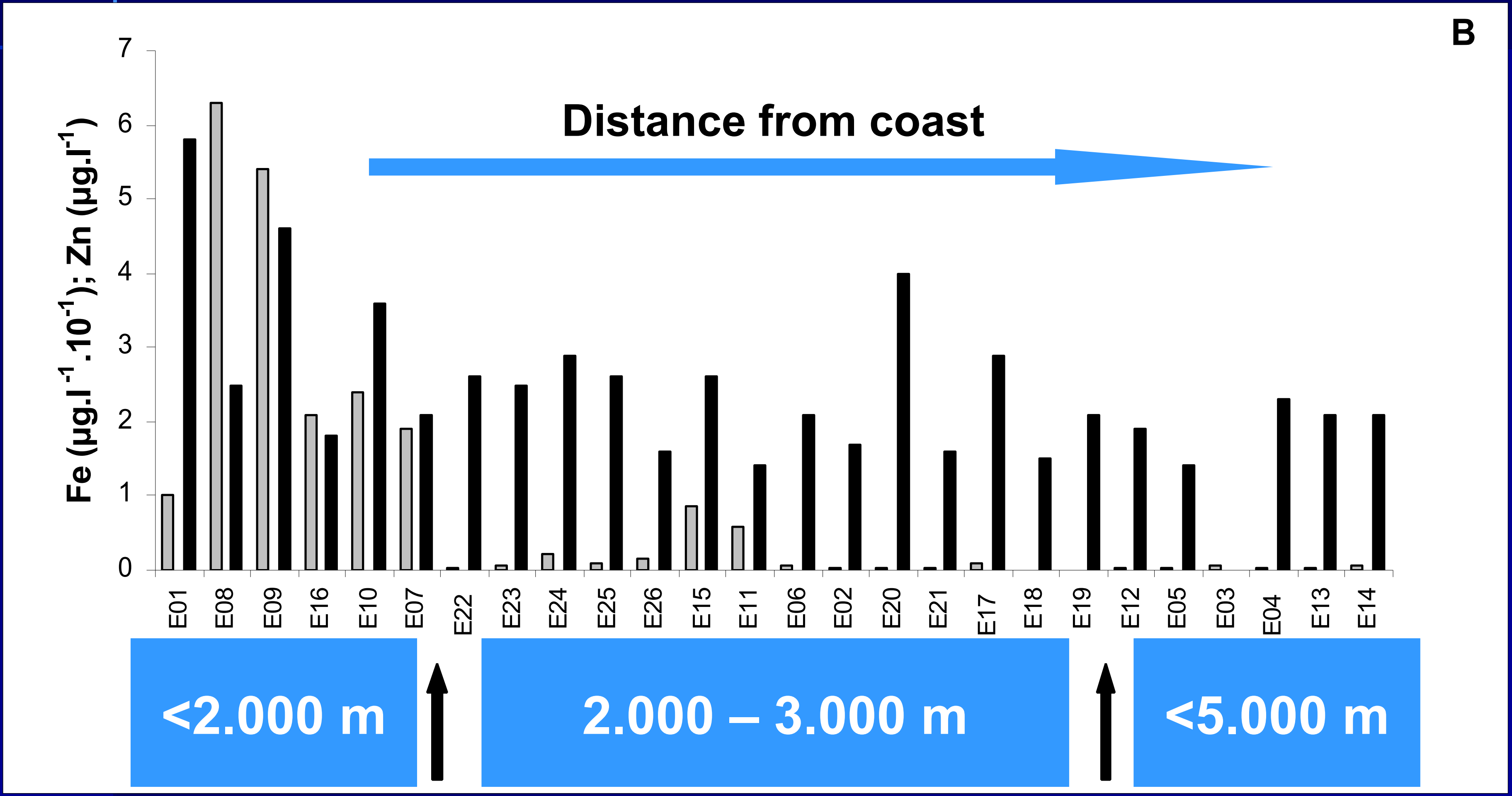
Typical granulometry of shelf sediments





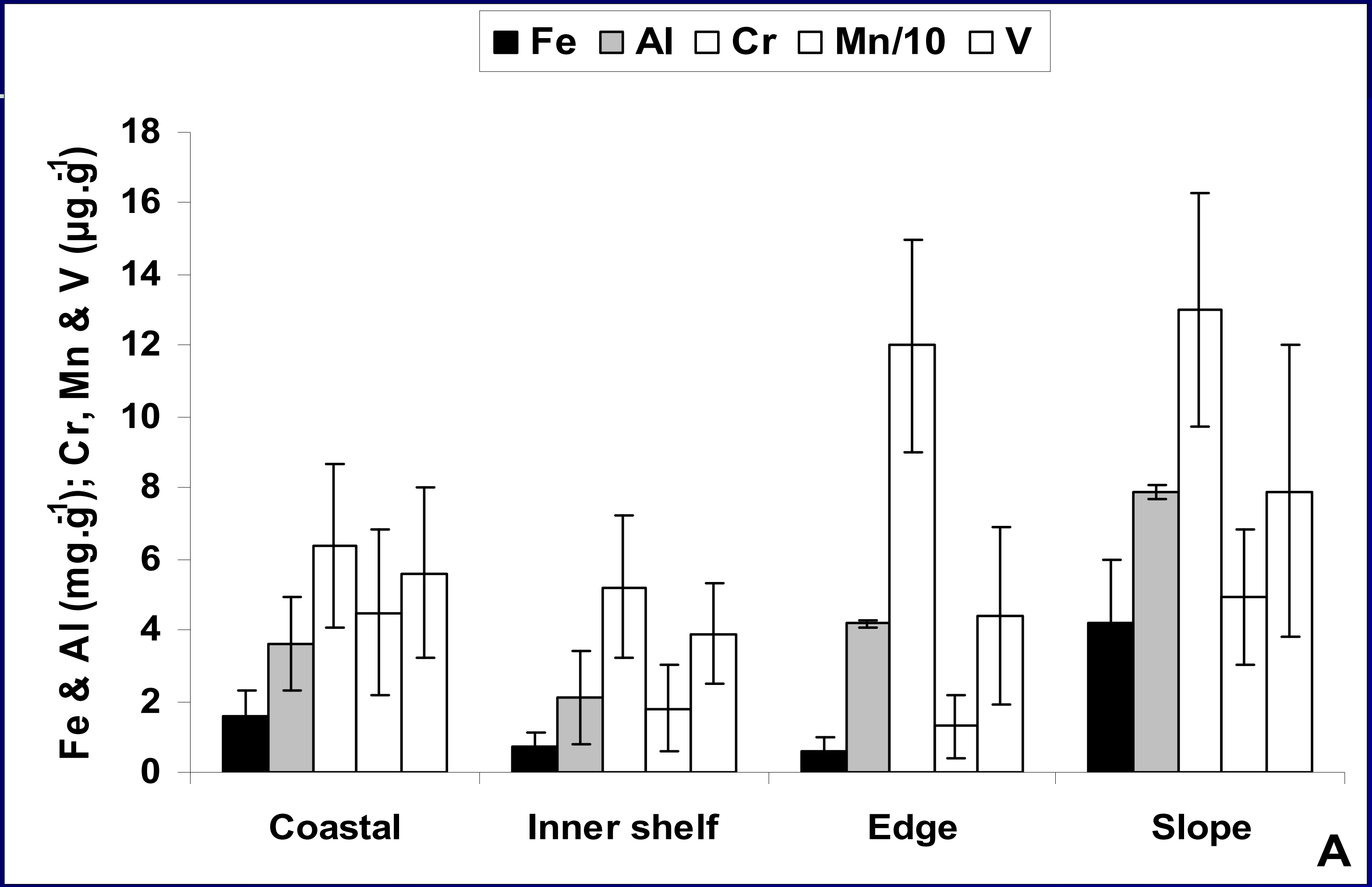
y = 0,236 + 1,45
R² = 0,57, p<0,01
Hg(ng.g-1)
35
30
25
20
15
10
5
-
0
20
40
60
80
100
Silte+Argila (%)

Metal distribution in NE Brazil shelf sediments



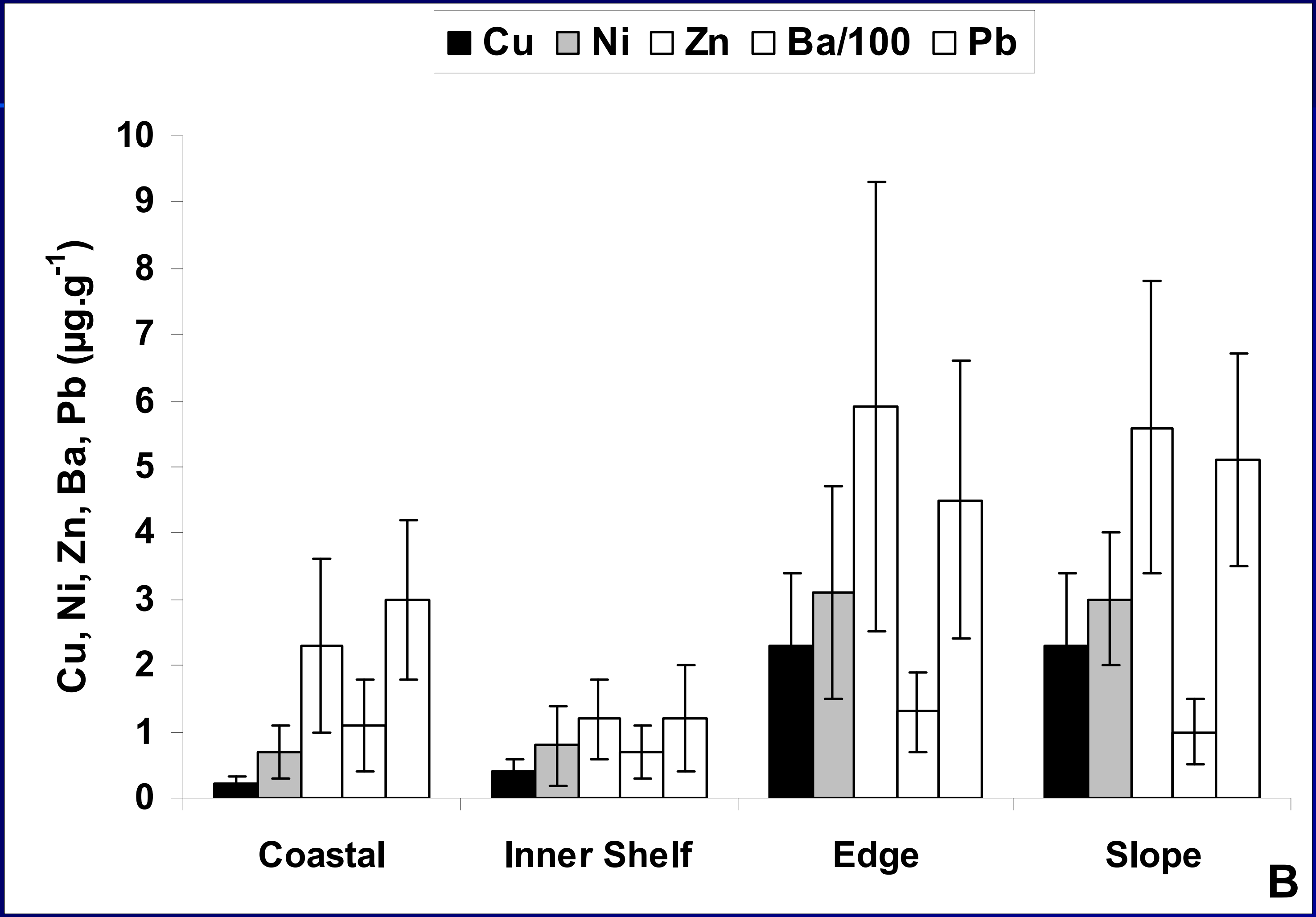
Influence of contineetal sources

Metal distribution in NE Brazil shelf sediments



Influenced by marine processes

Metal distribution in NE Brazil shelf sediments



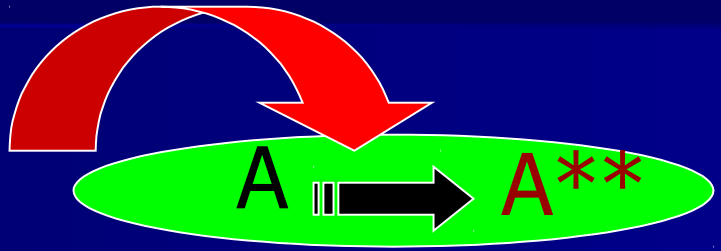
Influenced by marine processes

“The magnitude of transfer processes are today controlled mostly by anthropogenic drives”.

Forms of action

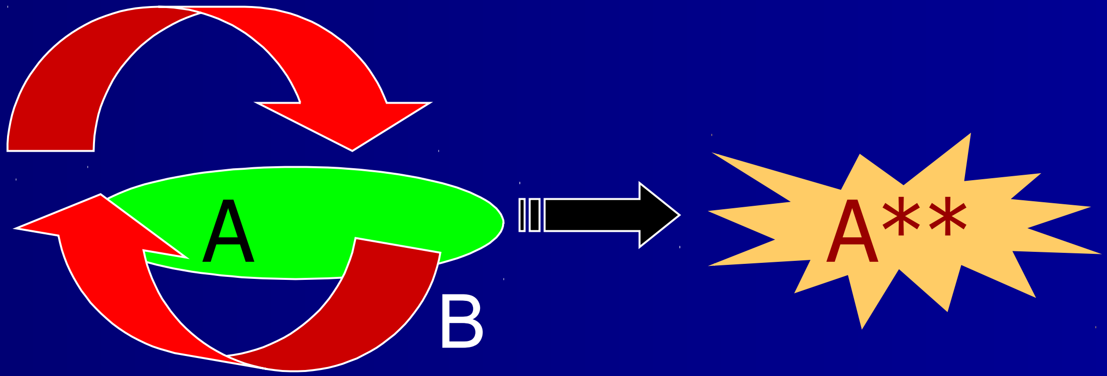
1

Vectors causing direct changes on the biogeochemical properties of the environment through emission of alien substances (mostly typical of the last century)

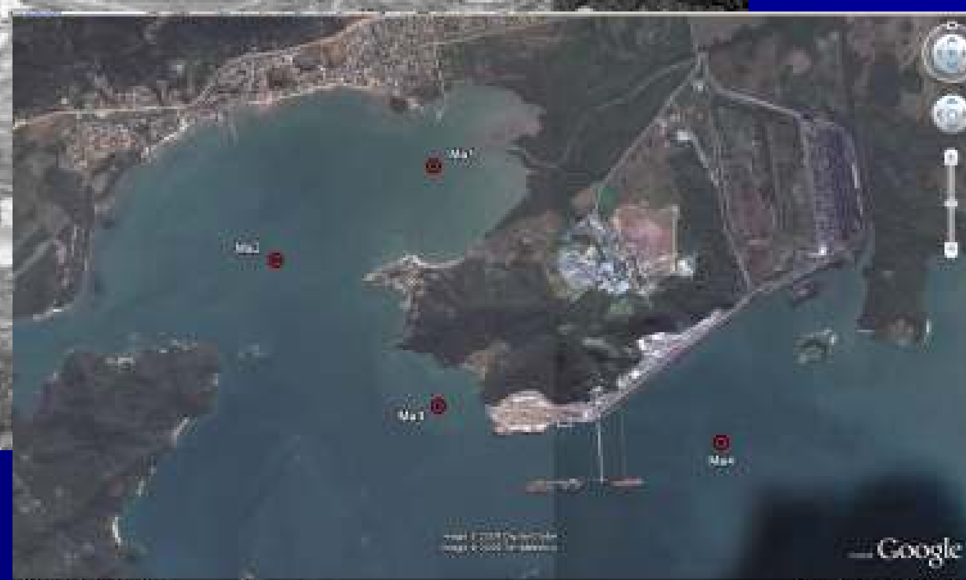


2

Vectors causing direct changes on the biogeochemical properties of the environment through interactions with its properties or among themselves (our challenger today).

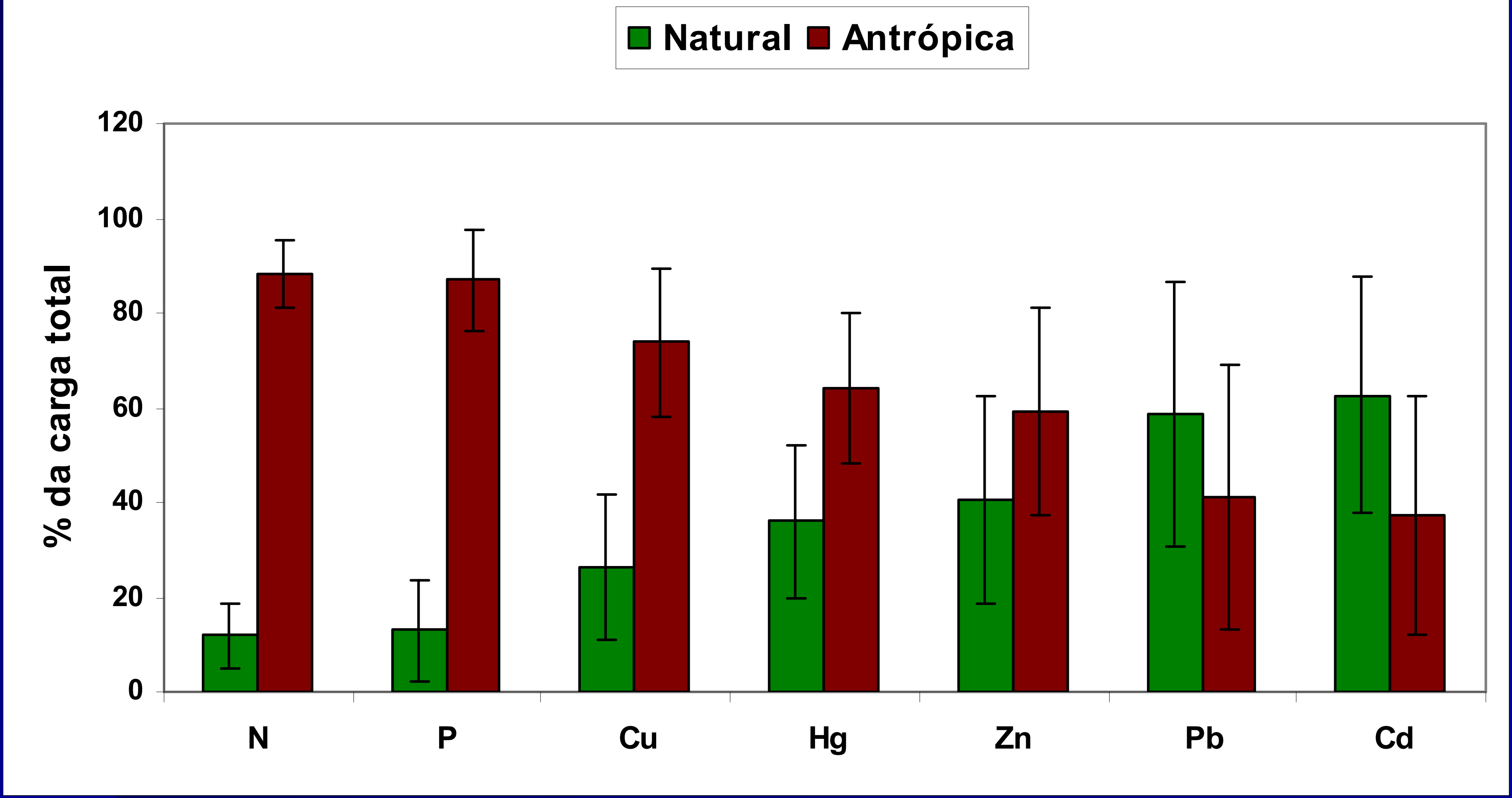


Lacerda, 2009

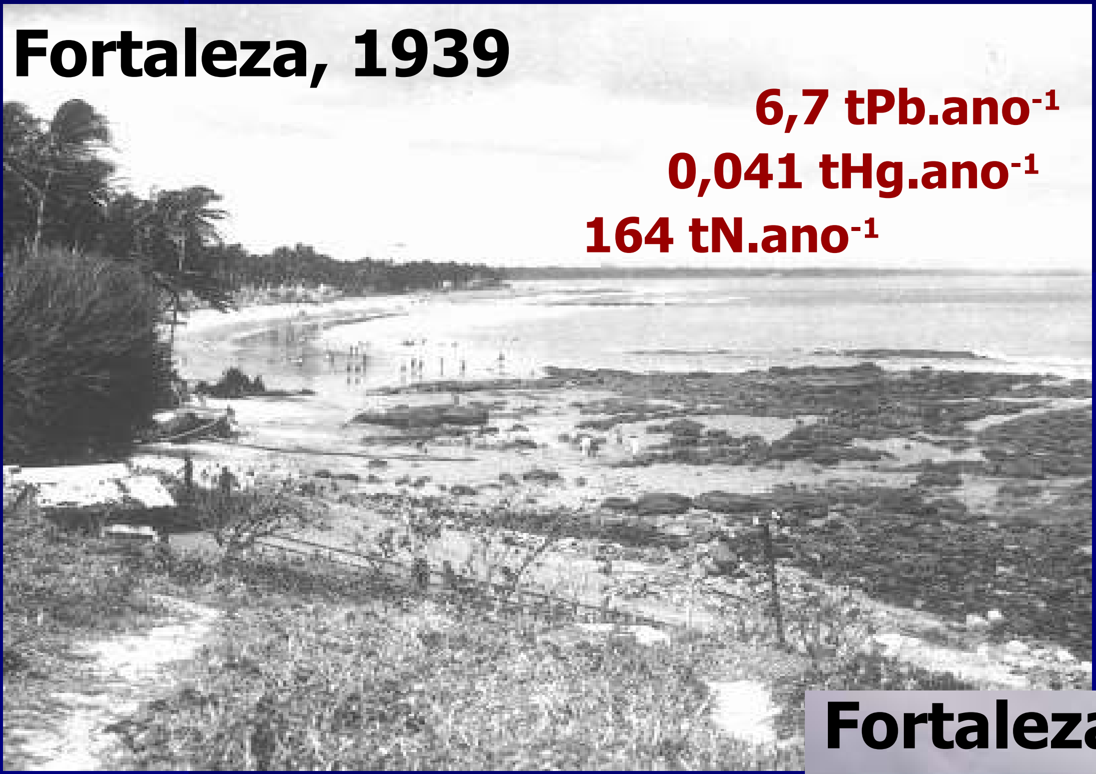



Urbanization & Industrialization & Agriculture/Husbandry
Increasing discharges of natural and anthropogenic substances

Relative importance of natural and anthropogenic sources of nutrients and metals to the NE Coast of Brazil. Average values from 19 estuaries.



Sources	Emission factors N and P ($t/km^2/year$); Cu, Hg and Zn ($kg/km^2/year$)		Substances present in effluent		
Natural sources	N = 0.05 – 0.9 P = 0.01 – 0.06	Cu = 2.0 – 2.6 Zn = 5.0 – 6.5 Hg = <0.001	Mostly associated with particulate matter		Receiving body
Agriculture	N = 0.05 – 2.65 P = 0.12 – 0.56	Cu = 0.7 – 13.5 Zn = 0.04 – 0.13 Hg = 0.02	Nitrate; Ammonia; Phosphate	Cu^{2+}, Zn^{2+}, Particulate- Cu and Zn	Soil
Husbandry	N = 0.09 – 1.31 P = 0.09 – 1.73	Cu = 0.3 – 1.0 Zn = 0.4 – 7.3 Hg = <0.001	Ammonia; Phosphate	Particulate- Cu and Zn	Soil
Urban waste waters and runoff	N = 0.03 – 0.55 P = 0.01 – 0.14	Cu = 0.1 – 15.3 Zn = 0.01 – 47.2 Hg = < 0.001	Nitrate; Ammonia; Phosphate; Particulate-P	Cu^{2+}, Zn^{2+}, Hg^{2+}; Particulate- Cu and Zn	Soil, waterways and estuaries
Urban solid wastes disposal	N = 0.001 – 0.2 P < 0.0001	Cu = 0,001 – 0,03 Zn = 0,001 – 0,07 Hg = 0.04	Dominant forms of N and P are too site-specific	Cu^{2+}, Zn^{2+}, Hg^{2+}; Particulate- Cu and Zn	Soil
Shrimp aquaculture	N = 1.25 – 4.09, P = 0.13 – 0.32	Cu = 38.6 – 59.8 Hg = 0.03 – 0.04 Zn = 508	PON (70%); NO_3^-; Ammonia; NO_2^-; POP; Phosphate	Particulate- Cu, Zn and Hg	Waterways and estuaries

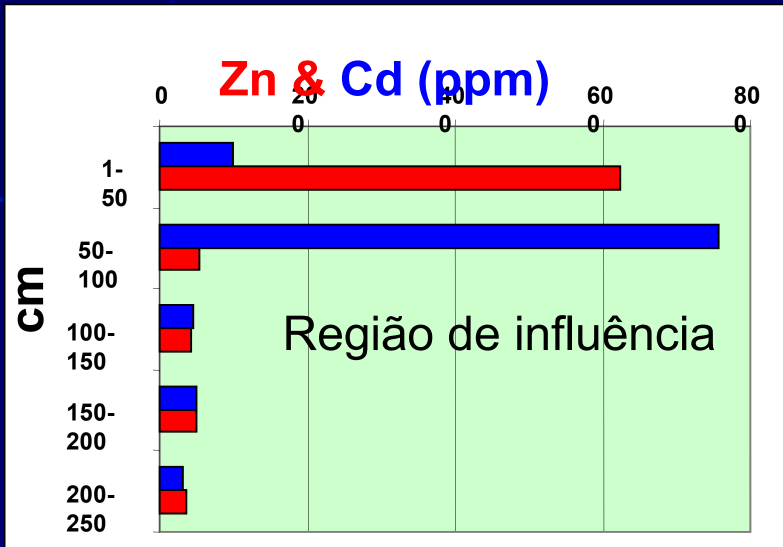


Changes in soil uses

Urbanization

Legacy of irresponsible technologis faces lack of governance

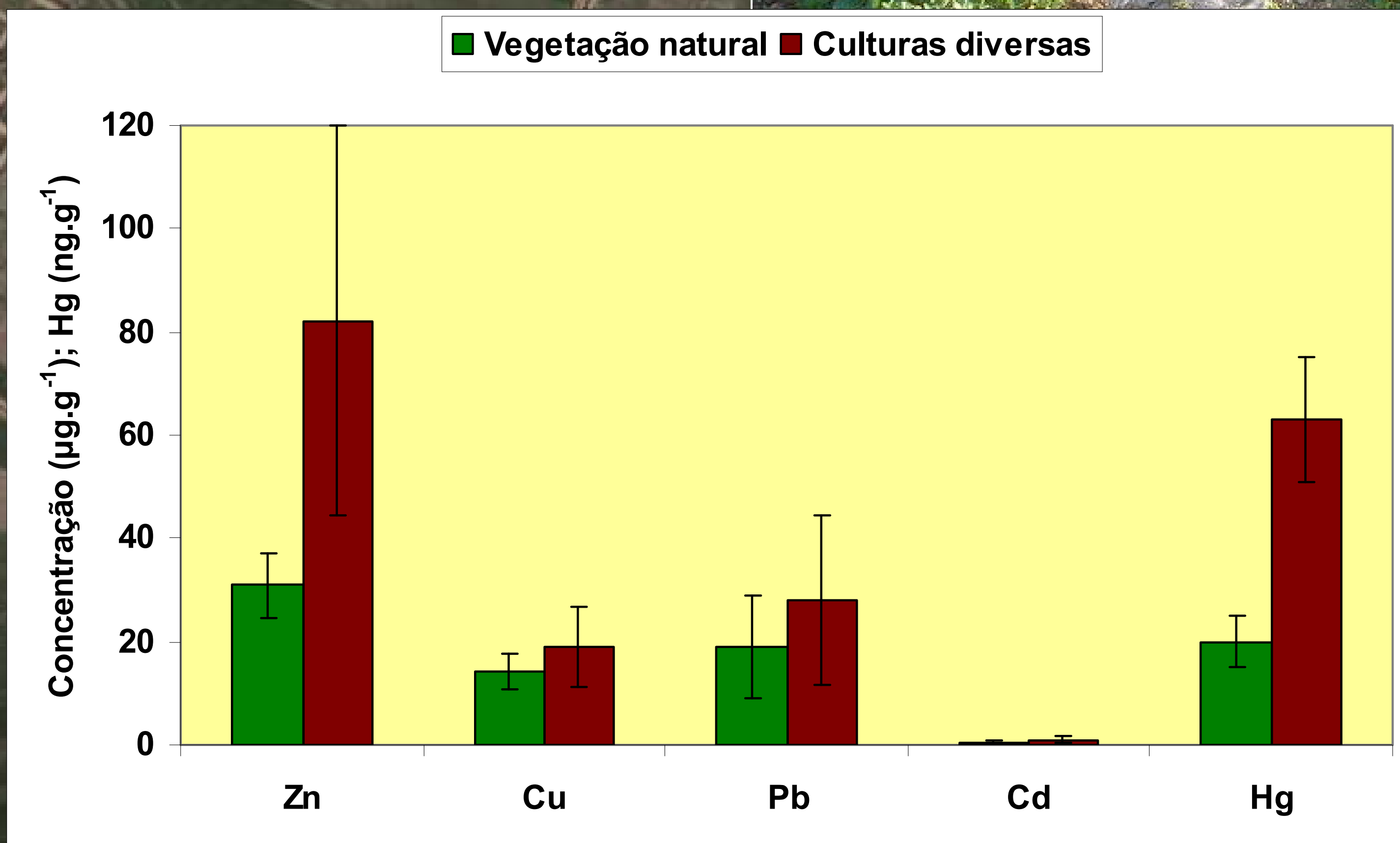
Industrialization



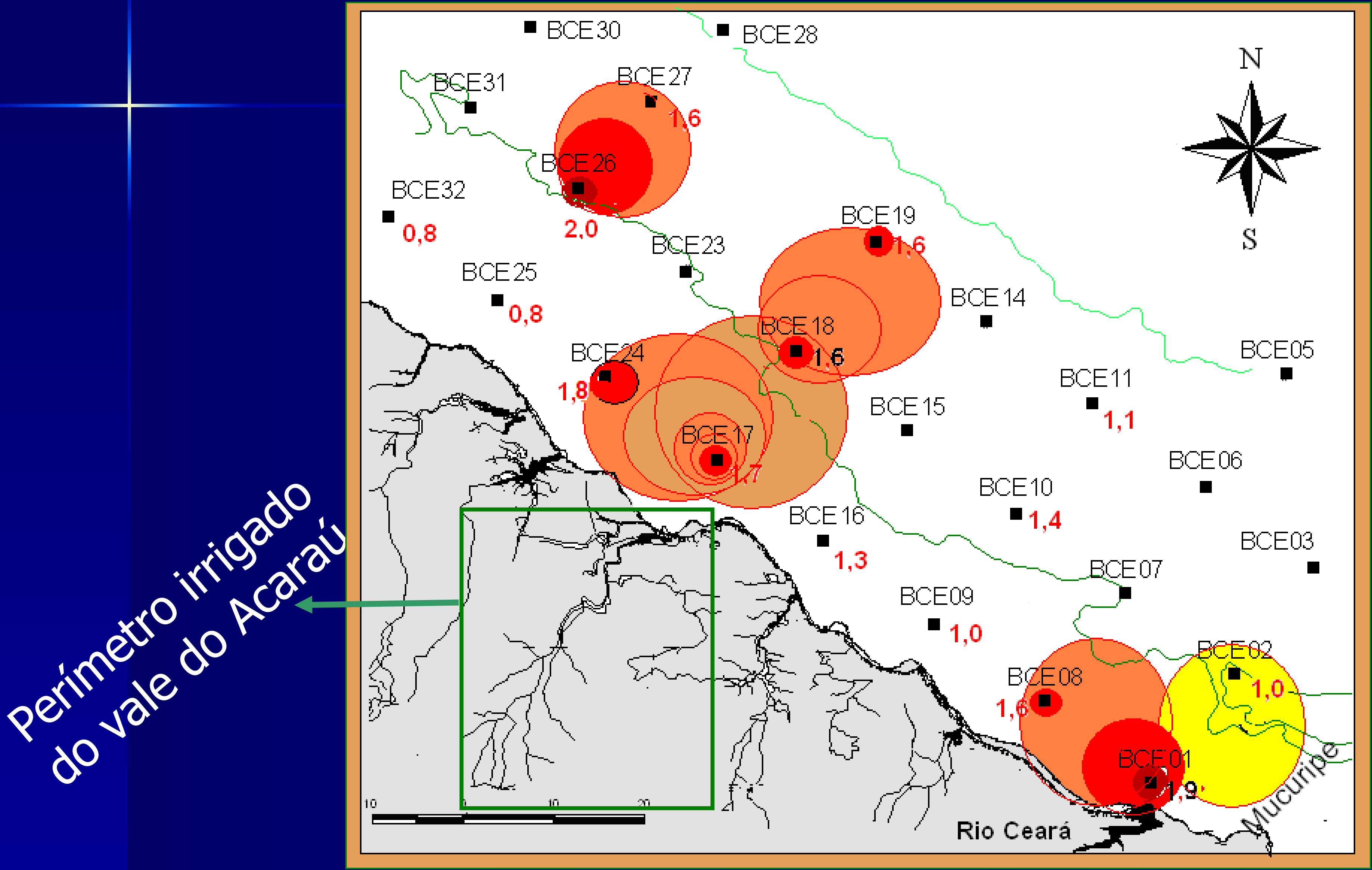
Changes in soill use: Agriculture

Irrigated agriculture: Vale do Acaraú (CE): metals in soils

(c.f. Lacerda & Senna, 2005, baseado em várias fontes)

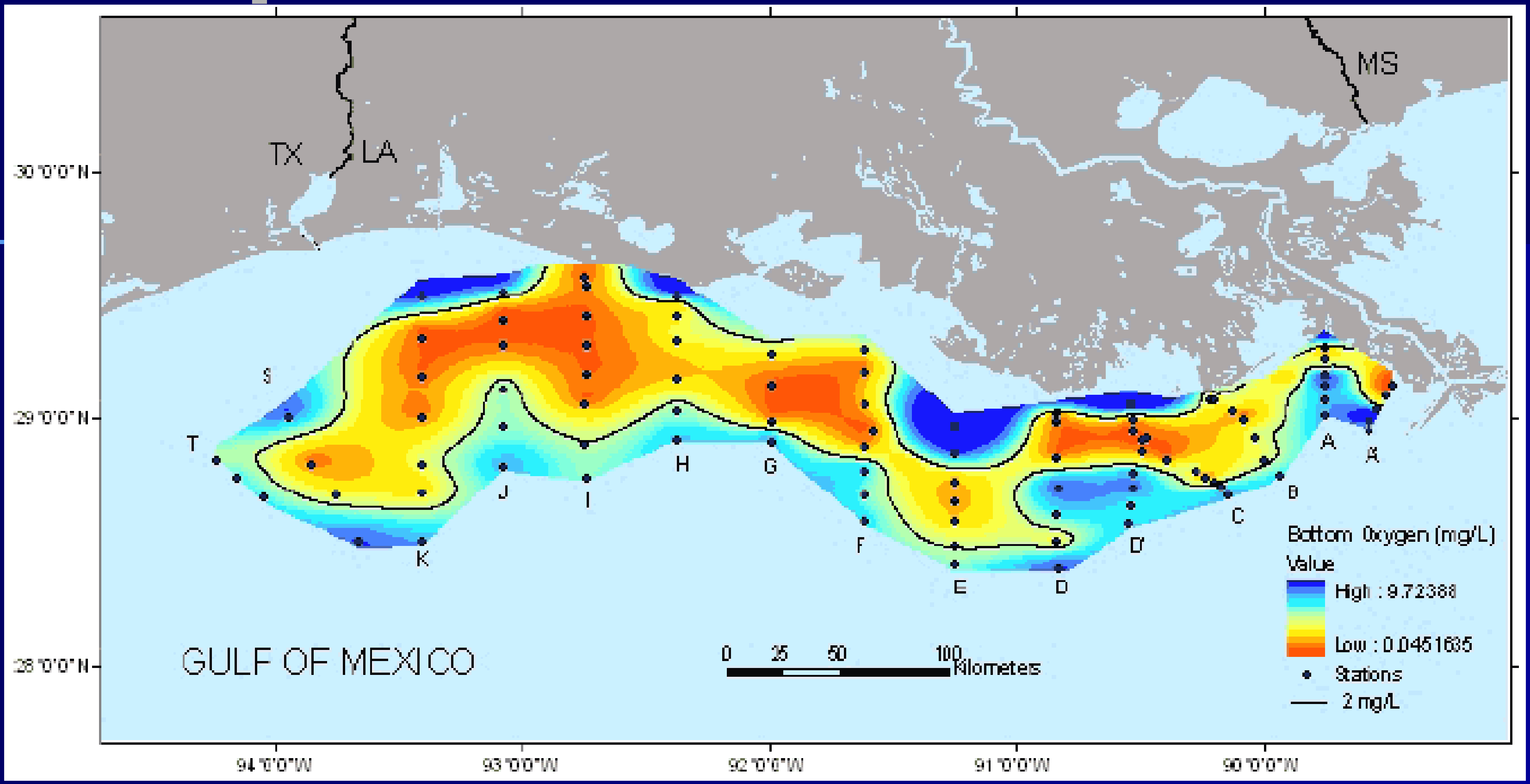


The management of the area exports continental material out to shelf sediments



A question of scale: Mississipi Delta, Gulf of Mexico, USA

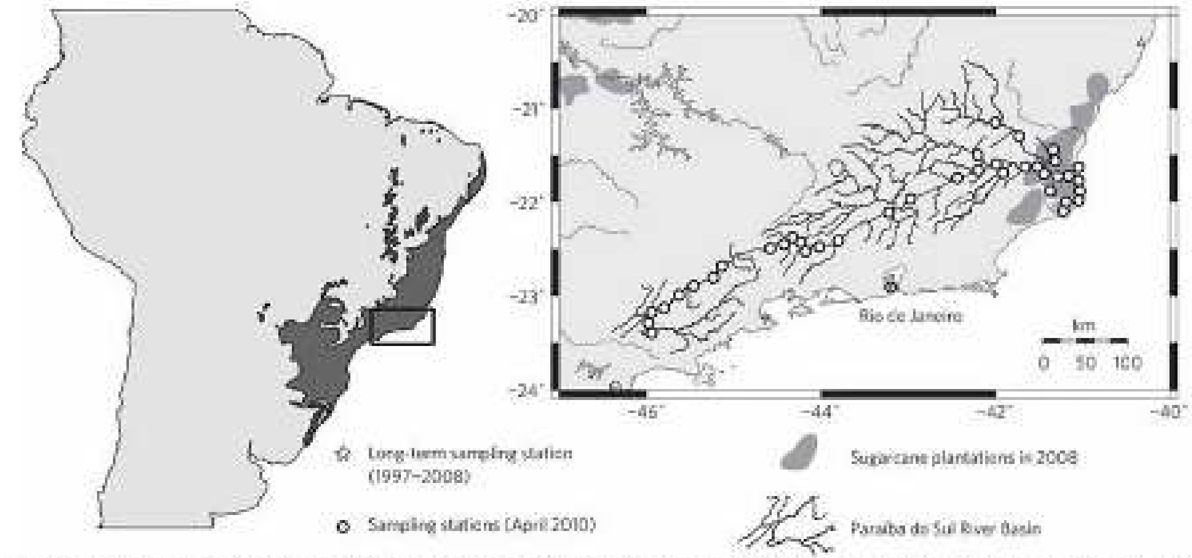
Hipoxia in coastal seas



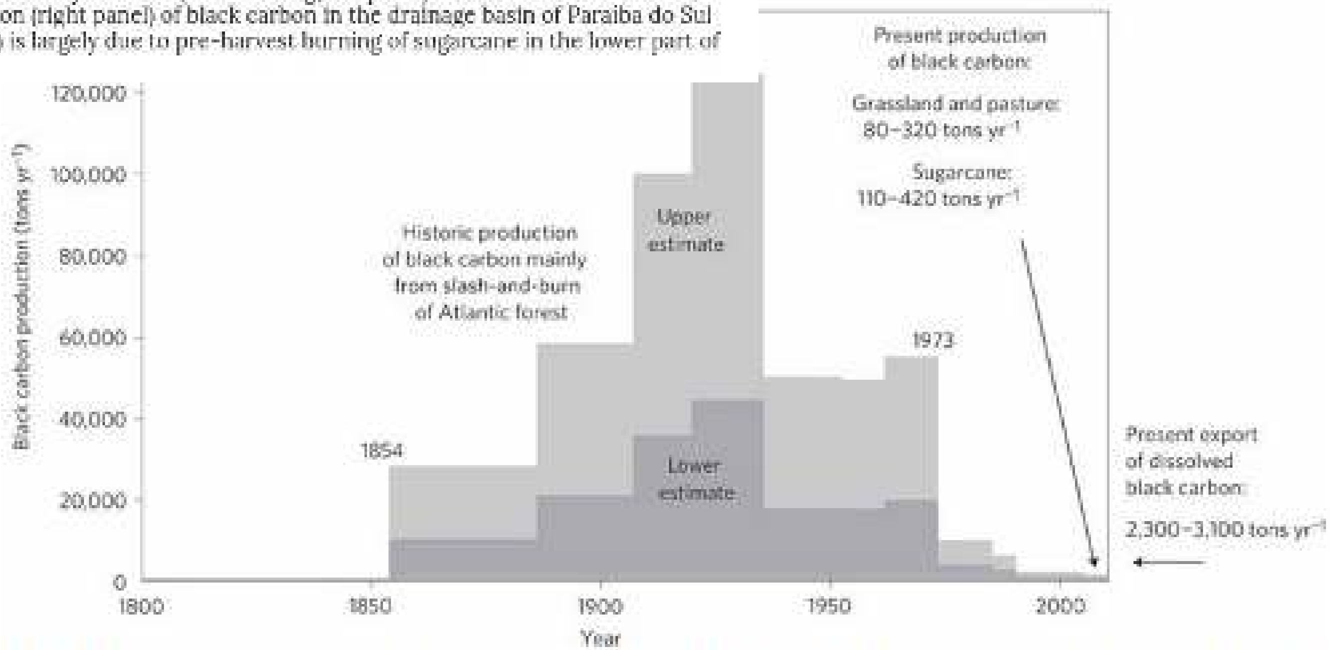
- Increasing globally due to excessive loads of nutrients and oxygen consumption
- Today, affects over 18,000 km^2 of the Texas-Louisiana shelf during summer

Continental carbon to the South Atlantic

From: Continuous flux of dissolved black carbon from a vanished tropical forest biome



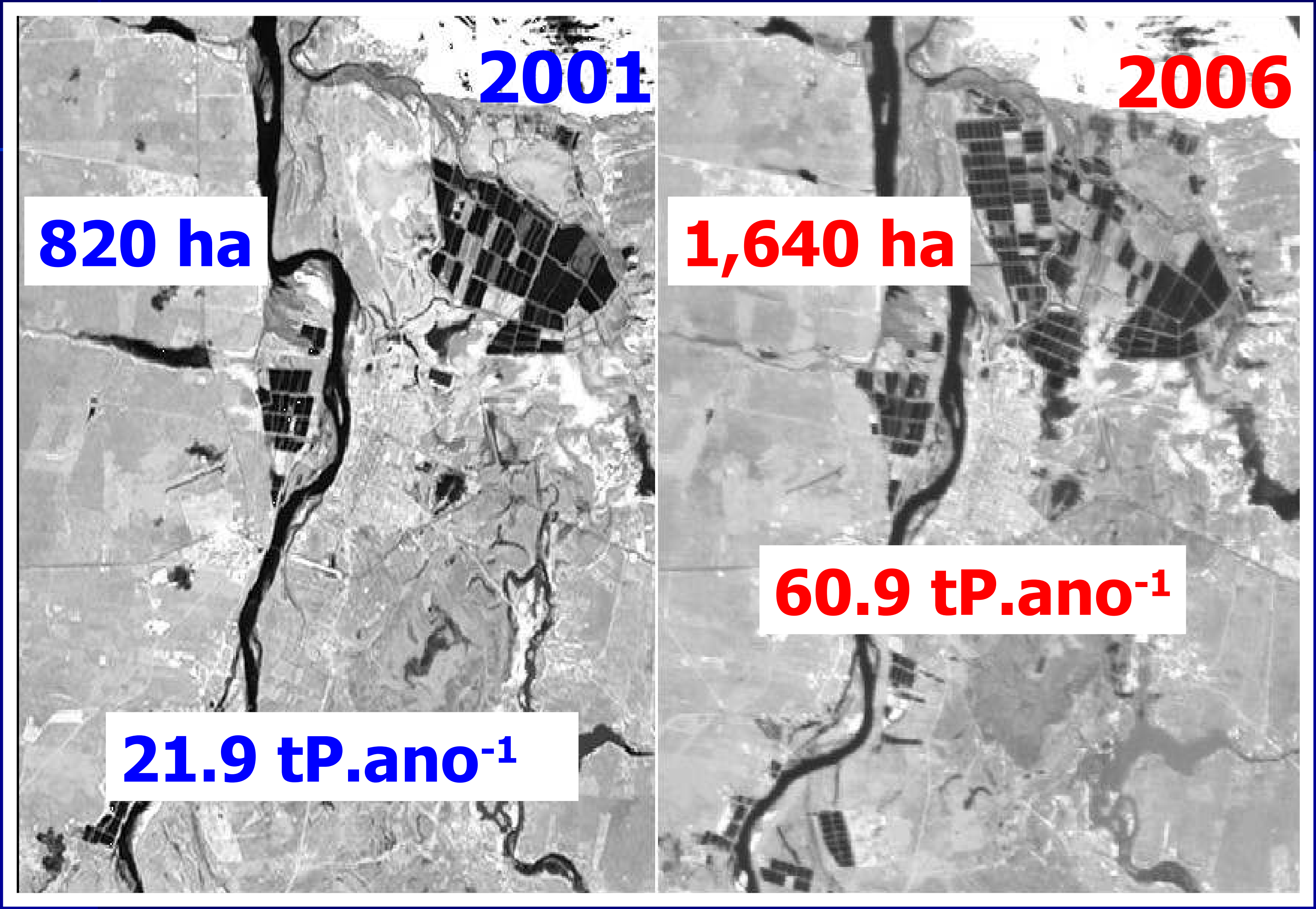
The original coverage of the tropical Atlantic forest in the year 1500[1] (dark shading, left panel) was reduced to about 8%, consisting of fragmented patches. Today's production (right panel) of black carbon in the drainage basin of Paraiba do Sul River (the area outlined by the box in the left panel) is largely due to pre-harvest burning of sugarcane in the lower part of the catchment area.



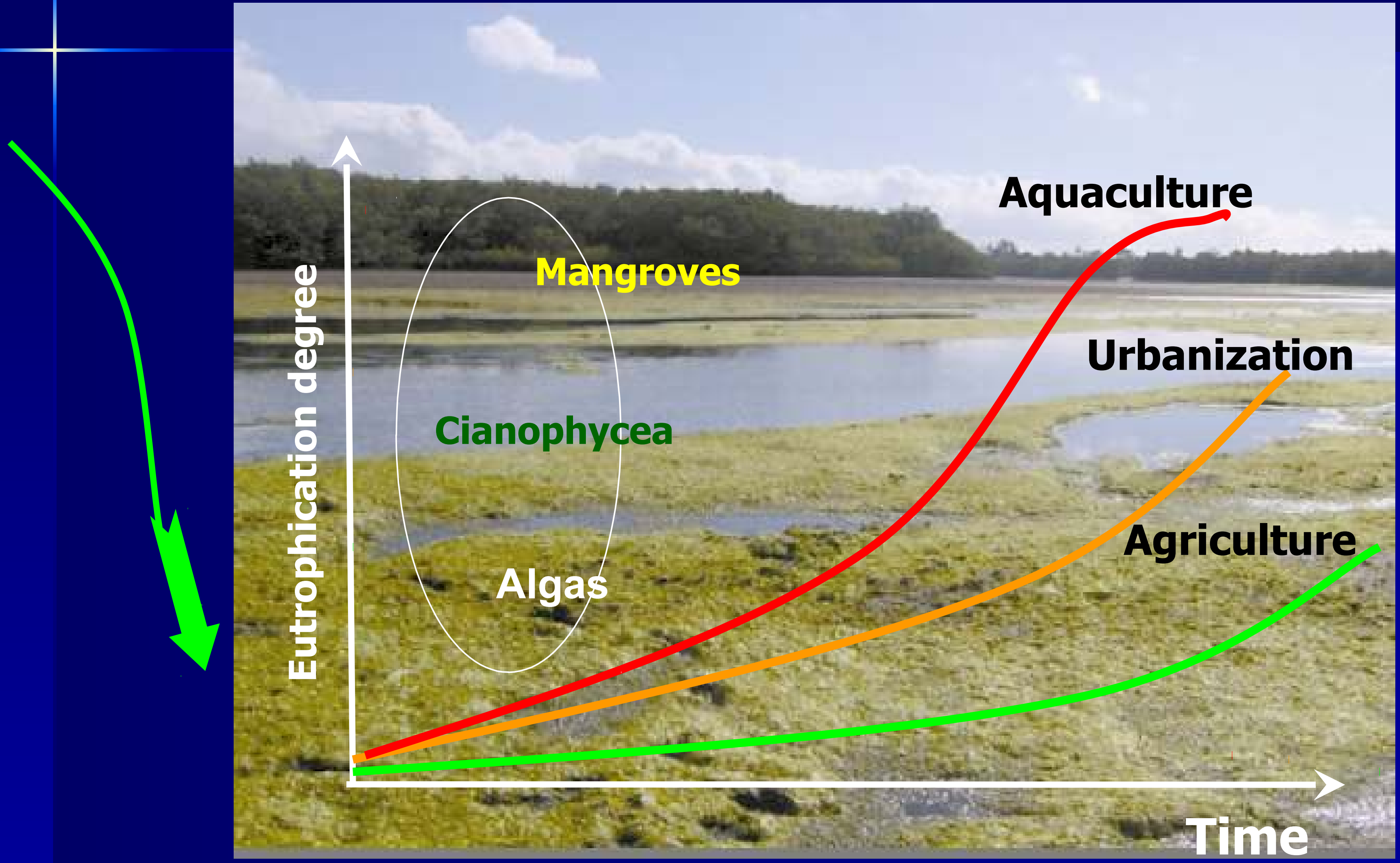
Annual production rates are for the polycyclic aromatic fraction of black carbon. The rate shown for the period 1800–1854 also represents the period 1500–1800. Black carbon was mainly produced by slash-and-burn clearing of the Atlantic forest. Today's production is mainly due to pasture management and pre-harvest burning of sugarcane.

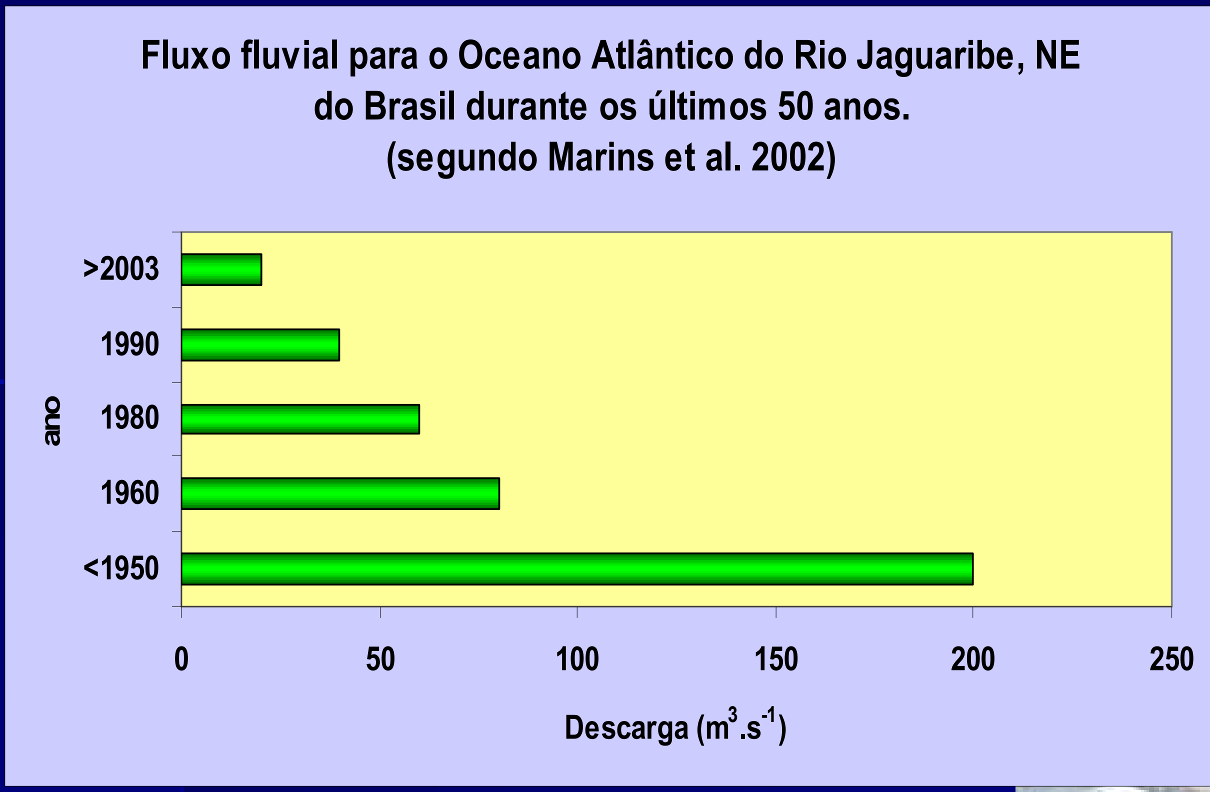
Changes in land use: **Shrimp aquaculture**

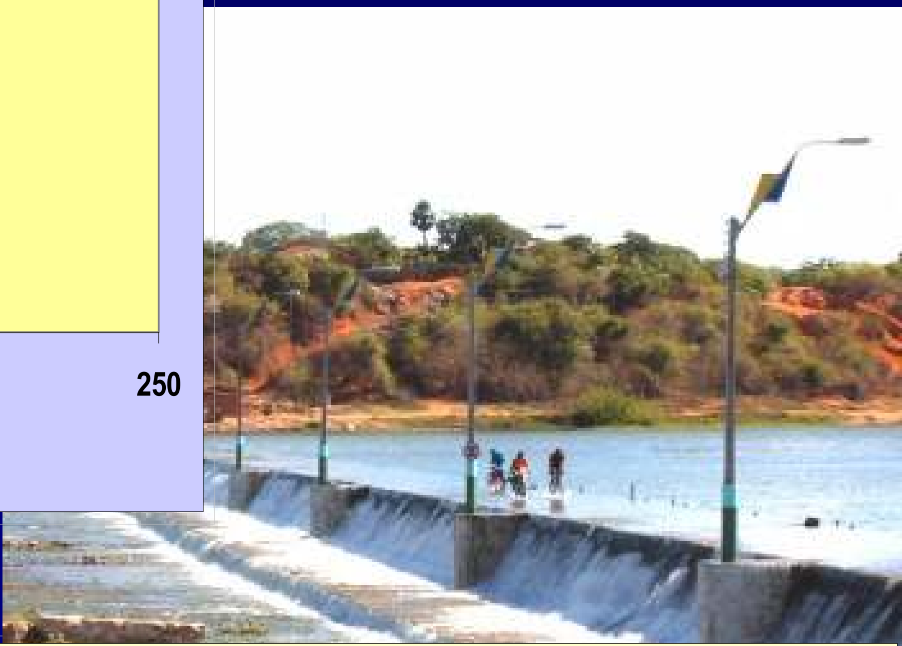
(*c.f.* Marins et al., 2009)



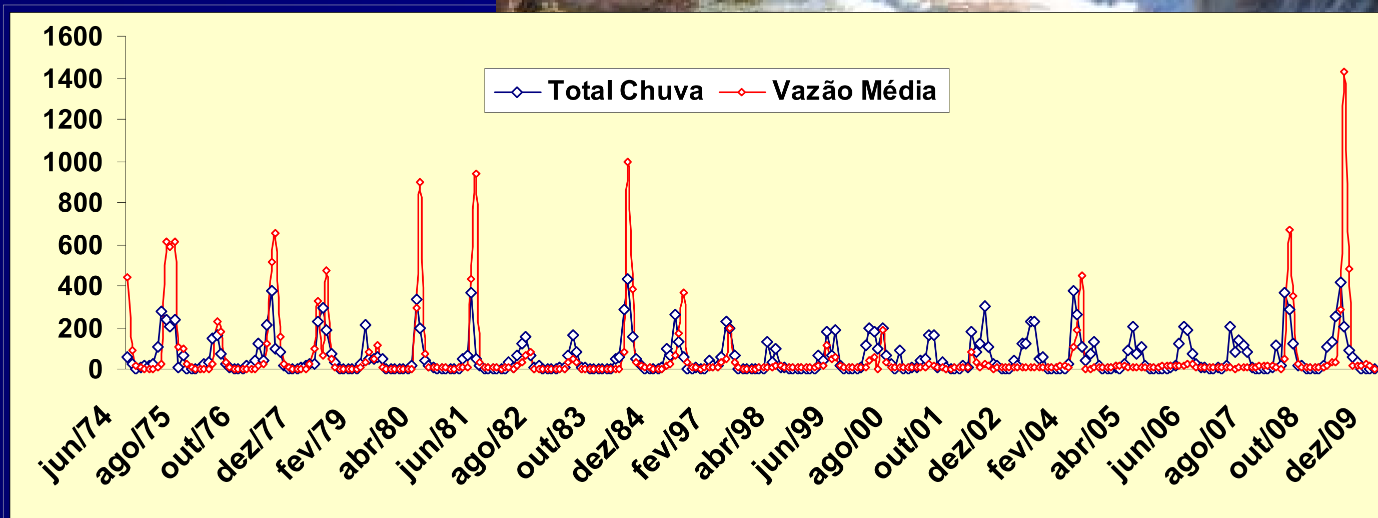
Speed of response (eutrophication) to increasing nutrient emissions from different non-industrial activities




Fluxo fluvial para o Oceano Atlântico do Rio Jaguaribe, NE
do Brasil durante os últimos 50 anos.
(segundo Marins et al. 2002)
ano
>2003
1990
1980
1960
<1950
0
50
100
150
200
250
Descarga ($m^3.s^{-1}$)



Dams


Total Chuva
Vazão Média
1600
1400
1200
1000
800
600
400
200
0
jun/74
ago/75
out/76
dez/77
fev/79
abr/80
jun/81
ago/82
out/83
dez/84
fev/97
abr/98
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ago/00
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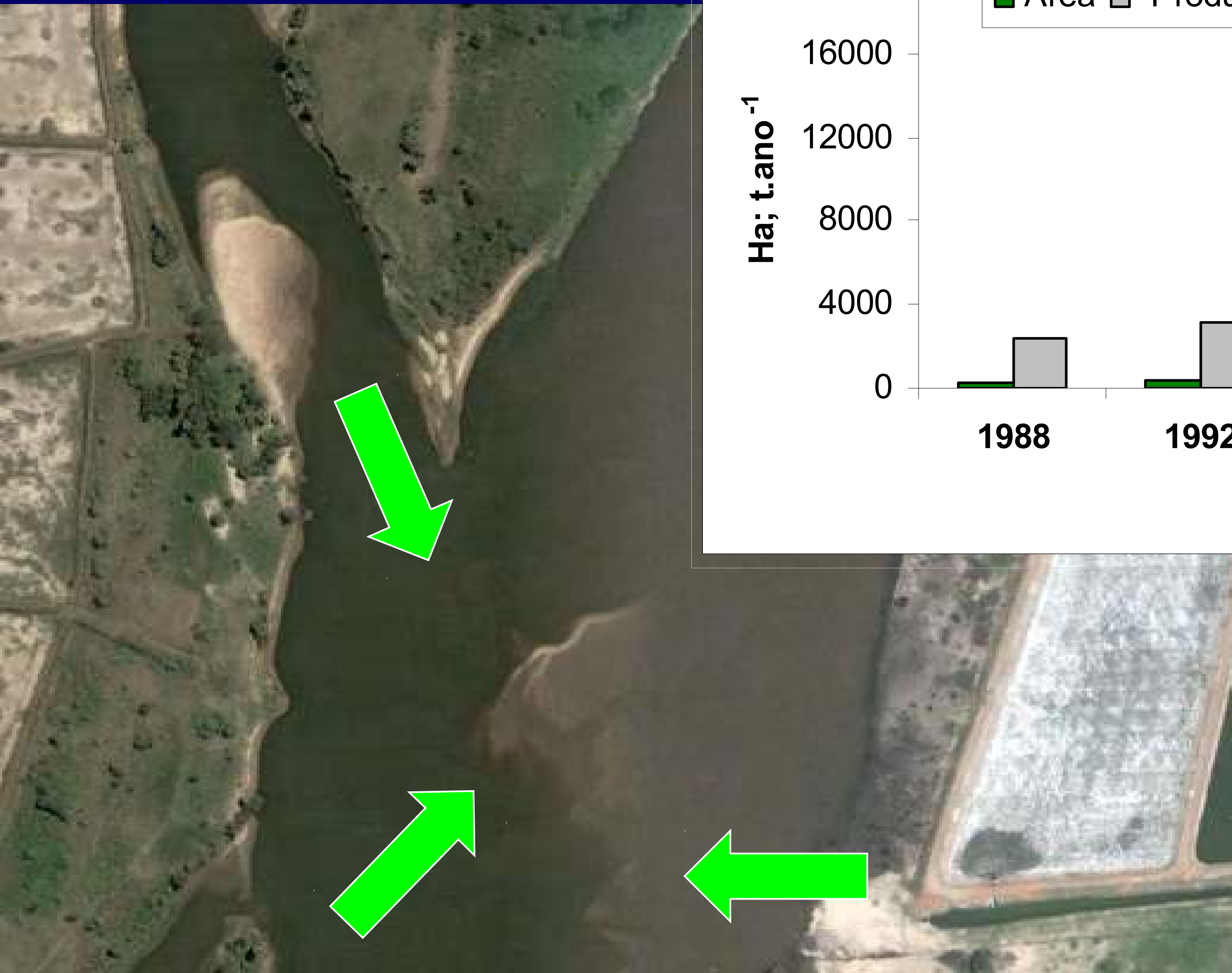
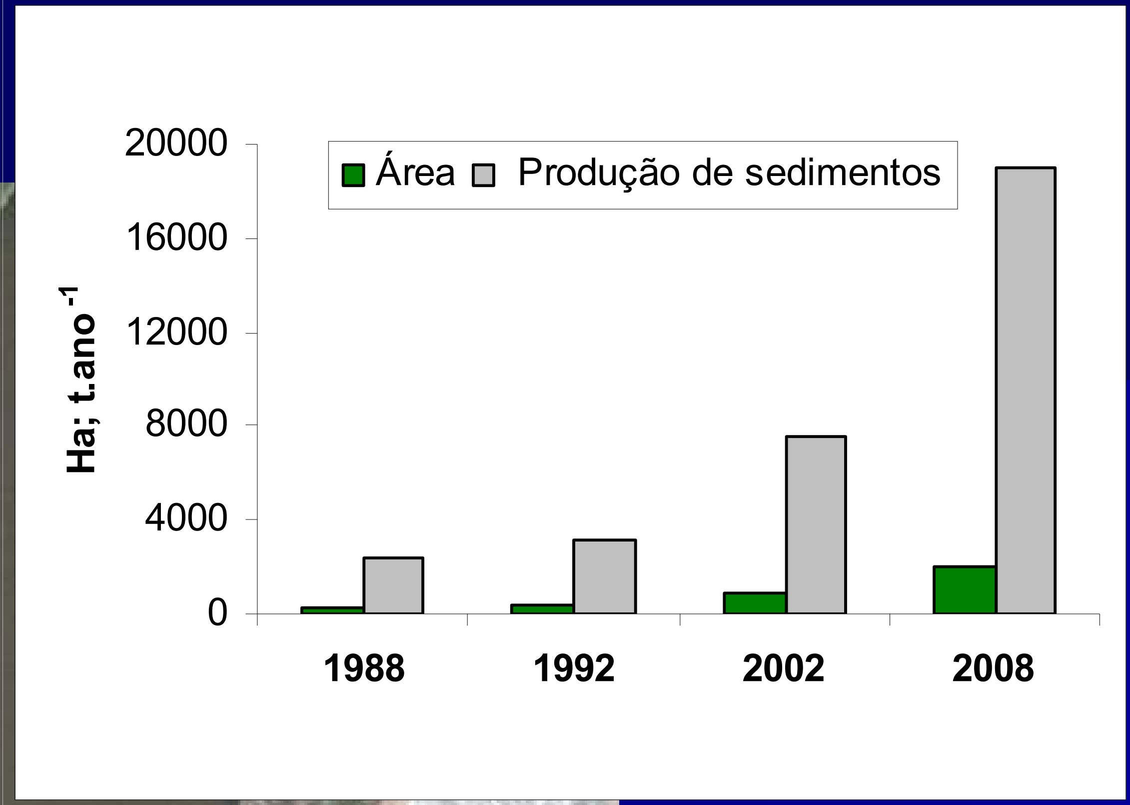
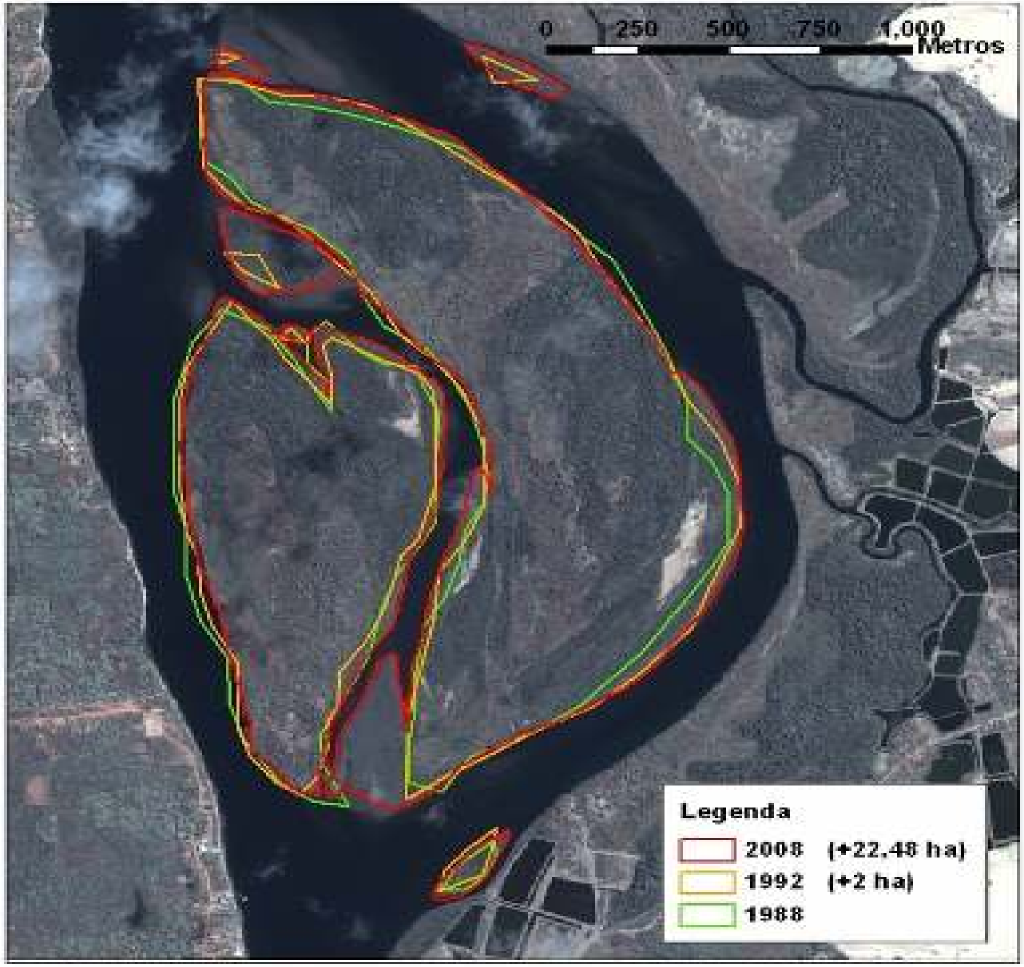
ago/07
out/08
dez/09





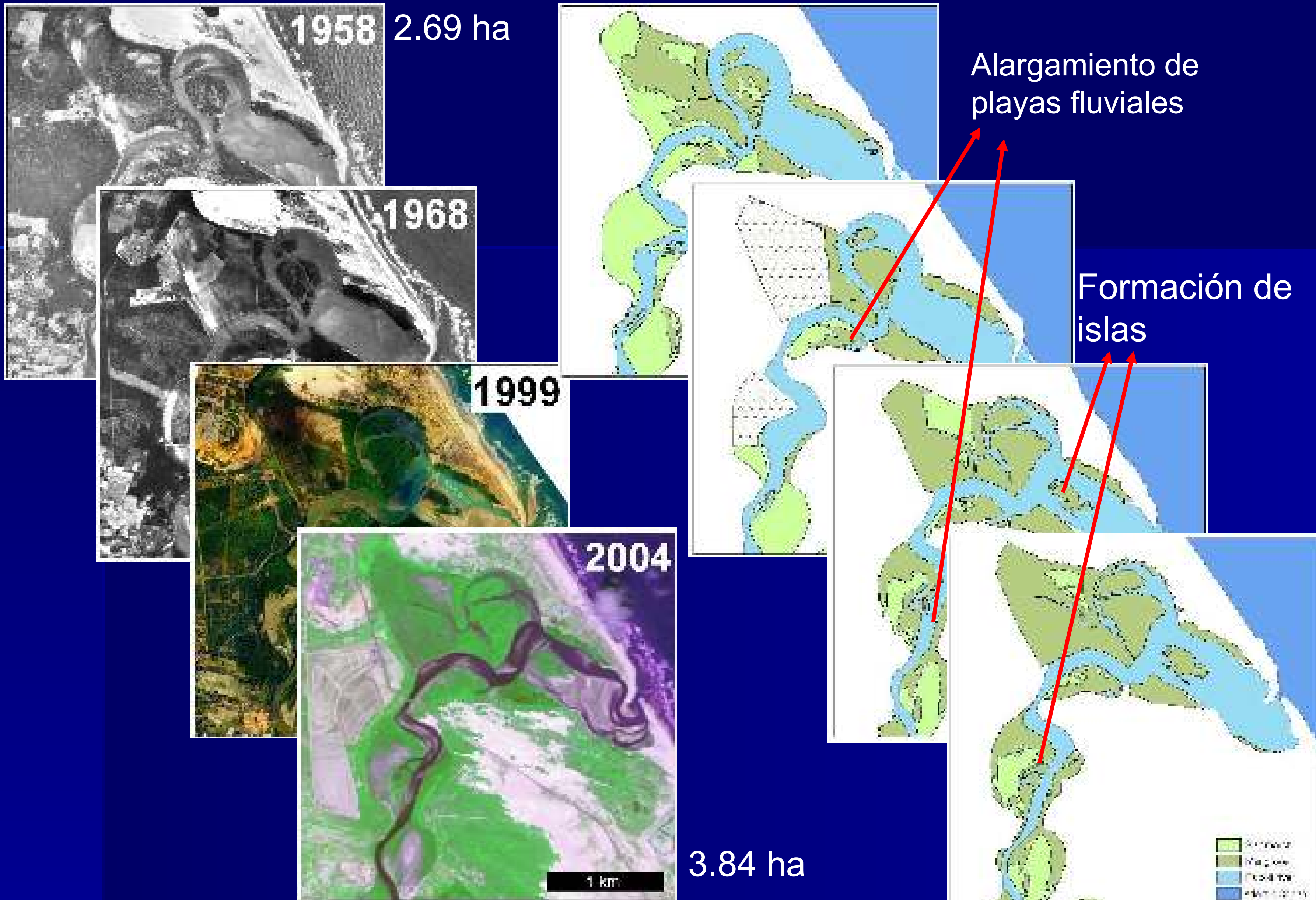
Godoy (2010)

Aquaculture & sediment production



Increasing sedimention areas

Godoy (2010)

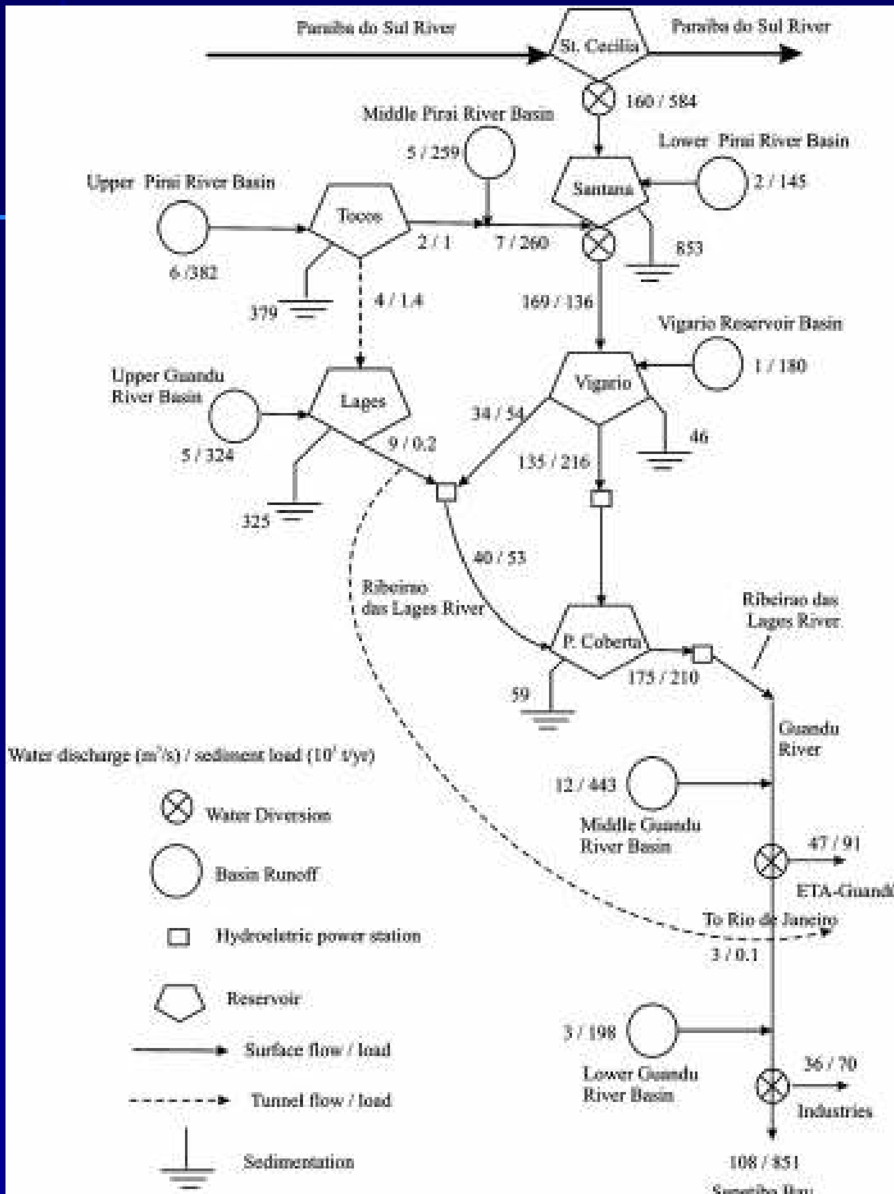


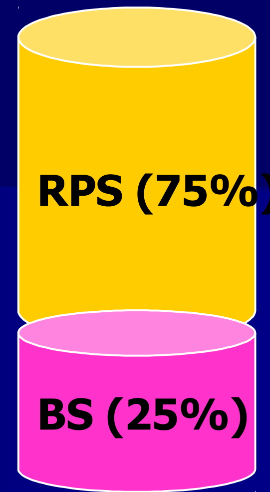
Lacerda *et al*. (2007

Alteración en la morfología del estuario de Río Pacotí (CE)

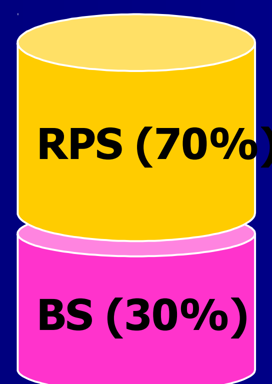
Water diversion

Contribuição de água e sedimentos pela transposição do Rio Paraíba do Sul para a Baia de Sepetiba





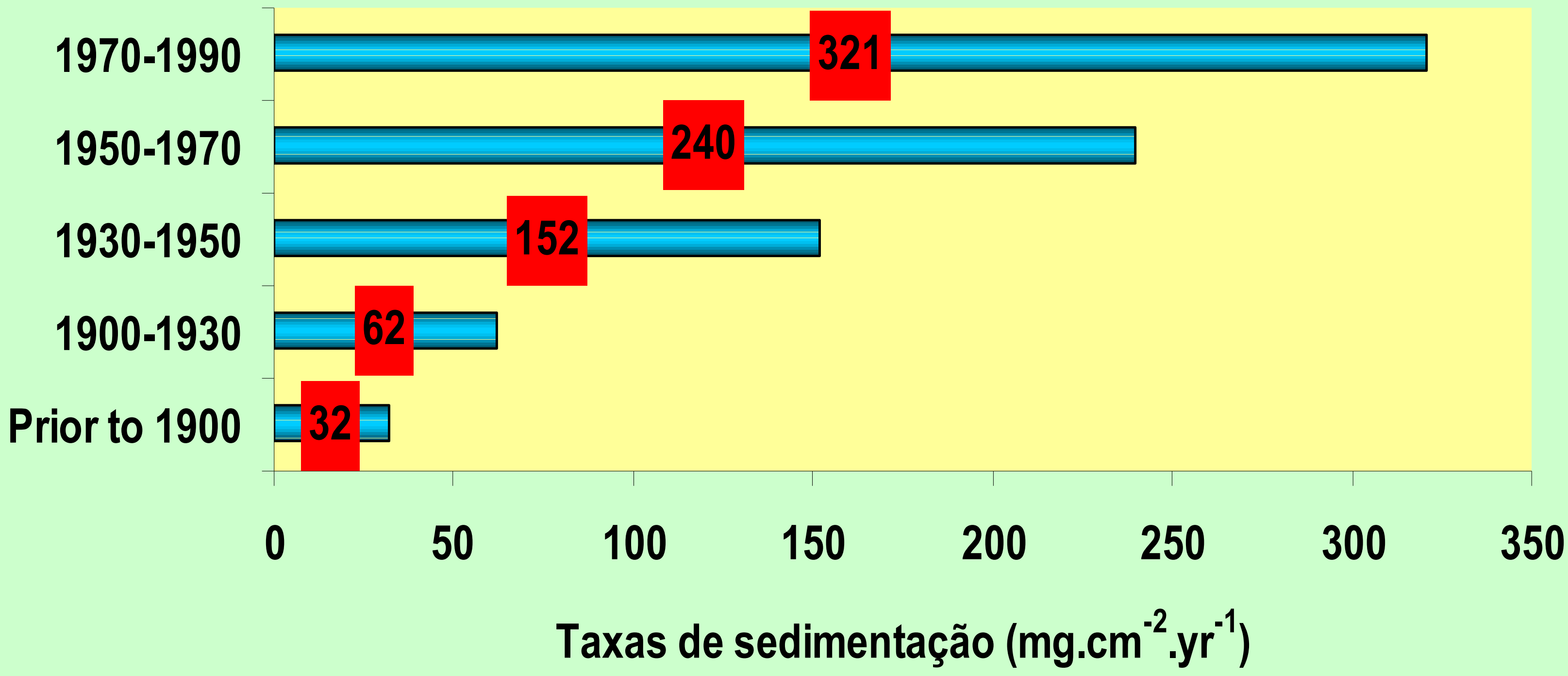
Água



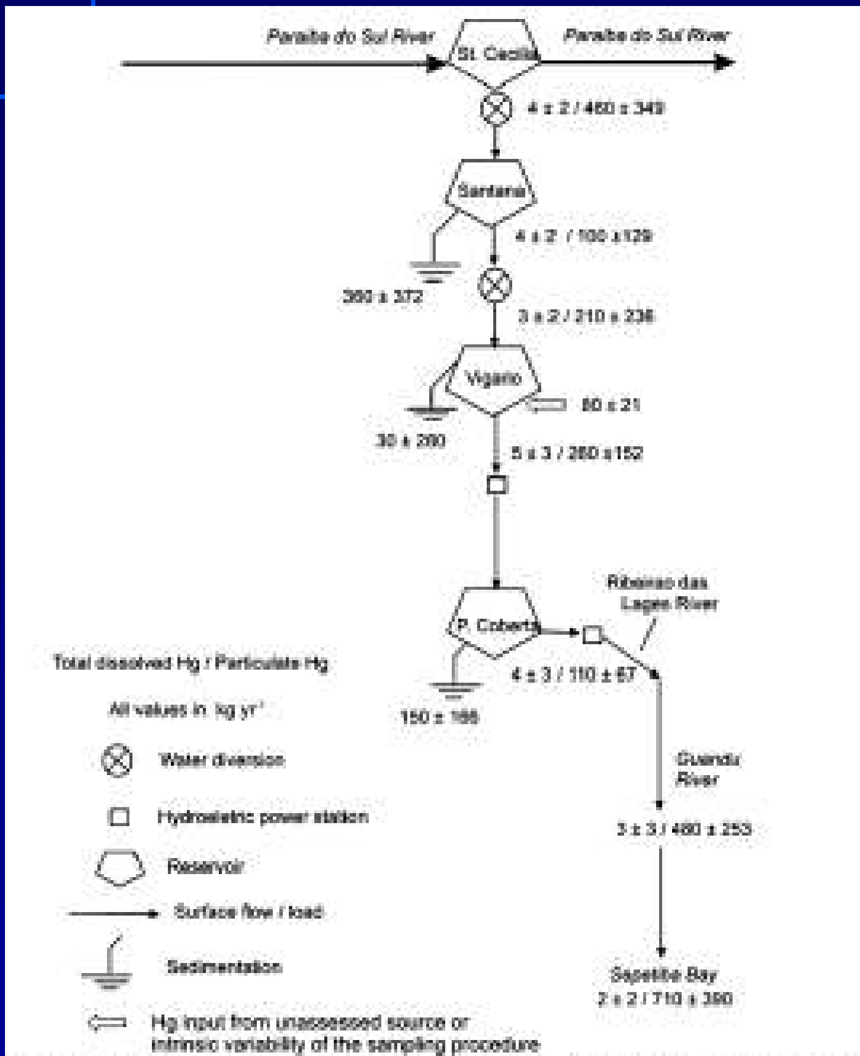
Sedimento

Molisani et al. (2007)

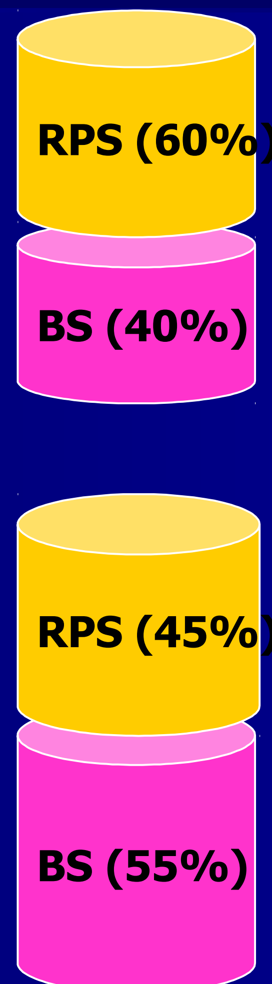
Mudanças nas taxas de sedimentação na Baía de Sepetiba, RJ devido a diversão de águas do Rio Paraíba do Sul (Lacerda et al. 2002)



Contribuição de Hg pela transposição do Rio Paraíba do Sul para a Baia de Sepetiba



Mass-balance budget of Hg (mean ± standard deviation, kg yr⁻¹) along the engineered-modified watershed.



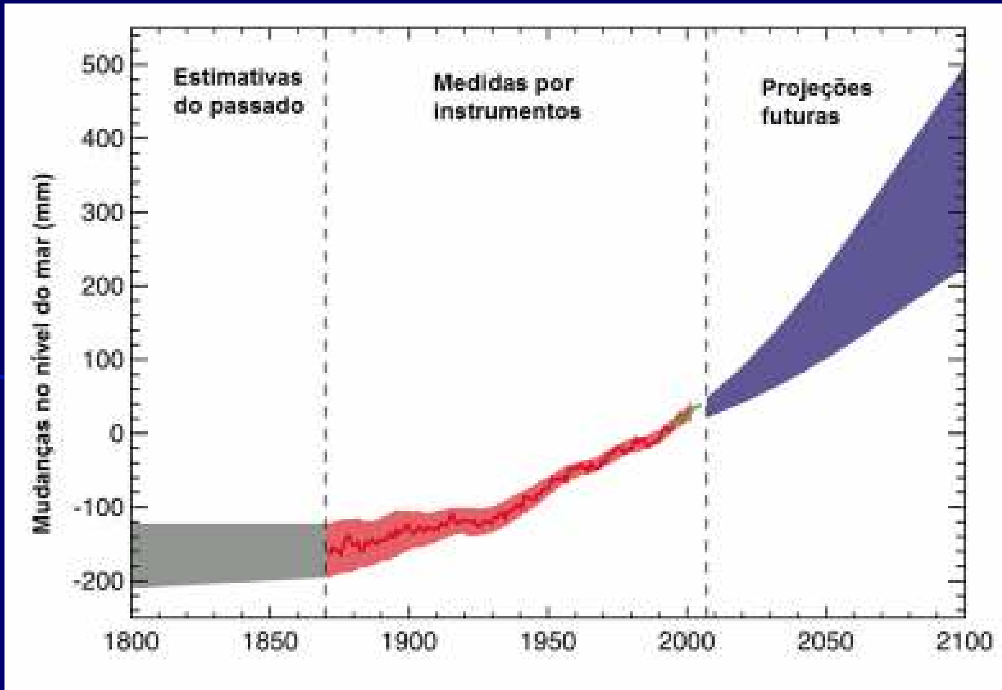
Hg-particulae

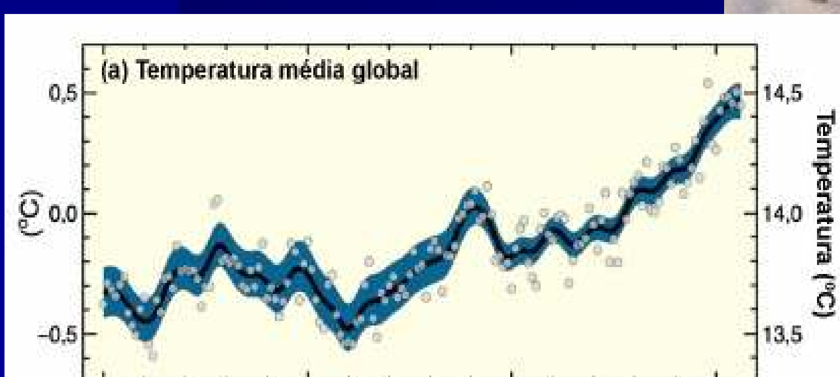
Hg-dissolved

Molisani et al. (2008)

is

Global climate change: Sea level rise





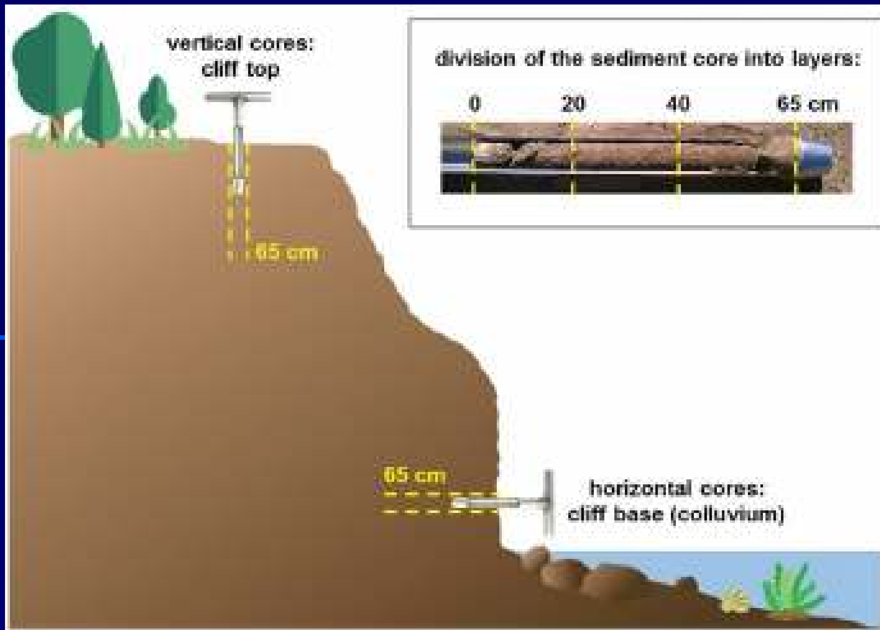
Efeitos pouco óbvios: Impacto na biogeoquímica costeira

- In areas of small supply of sediments, e.g. semiarid littorals, seafront mangroves, sea clifs; coastal deposits are increasing the remobilization of pollutants.

- On the other hand, coastal plain areas in the tropics and subtropics dominated by mangroves, sea level rise will induce mangrove migration inland, creating typical areas dominated by the mangrove metabolism (e.g. anerobic respiration through sulfate reduction).

- Trace metal biogeochemistry and bioavailability are highly affected by the sulfate reduction metabolism.

- Part of the metal load will be accumulated as metallic sulfides in sediments, but part, with the abundant dissolved organic carbon compounds due to incomplete oxidation of organic matter, will be made more bioavailable, increasing bioaccumulation and enhancing biota and human exposure through food chains.



Sea level rise and Hg contribution through erosion
(Kwasigroch et al., 2018 (in press)
Up to 14.5 $kg.yr^{-1}$; the 3rd most important Hg source to Gdansk Bay.

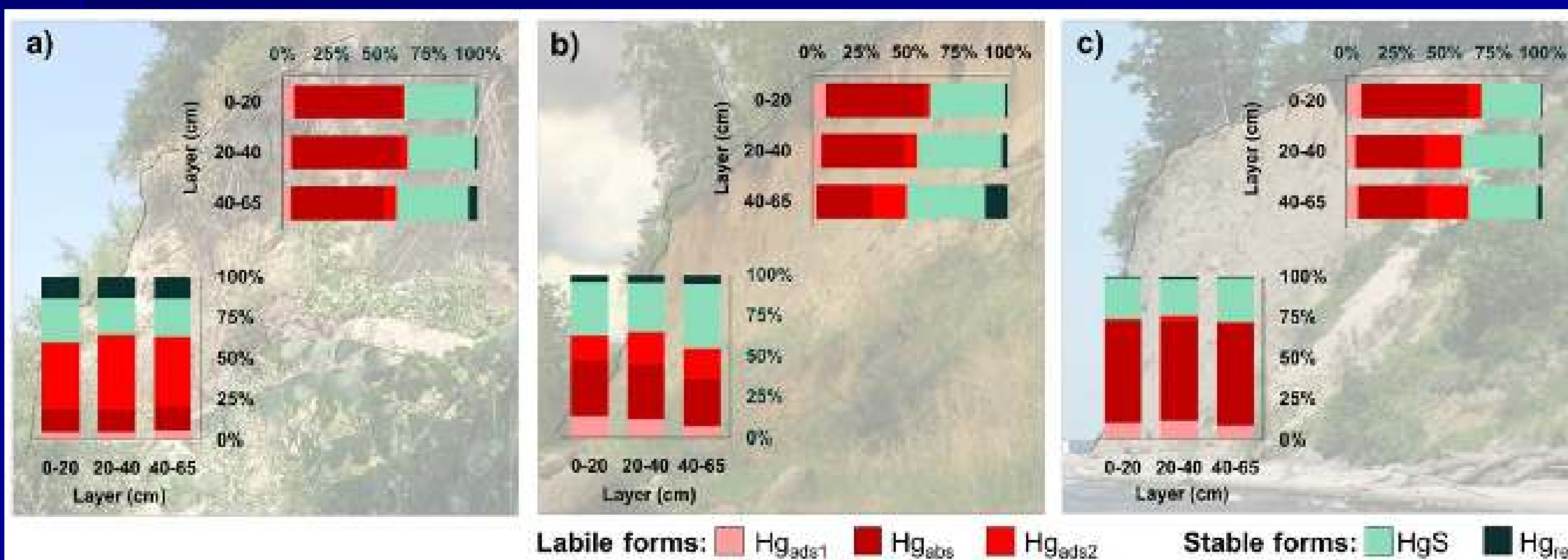
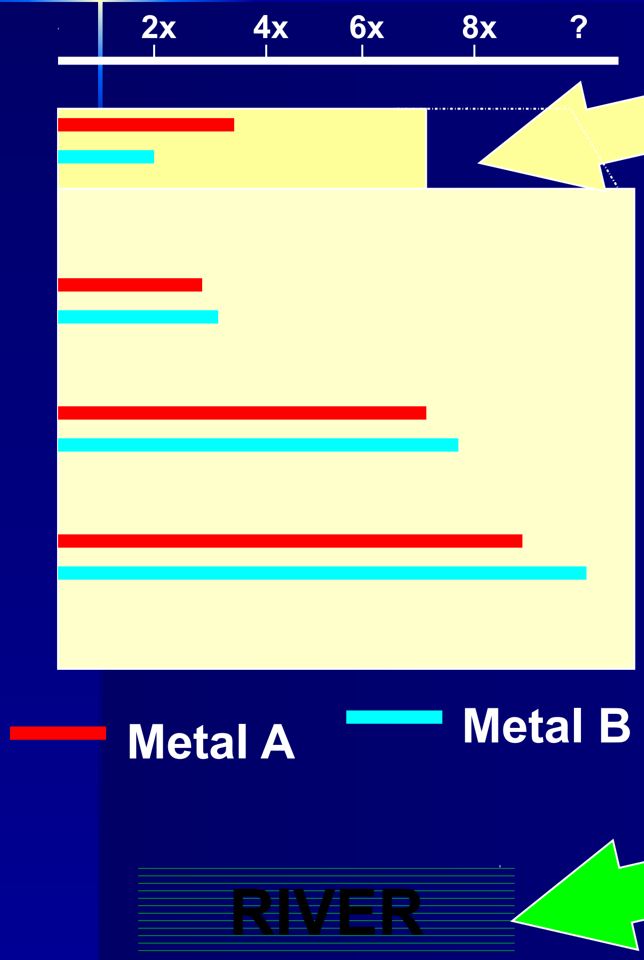


Fig. 3 The percentage of Hg fractions in horizontal and vertical profiles of investigated cliffs. a Puck cliff. b Oslonino cliff. c Mechelinki cliff

Erosion of coastal mangroves sediments in NE Brazil

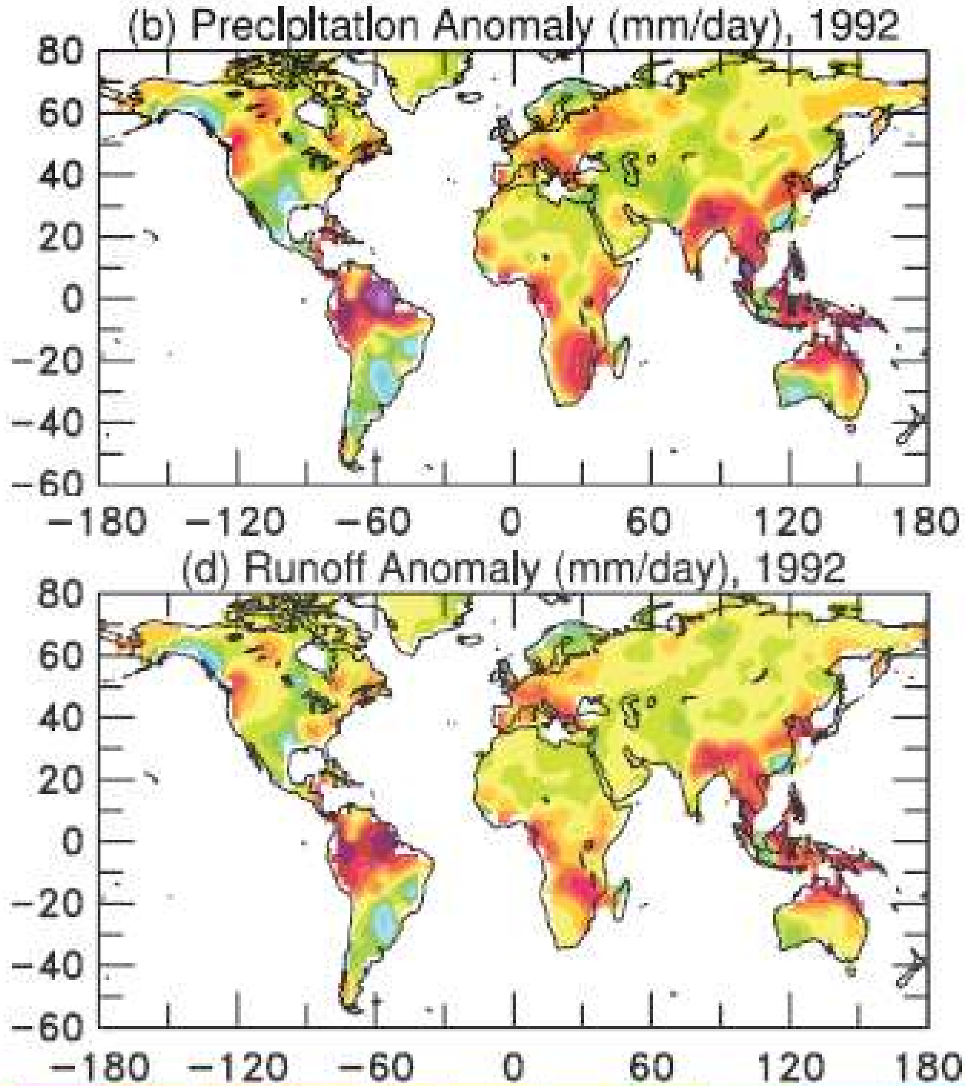
Metal concentrations (µg/g)



Variação do escorrimento superficial e precipitação global

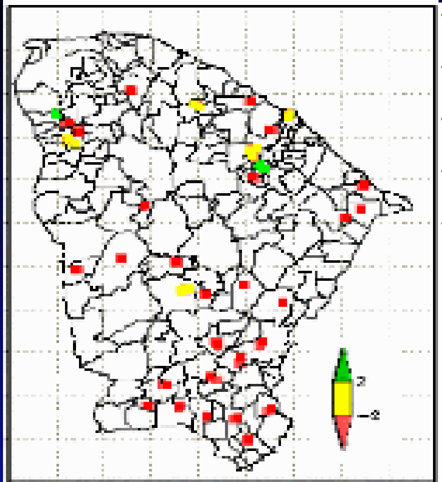
Out of 200 rivers, **45**, mostly in lower latitudes, have their flows decreased between 1984 and 2004, whereas **19**, have them increased

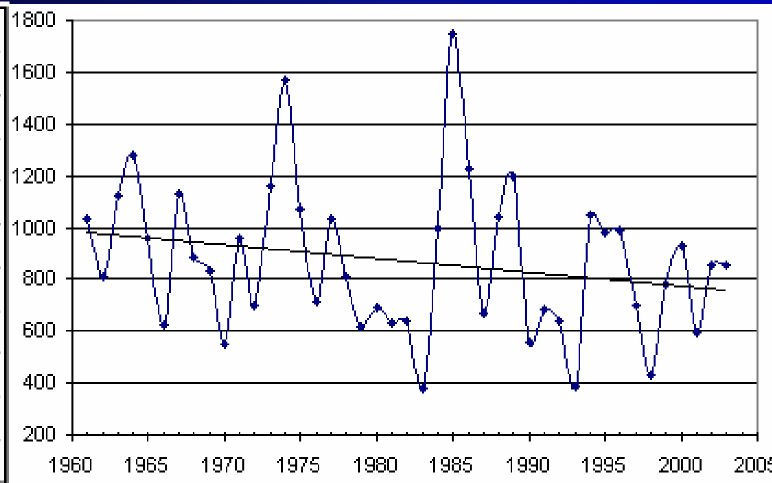
Increasing fluxes are frequently in higher latitudes and increasing flux **do not relates to increasing rainfall**, a probable reflect of ice and glacier melt.



Dai et al., 2009)

Reduction Annual precipitation and runoff anomalies

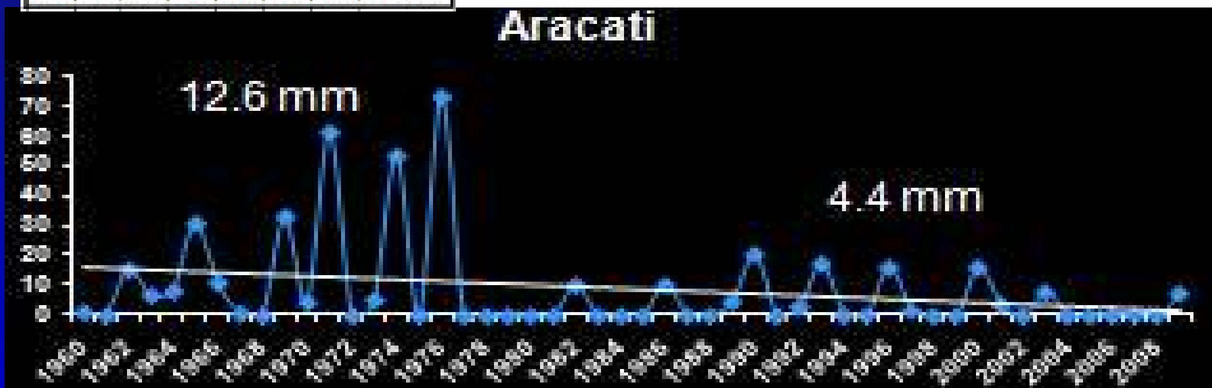




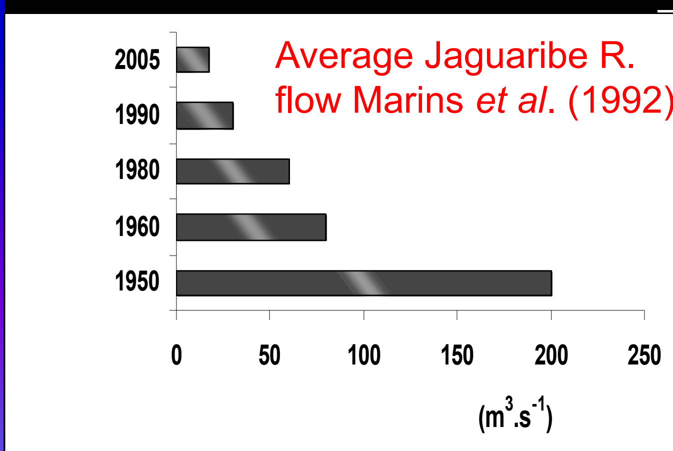
Rainfall reduction in Ceara, NE Brazil

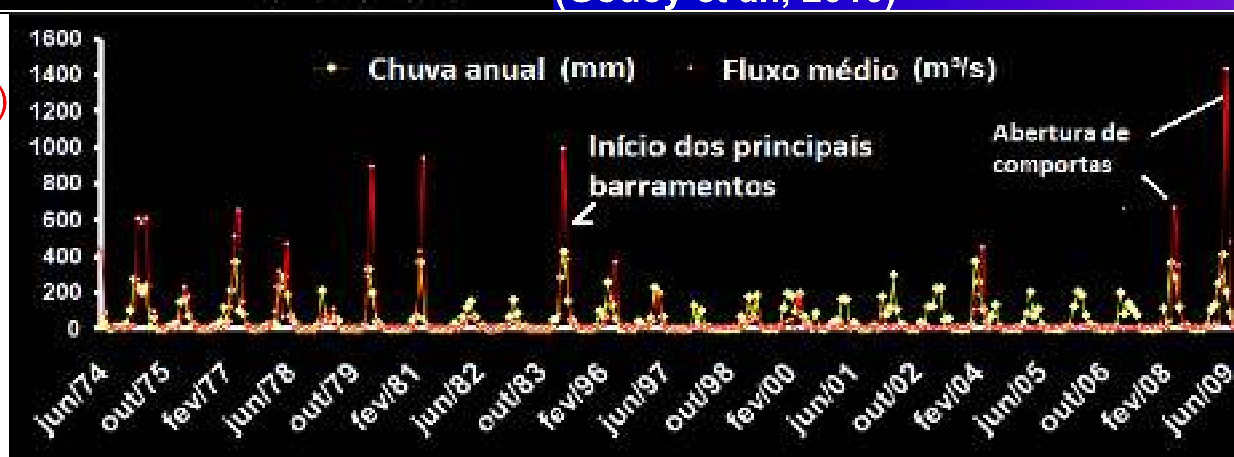
Evolution Trend (1961 – 2008) in annual precipitation over Ceará. (4 - 5 mm.yr^{-1} reduction) (Moncuil, 2006).

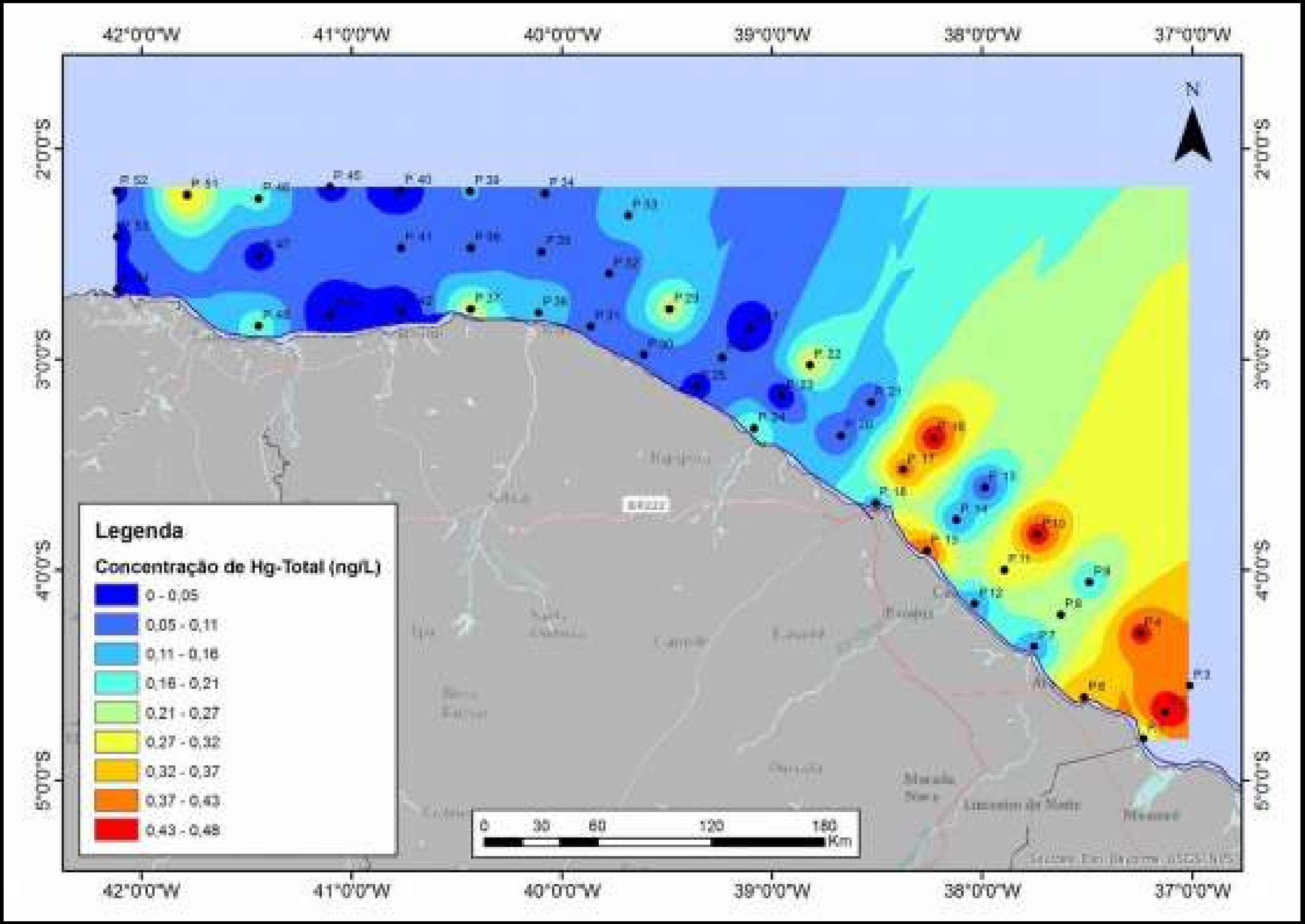
Reduction is more critical (3 times) during the dry season (Godoy *et al*., 2010)



River discharges also decrease and arefurther affected by damming (Godoy *et al*., 2010)

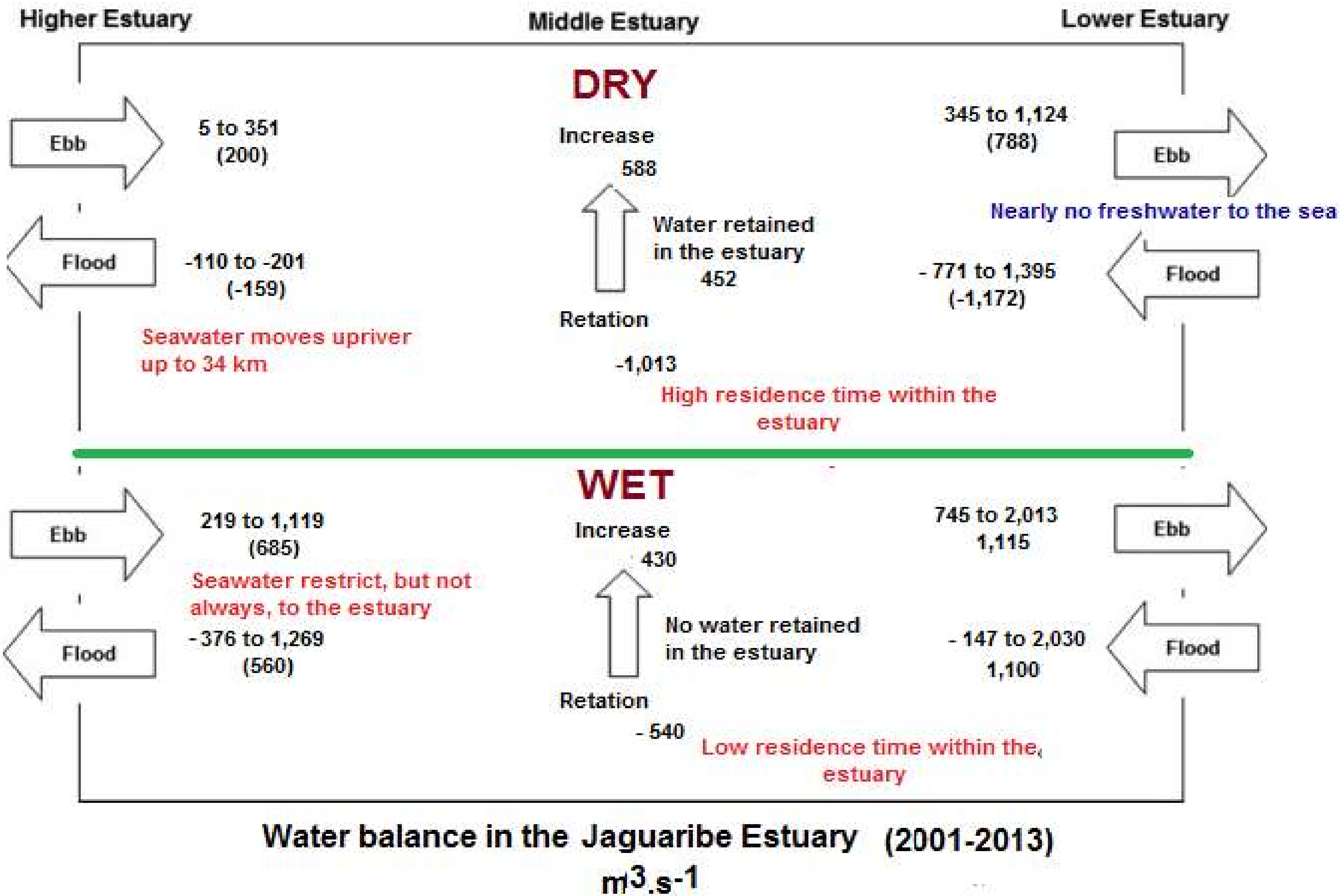




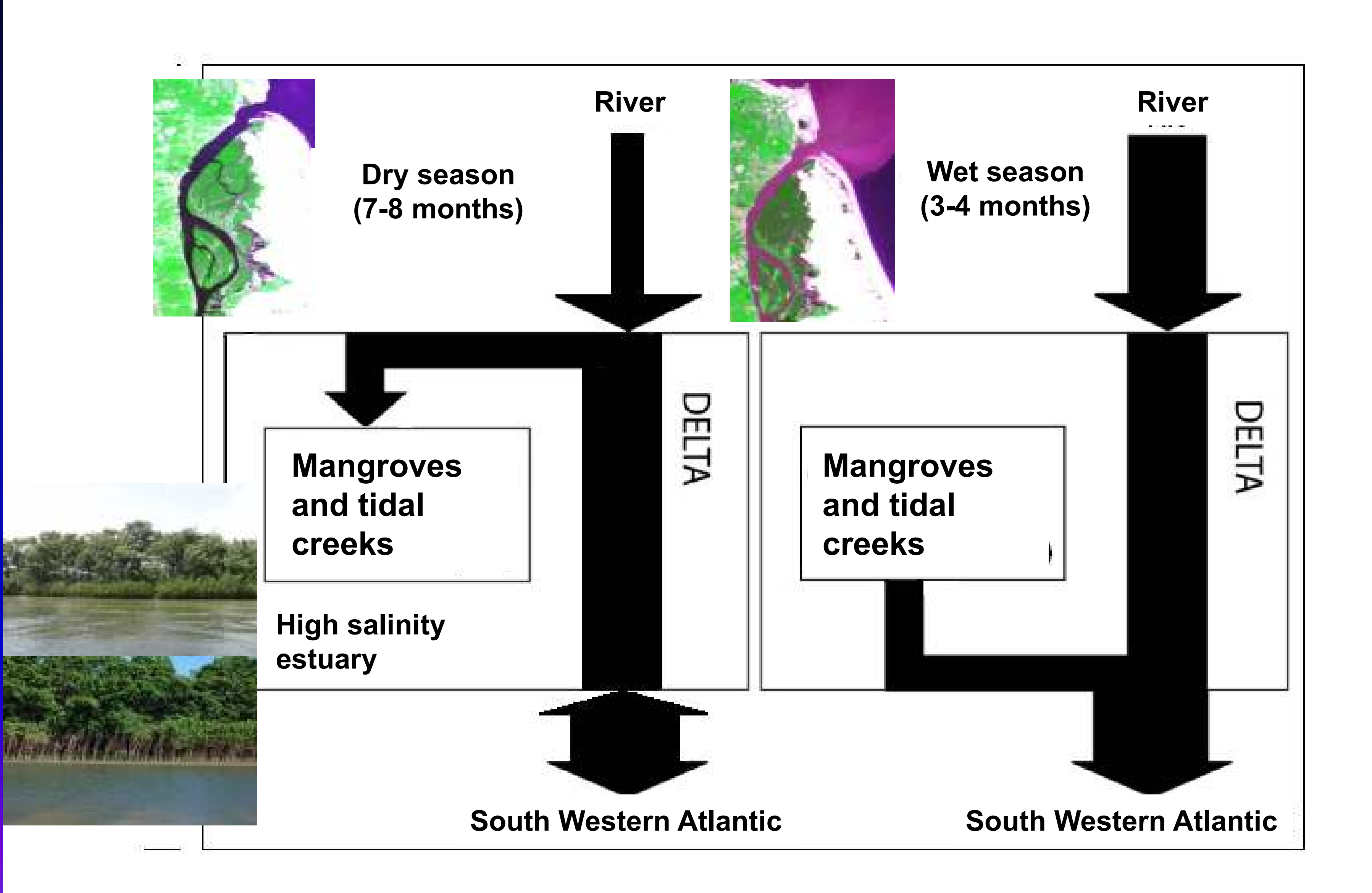


Mercury distribution in coastal waters of the semiarid northeast as a proxy of regional changes in the NE region's watersheds. The clear pattern of higher concentrations to the east are a result of such changes.

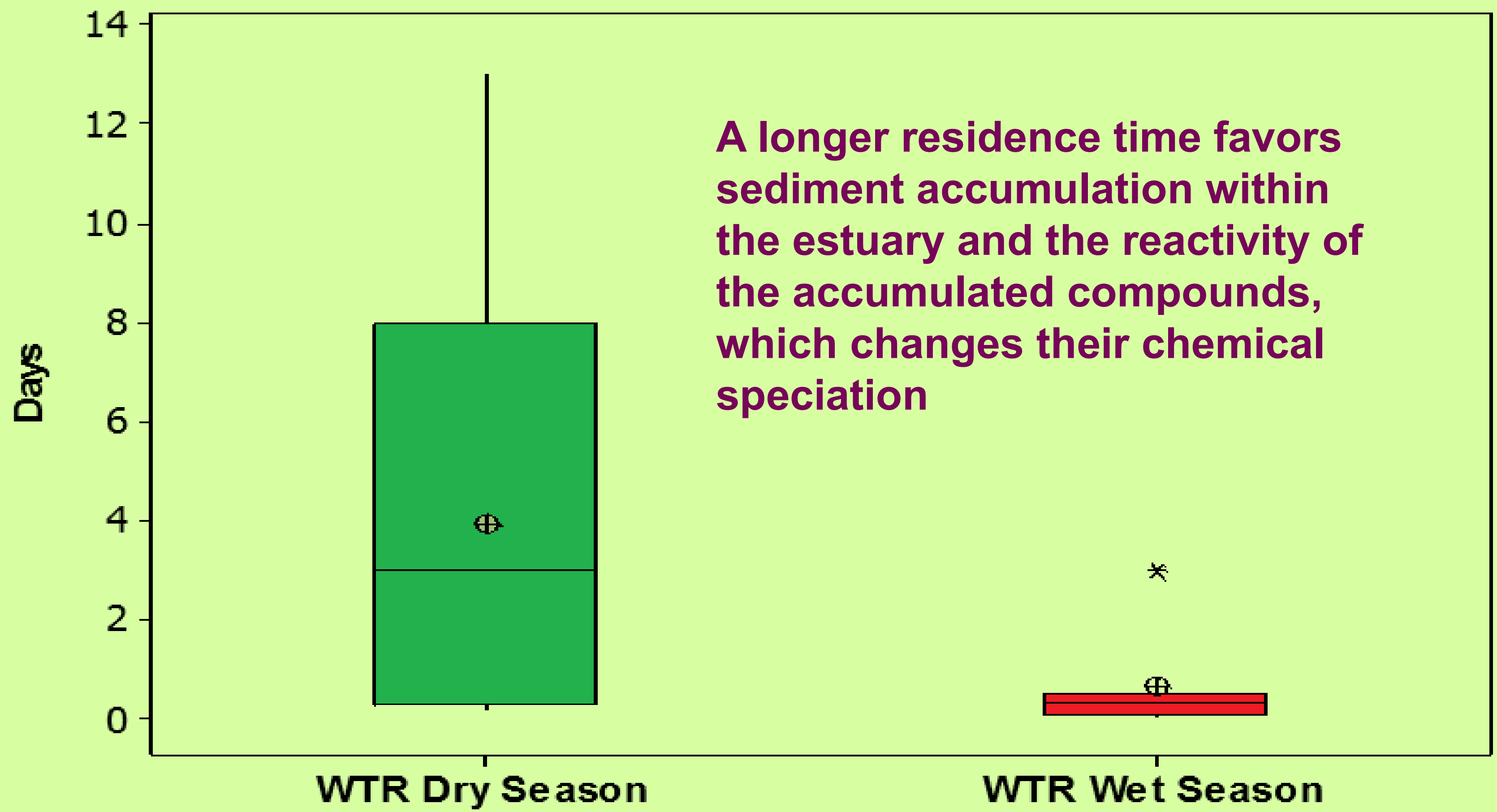
Water balance ($m^3.s^{-1}$) at the Jaguaribe estuary, NE Brazil (Dias, Lacerda & Marins 2011) pluriannual average.



Conceptual hydrodynamics model of semi-arid rivers, from Lacerda , Marins & Dias (2012)



Choking of the lower estuary due to decreasing continental runoff and increasing the strength of ocean forcing over the continental shelf, results in longer residence time of water masses within the estuary during the dry season (Lacerda, Marins & Dias, 2012)



The hydrodynamics of rivers in the semi-arid at the continent - ocean interface and therefore the distribution and biogeochemistry of their ecosystems depends on:

1 – the magnitude of the fluvial flux & continental runoff;

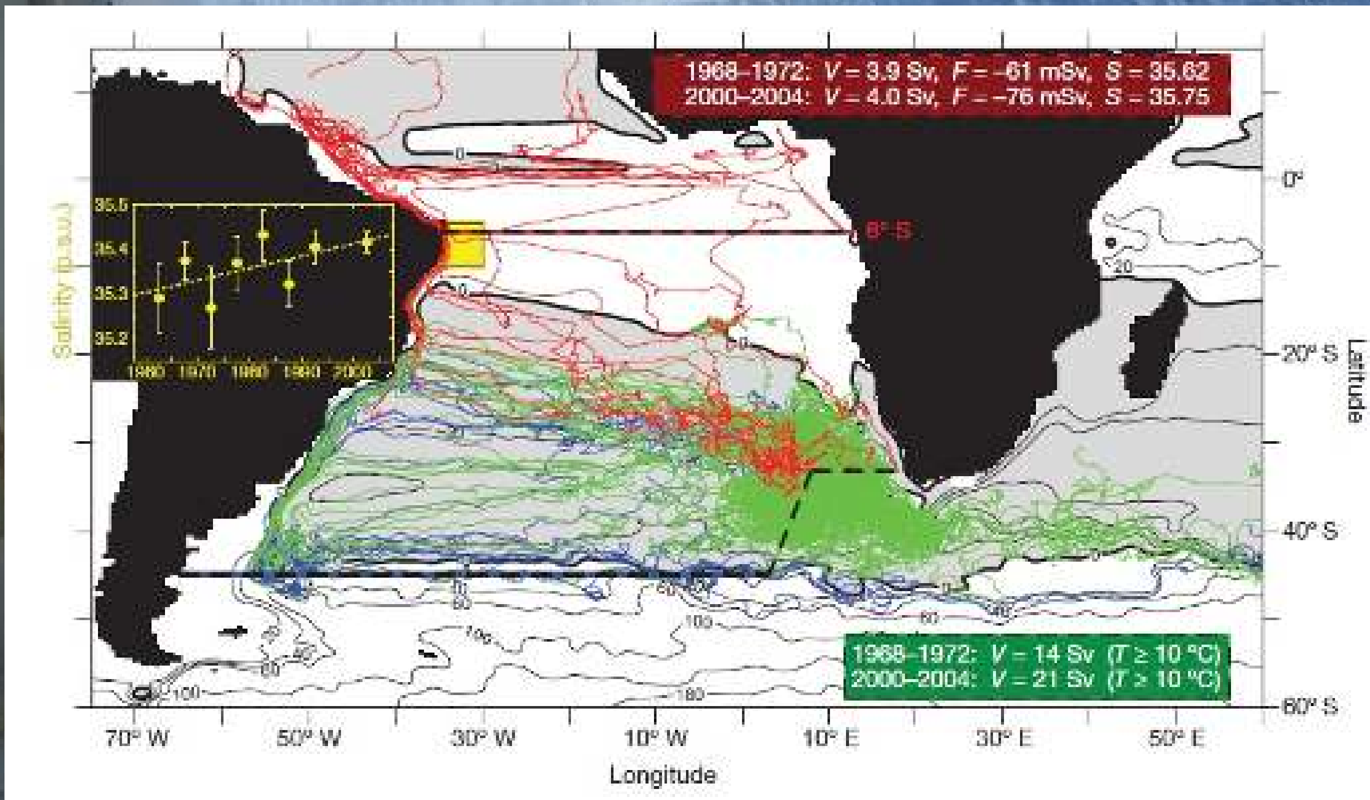
2 – the residence time of water masses in flooded areas and;

3 – sea level variation and the volume of the tidal prism.

All these variables are highly sensitive to global climate change.

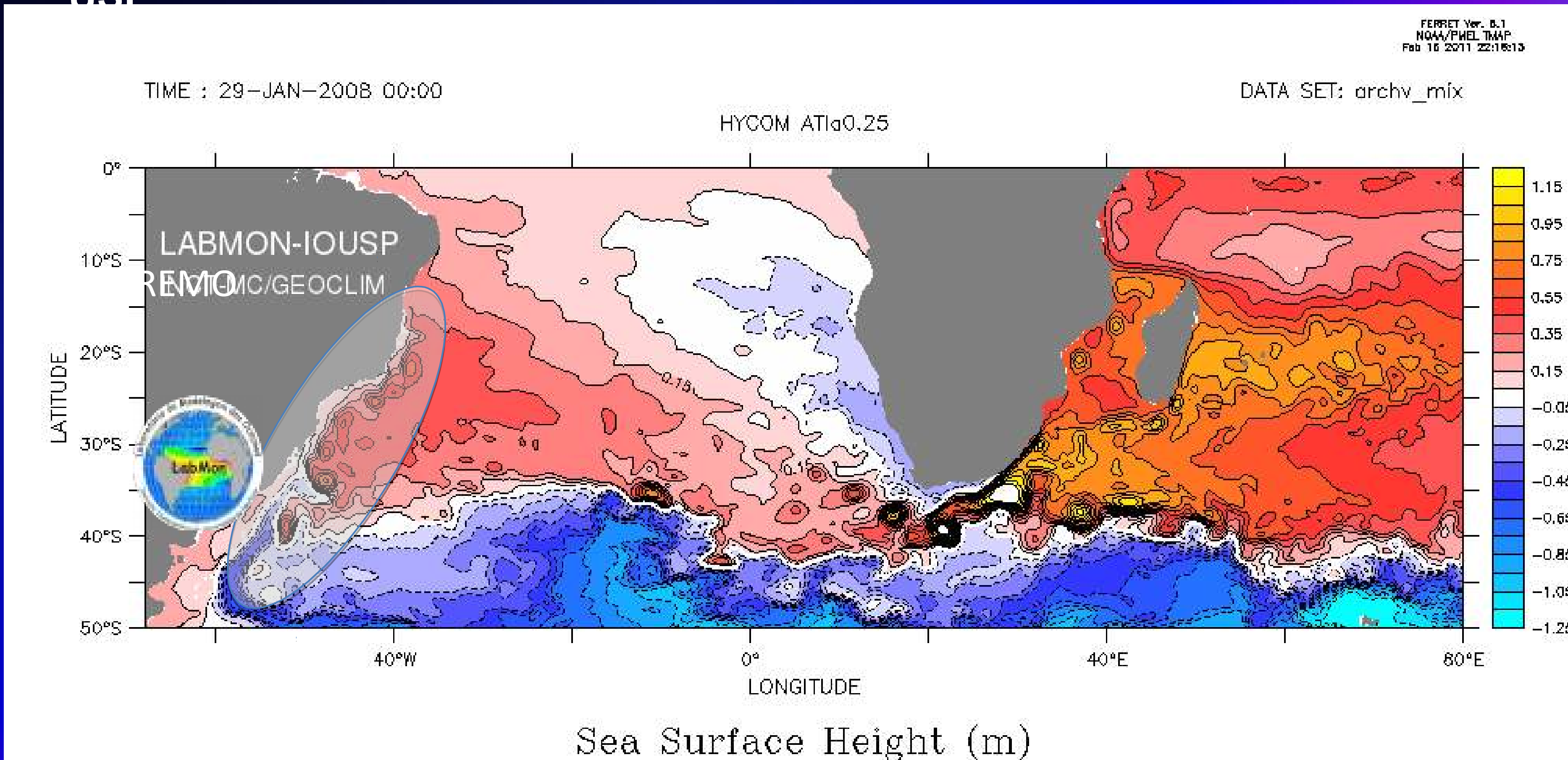
Therefore, how global climate change is already affecting the functioning of the semi-arid ecosystems and what can we expect in the future?

Apart from the effects of global and regional changes at the semi arid region itself, tele-conections & large scale transfer in the South Atlantic Ocean may also affect the residence time in estuaries and eventually the export and mobility of substances to marine food chains.



E.g. **The increasing strength of the Agulhas leakage** *(Biastoch, A., C.W. Böning, F.U. Schwarzcopf and J.R.E. Lutjeharms,* ***Nature*** *462, 495-498, Nov/2009).*

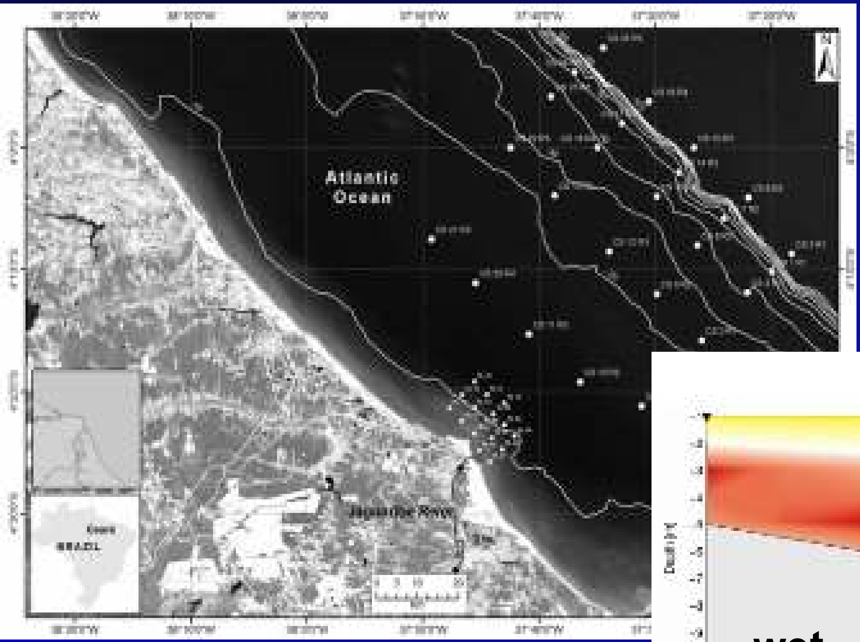
The impact of ocean water on continental shelf off the semi-arid coast of Brazil. Slide & Model, cortesy of Dr. Edmo Campos, USP

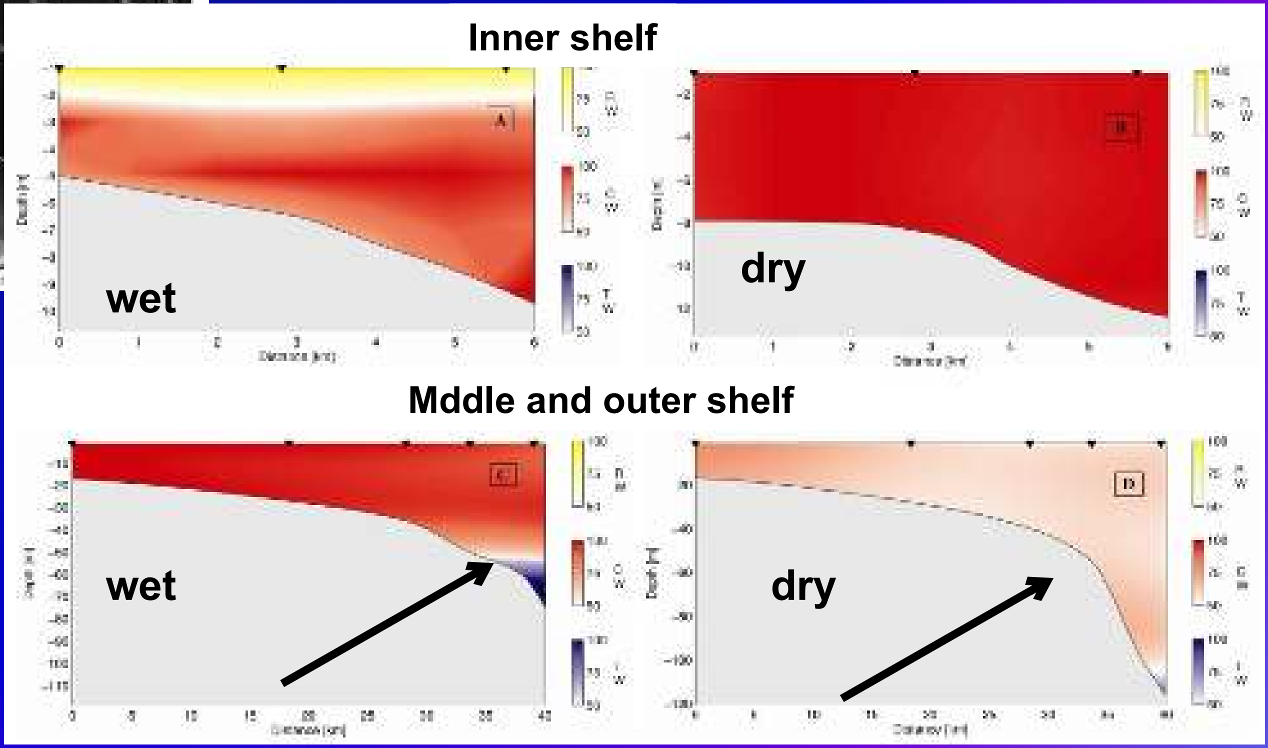


Surface circulation off the Brazilian coast is part of a "Super Gire" connecting the South Atlantic ocean with the Indian Ocean. The South Atlantic is the ocean where highest heat accumulation occurs due to global warming.

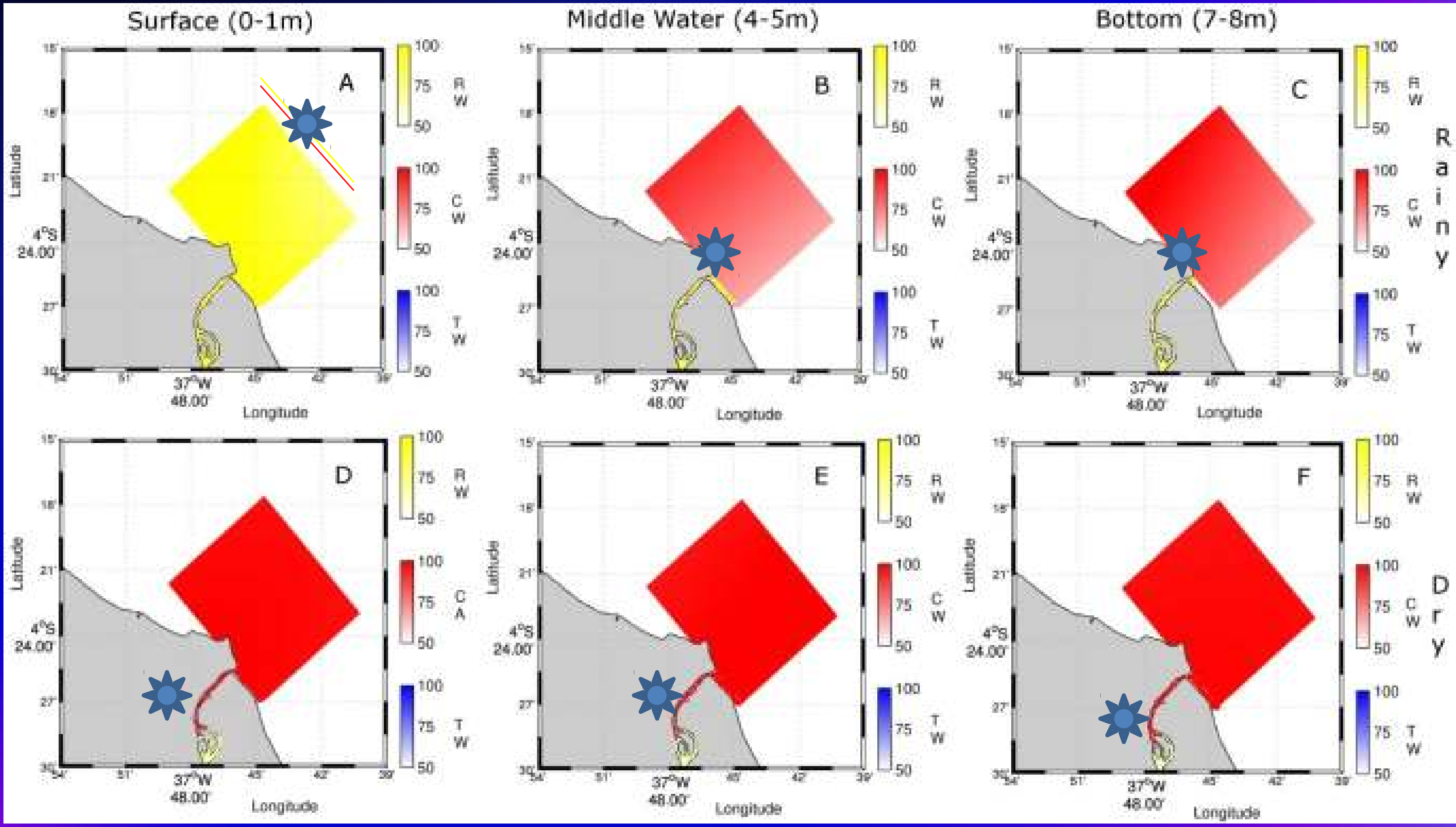
Indian Ocean waters "leek" to the South Atlantic, a key element in the global thermohaline circulation. Courtesy Dr. Edmo Campos, USP.

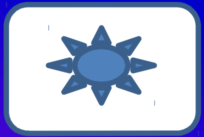
✓**Temporal and spatial distribution of continental water masses combining multi-tracers analysis and simultaneous sampling grids in river, estuary, plume and continental shelf, show freshwater plume during the rainy season and penetration of Tropical Waters (Oceanic) into the shelf. (↗) (Dias, Castro & Lacerda, 2011)**





Choking the estuary increases water residence time, augmenting reactivity and bioavailability of substances. Stronger ocean forcing moves mixing zone and reactivity processes landward (Dias, Castro & Lacerda, 2011)



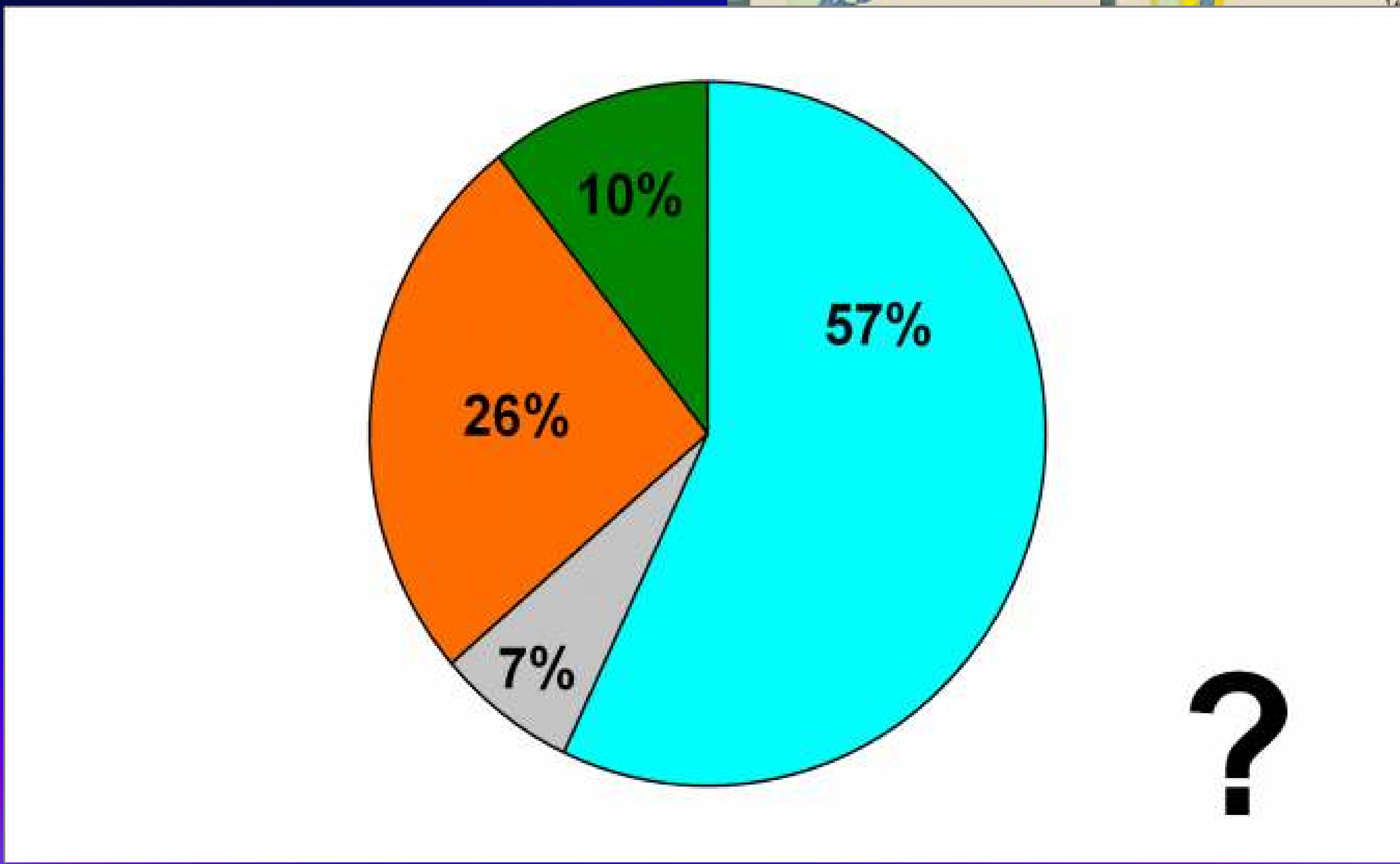


Mixing zone

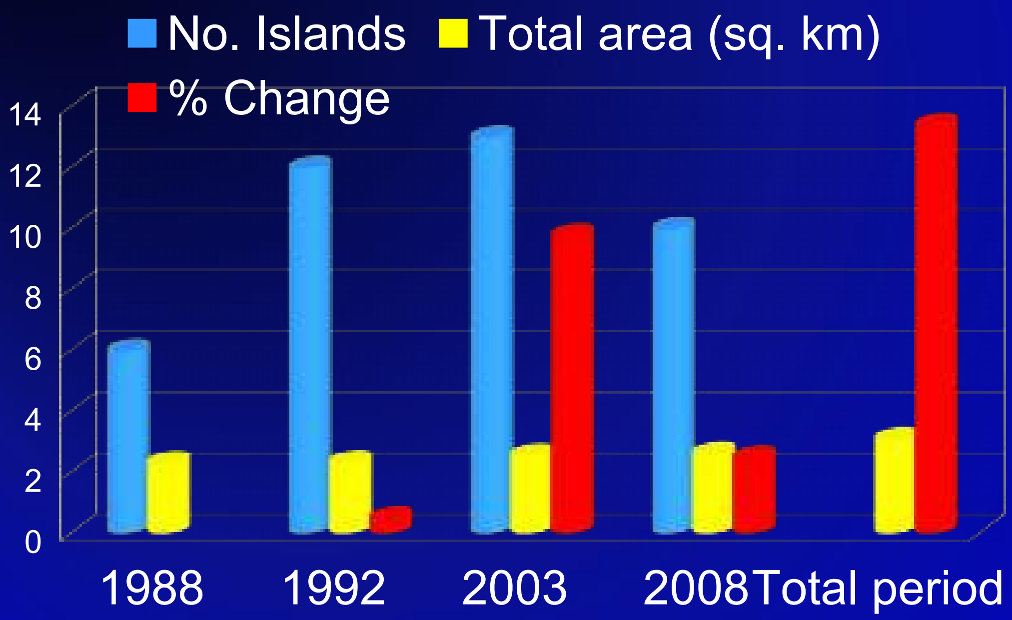
What are the major impacts of the processes described above on the fate of pollutants?

How the chemistry of pollutants responds to the increasing choking of estuaries and decreasing continental runoff, sedimentation in estuaries, mangrove expansion and longer water residence time there?

Origins of alterations identified in 41 estuaries of the semiarid littoral of NE Brazil. Comparing radar data from 1980 to Landsat, SPOT & Quickbird data from 1999 to 2013



Changes in island area in the Jaguaribe River estuary between 1988 and 2008 (Godoy & Lacerda, 2013)



Three generations of mangroves along the Jaguaribe River, NE Brazil

Mangrove expansion in NE Brazil (Maia, Gentil & Lacerda, 2006)

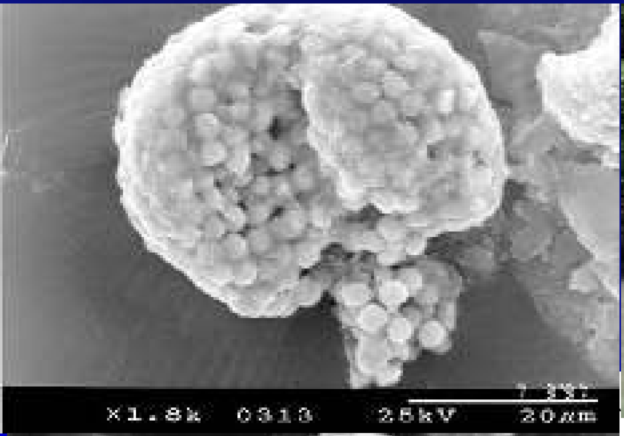
Parameter	km	%
Total mangrove area in 1978	278	
Total mangrove area in 2004	352	
Increase (uncertainty)	74	21% (3%)

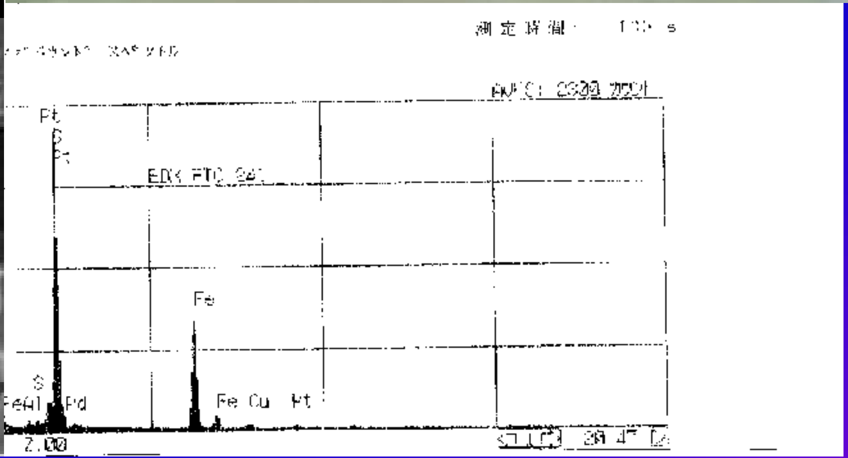
Biogeochemical Scenario

✓**Augmenting water residence time and sedimentation at the estuary increases mangrove areas and its metabolism based on dissimilatory sulfate reduction expands to larger areas.**

✓**There is a larger export of DOC from the incomplete respiration of organic matter by anaerobes.**

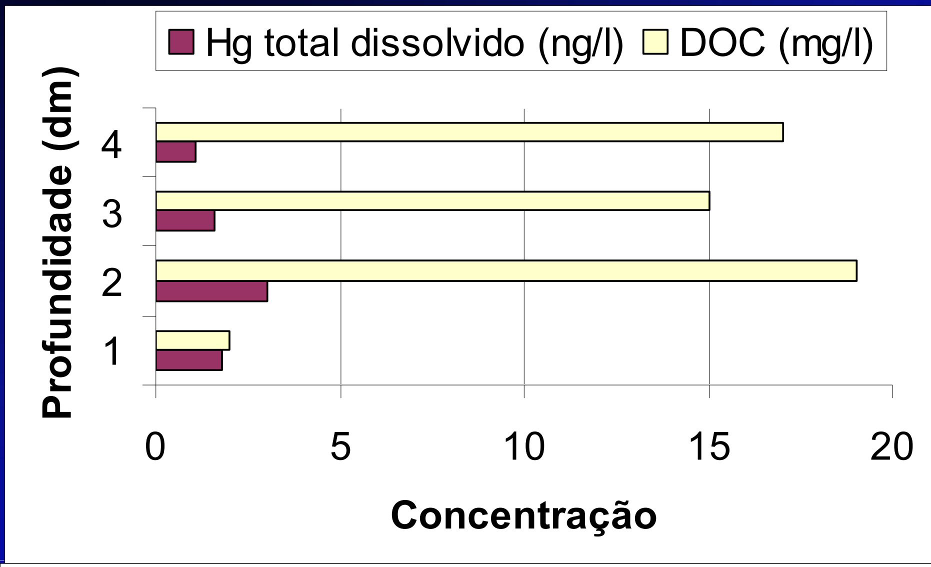
✓**Deposited metals from continental origin accumulate and suffer chemical changes instead of rapid being exported to the continental shelf.**

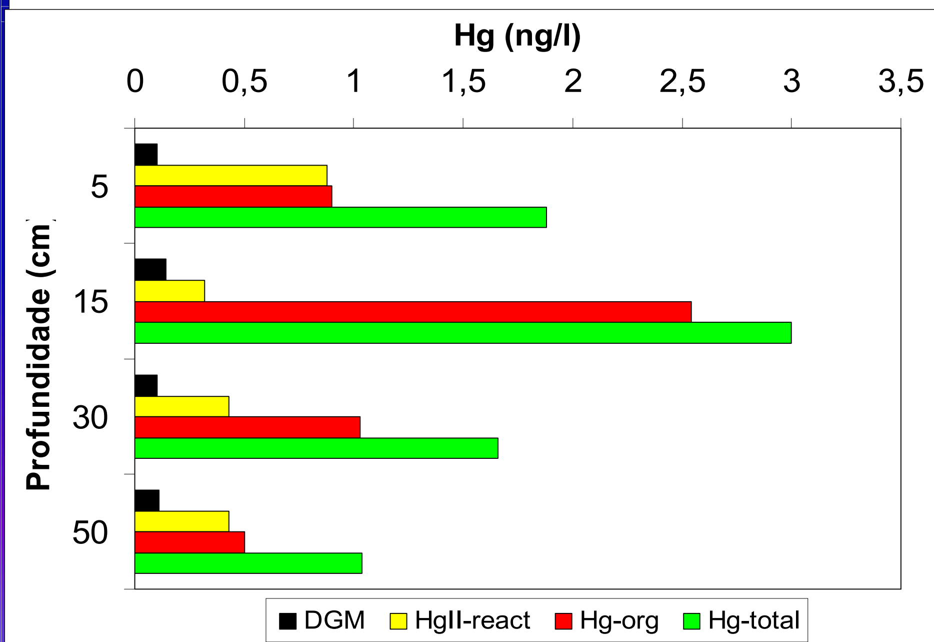


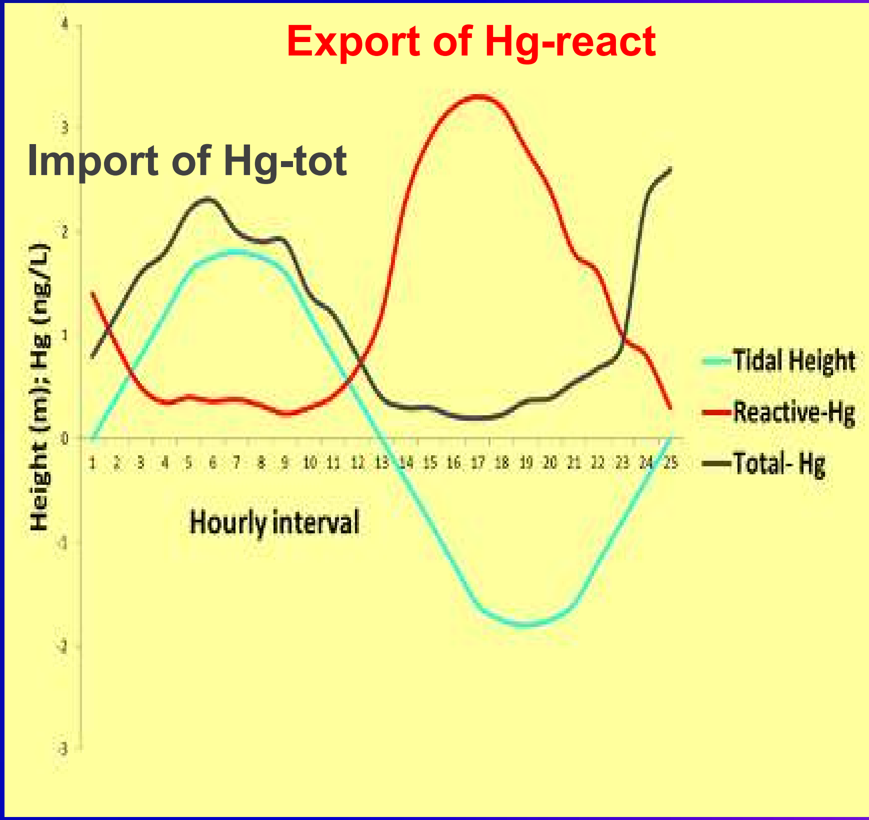


Pires & Lacerda (1997)
Lacerda (1998)
Lacerda (2007)

Organic-Hg complexes production in porewater facilitates Hg export from sediments

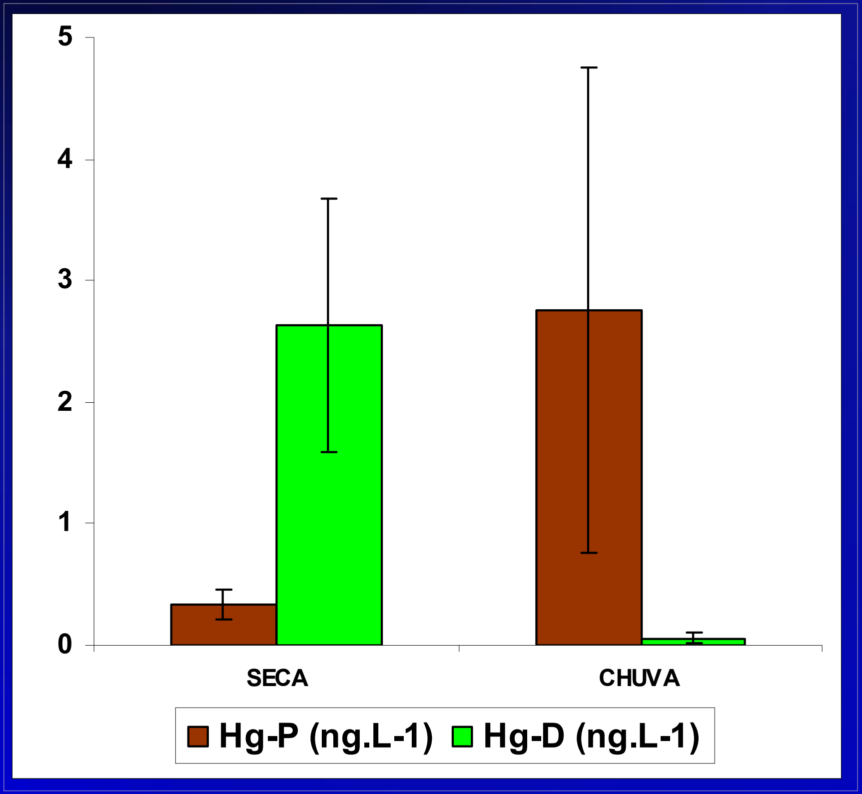


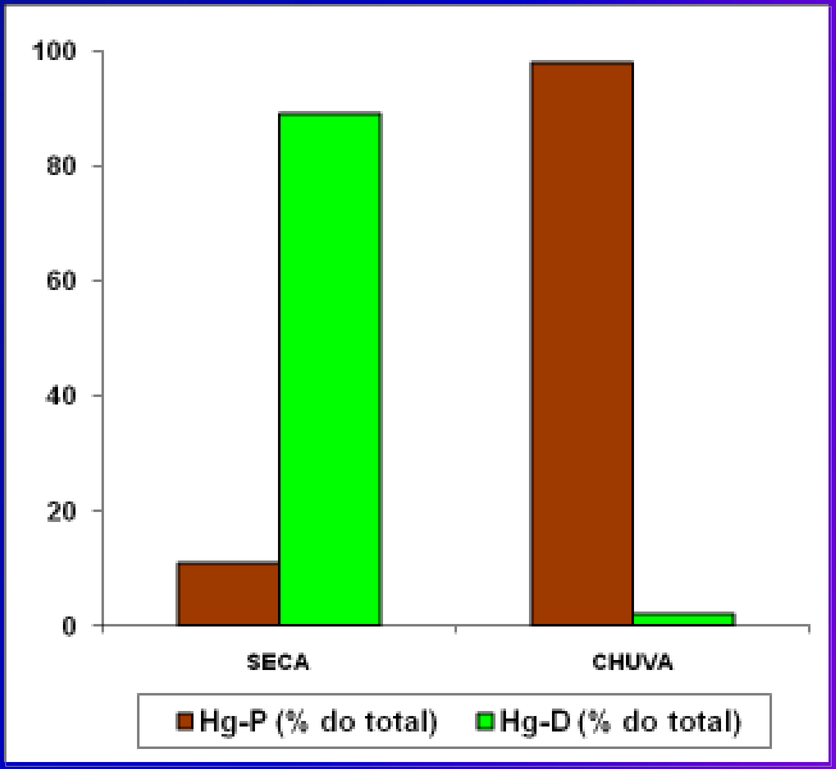




Tidal export of Hg from the from a mangrove forest (Lacerda et al., 2001)

Relative Speciation of Hg in the dry and wet season at the Jaguaribe Estuary (Lacerda et al., 2013)



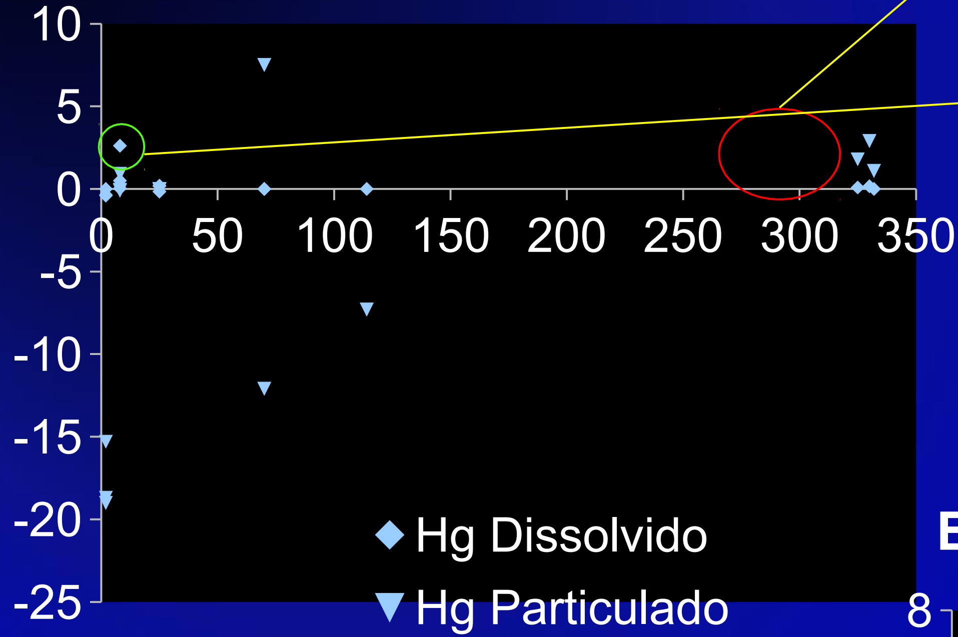


Dissolved Hg species dominate the flux during the dry season.

Particulate Hg species dominate the flux during the wet season.

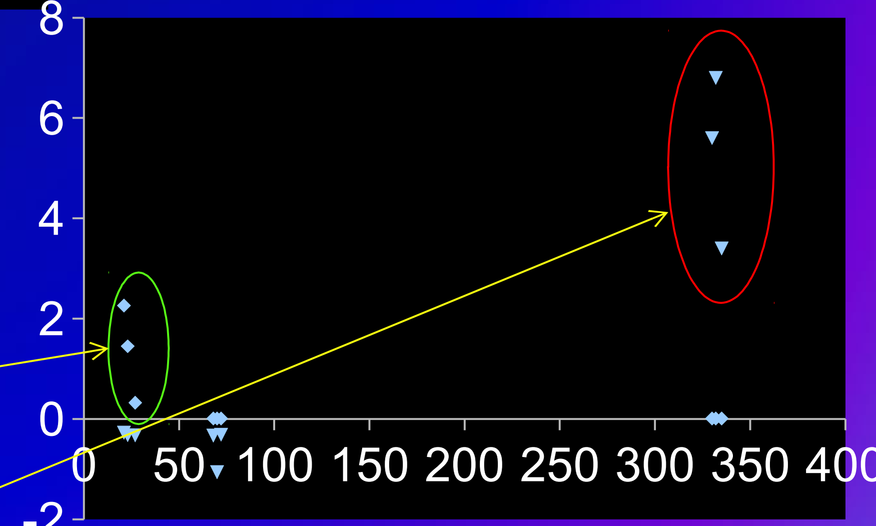
Rain vs Transport

River to estuary

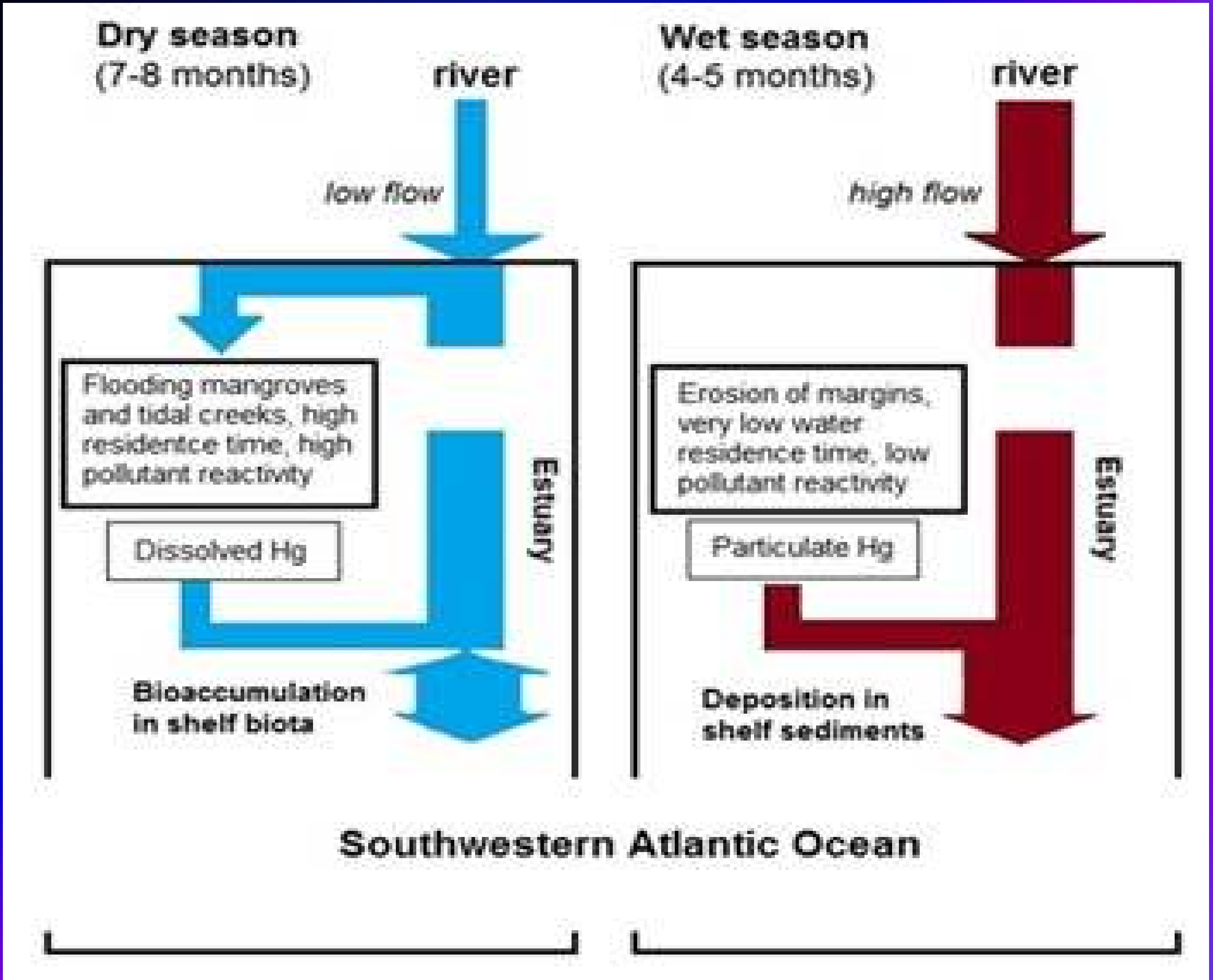


Export of particulate Hg from river to estuary occurs only under **intermediate and high fluvial fluxes**; Dissolved Hg export occurs with **fluvial fluxes close to zero**

Estuary to Sea



Export of dissolved Hg occurs only during the dry season **with discharge close to zero**. Particulate Hg export occurs only under **very high water discharge**



Dry season
(7-8 months)
river
low flow
Flooding mangroves and tidal creeks, high residence time, high pollutant reactivity
Dissolved Hg
Estuary
Bioaccumulation in shelf biota
Wet season
(4-5 months)
river
high flow
Erosion of margins, very low water residence time, low pollutant reactivity
Particulate Hg
Estuary
Deposition in shelf sediments
Southwestern Atlantic Ocean

Mechanisms involved in the augment of Hg dissolved species (bioavailable), favored by the augment of the water residence time within the estuary

- **Desorption of Hg from suspended particles due to salinity increase and saline intrusion landward**
- **Export of pore waters enriched in DOC from ever larger mangrove forests**
- **Formation and export of soluble Hg-organic complexes**
- **Increased uptake by the phytoplankton associated with higher water transparency.**
- **Faster assimilation and accumulation in the food chain**

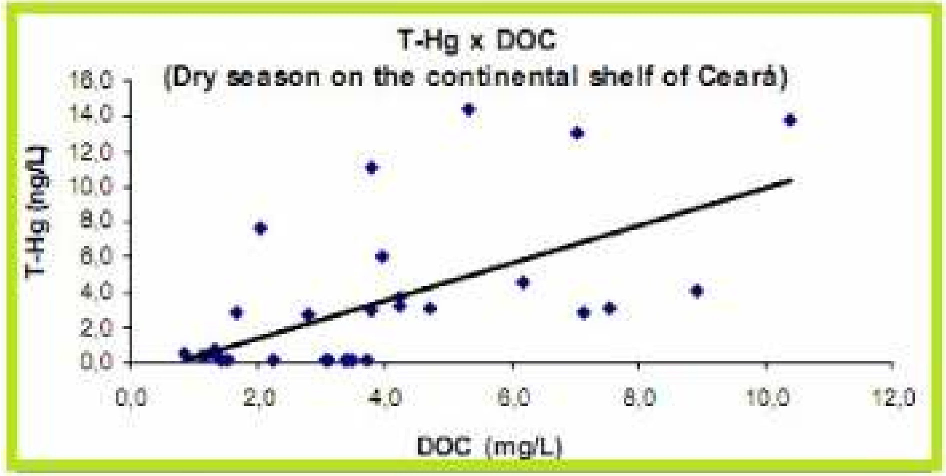


Figure 1: Correlation of T-Hg concentration (ng/L) with DOC (mg/L) ($r = 0.6003$, $n = 31$, $p < 0.05$) during the dry season on the continental shelf of Ceará - Brazil.

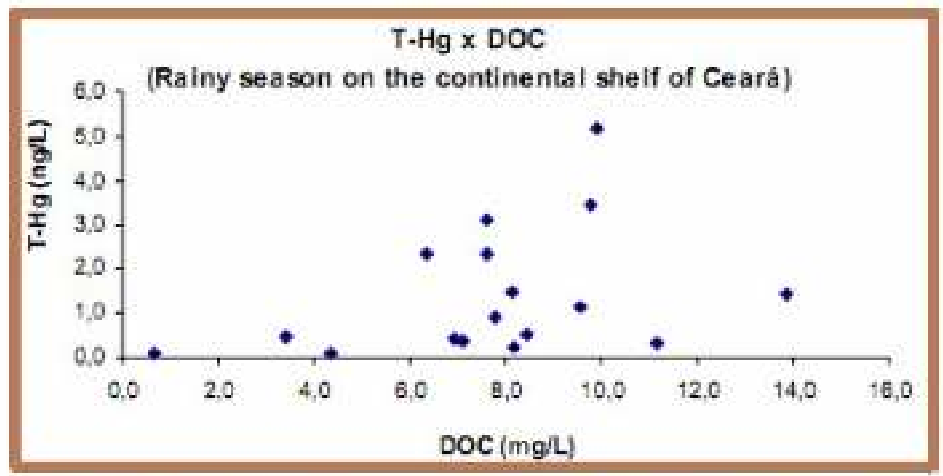
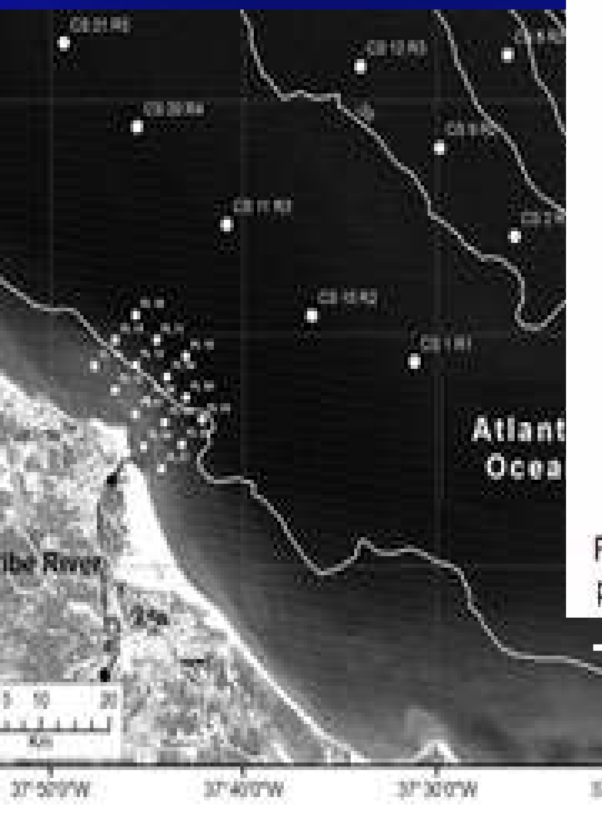


Figure 2: Correlation of T-Hg concentration (ng/L) with DOC (mg/L) ($r = 0.3604$, $n = 20$, $p < 0.05$) for the rainy season on the continental shelf of Ceará - Brazil.



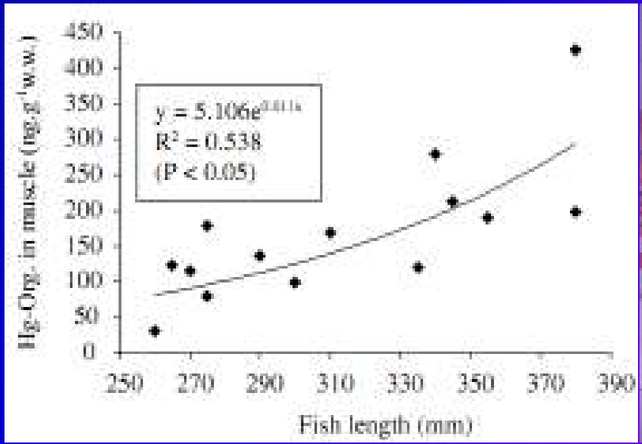
Total Hg in coastal waters off the Jaguaribe River (Soares, Marins & Lacerda, 2011)

Augment of water mass chocking and water residence time in estuaries. Increasing saline intrusion and accumulation of continental materials inside the estuary

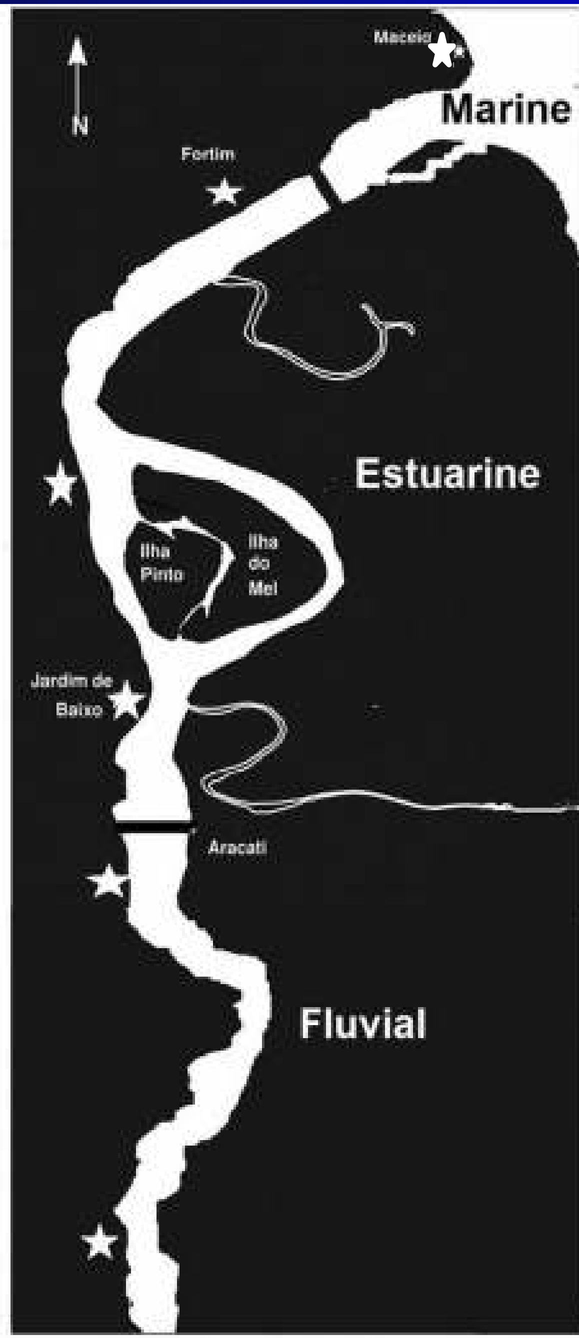
Hg-Org

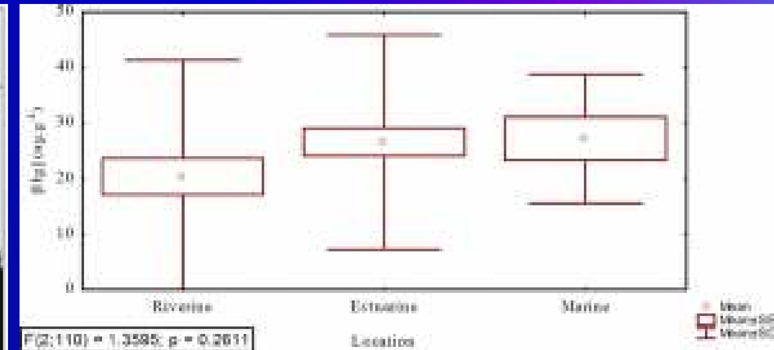
Continental fluxes may decrease in total but qualitative changes occur due to longer residence time augmenting reactive and bioavailable species (e.g. Hg)

Increasing reactive species increases biological uptake, food chain transfer and human exposure.



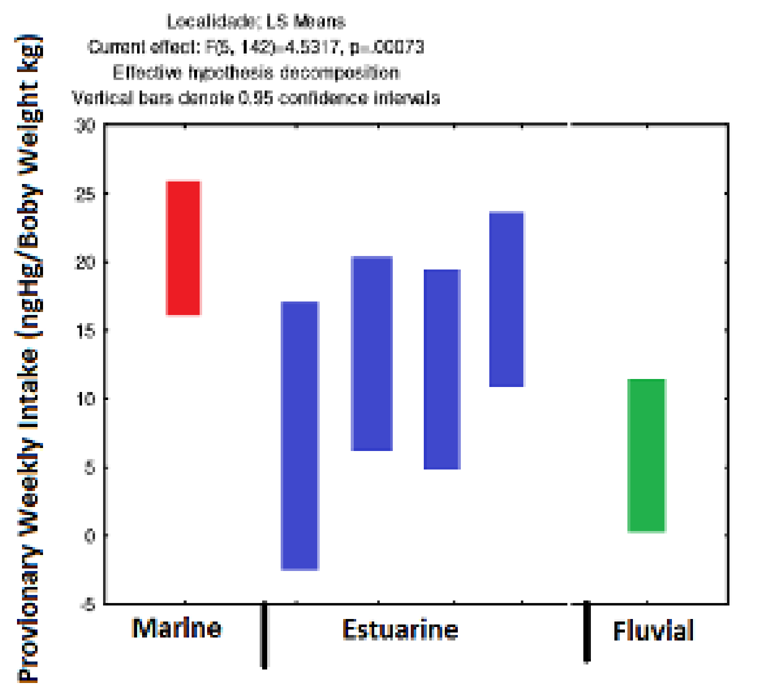
Hg em *Cephalopholis fulva* do mar cearense (Lacerda *et al.*, 2006)





Hg in Fish

Human exposure



Obrigado!

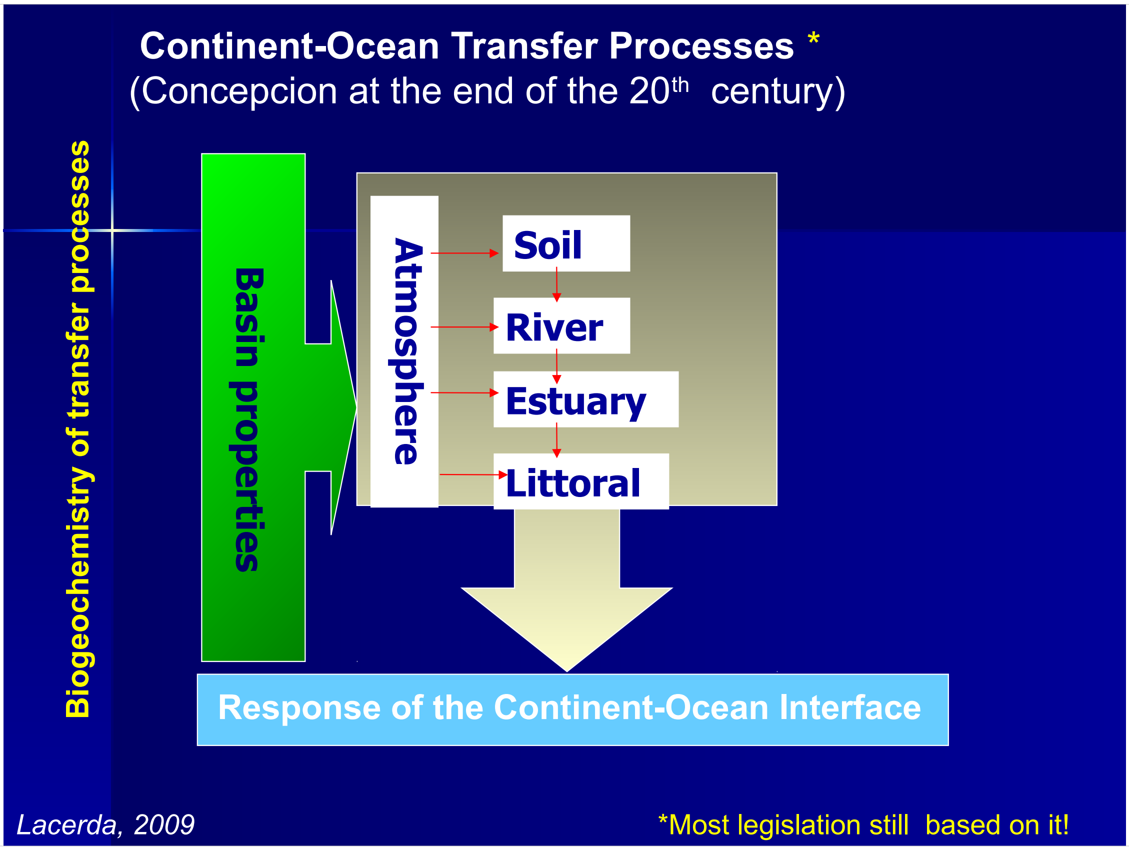
http://inct.cnpq.br/web/inct-tmcocean/home/

Materials Transfer at the Continent-Ocean Interface under the Scenario of the Anthropocene

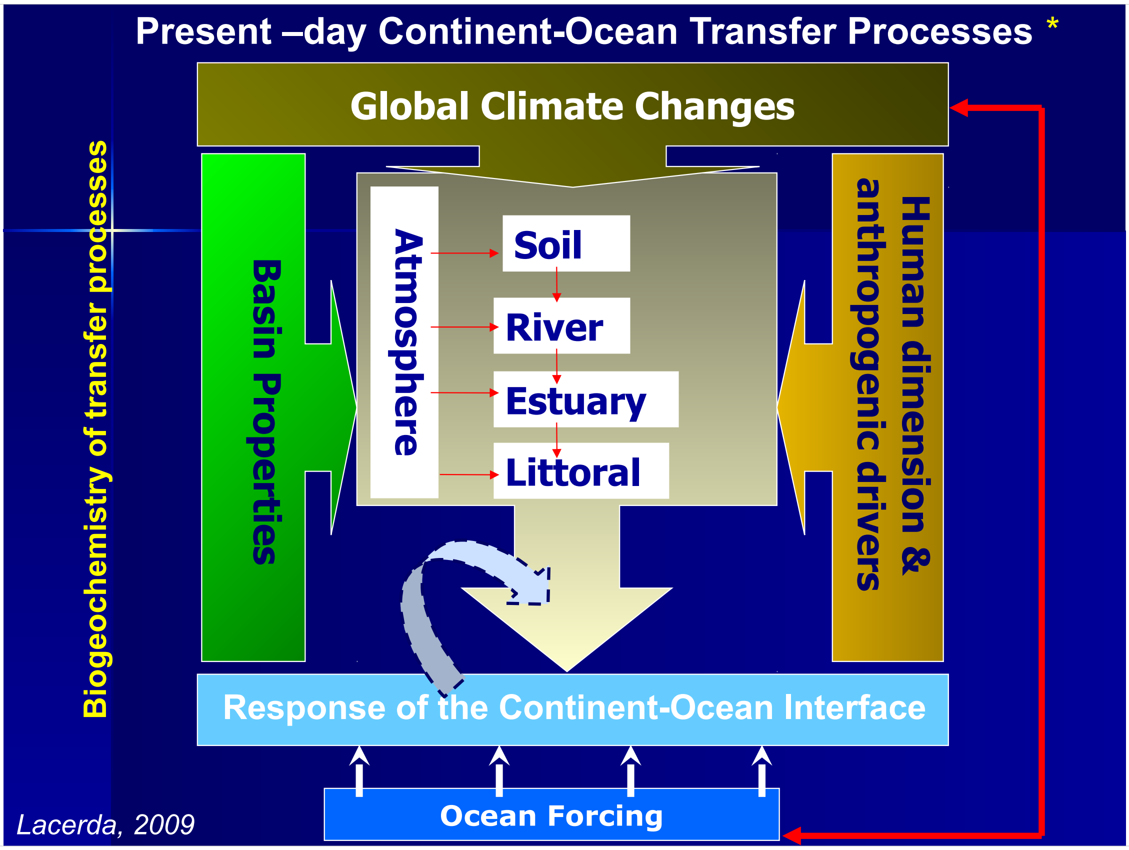
Luiz Drude de Lacerda

Instituto de Ciencias do Mar, UFC

http://inct.cnpq.br/web/inct-tmcocean/home/



Continent-Ocean Transfer Processes *
(Concepcion at the end of the 20th century)
Biogeochemistry of transfer processes
Basin properties
Atmosphere
Soil
River
Estuary
Littoral
Response of the Continent-Ocean Interface
Lacerda, 2009
*Most legislation still based on it!

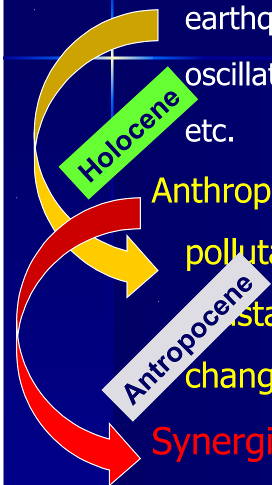

Present –day Continent-Ocean Transfer Processes *
Global Climate Changes
Biogeochemistry of transfer processes
Basin Properties
Atmosphere
Soil
River
Estuary
Littoral
Human dimension & anthropogenic drivers
Response of the Continent-Ocean Interface
Ocean Forcing
Lacerda, 2009

Principals characteristics of the COI

- **1 – T**ransfer of water, mass and energy occur through the continent-ocean interface at large spatial scale both in terrestrial and marine adjacent areas
- **2 - T**ransfer occurs simultaneously both at continent-ocean and ocean-continent directions at different temporal e spatial scales.
- **3 – T**ransfer is affected by natural and anthropogenic vectors.

c.f. Kjerfve, 2007

Vectors affecting the continent-ocean transport



Naturals: geotectonic (subsidence/elevation), wind, earthquakes, hurricanes, tsunamis, inundations, sea level oscillation, type and abundance of coastal vegetation, etc.

Anthropogenic: wastewaters, agriculture runoff, pollutant emissions and remobilization, conversion of coastal areas, engineering works, global climate changes.

Synergies: vectors act simultaneously and do affect each other, including through feedback mechanisms, in generally very poorly known.

c.f. Kjerfve, 2007

Major effects of anthropogenic vectors

(i) Human activities largely accelerate biogeochemical cycles and the transfer of materials at the planetary levels;

(ii) Natural fluvial filters have been constantly altered, particularly by the construction of dams and deforestation of gallery forests and conversion of coastal vegetation;

(iii) Fluvial discharges to the oceans are presently artificially controlled and reduced by engineering interventions (dams, diversion withdraw) and due to global climate change, at least in lower latitudes).

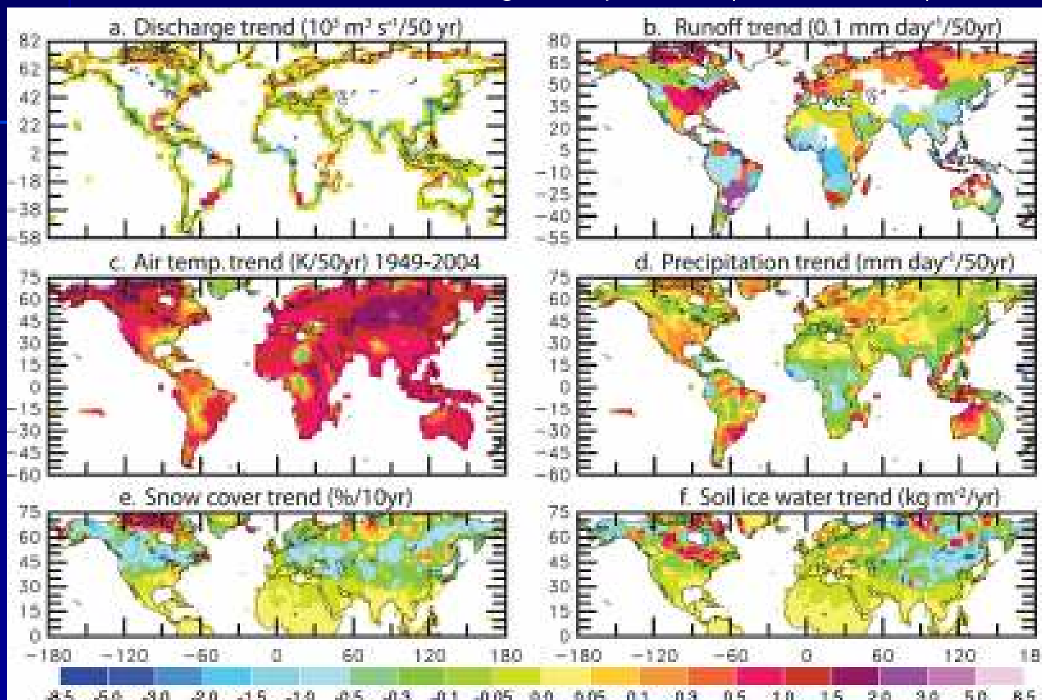
Meybeck a & Vörösmarty (2005)

Principals classes of anthropogenic vectors affecting the transport of materials at the continent-ocean interface

Vectors	Pressure	Impact
Agribusiness/ Aquaculture	Increasing loads of sediments, nutrients and contaminants, permeability of surfaces, decreasing water availability	Sedimentation Eutrophication
Urbanization / Industrialization		Sedimentation Eutrophication Contamination
Dams	Retention of sediments and nutrients Regularization of the fluvial flux	Sedimentation Erosion Oligotrophy
Global climate change	Sea level rise, alteration of the rainfall regime	Sedimentation Erosion

Marins et al. (2002)

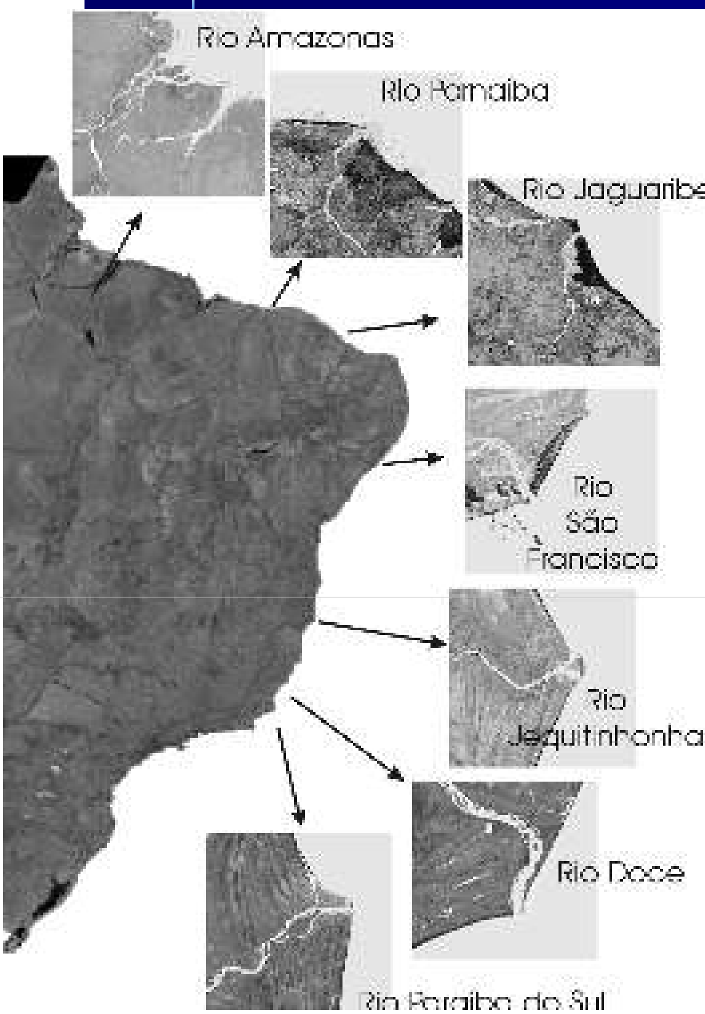
Global changes augment continental runoff in high latitudes, and decrease in lower latitudes and in semiarid regions in particular (Dai et al., 2009).



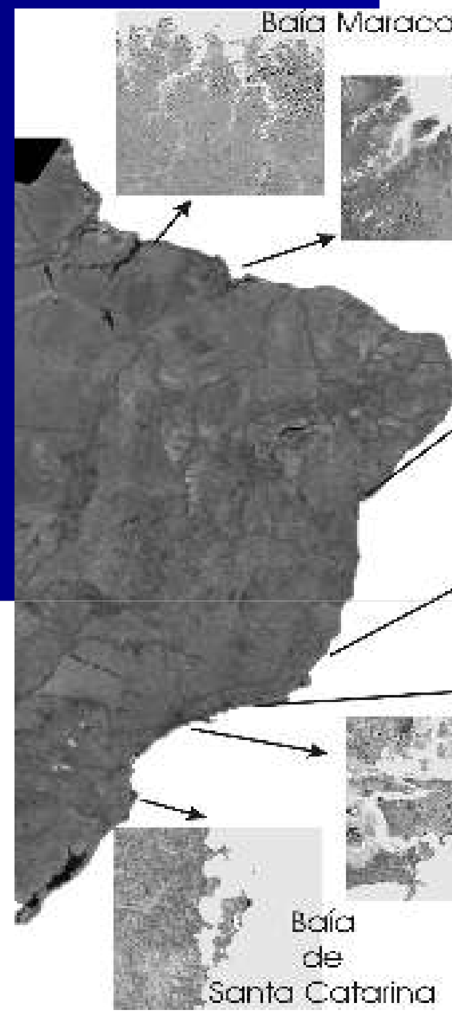
Clases of interface systems in Brazil (Knoppers *et al.*, 2009).

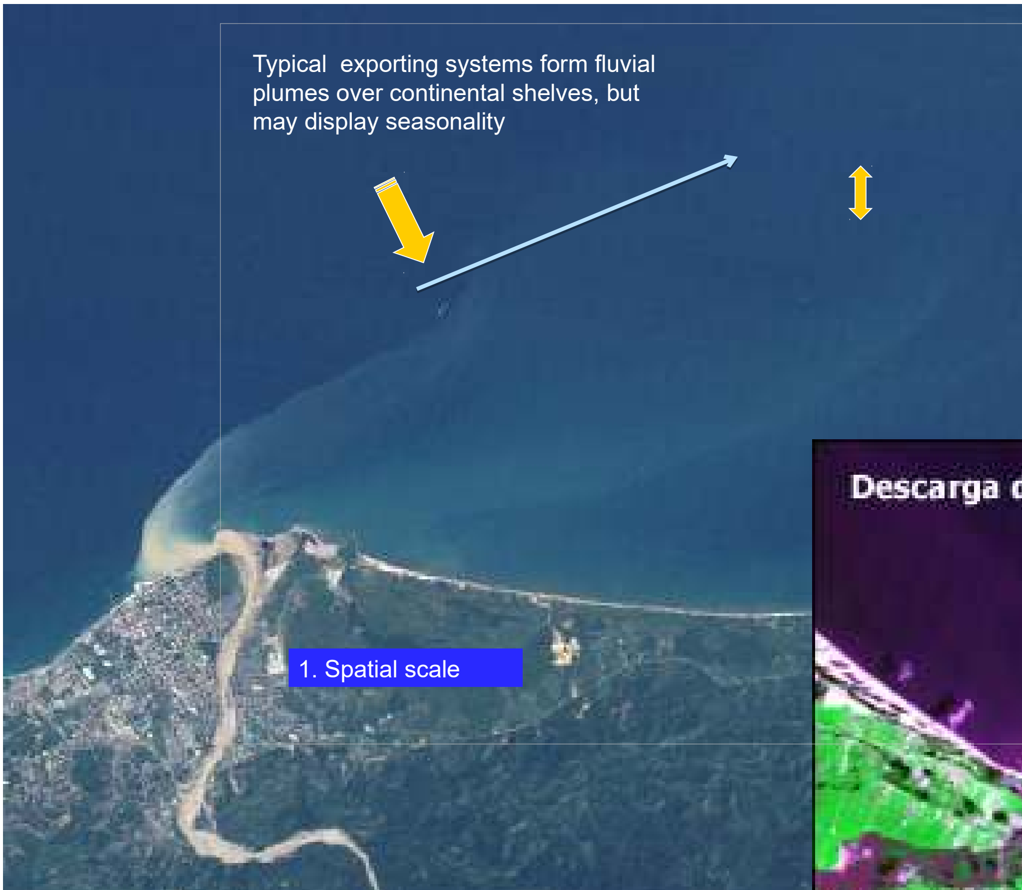
1. Spatial Scale

Exporters / Accumulators

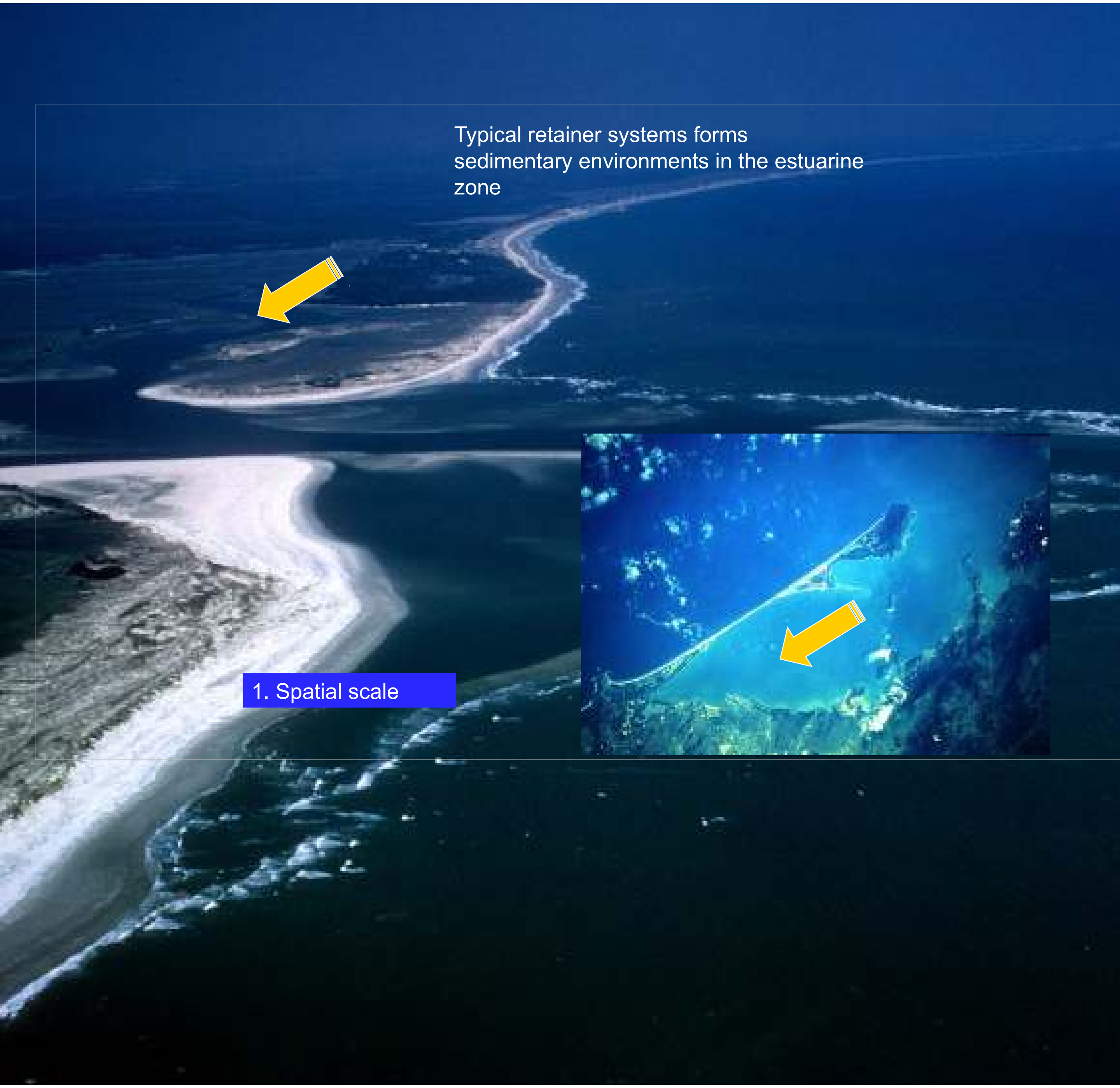


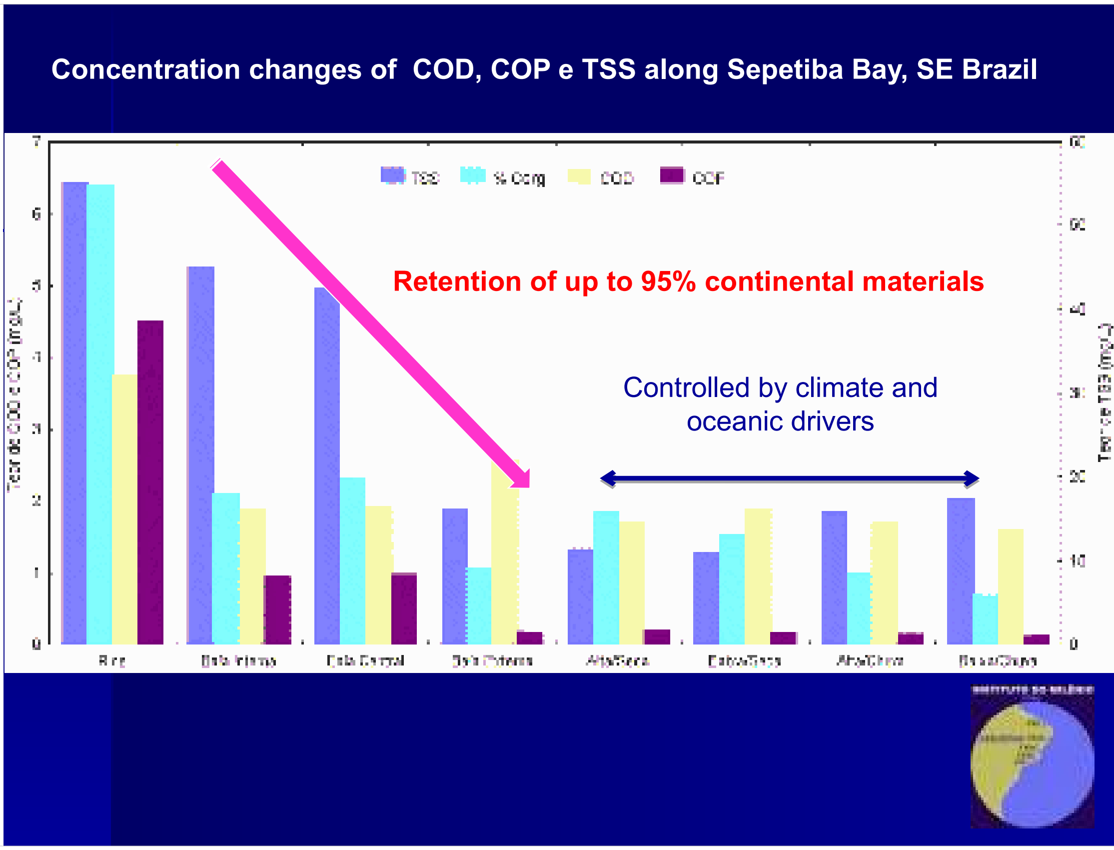
Accumulators/ Exporters



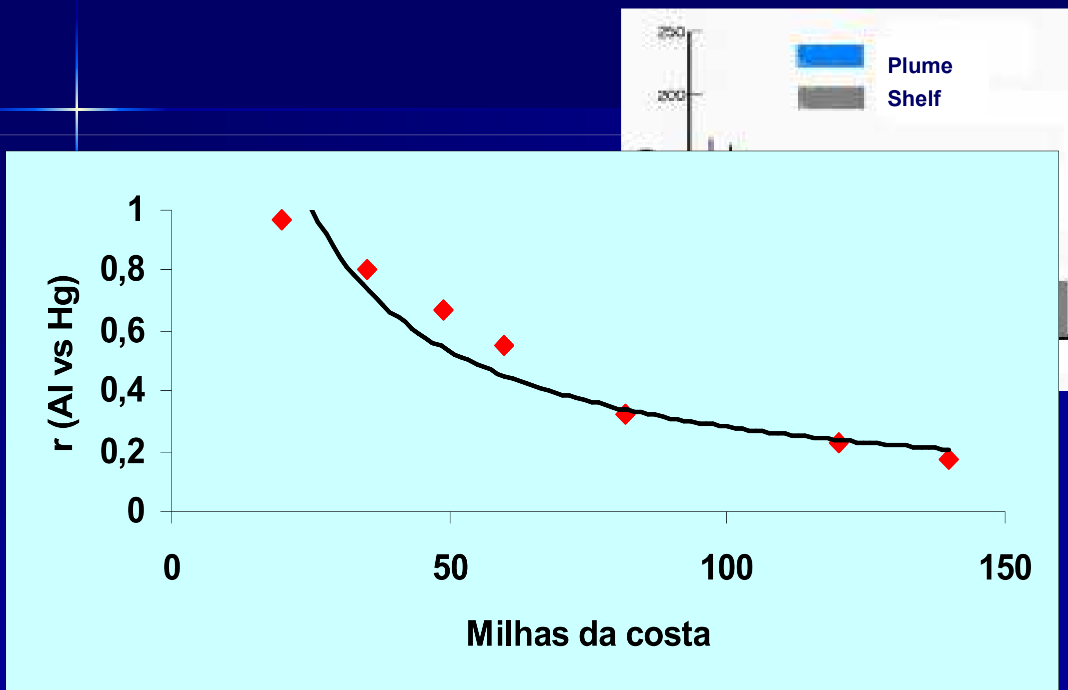

Typical exporting systems form fluvial plumes over continental shelves, but may display seasonality
1. Spatial scale


Descarga de sedimentos pelo Rio Ja


Typical retainer systems forms
sedimentary environments in the estuarine
zone
1. Spatial scale

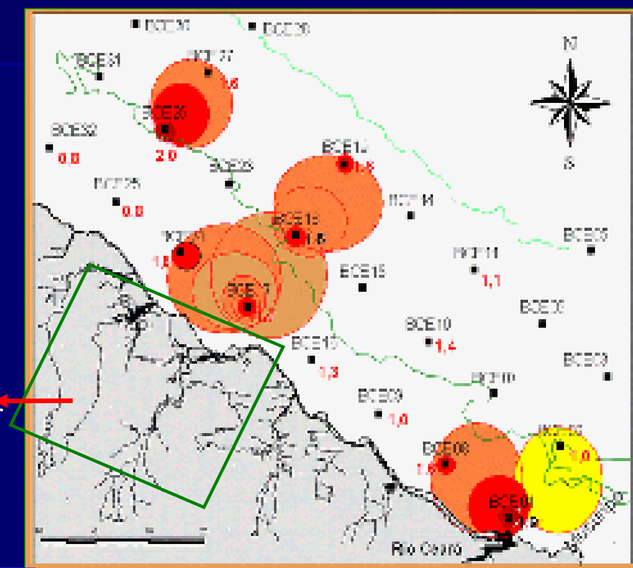

Concentration changes of COD, COP e TSS along Sepetiba Bay, SE Brazil
TSS
% Corg
COD
COP
Retention of up to 95% continental materials
Controlled by climate and oceanic drivers

Hg *vs* Al in sediments along the continental shelf in SE Brazil



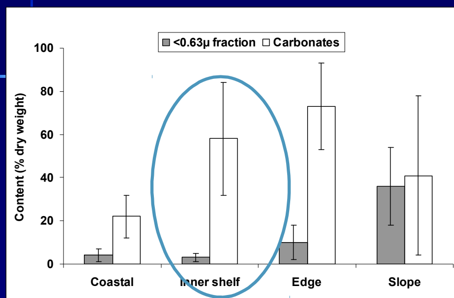
Al distribution in shelf sediments from NE Brazil

Irrigated perimeter

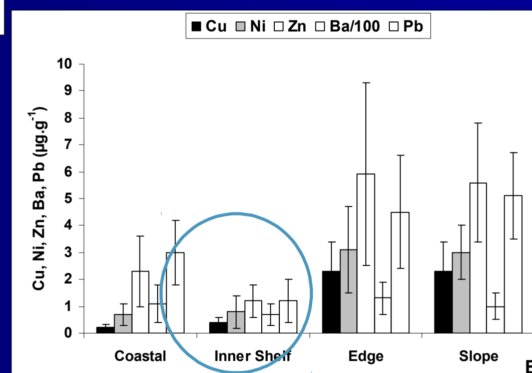


1. Spatial scale

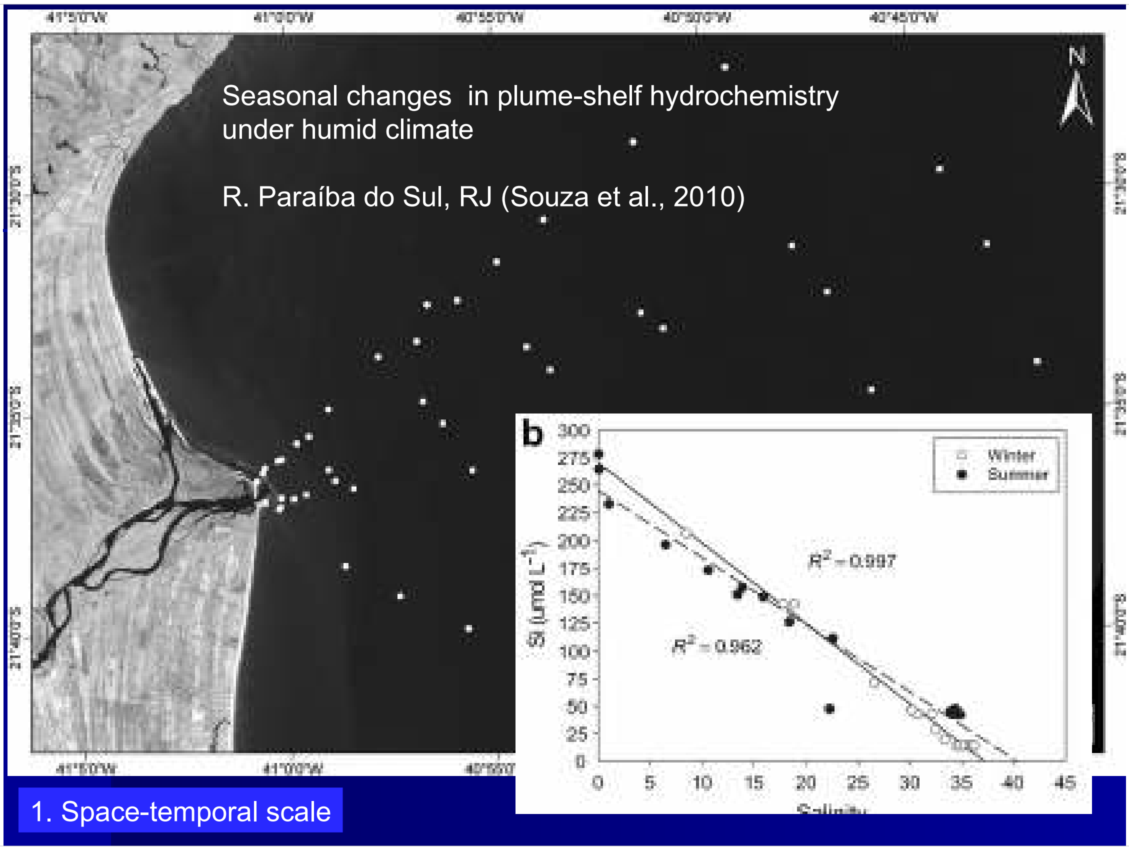
Trace metals in shelf sediments ina offshore oil and gas exploration area in NE Brazil (Lacerda et al., 2013)



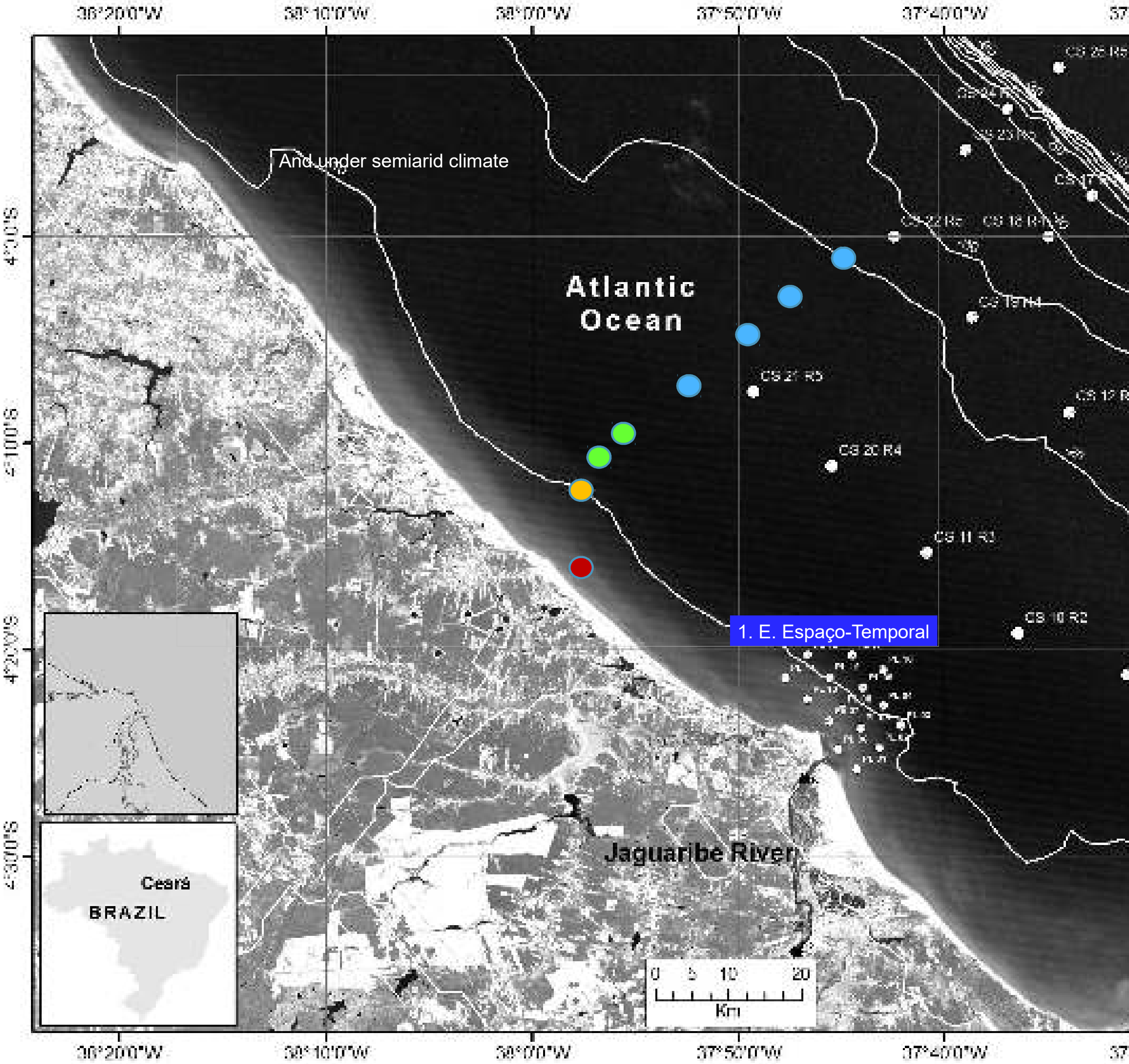
Potiguar Basin, RN



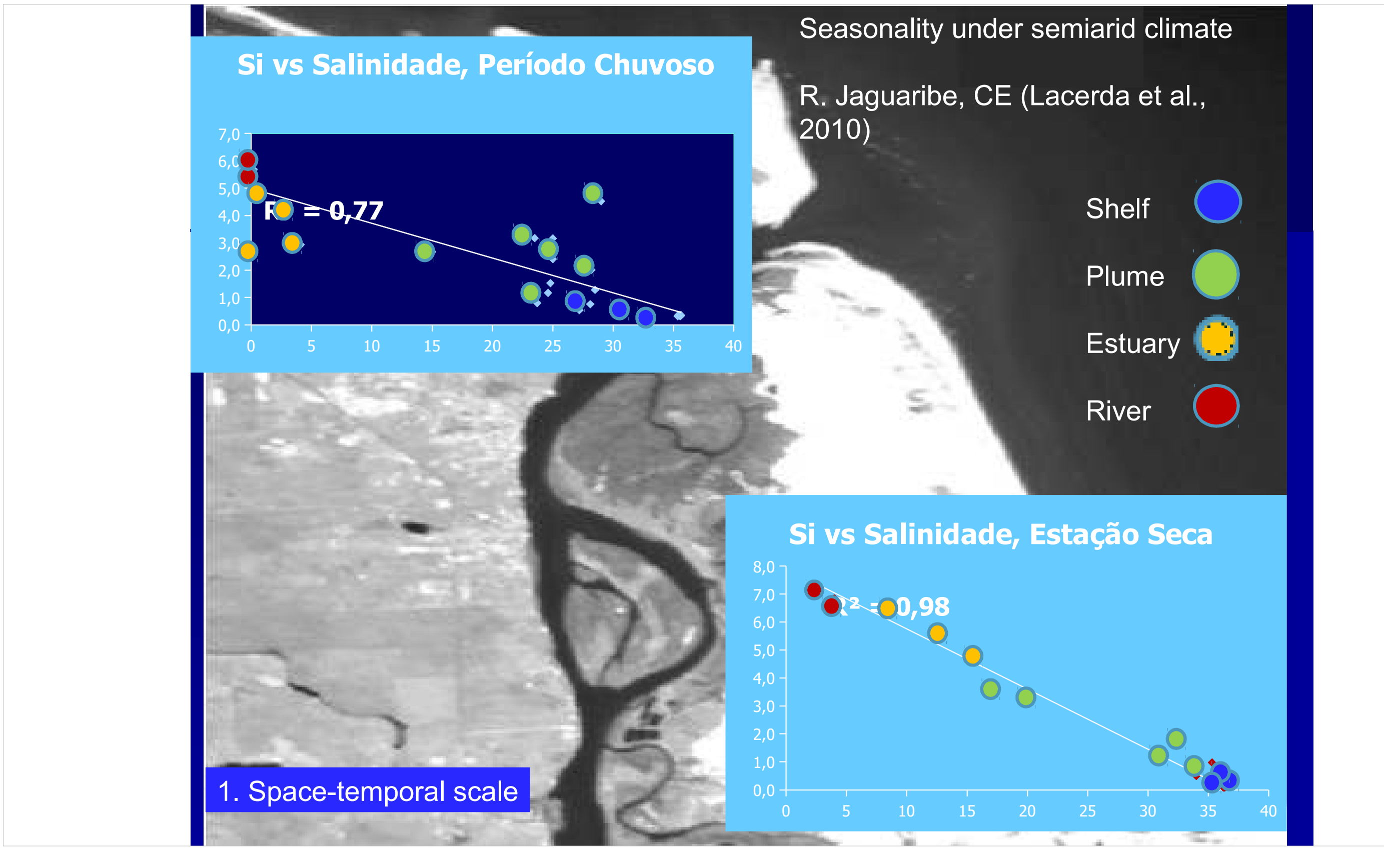
1. Spatial scale



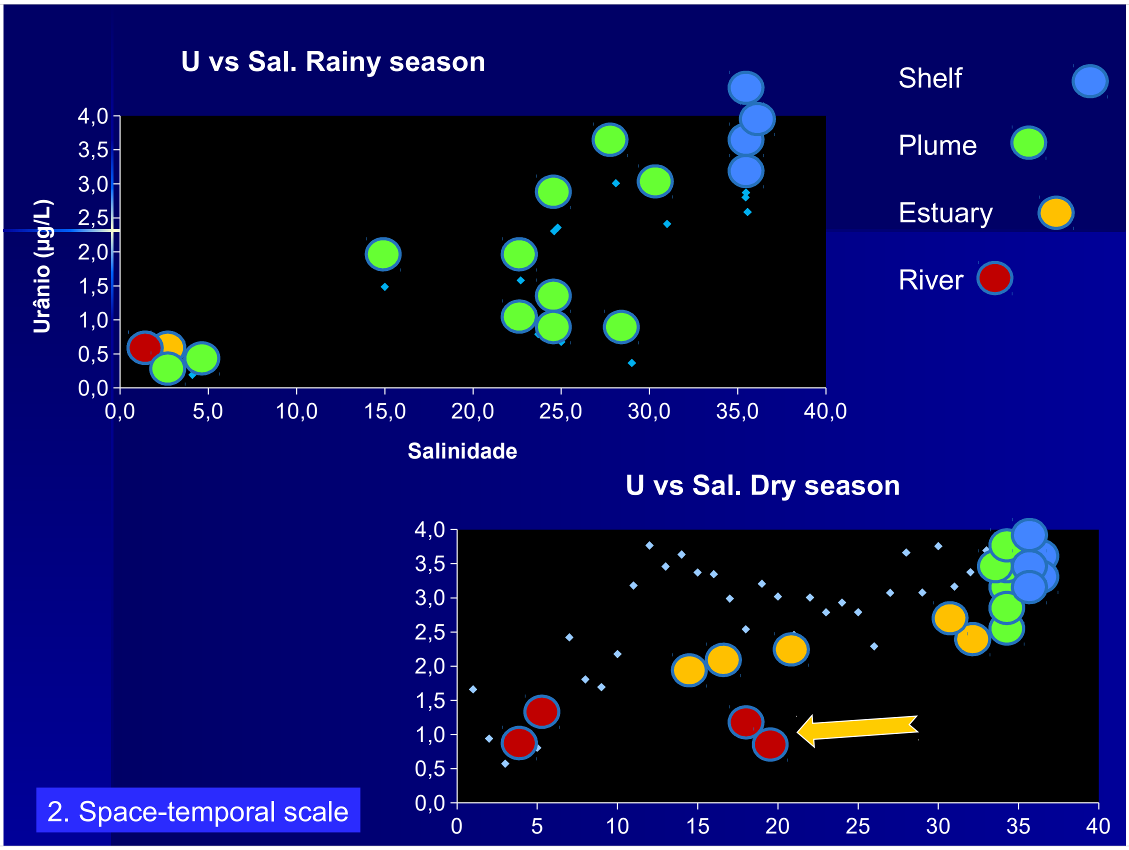
Seasonal changes in plume-shelf hydrochemistry
under humid climate
R. Paraíba do Sul, RJ (Souza et al., 2010)
N
b
Winter
Summer
R^2 = 0.997
R^2 = 0.962
Si (µmol L^{-1})
1. Space-temporal scale

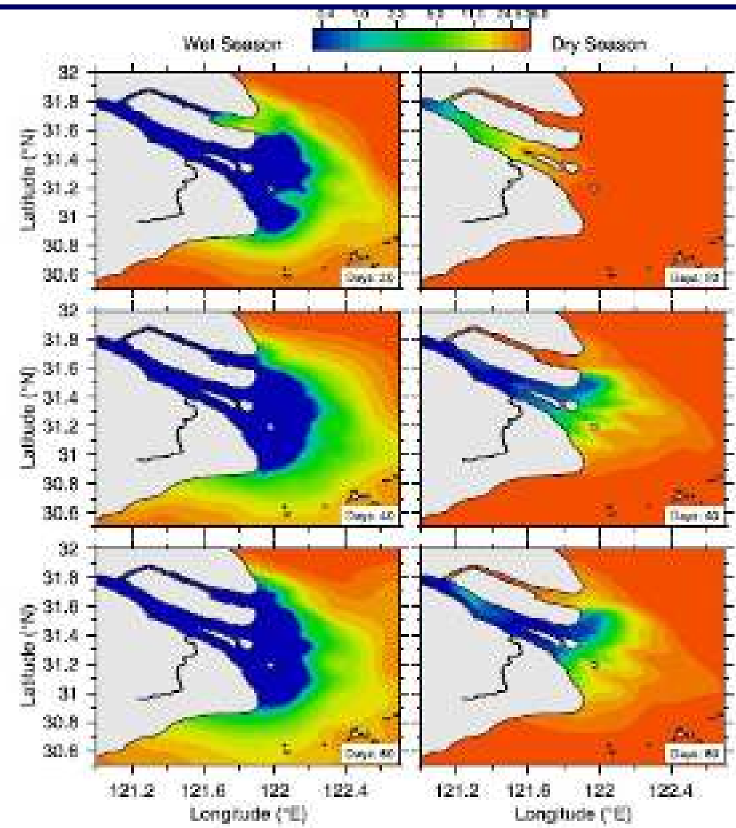


And under semiarid climate
Atlantic Ocean
1. E. Espaço-Temporal
Jaguaribe River
Ceará
BRAZIL
Km

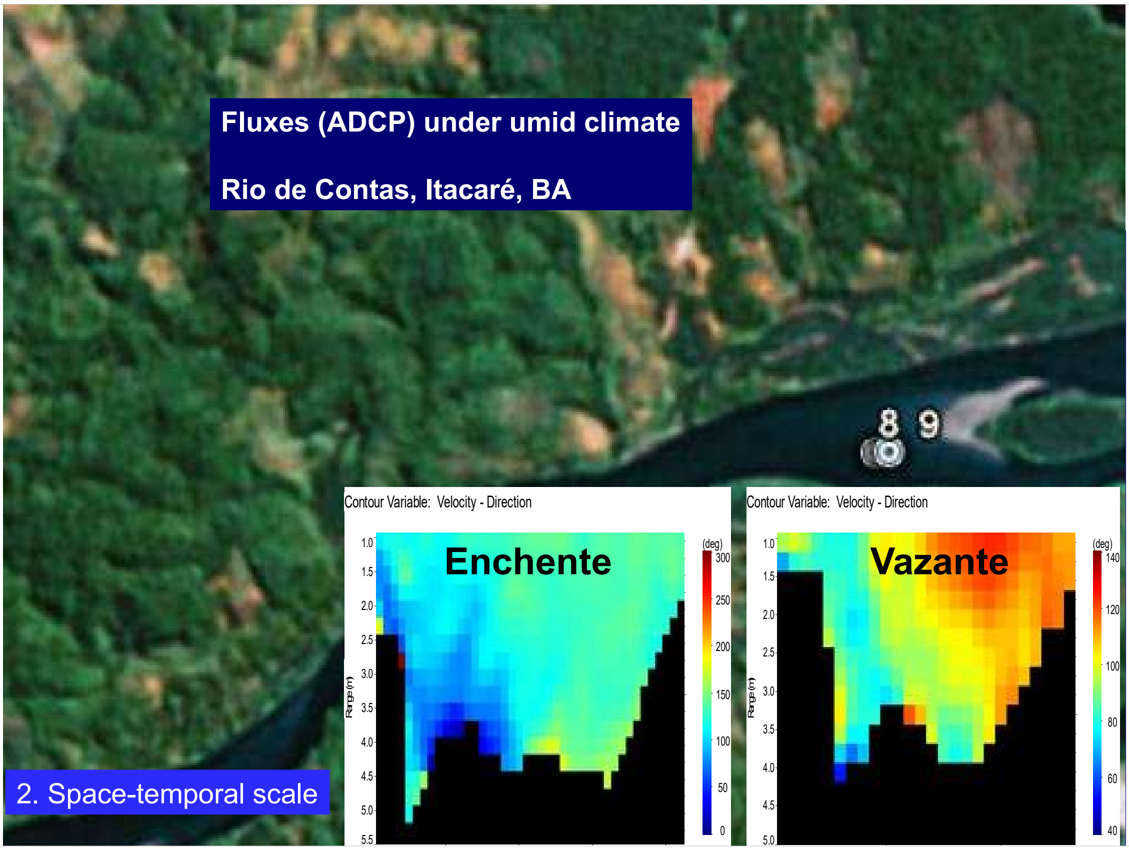


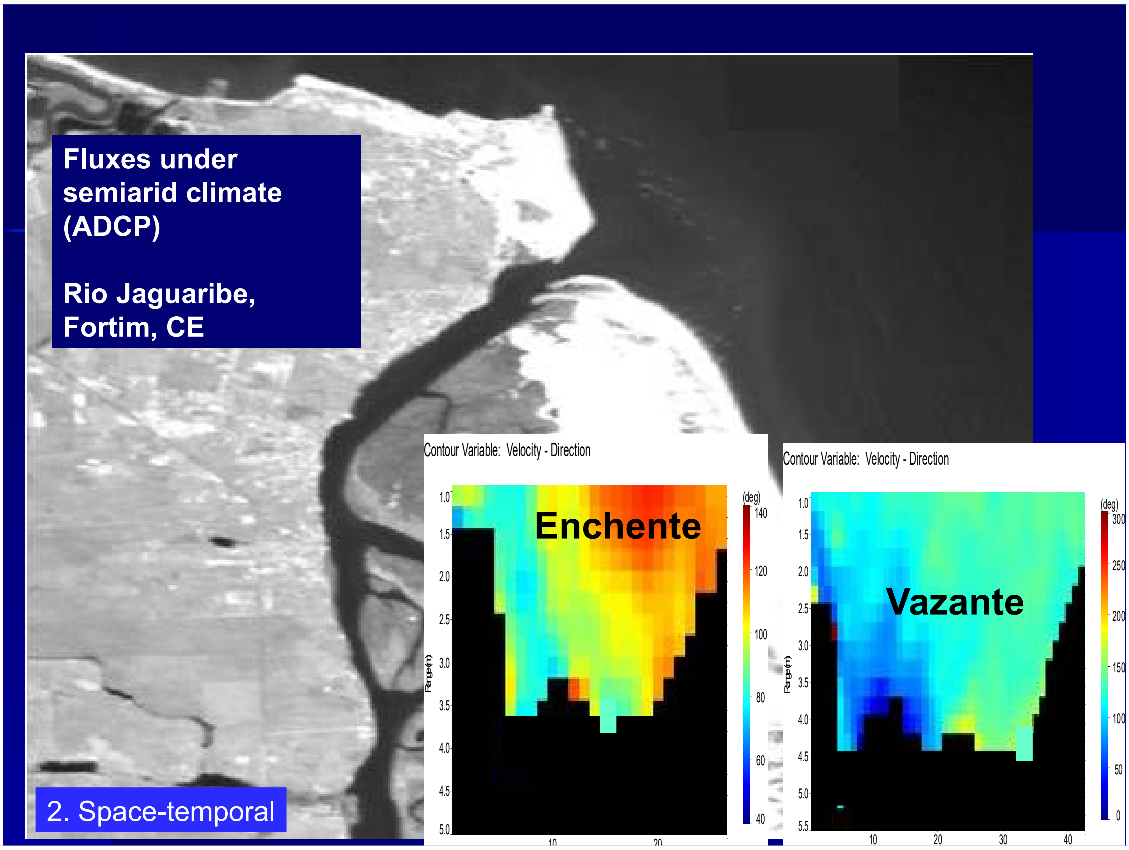
Seasonality under semiarid climate
R. Jaguaribe, CE (Lacerda et al., 2010)
Si vs Salinidade, Período Chuvoso
= 0,77
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
0
5
10
15
20
25
30
35
40
Shelf
Plume
Estuary
River
Si vs Salinidade, Estação Seca
= 0,98
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
0
5
10
15
20
25
30
35
40
1. Space-temporal scale


U vs Sal. Rainy season
Shelf
Plume
Estuary
River
Urânio (µg/L)
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,0
5,0
10,0
15,0
20,0
25,0
30,0
35,0
40,0
Salinidade
U vs Sal. Dry season
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
5
10
15
20
25
30
35
40
2. Space-temporal scale



Salt intrusion at the Yangtze, China
c.f. LOICZ (2010)


Fluxes (ADCP) under umid climate
Rio de Contas, Itacaré, BA
8
9
Contour Variable: Velocity - Direction
Enchente
Range(m)
(deg)
Contour Variable: Velocity - Direction
Vazante
Range(m)
(deg)
2. Space-temporal scale


Fluxes under semiarid climate (ADCP)
Rio Jaguaribe, Fortim, CE
2. Space-temporal
Contour Variable: Velocity - Direction
Enchente
Contour Variable: Velocity - Direction
Vazante

Globally, about 40% of traported materials from continental origin by rivers are trapped in estuarine and deltaic sediments.

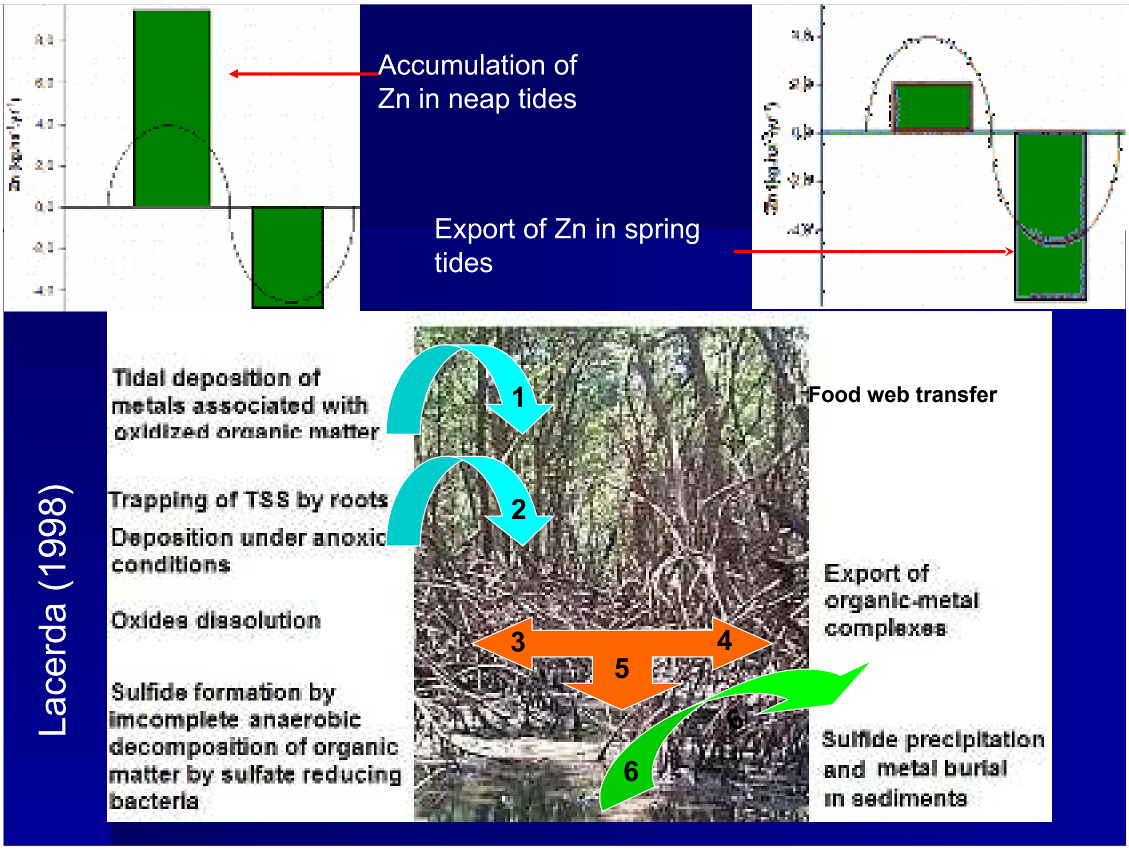
Materials passing through the estuarine-deltaic filter are deposited in the continental shelf according to shelf characteristics.

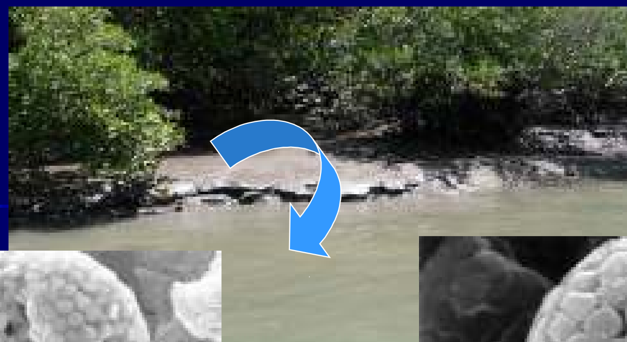
Less than 10% is eventually exported to the deep ocean

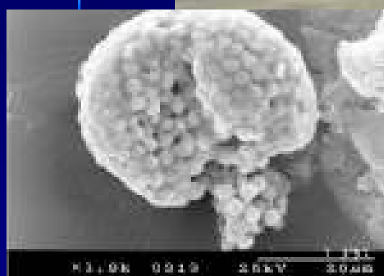

Post-depositional colonization of estuarine and deltaic sediments by plants changes the biogeochemical nature of the environment

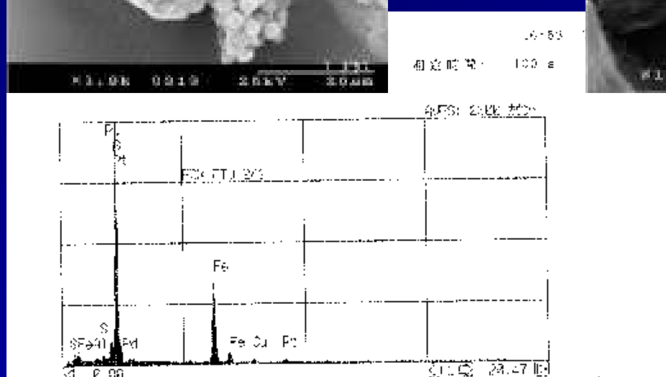
e.g. Impact from mangrove colonization of significance to estuarine ecology and sustainable use

- Augment of the deposition of fine sediments and sedimentation rates
- Decreasing aeration of sediments
- Increasing organic matter deposition and preservation in sediemts
- Increasing consumpion of dissolved oxygen
- Anoxia & sulfate reduction


Accumulation of
Zn in neap tides
Export of Zn in spring
tides
Lacerda (1998)
Tidal deposition of
metals associated with
oxidized organic matter
Trapping of TSS by roots
Deposition under anoxic
conditions
Oxides dissolution
Sulfide formation by
imcomplete anaerobic
decomposition of organic
matter by sulfate reducing
bacteria
1
2
3
4
5
6
Food web transfer
Export of
organic-metal
complexes
Sulfide precipitation
and metal burial
in sediments



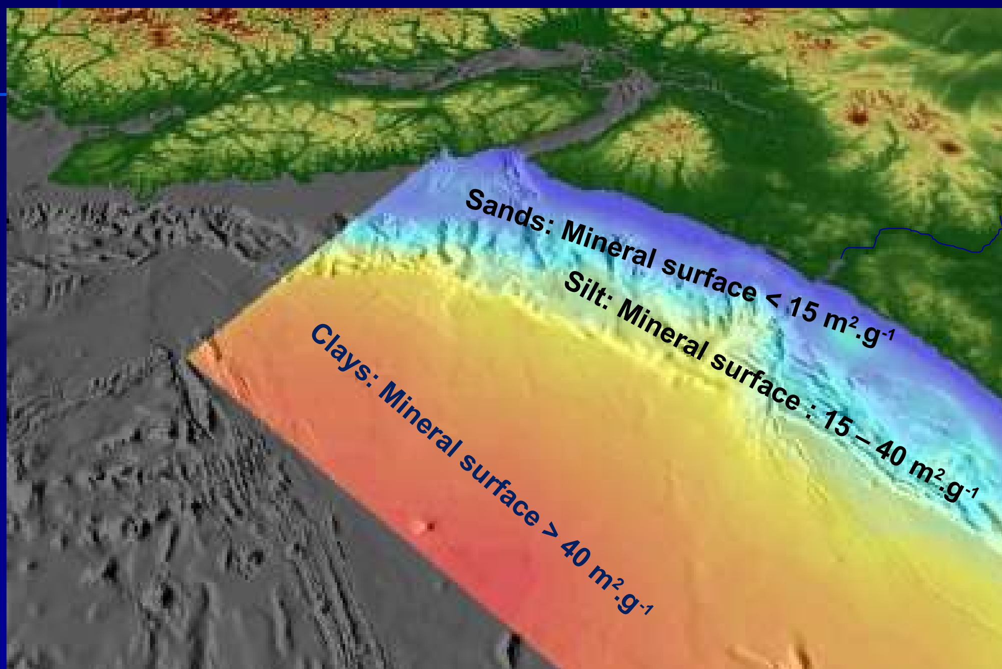


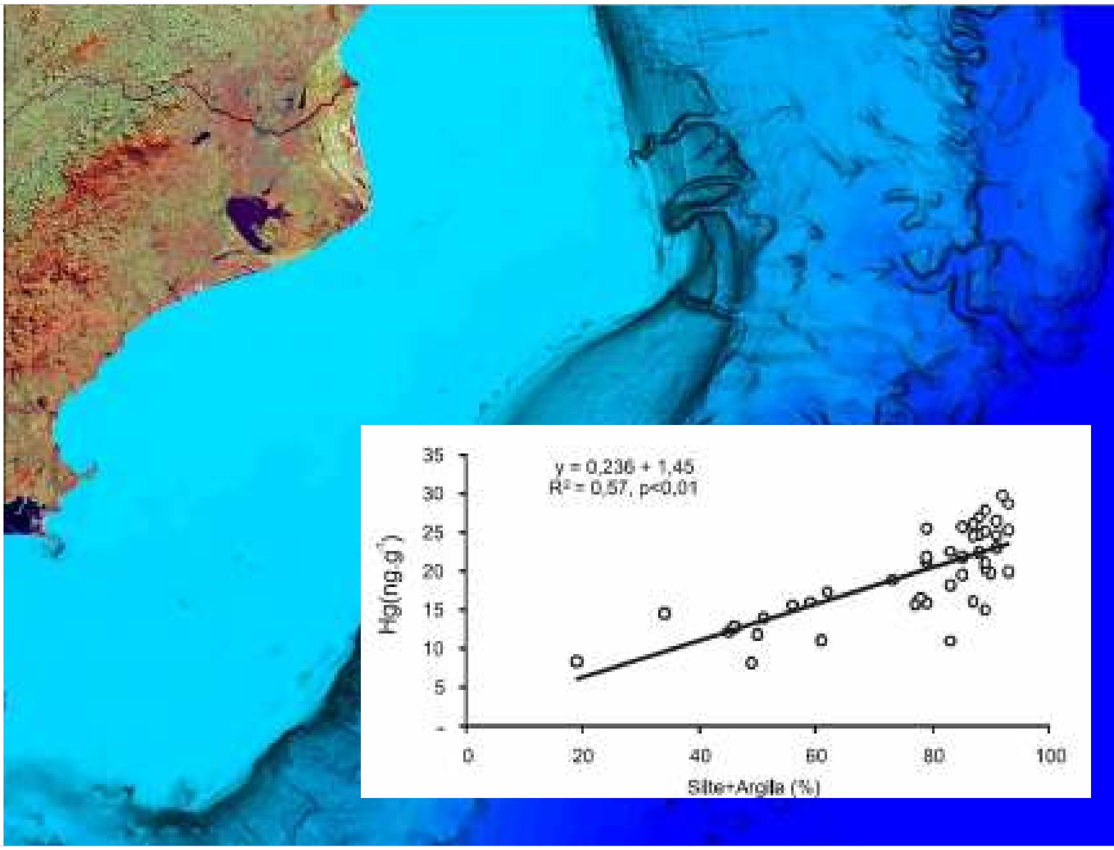


Framboids of pyrites that release metals upon oxidation due to erosion and sea level rise or decreasing fluvial sediment transport

Pires & Lacerda (2007)

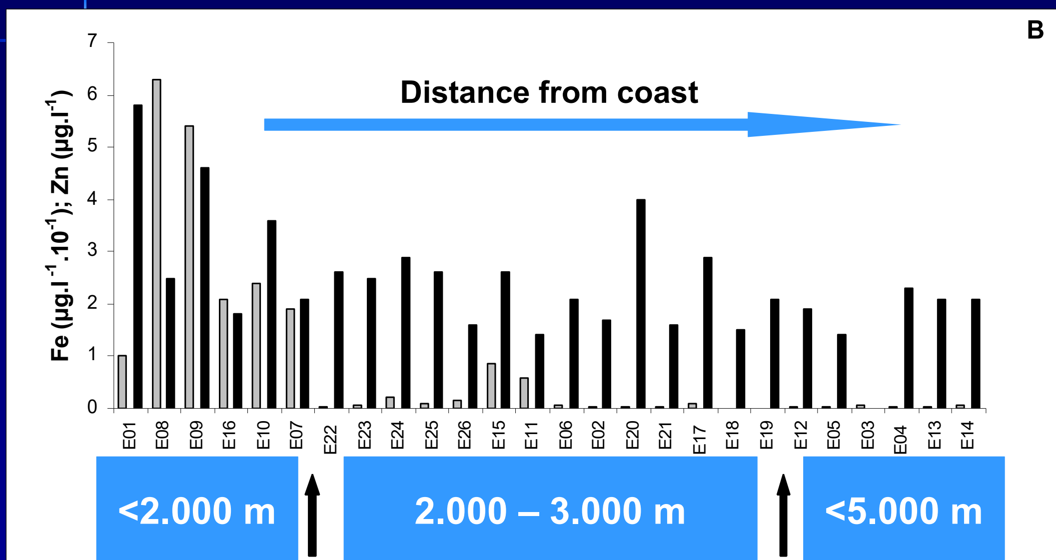
Typical granulometry of shelf sediments





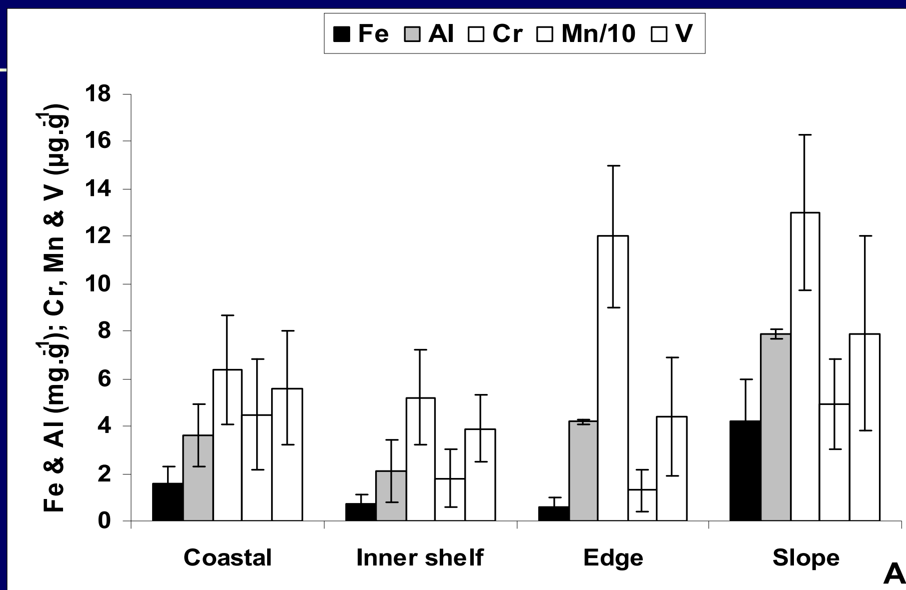
y = 0,236 + 1,45
R² = 0,57, p<0,01
Hg(ng.g-1)
35
30
25
20
15
10
5
0
20
40
60
80
100
Silte+Argila (%)

Metal distribution in NE Brazil shelf sediments



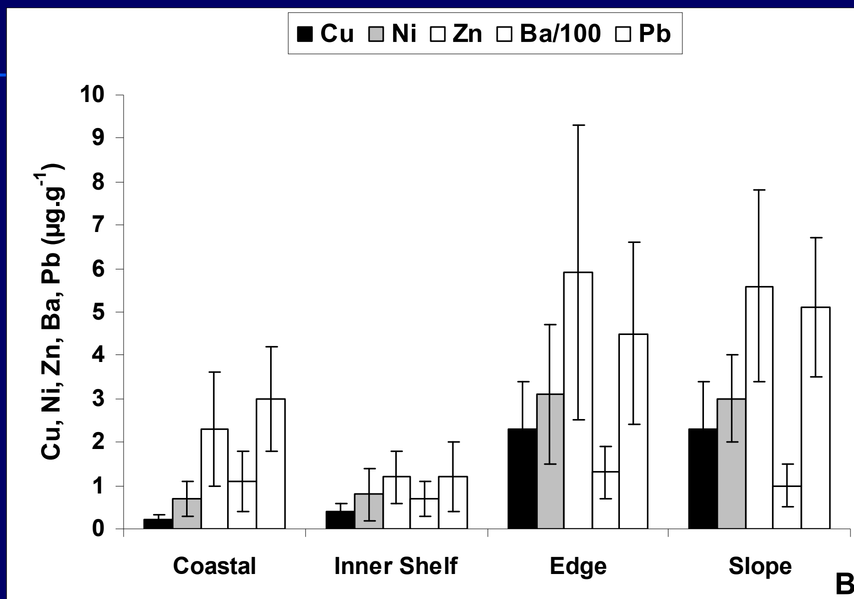
Influence of contineetal sources

Metal distribution in NE Brazil shelf sediments



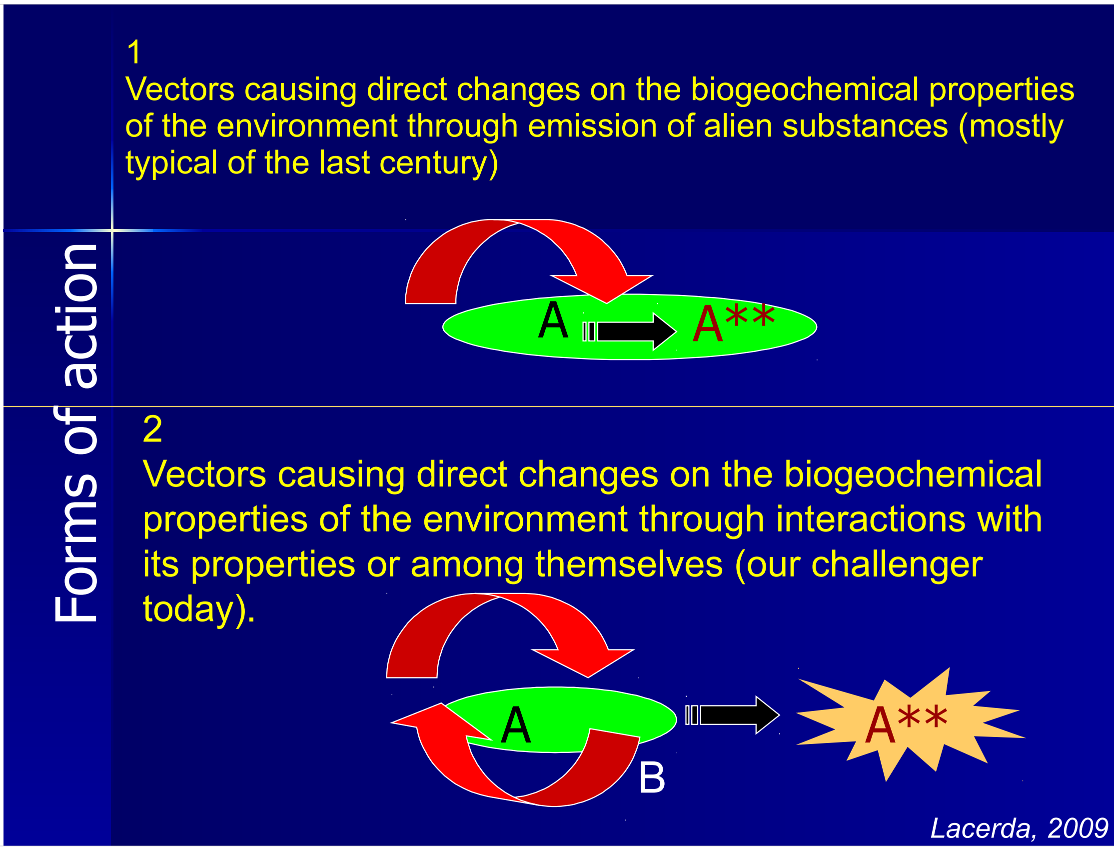
Influenced by marine processes

Metal distribution in NE Brazil shelf sediments



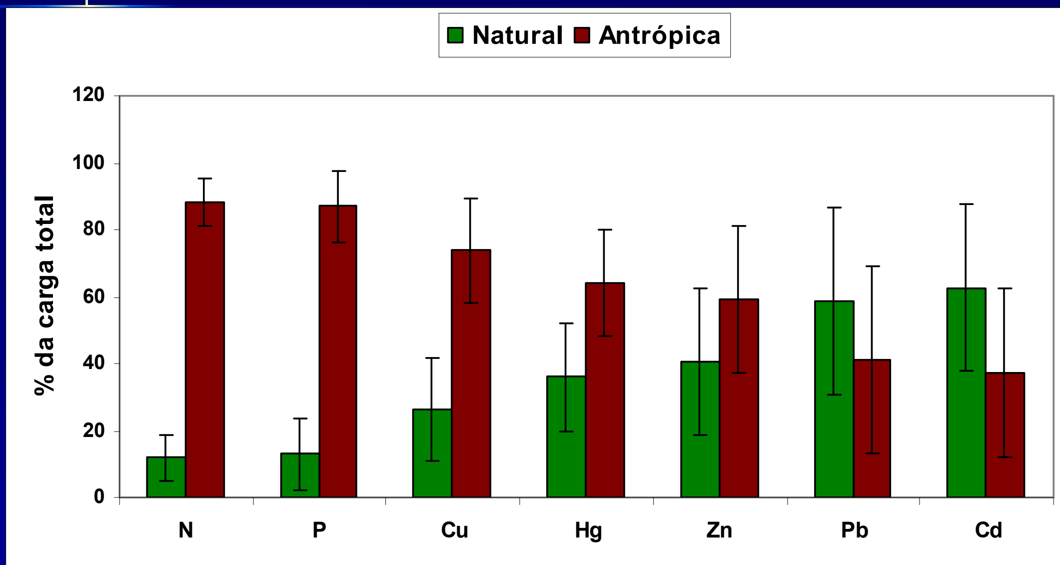
Influenced by marine processes

"The magnitude of transfer processes are today controlled mostly by anthropogenic drives".


Forms of action
1
Vectors causing direct changes on the biogeochemical properties of the environment through emission of alien substances (mostly typical of the last century)
A
A**
2
Vectors causing direct changes on the biogeochemical properties of the environment through interactions with its properties or among themselves (our challenger today).
A
B
A**
Lacerda, 2009

Urbanization & Industrialization & Agriculture/Husbandry
Increasing discharges of natural and anthropogenic substances

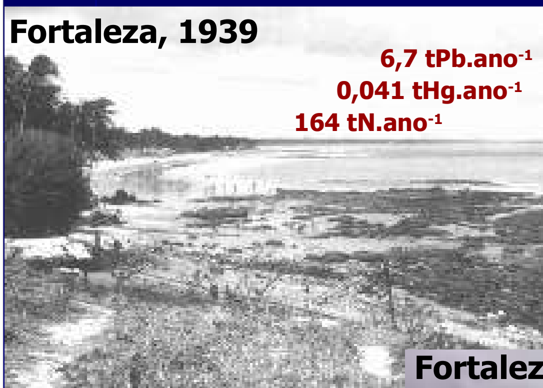
Relative importance of natural and anthropogenic sources of nutrients and metals to the NE Coast of Brazil. Average values from 19 estuaries.



Sources	Emission factors N and P ($t/km^2/year$); Cu, Hg and Zn ($kg/km^2/year$)		Substances present in effluent		
Natural sources	N = 0.05 – 0.9 P = 0.01 – 0.06	Cu = 2.0 – 2.6 Zn = 5.0 – 6.5 Hg = <0.001	Mostly associated with particulate matter		Receiving body
Agriculture	N = 0.05 – 2.65 P = 0.12 – 0.56	Cu = 0.7 – 13.5 Zn = 0.04 – 0.13 Hg = 0.02	Nitrate; Ammonia; Phosphate	Cu^{2+}, Zn^{2+}, Particulate- Cu and Zn	Soil
Husbandry	N = 0.09 – 1.31 P = 0.09 – 1.73	Cu = 0.3 – 1.0 Zn = 0.4 – 7.3 Hg = <0.001	Ammonia; Phosphate	Particulate- Cu and Zn	Soil
Urban waste waters and runoff	N = 0.03 – 0.55 P = 0.01 – 0.14	Cu = 0.1 – 15.3 Zn = 0.01 – 47.2 Hg = < 0.001	Nitrate; Ammonia; Phosphate; Particulate-P	Cu^{2+}, Zn^{2+}, Hg^{2+}; Particulate- Cu and Zn	Soil, waterways and estuaries
Urban solid wastes disposal	N = 0.001 – 0.2 P < 0.0001	Cu = 0,001 – 0,03 Zn = 0,001 – 0,07 Hg = 0.04	Dominant forms of N and P are too site-specific	Cu^{2+}, Zn^{2+}, Hg^{2+}; Particulate- Cu and Zn	Soil
Shrimp aquaculture	N = 1.25 – 4.09, P = 0.13 – 0.32	Cu = 38.6 – 59.8 Hg = 0.03 – 0.04 Zn = 508	PON (70%); NO_3^-; Ammonia; NO_2^-; POP; Phosphate	Particulate- Cu, Zn and Hg	Waterways and estuaries

Changes in soil uses

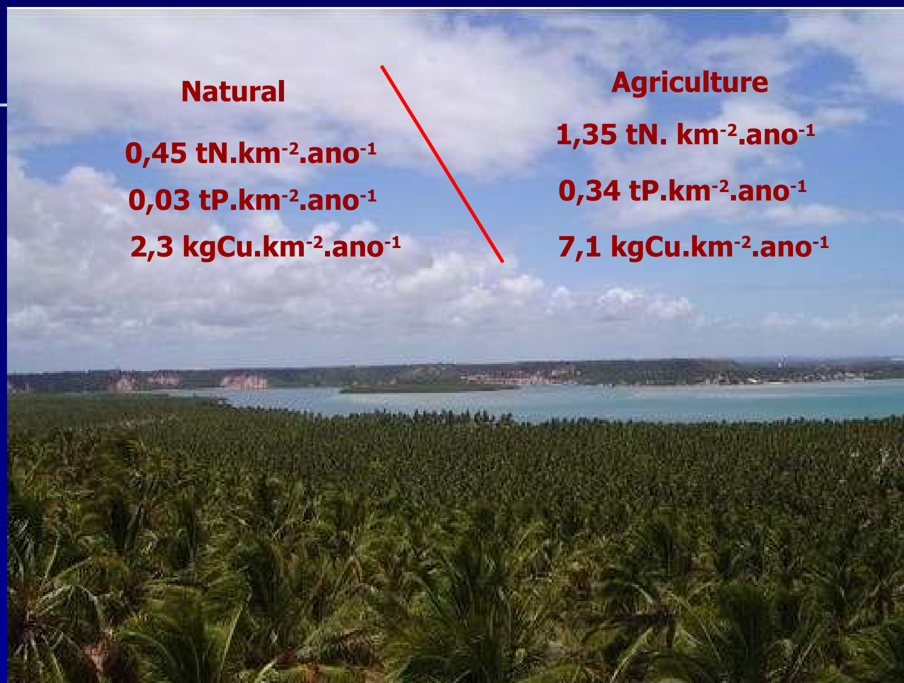
Urbanization



Legacy of irresponsible technologis faces lack of governance

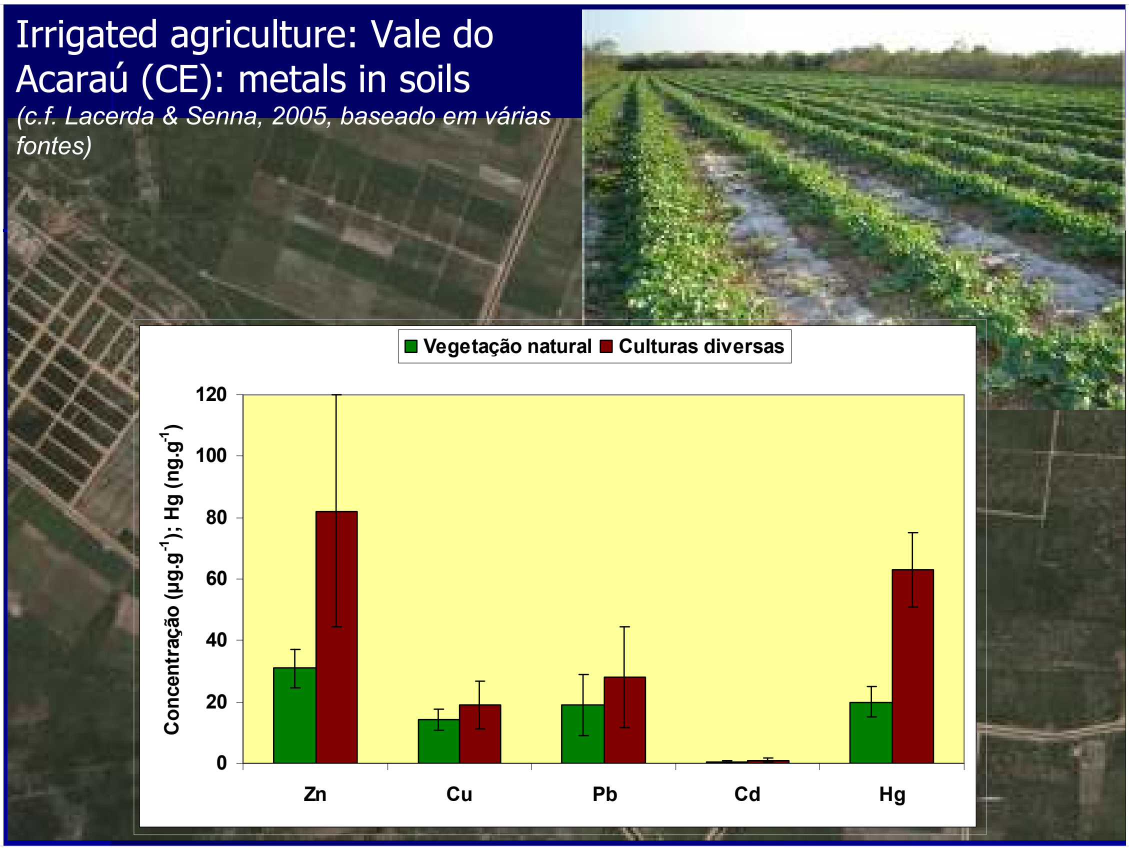
Industrialization

Changes in soill use: Agriculture

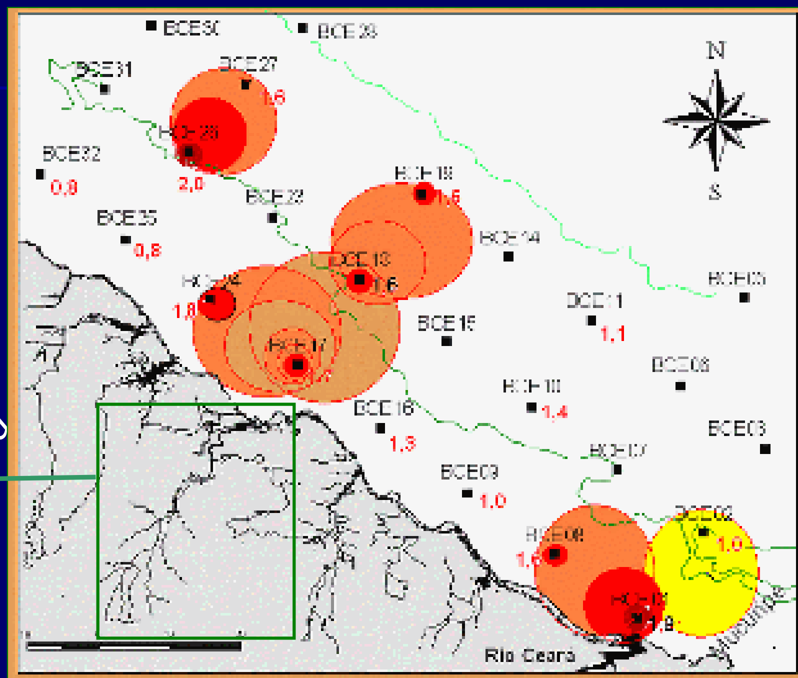


Irrigated agriculture: Vale do Acaraú (CE): metals in soils

(c.f. Lacerda & Senna, 2005, baseado em várias fontes)



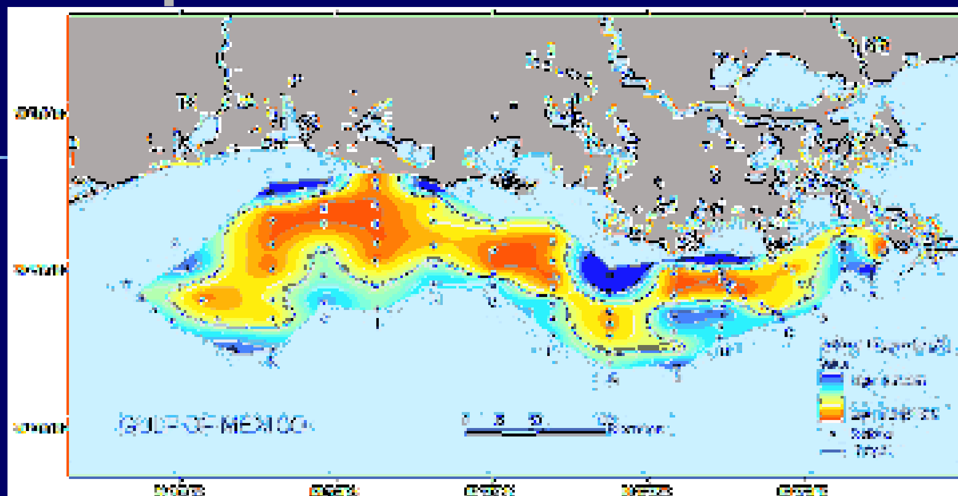
The management of the area exports continental material out to shelf sediments



Perímetro irrigado do vale do Acaraú

A question of scale: Mississipi Delta, Gulf of Mexico, USA

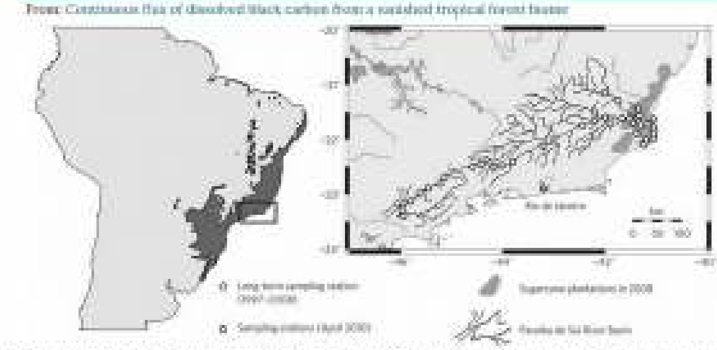
Hipoxia in coastal seas



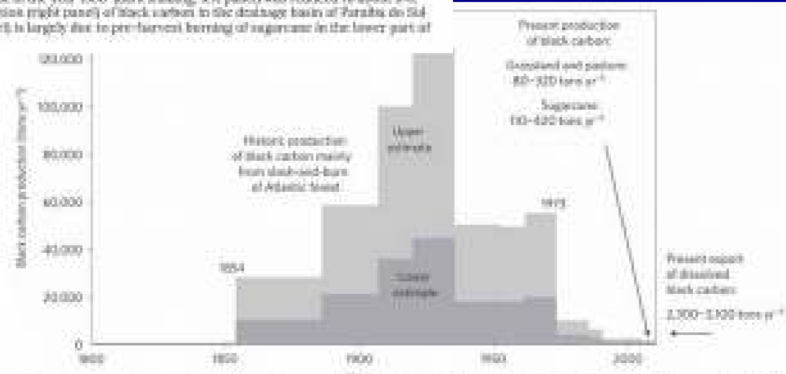
- Increasing globally due to excessive loads of nutrients and oxygen consumption
- Today, affects over 18,000 km^2 of the Texas-Louisiana shelf during summer

Continental carbon to the South Atlantic

From: Continuous flux of dissolved black carbon from a vanished tropical forest biome



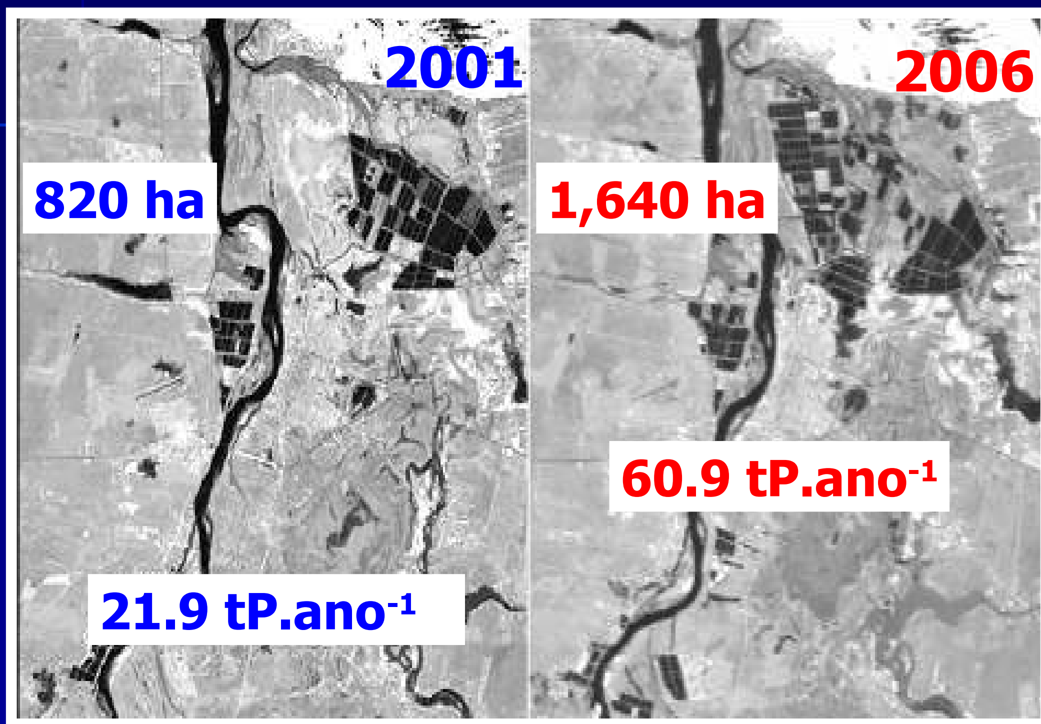
The original coverage of the tropical Atlantic forest in the year 1500 (dark shading, left panel) was reduced to about 8%, consisting of fragmented patches. Today's production (right panel) of black carbon in the drainage basin of Paraíba do Sul River (the area outlined by the box in the left panel) is largely due to pre-harvest burning of sugarcane in the lower part of the catchment area.



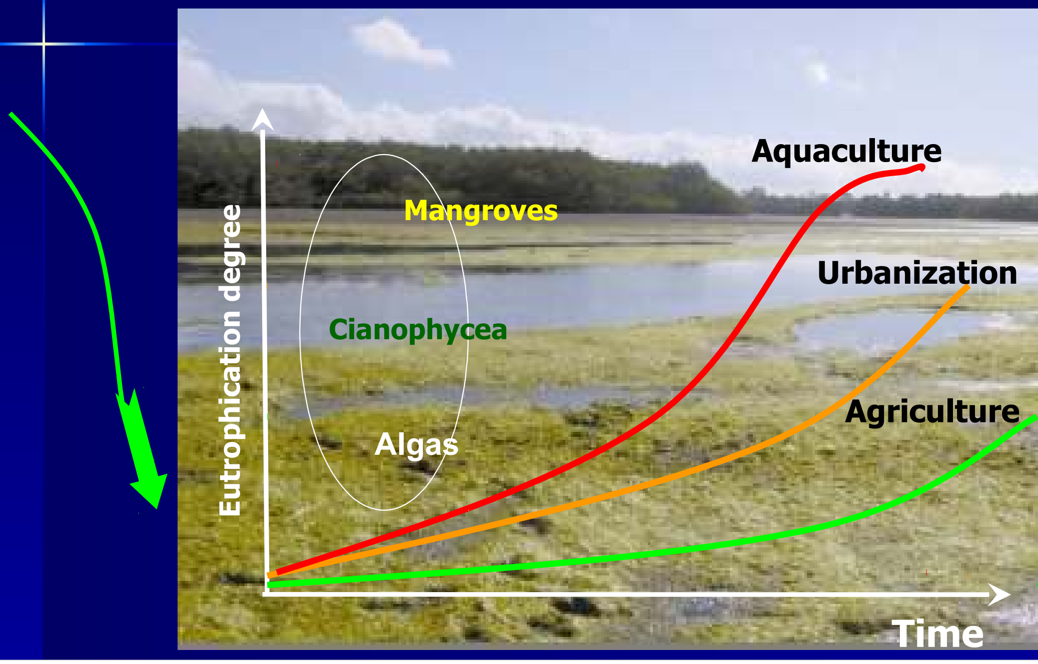
Annual production rates are for the polycyclic aromatic fraction of black carbon. The rate shown for the period 1800–1854 also represents the period 1500–1800. Black carbon was mainly produced by slash-and-burn clearing of the Atlantic forest. Today's production is mainly due to pasture management and pre-harvest burning of sugarcane.

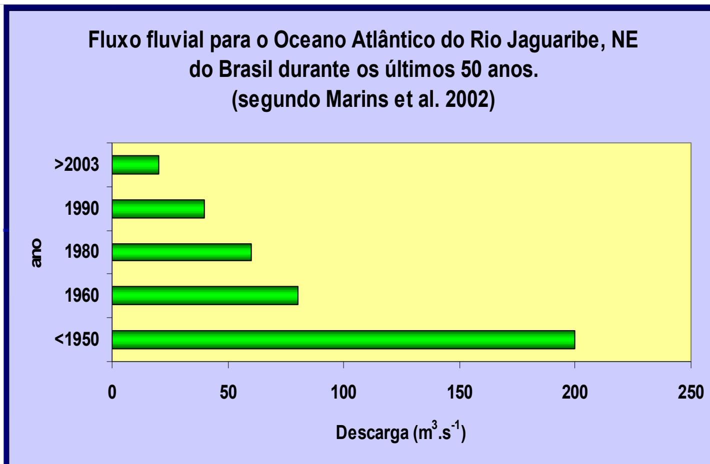
Changes in land use: **Shrimp aquaculture**

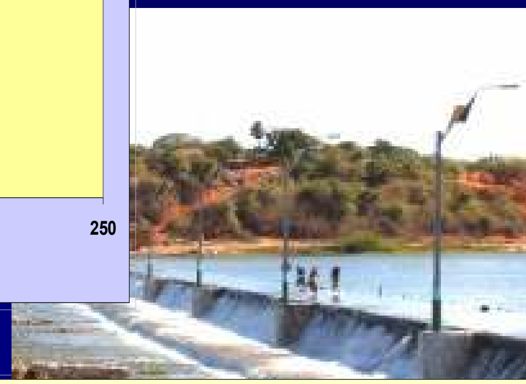
(*c.f.* Marins et al., 2009)



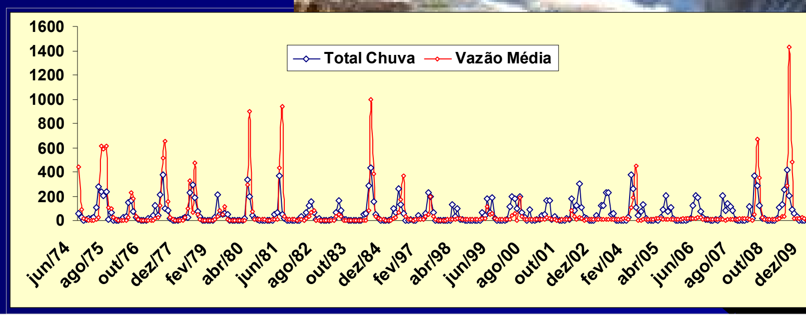
Speed of response (eutrophication) to increasing nutrient emissions from different non-industrial activities

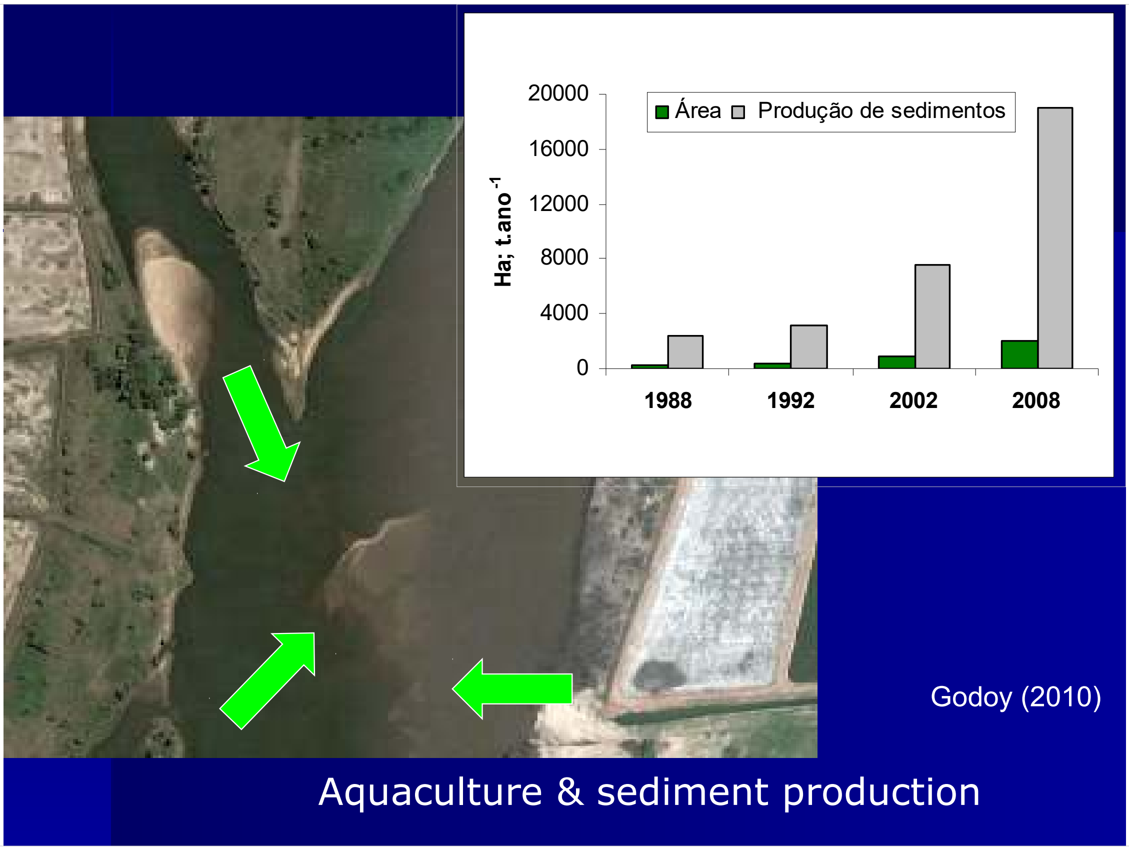


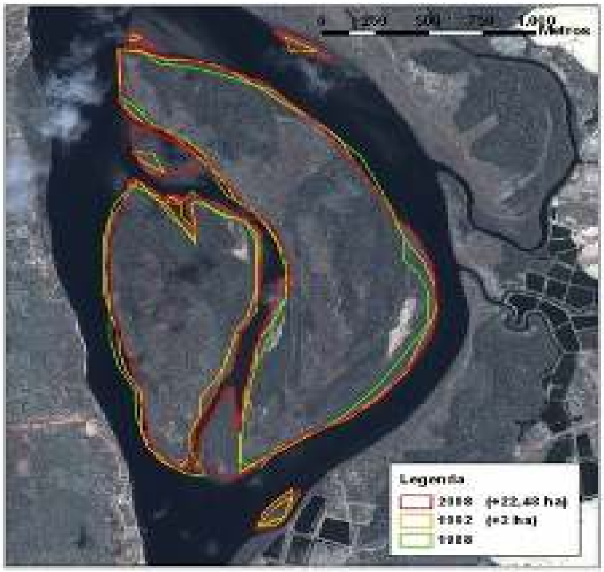

Fluxo fluvial para o Oceano Atlântico do Rio Jaguaribe, NE do Brasil durante os últimos 50 anos.
(segundo Marins et al. 2002)
ano
>2003
1990
1980
1960
<1950
0
50
100
150
200
250
Descarga (m³.s⁻¹)



Dams

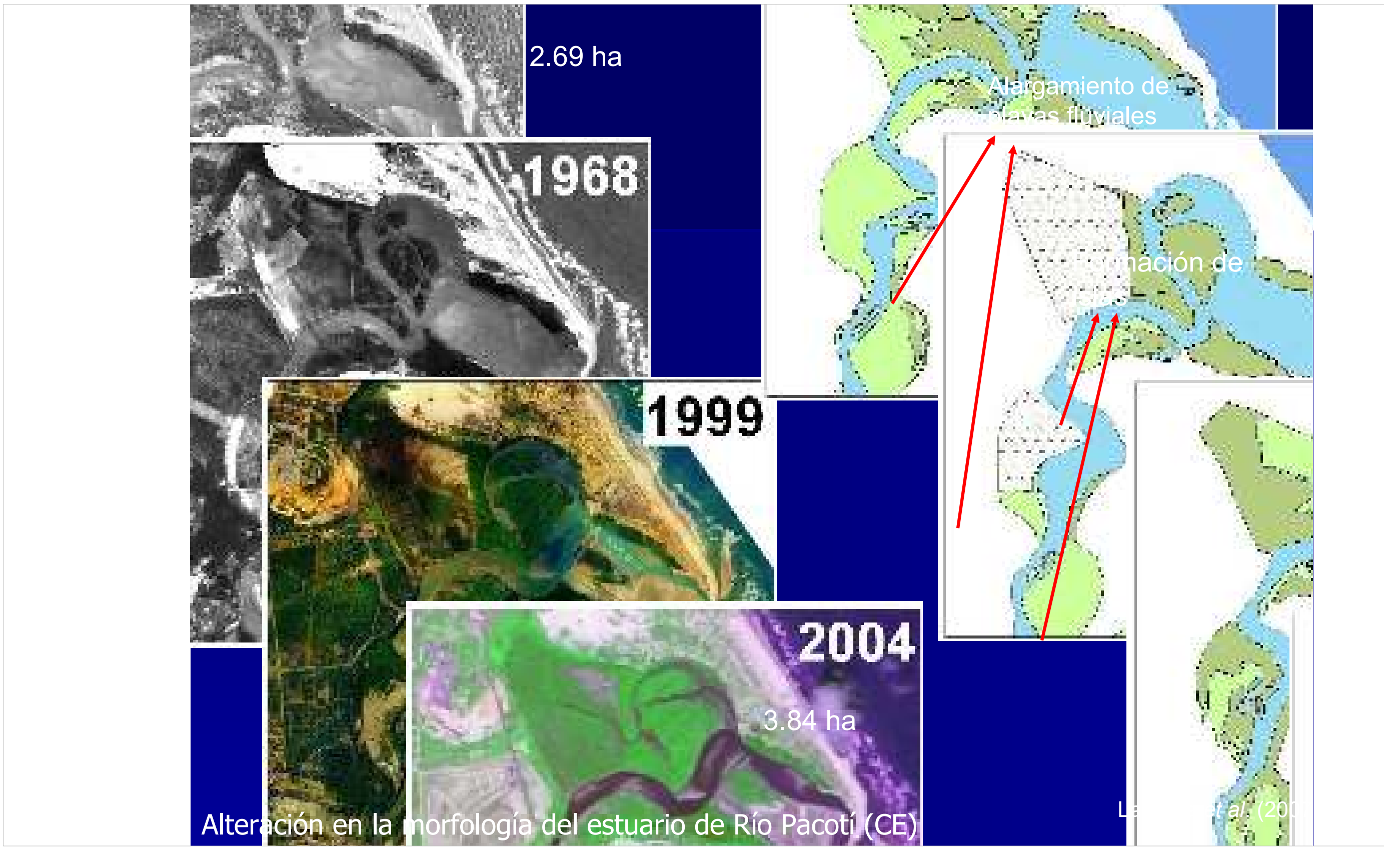

1600
1400
1200
1000
800
600
400
200
0
Total Chuva
Vazão Média
jun/74
ago/75
out/76
dez/77
fev/79
abr/80
jun/81
ago/82
out/83
dez/84
fev/97
abr/98
jun/99
ago/00
out/01
dez/02
fev/04
abr/05
jun/06
ago/07
out/08
dez/09


20000
16000
12000
8000
4000
0
Ha; t.ano-1
Área
Produção de sedimentos
1988
1992
2002
2008
Godoy (2010)
Aquaculture & sediment production



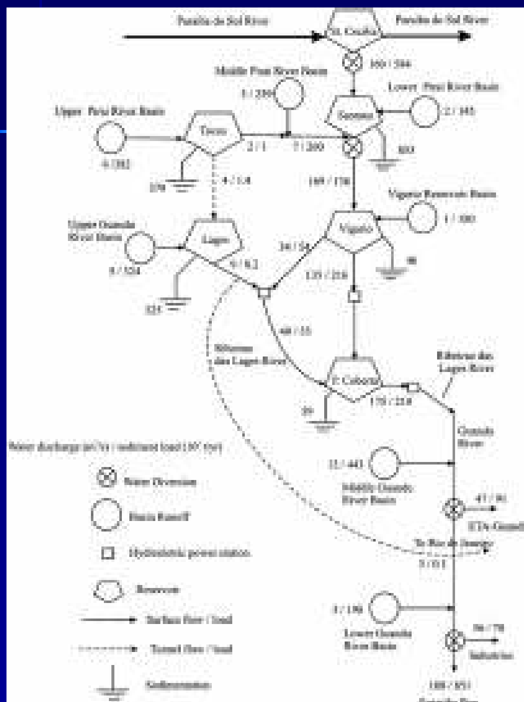
Increasing sedimention areas

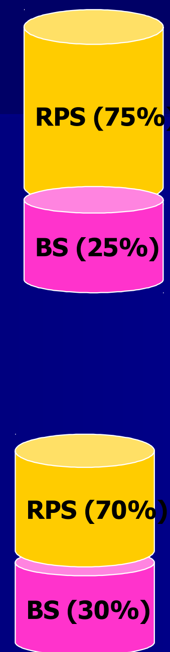
Godoy (2010)


2.69 ha
1968
1999
2004
3.84 ha
Alargamiento de
playas fluviales
Alteración en la morfología del estuario de Río Pacotí (CE)

Water diversion

Contribuição de água e sedimentos pela transposição do Rio Paraíba do Sul para a Baia de Sepetiba

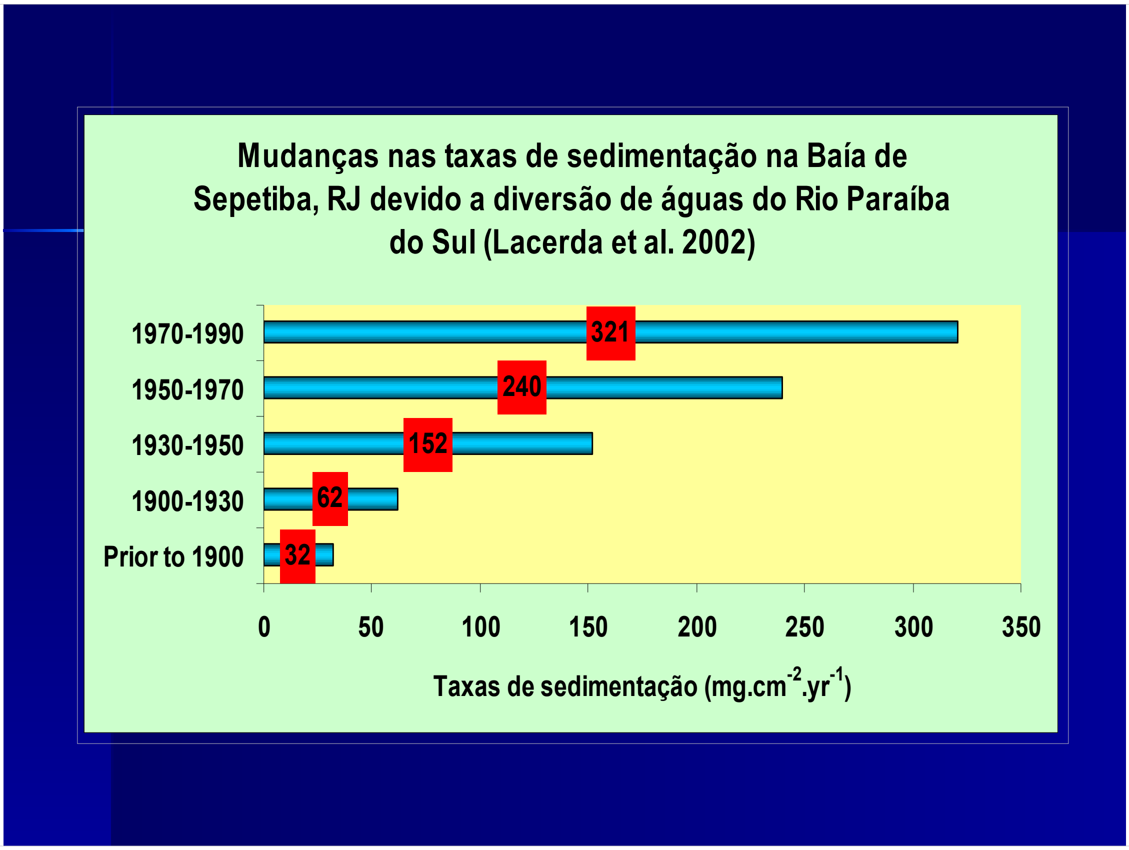




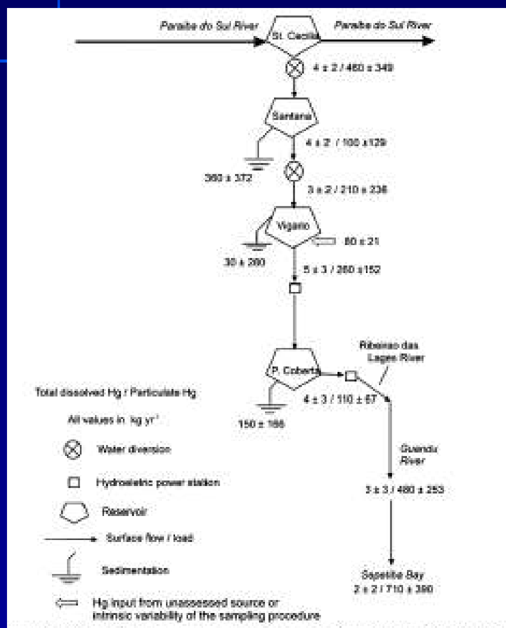
Água

Sedimento

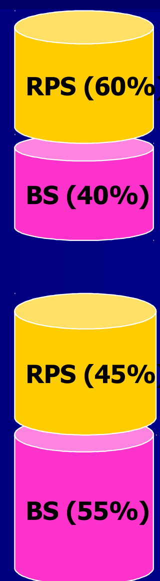
Molisani et al. (2007)


Mudanças nas taxas de sedimentação na Baía de Sepetiba, RJ devido a diversão de águas do Rio Paraíba do Sul (Lacerda et al. 2002)
1970-1990
1950-1970
1930-1950
1900-1930
Prior to 1900
321
240
152
62
32
0
50
100
150
200
250
300
350
Taxas de sedimentação (mg.cm-2.yr-1)

Contribuição de Hg pela transposição do Rio Paraíba do Sul para a Baia de Sepetiba



Mass-balance budget of Hg (mean ± standard deviation, kg yr⁻¹) along the engineered-modified watershed.



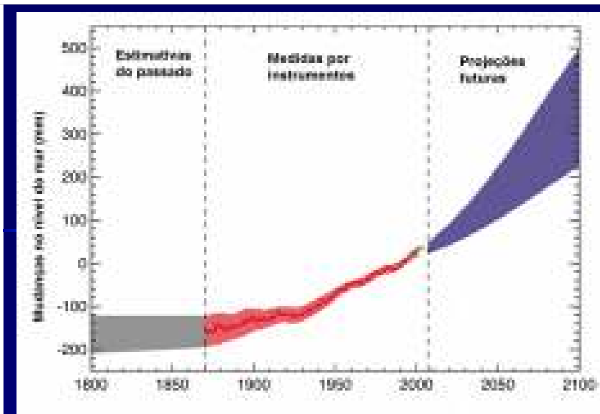
Hg-particulae

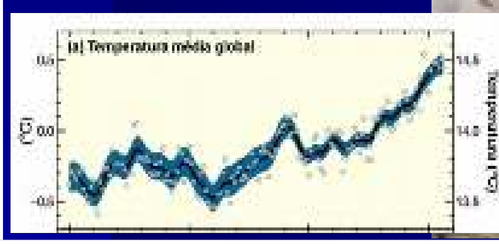
Hg-dissolved

Molisani et al. (2008)

is

Global climate change: Sea level rise





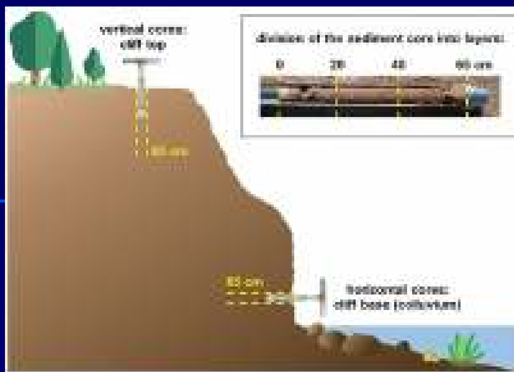
Efeitos pouco óbvios: Impacto na biogeoquímica costeira

- In areas of small supply of sediments, e.g. semiarid littorals, seafront mangroves, sea clifs; coastal deposits are increasing the remobilization of pollutants.

- On the other hand, coastal plain areas in the tropics and subtropics dominated by mangroves, sea level rise will induce mangrove migration inland, creating typical areas dominated by the mangrove metabolism (e.g. anerobic respiration through sulfate reduction).

- Trace metal biogeochemistry and bioavailability are highly affected by the sulfate reduction metabolism.

- Part of the metal load will be accumulated as metallic sulfides in sediments, but part, with the abundant dissolved organic carbon compounds due to incomplete oxidation of organic matter, will be made more bioavailable, increasing bioaccumulation and enhancing biota and human exposure through food chains.



Sea level rise and Hg contribution through erosion
(Kwasigroch et al., 2018 (in press)
Up to 14.5 kg.yr^{-1}; the 3rd most important Hg source to Gdansk Bay.

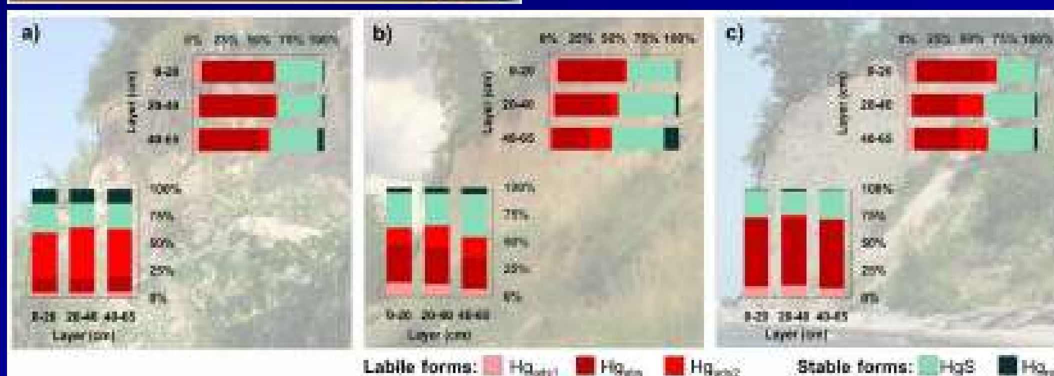
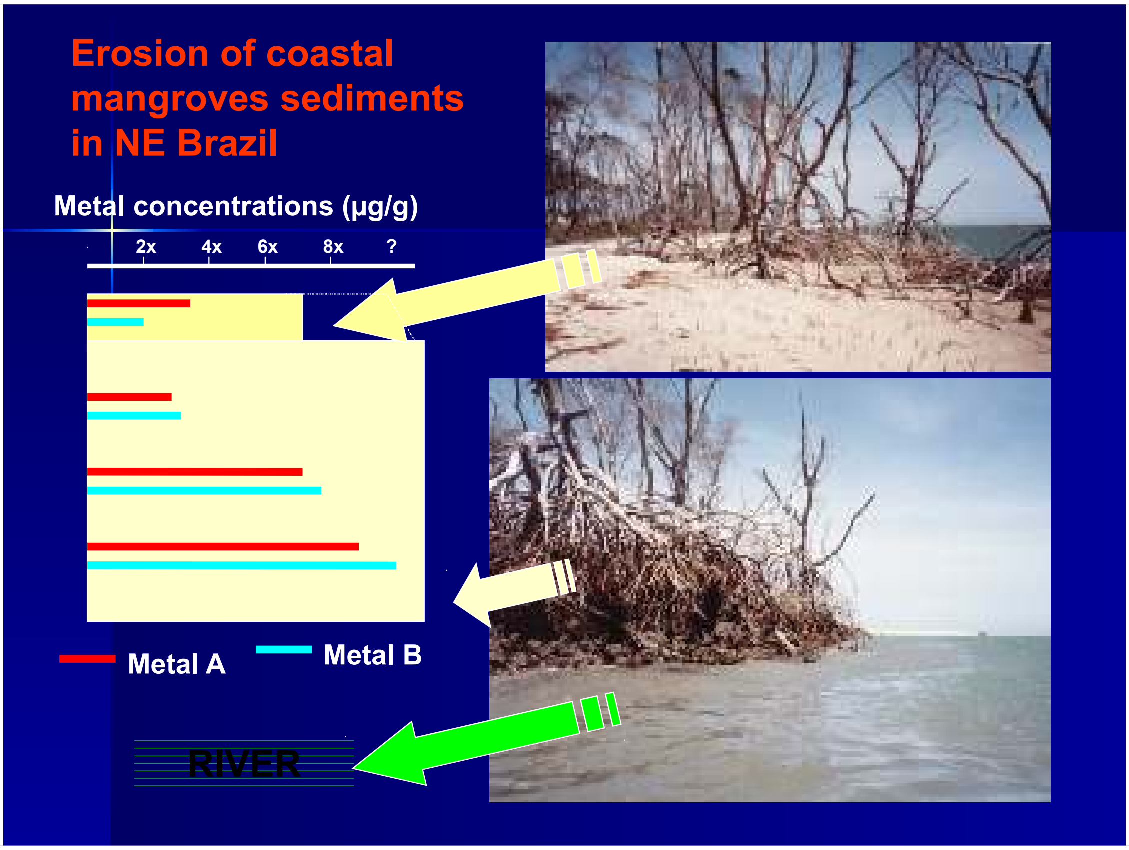


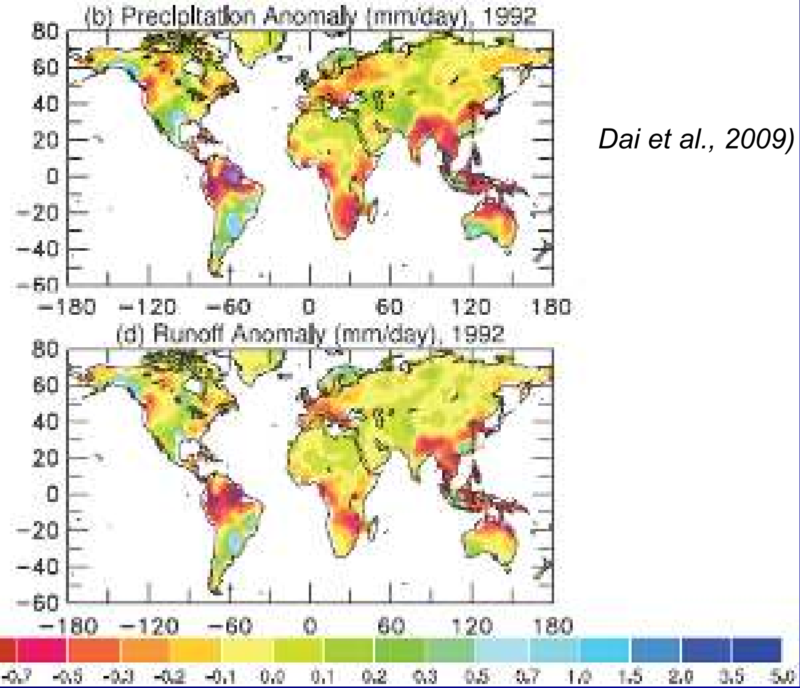
Fig. 3 The percentage of Hg fractions in horizontal and vertical profiles of investigated cliffs. a Puck cliff. b Osłonino cliff. c Mechelinki cliff


Erosion of coastal mangroves sediments in NE Brazil
Metal concentrations (µg/g)
2x
4x
6x
8x
?
Metal A
Metal B
RIVER

Variação do escorrimento superficial e precipitação global

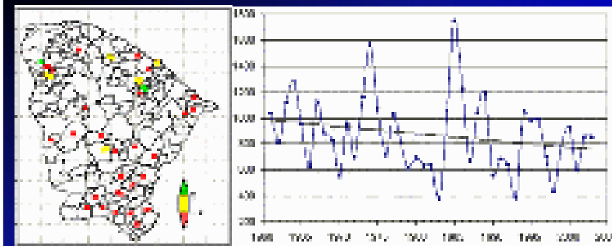
Out of 200 rivers, **45**, mostly in lower latitudes, have their flows decreased between 1984 and 2004, whereas **19**, have them increased

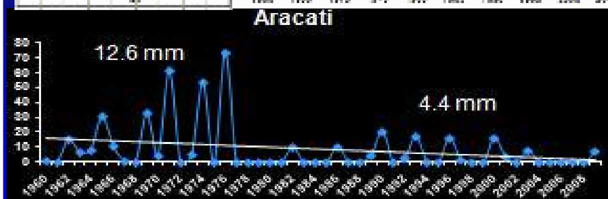
Increasing fluxes are frequently in higher latitudes and increasing flux **do not relates to increasing rainfall**, a probable reflect of ice and glacier melt.



Dai et al., 2009)

Reduction Annual precipitation and runoff anomalies



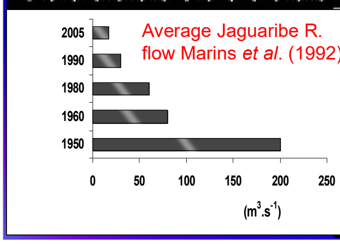


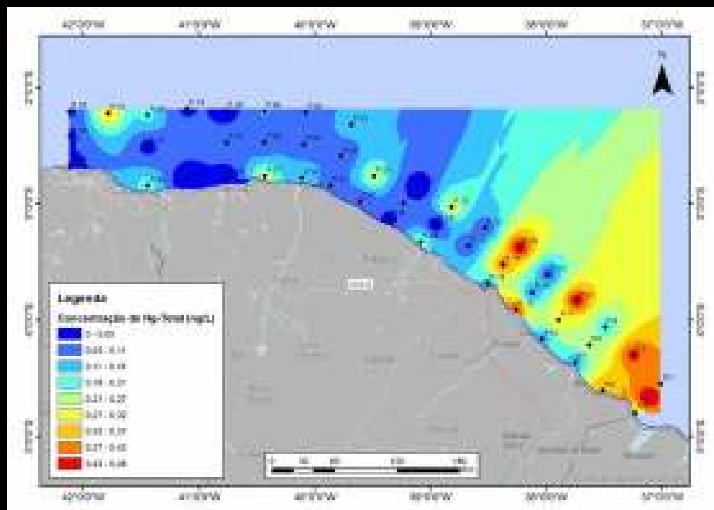
Rainfall reduction in Ceara, NE Brazil

Evolution Trend (1961 – 2008) in annual precipitation over Ceará. (4 - 5 $mm.yr^{-1}$ reduction) (Moncuil, 2006).

Reduction is more critical (3 times) during the dry season (Godoy *et al.*, 2010)

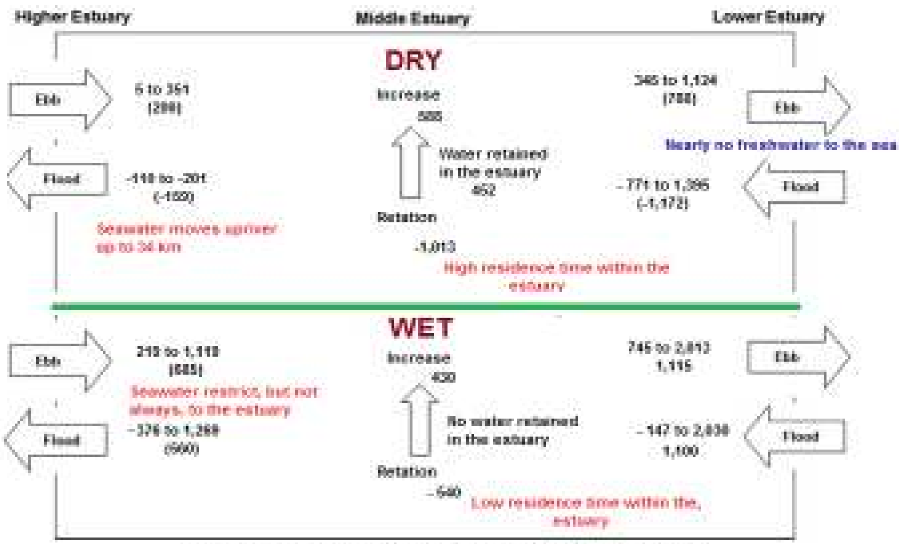
River discharges also decrease and arefurther affected by damming (Godoy *et al.*, 2010)





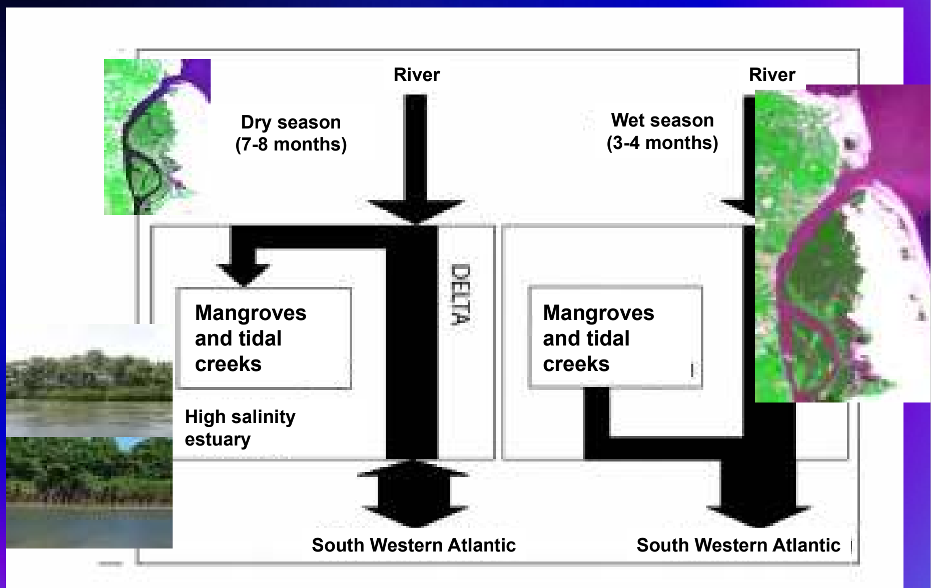
Mercury distribution in coastal waters of the semiarid northeast as a proxy of regional changes in the NE region's watersheds. The clear pattern of higher concentrations to the east are a result of such changes.

Water balance ($m^3.s^{-1}$) at the Jaguaribe estuary, NE Brazil (Dias, Lacerda & Marins 2011) pluriannual average.

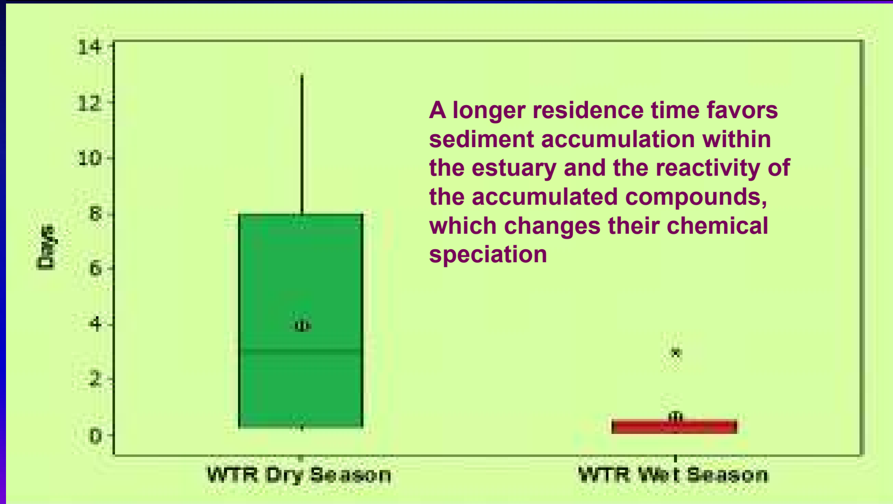


Water balance in the Jaguaribe Estuary (2001-2013)
$m^3.s^{-1}$

Conceptual hydrodynamics model of semi-arid rivers, from Lacerda , Marins & Dias (2012)



Choking of the lower estuary due to decreasing continental runoff and increasing the strength of ocean forcing over the continental shelf, results in longer residence time of water masses within the estuary during the dry season (Lacerda, Marins & Dias, 2012)



The hydrodynamics of rivers in the semi-arid at the continent - ocean interface and therefore the distribution and biogeochemistry of their ecosystems depends on:

1 – the magnitude of the fluvial flux & continental runoff;

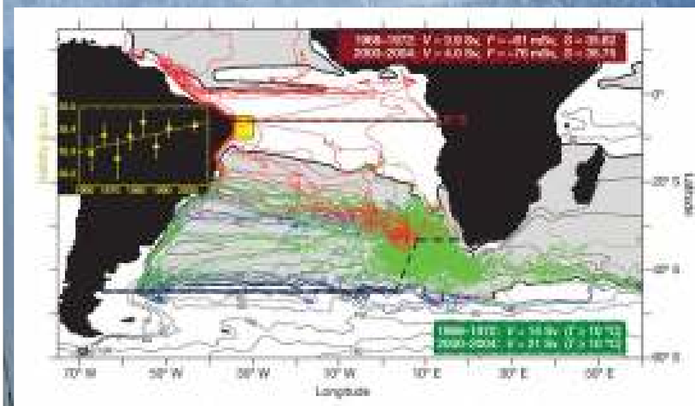
2 – the residence time of water masses in flooded areas and;

3 – sea level variation and the volume of the tidal prism.

All these variables are highly sensitive to global climate change.

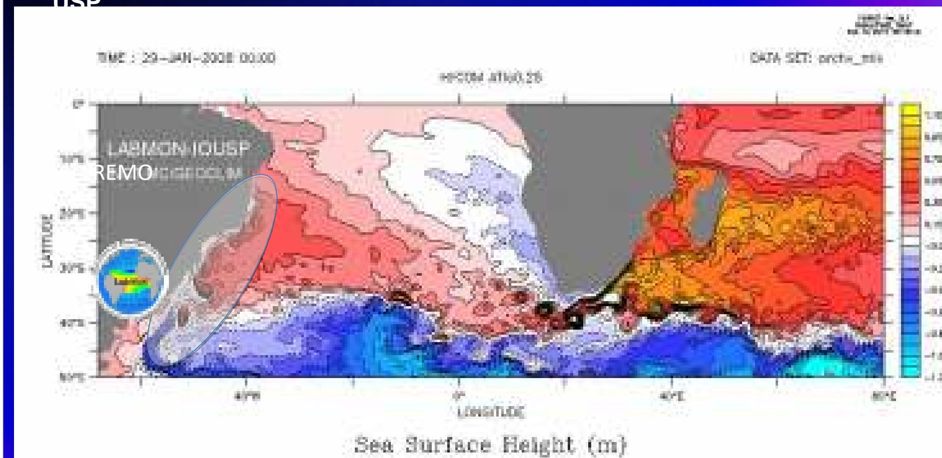
Therefore, how global climate change is already affecting the functioning of the semi-arid ecosystems and what can we expect in the future?

Apart from the effects of global and regional changes at the semi arid region itself, tele-conections & large scale transfer in the South Atlantic Ocean may also affect the residence time in estuaries and eventually the export and mobility of substances to marine food chains.



E.g. The increasing strength of the Agulhas leakage *(Biastoch, A., C.W. Böning, F.U. Schwarzcopf and J.R.E. Lutjeharms,* ***Nature*** *462, 495-498, Nov/2009).*

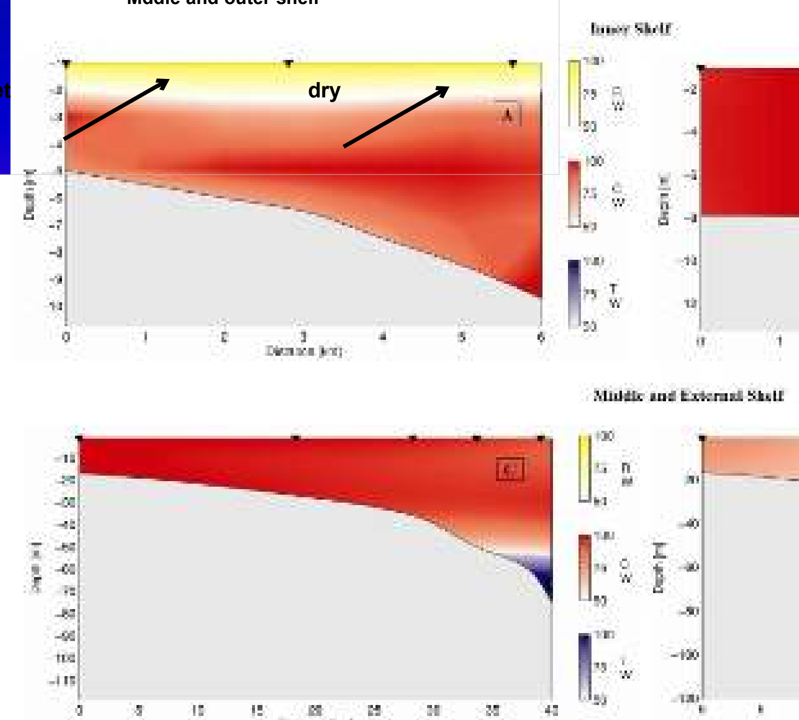
The impact of ocean water on continental shelf off the semi-arid coast of Brazil. Slide & Model, cortesy of Dr. Edmo Campos, USP



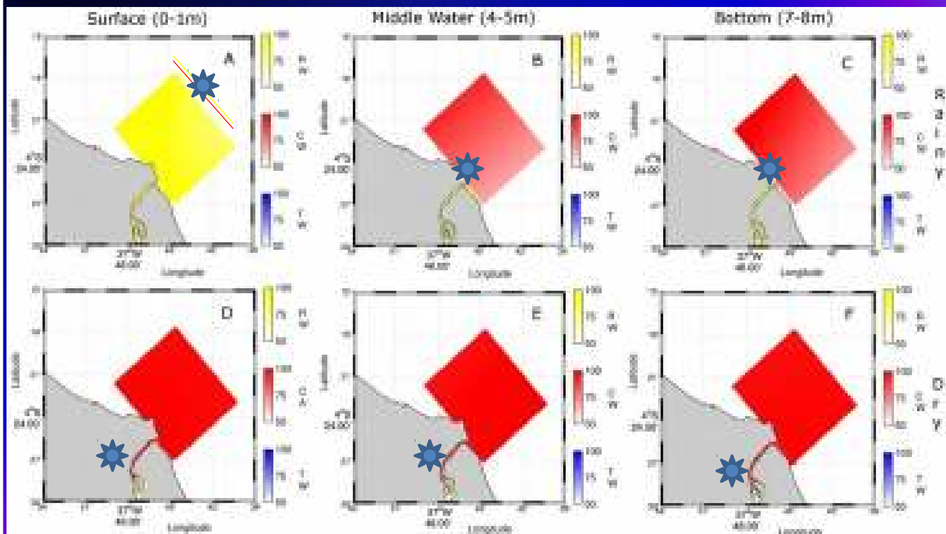
Surface circulation off the Brazilian coast is part of a "Super Gire" connecting the South Atlantic ocean with the Indian Ocean. The South Atlantic is the ocean where highest heat accumulation occurs due to global warming.

Indian Ocean waters "leek" to the South Atlantic, a key element in the global thermohaline circulation. Courtesy Dr. Edmo Campos, USP.

✓Temporal and spatial distribution of continental water masses combining multi-tracers analysis and simultaneous sampling grids in river, estuary, plume and continental shelf, show freshwater plume during the rainy season and penetration of Tropical Waters (Oceanic) into the shelf. (↗) (Dias, Castro & Lacerda, 2011)



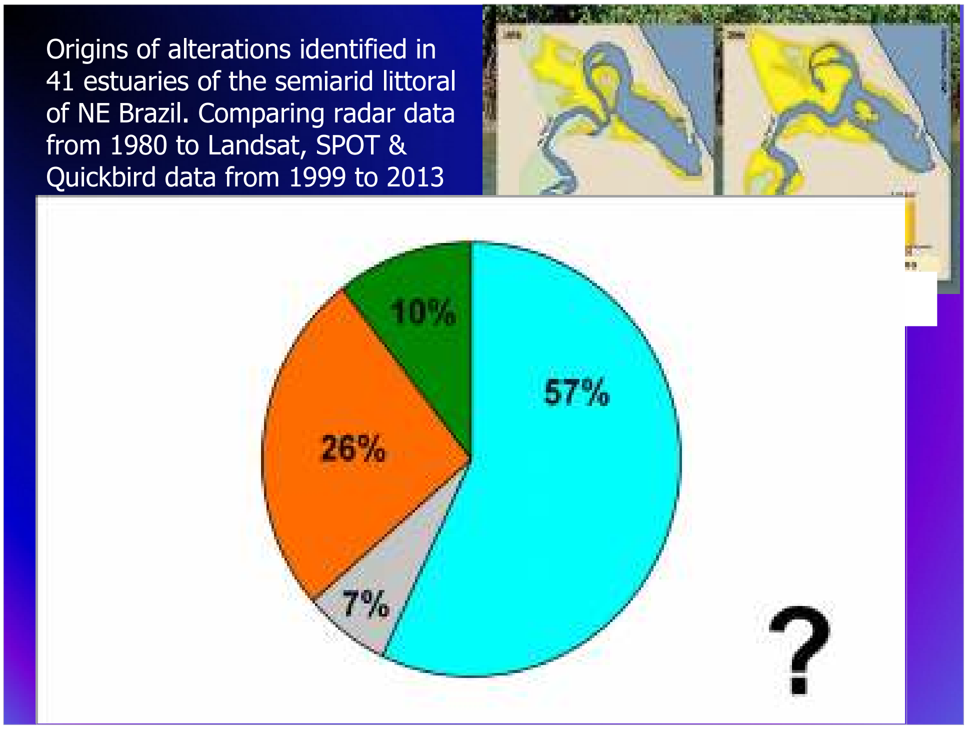
Choking the estuary increases water residence time, augmenting reactivity and bioavailability of substances. Stronger ocean forcing moves mixing zone and reactivity processes landward (Dias, Castro & Lacerda, 2011)



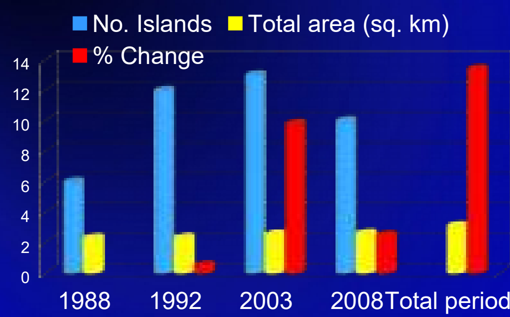
Mixing zone

What are the major impacts of the processes described above on the fate of pollutants?

How the chemistry of pollutants responds to the increasing choking of estuaries and decreasing continental runoff, sedimentation in estuaries, mangrove expansion and longer water residence time there?


Origins of alterations identified in 41 estuaries of the semiarid littoral of NE Brazil. Comparing radar data from 1980 to Landsat, SPOT & Quickbird data from 1999 to 2013
10%
57%
26%
7%
?

Changes in island area in the Jaguaribe River estuary between 1988 and 2008 (Godoy & Lacerda, 2013)



Mangrove expansion in NE Brazil (Maia, Gentil & Lacerda, 2006)

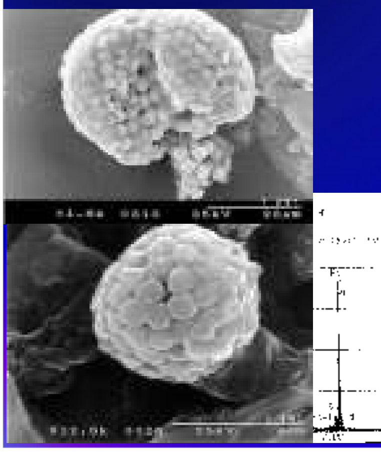
Parameter	km	%
Total mangrove area in 1978	278	
Total mangrove area in 2004	352	
Increase (uncertainty)	74	21% (3%)

Biogeochemical Scenario

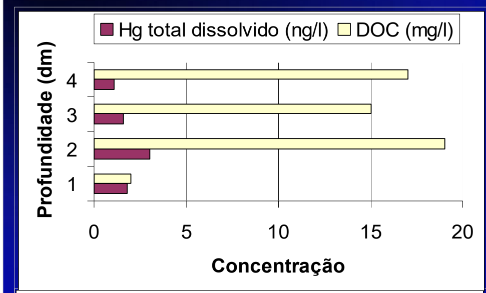
✓Augmenting water residence time and sedimentation at the estuary increases mangrove areas and its metabolism based on dissimilatory sulfate reduction expands to larger areas.

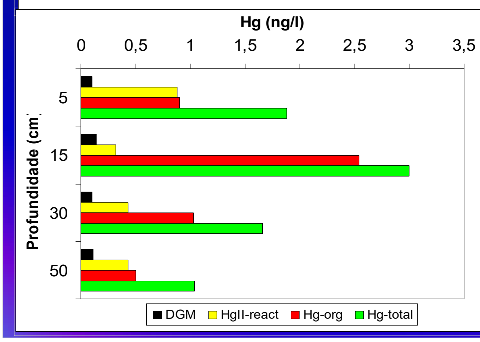
✓There is a larger export of DOC from the incomplete respiration of organic matter by anaerobes.

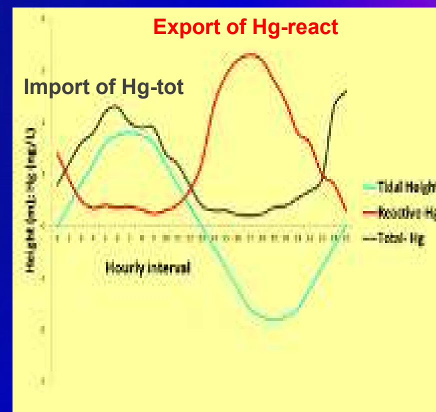
✓Deposited metals from continental origin accumulate and suffer chemical changes instead of rapid being exported to the continental shelf.



Organic-Hg complexes production in porewater facilitates Hg export from sediments

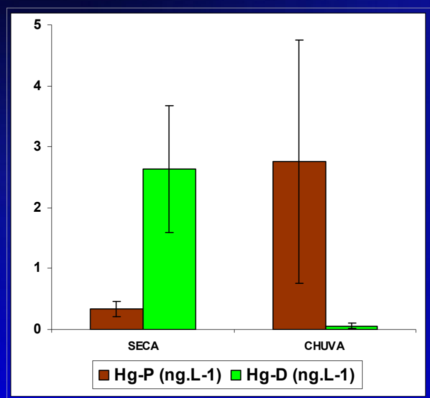


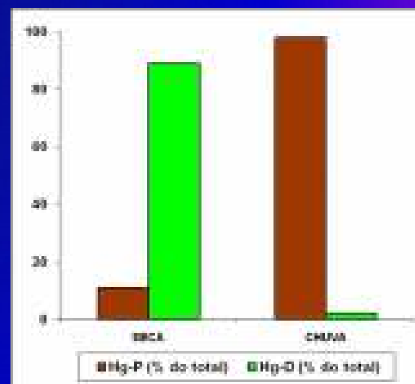




Tidal export of Hg from the from a mangrove forest (Lacerda et al., 2001)

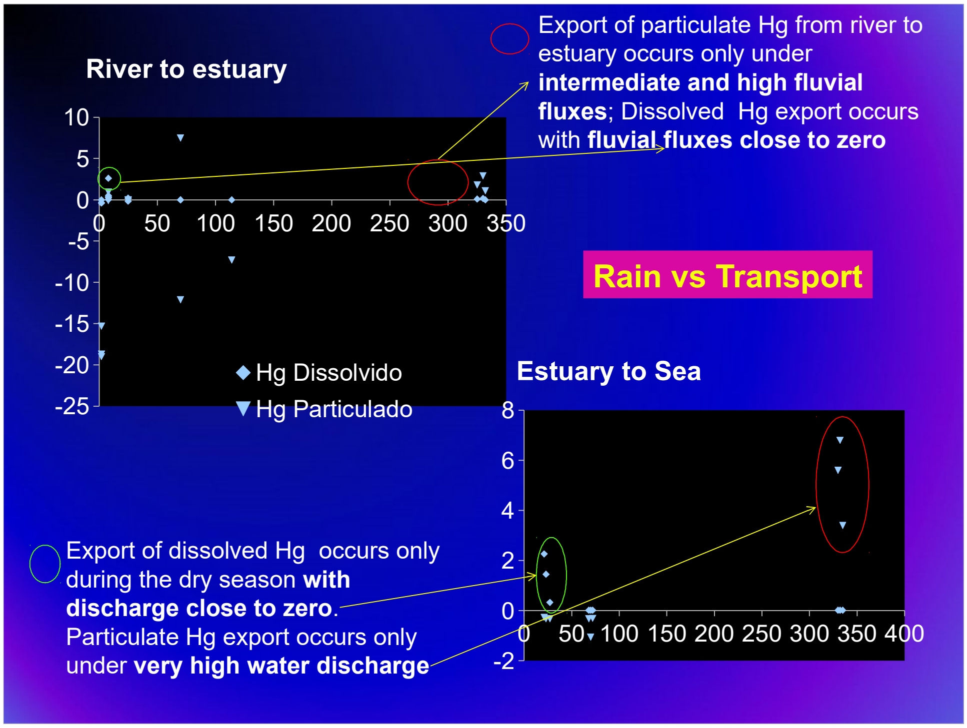
Relative Speciation of Hg in the dry and wet season at the Jaguaribe Estuary (Lacerda et al., 2013)

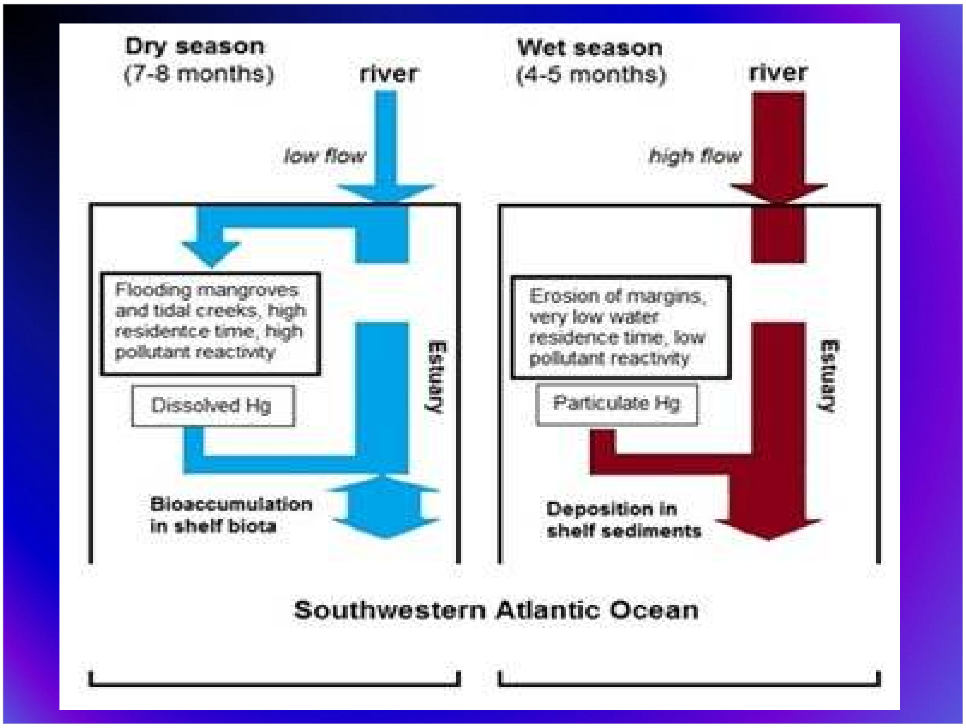




Dissolved Hg species dominate the flux during the dry season.

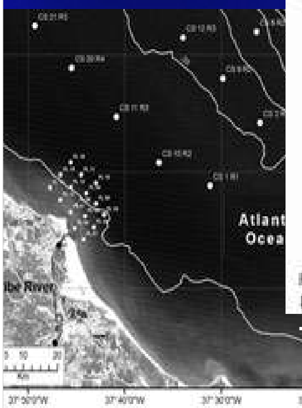
Particulate Hg species dominate the flux during the wet season.


River to estuary
Export of particulate Hg from river to estuary occurs only under intermediate and high fluvial fluxes; Dissolved Hg export occurs with fluvial fluxes close to zero
Rain vs Transport
Hg Dissolvido
Hg Particulado
Estuary to Sea
Export of dissolved Hg occurs only during the dry season with discharge close to zero. Particulate Hg export occurs only under very high water discharge
10
5
0
-5
-10
-15
-20
-25
0 50 100 150 200 250 300 350
8
6
4
2
0
-2
0 50 100 150 200 250 300 350 400


Dry season
(7-8 months)
river
low flow
Flooding mangroves and tidal creeks, high residentce time, high pollutant reactivity
Dissolved Hg
Estuary
Bioaccumulation in shelf biota
Wet season
(4-5 months)
river
high flow
Erosion of margins, very low water residence time, low pollutant reactivity
Particulate Hg
Estuary
Deposition in shelf sediments
Southwestern Atlantic Ocean

Mechanisms involved in the augment of Hg dissolved species (bioavailable), favored by the augment of the water residence time within the estuary

- **Desorption of Hg from suspended particles due to salinity increase and saline intrusion landward**
- **Export of pore waters enriched in DOC from ever larger mangrove forests**
- **Formation and export of soluble Hg-organic complexes**
- **Increased uptake by the phytoplankton associated with higher water transparency.**
- **Faster assimilation and accumulation in the food chain**



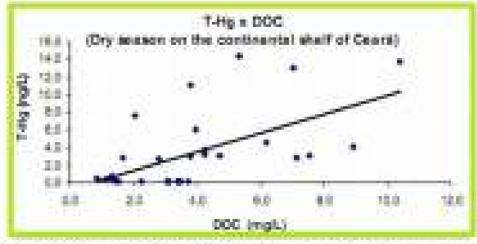


Figure 1: Correlation of T-Hg concentration (ng/L) with DOC (mg/L) ($r = 0.6003$, $n = 31$, $p < 0.05$) during the dry season on the continental shelf of Ceará - Brazil.

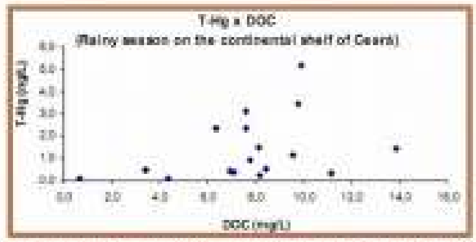


Figure 2: Correlation of T-Hg concentration (ng/L) with DOC (mg/L) ($r = 0.3604$, $n = 20$, $p < 0.05$) for the rainy season on the continental shelf of Ceará - Brazil.

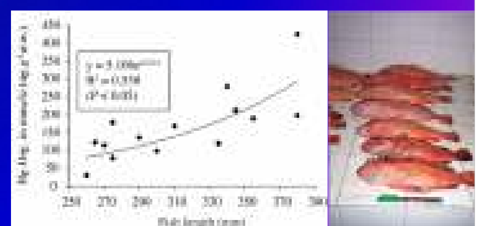
Total Hg in coastal waters off the Jaguaribe River (Soares, Marins & Lacerda, 2011)

Augment of water mass chocking and water residence time in estuaries. Increasing saline intrusion and accumulation of continental materials inside the estuary

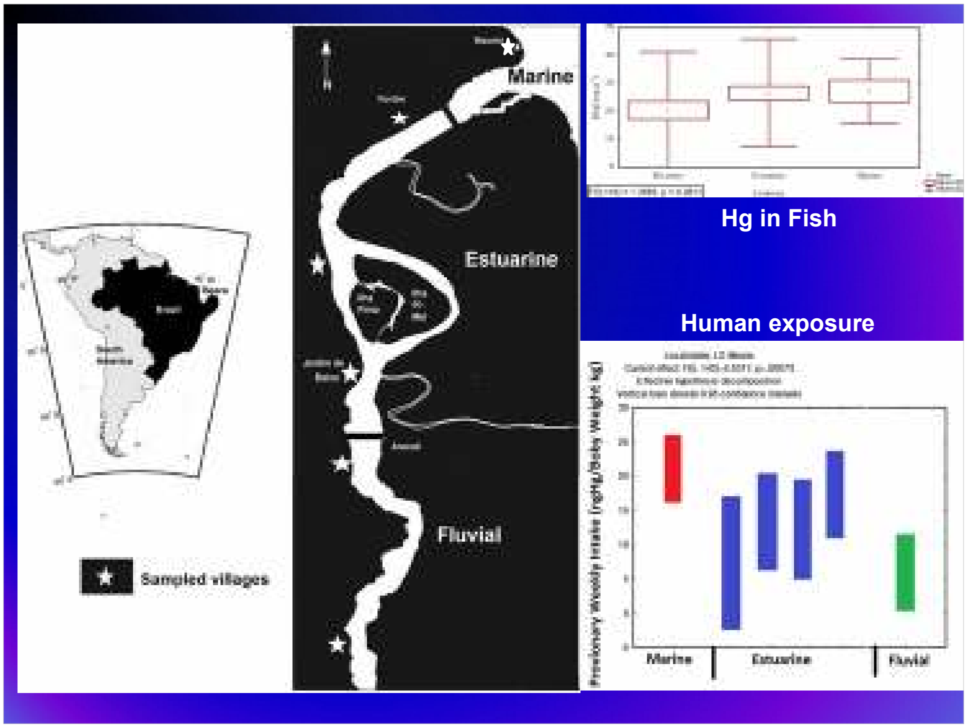
Hg-Org

Continental fluxes may decrease in total but qualitative changes occur due to longer residence time augmenting reactive and bioavailable species (e.g. Hg)

Increasing reactive species increases biological uptake, food chain transfer and human exposure.



Hg em *Cephalopholis fulva* do mar cearense (Lacerda *et al.*, 2006)



Marine
Estuarine
Fluvial
Sampled villages
Hg in Fish
Human exposure
Marine
Estuarine
Fluvial

Obrigado!

http://inct.cnpq.br/web/inct-tmcocean/home/